高等学校专业英语丛书

新编机械工程专业英语

English for Special Purposes in Mechanical Engineering

赵海恒 编著

Internet 信息检索和阅读

专业文献检索、阅读和翻译

科技论文写作

专业文献选读

西南交通大学出版社

新编机械工程专业英语

赵 海 恒　编著

西 南 交 通 大 学 出 版 社

· 成 都 ·

内 容 提 要

本书根据机械工程及其相关领域的发展现状，系统地介绍了这些学科专业英语的基础和实用知识，其中包括专业英语基础知识、专业文献检索、专业文献翻译、科技论文写作和机械工程专业文献选读。随着电子信息技术和材料科学的迅猛发展，机械工程的面貌也发生了重大的变化。本书在选材方面也力求注意反映这些变化。随着 Internet 的迅猛发展，从互联网上获取信息将越来越重要，本书对这方面的内容也作了适当的介绍。

本书可作为大学机械工程"专业英语"教材或参考书，也可作为机械工程及其相关领域的科技工作者学习专业英语的自学用书。

图书在版编目（CIP）数据

新编机械工程专业英语 / 赵海恒编著. —成都：西南交通大学出版社，2001.9
（高等学校专业英语丛书）
ISBN 7-81057-578-3

Ⅰ. 新… Ⅱ. 赵… Ⅲ. 机械工程－英语－高等学校－教材 Ⅳ. H31

中国版本图书馆 CIP 数据核字（2001）第 065013 号

新编机械工程专业英语
赵 海 恒 编著
*
出 版 人 宋绍南
责任编辑 王培俊
封面设计 唐利群
西南交通大学出版社出版发行
（成都二环路北一段 111 号 邮政编码: 610031 发行科电话: 7600564）
http: //press. swjtu. edu. cn
E-mail: cbs@center2. swjtu.edu.cn
四川森林印务有限责任公司印刷
*
开本: 787 mm × 1092 mm 1/16 印张: 13.375
字数：257 千字 印数：1～3000 册
2001 年 9 月第 1 版 2001 年 9 月第 1 次印刷
ISBN 7-81057-578-3/H · 054
定价：18.70 元

内容简介

本书较全面、系统地介绍了机械工程专业英语的基础和实用知识，包括：专业英语基础知识、Internet信息检索和阅读、专业文献检索、专业文献翻译、科技论文写作和机械工程各专业文献的选读等。

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第 1 章　专业英语基础

1.1　绪　论

随着科学技术的飞速进步和全球经济一体化的迅速推进，国际间的经济和科技交流与合作日趋频繁，这对科技人员的外语提出了更高的要求。随着我国进一步对外开放，尤其是我国加人 WTO 之后，社会将需要越来越多的能与国外同行直接交流的专业技术人员。如何改进理工科大学生的外语教学，提高学生应用外语的能力，受到了广泛的重视。新的大学英语教学大纲把专业英语阅读课列为必修课，这门课的教学的目的是培养学生对专业语言的理解能力和应用能力，让学生掌握专业阅读必需的基本技能和知识，使学生能够以英语为工具获取专业科技知识及其他与专业有关的信息。

专业英语的英文原文是 English for Special Purpose，这个术语最初出现于 20 世纪 50 年代，专业英语教学的特点是语言教学密切结合专业知识，教材大都来源于相关的专业文献。理工科的专业文献大致可分为文摘、论文、专著、教科书、研究报告、专利说明书、标准、产品样本和说明书等。其中论文、专著和教科书的语言风格相近，又是科技人员的主要阅读对象，应该作为专业阅读课的主要内容。阅读文摘是阅读其它文献的前奏。对一篇文献，一般都是先看它的摘要，以决定是否阅读全文，因此文摘的阅读也应予以重视。专利文献一方面要阐述技术问题，另一方面它涉及到权益，因此它具有法律文体的特点，在语言上比较难，也是需要学习的内容。

近年来由于电子信息技术，材料科学技术和计算机技术的渗透，机械工程领域发生了深刻的变化，新产品新技术不断出现，研究的课题和教学的内容也都在迅速地更新。本书在选材方面注意反映近年来机械工程领域的发展变化。

近年来另一个对技术进步产生重大影响的因素是因特网的迅猛发展和普及，这使得世界范围内的信息交流和共享成为可能，从网上检索信息查阅资料，进行讨论交流已越来越成为学习和工作的重要手段。网上英语科技信息非常丰富，应该予以充分重视，因此本书对因特网信息资源检索与利用也作了初步介绍。

科技人员阅读专业英语科技文献的目的是理解掌握文献所述的理论或方法，以便在科研或生产实践中实施这些理论方法，或者是进一步发展改进这些理论方法。为了达到这些目的，首先要准确地理解原文。另一方面科技文献的写作特点是严谨，简洁。在论述理论和方法时一般都只给出重要的的步骤。对有关的基础知识一般不详细阐述，也不给出公式的详细推导过程。读者往往需要通过认真地思索才能领会所述的关键问题。因此专业英语阅读与普通英语的快速阅读的方法也所不同，专业英语阅读要把准理解放在首位，在准确理解的基础上提高阅读速度。和其他的英语能力一样，专业英语阅读能力，需要通过长期的实践才能获得，不可能一蹴面就，多读多练是提高专业英语阅读能力的最有效的方法。

1.2 专业英语的基本特点

为了了解专业英语的特点，我们先阅读下面一段关于许用应力的课文。

Despite the tests described in Chapters 11 and 12, materials may still fail in service, sometimes with disastrous results (e.g. when the failure occurs in aircraft, bridges, ships, etc.). To try to avoid such disastrous occurring, the designer avoids using materials continuously at their maximum allowable stress. This is done by employing a *factor of safety.*

Unfortunately, increasing the strength of a component in the interests of safety not only increases the initial material costs, but also the operating costs. For example, the stronger and heavier the structural members of an aircraft, the fewer passengers it can carry and the more fuel it consumes. Therefore a balance has to be maintained between safety, initial cost and operating costs. The designer is constantly striving to improve the former whilst reducing the latter.

Allowable working stress is taken as a proportion of the yield or proof stress; that is, the component is only stressed within its elastic range when in service. For example, consider the screwed fastening shown in Fig.1.1. When the nut is tightened normally the bolt is stretched slightly and, providing it is stressed within its elastic range, it will behave like a very powerful spring and will pull the joint faces together very firmly.

The stress in the bolt is made up of two elements. Firstly, the stress imparted by the initial tightening of the bolt; secondly, the stress imparted by the load on the fastening in service. The sum of these stresses must not be allowed to approach, let alone exceed, the yield stress for the material or it will cease to act in an elastic manner. Therefore the designer proportions the fastening (and other components) so as that there is a factor of safety. Usually the designer assumes an allowable working stress of only half the yield stress for the material.

If the fastening shown in Fig.1.1 is overstressed by applying excess torque to the nut (for example, by extending the length of the spanner with a tube), the bolt will be stressed beyond its elastic range. Once the yield stress for the bolt has been exceeded it exhibits plastic properties and takes a *permanent set* that is, it becomes permanently lengthened, the "spring back" is seriously reduced and the joint faces are no longer held firmly together. Thus for critical assemblies, the designer will seek to control the stress in the fastening and associated components by specifying the torque to be applied to the nut as it is tightened by the use of a "torque spanner" set to a specific value.

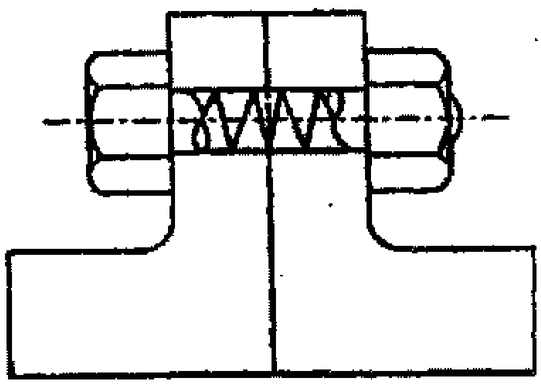

Fig1.1 Screwed Fastening

课文有五段，每一段都说明一个问题：

第一段提出安全系数的概念。

第二段指出设计人员既要保证安全也要注意降低初投资和运行成本。

第三段给出许用应力的定义并以螺栓连接为例予以说明。

第四段分析螺栓的应力。

第五段说明在实际操作过程中控制螺栓应力的重要性及方法。

从整体上看，文中表达的概念清楚，段与段之间的逻辑关系严谨，文章的条理清晰，说服力强。从语言上看，文中的用字用词准确简洁，不追求修饰。文中用了一些机械工程的专业术语如：yield stress（屈服应力），elastic range（弹性范围），torque（转矩）等，还提到了一些机械零件和工具的名称如：bolt（螺栓），nut（螺母），spanner（扳手）等。通过阅读这篇课文，我们可以感觉到专业科技英语的特点：在文章结构方面，逻辑严谨，层次分明，在用词方面，必然要用到专业术语和专业单词。此外在语法方面，专业英语也有它自己的特色，主要的是：非人称的语气和客观的态度，较多地使用被动语态。专业科技英语的另一个重要特点是采用图表等非语言因素表达思想。

掌握专业词汇是学好专业英语的基础，专业词汇的含意和上下文有关，因此查阅专业书籍的 Index 并参照课文确定词意是学习和掌握专业词汇的有效方法。请看下面的英语词汇，它们是从 Engineering Materials 教材的 Index 中摘录出来的。

impact
resistance *see* toughness
testing
testing，interpretation of
impact adhesive *see* joints，adhesive
impact extrusion
inclusions
dissolved
undissolved
induction hardening *see* hardening
insulating materials
intrinsic materials *see* semiconductors materials
ionic bond *see* bond
ions
ironcarbon system
isotopes
Izod impact test

joining materials
joints
adhesive
impact
thermosetting
brazed

malleability
manganese
martensitic structure
mass effect
material properties，factors affecting
material selection
aviation industry
civil engineering（spanning the Firth of Forth）
economic requirements
lessons from disasters
processing requirements
property requirements
materials
engineering
failure in service
creep
corrosion
fatigue
racture
melting temperature of
mature
testing
destructive

compression	non-destructive
mechanical	"Mazac" see zinc based alloys
thermal	melamine formaldehyde

可以看出，其中有些词是机械工程的专用的词汇或术语，如：

ironcarbon system	铁碳系统
martensitic structure	马氏体结构
zinc based alloys brazed	锌基合金
inclusions	夹渣（铸件中的）
induction hardening	感应淬硬

还有些词，在其他专业也通用，但有些词在不同的专业可能有不同的含义，如：

dissolved	可溶的
hardening	硬化
compression	压缩
failure	失效
insulating	绝缘，绝热
processing	加工，处理

这两类词汇都应该掌握，而且相比较而言，更应该重视对后一类词汇的掌握。

词缀和词根

由于历史原因，英语中有很多词来自其它语言，如希腊语，拉丁语，法语等。专业英语中广泛使用外来语的词根和词缀来构成新词，因此适当掌握一些词根和词缀有助于扩大专业词汇。本书的附录 A 给出了专业英语常用词缀和词根。

例如：

macro-	大……宏
macroeconomics	宏观经济学
macroeffect	宏观效应
poly-	多
polygon	多边形
polynomial	多项式
polymerize	聚合
-ics	学……术
informatics	信息学
kinematics	运动学
thermodynamics	热力学
able，ible	可……的，能……的，易于……的
flammable，inflammable	易燃的
adaptable	可适应的
convertible	可变换的
accessible	易接近的
pend	悬挂

pendulum	摆
pendant	吊挂悬垂物
depend	依赖
cert	**确实**
certify	证实，证明
certain	确实的，一定的
ascertain	确定，查明
uncertainty	不确定，误差

第2章 因特网的信息检索

近年来，因特网的高速发展和广泛普及使得人类社会的信息的传播和交流方式发生了深刻的变化。今后人机互动（Human-Machine Interaction）的信息交流方式将会越来越重要。工程技术人员必须具备在网上高效率地获取专业信息的能力，并积极地参与网上的学术交流，才能及时地更新自己的知识，为科学技术的进步做出贡献。由于科学技术发展的历史上的原因，在因特网上的信息资源中，英文资料占据了主要地位，因此培养阅读因特网上的英文资料的能力成了工程技术人员的迫切需要。本章将简要地介绍因特网的信息检索的基础知识以及机械工程的专业信息的检索和阅读。

2.1 因特网的信息资源

因特网的信息资源有正式出版的信息也有非正式出版的信息，内容繁多，变化迅速，没有统一的组织管理机构，也没有统一的目录，但按照其所采用的网络传输协议的不同，可将因特网信息资源划分为以下几种类型：

1 World Wide Web 信息资源

World Wide Web 简称 WWW 或 Web，它是因特网上最重要的信息系统，它采用超文本技术、多媒体技术，把文本、图形、图像、声音信息集成一体，并采用统一资源定位器 URL 技术，把全世界的联网计算机的信息资源连接在一起，通过直观的图形界面为用户提供多媒体信息服务。它的使用简单，功能强大，是因特网的信息资源的最主要和最常用的形式。

在因特网上查询 WWW 信息时需要用统一资源定位器 URL（Uniform Resource Locator）指明网上信息资源的位置。URL 包括三部分：所使用的传输协议；服务器地址；该服务器上定位文档的路径。例如 http://www.chinainfo.gov.cn/database/。其中 http 的全文是 Hypertext Transfer Protocol，中文称为超文本传输协议，它是浏览器与 Web 服务器之间相互通信的协议。其他通信协议还有 FTP，Gopher，Telnet 等。Web 服务器的信息是用超文本标记语言 HTML（Hypertext Markup Language）描述。HTML 文档由文本、格式代码和到其他文档的链接三个部分组成。

2 Telnet 信息资源

在网络通信协议 Telnet（Telecommunication Network Protocol）的支持下，网络用户可以登录远程的计算机，使自己的计算机暂时成为远程计算机的终端，进而使用远程计算机中对外开放的资源，包括硬件资源和软件资源。一些政府部门和研究机构通过 Telnet 方式提供信息服务。许多图书馆也通过 Telnet 方式提供联机图书馆公共检索目录（OPAC—Online Public Access Catalog）。一些商用联机检索系统如：Dialog，DataStar，Lexis-Nexis，OCLC，UMI 等也通过 Telnet 方式提供信息服务。

3　FTP 信息资源

FTP（File Transfer Protocol）是因特网使用的文件传输协议。联网的计算机在 FTP 的支持下可实现文件的相互传输。当需要从远程计算机获取某些文件的拷贝时，则要使用 FTP。FTP 是获取免费软件和共享软件资源不可缺少的工具。通过 FTP 可以获得的信息资源有：电子图书，电子期刊与杂志，政府信息，免费软件和共享软件等。

4　Usenet 用户服务组信息资源

各种各样的用户通信或服务组是因特网上最受欢迎的信息交流形式，例如新闻组（Usenet Newsgroup）、邮件列表（Mailing list）、专题讨论组（Discussion Group）等等。它们实质上都是由一组对某一特定主题有共同兴趣的网络用户组成的电子论坛。论坛的成员之间通过 E-mail 进行多向交流。这样交流的信息最具有开放性和直接性，其内容往往会涉及到某个学科领域的最新成果和研究动向等。工程技术人员应该重视这一个获取科技信息的渠道。

5　Gopher 信息资源

Gopher 是互联网提供的一种菜单驱动的网络信息查询系统，用户在一级级菜单的指引下，实现对因特网上远程联机信息系统的访问，获取自己感兴趣的信息。Gopher 的特点是使用简单，用户只需在菜单中进行选择而无需知道信息的存放位置和掌握有关的操作命令。Gopher 的另一个特点是其菜单可以指向互联网上任何一个 Gopher 服务器的菜单或文件，Gopher 还可以指向其他信息系统，如：WWW，FTP，Telnet 等。

2.2　因特网信息检索

2.2.1　因特网检索工具

近年来因特网的迅猛发展，使其能提供的信息数量激增，使用户感到信息过载，难以应付。在这样浩瀚的信息空间里，快速查找并获取所需要的信息，已成为人们的迫切要求。为了帮助用户准确迅速方便地查到所需要的资料，网络工作者研究开发了相应的因特网信息检索工具，这些工具可分为 Web 网资源检索工具和非 Web 网资源检索工具。前者以 Web 网资源为检索对象，水平较高，应用也最普遍。后者以非 Web 网资源为检索对象（如 FTP，Gopher，Talent，Usenet 等）。近年来，随着 Web 的迅猛发展，非 Web 网资源检索工具的作用相对减弱。

Web 网资源检索工具主要有三大类：

目录型检索工具（Web Directory），搜索引擎（Search Engine）和多元搜索引擎（Metasearch Engine or Megasearch Engine）。

1　目录型检索工具（Web Directory）

目录型检索工具一般称为网络目录（Web Directory），它是由人工搜集网络资源，并按照某种主题分类体系编制的可供检索的等级结构式目录。在每个目录类及子类下提供相关的网址，并给以简单扼要的描述，使用户能通过浏览该目录，在目录体系的引导下发现及检索到需要的信息。

著名的网络目录有：

Yahoo!	http://www.yahoo.com（图 2.1）
Galaxy	http://www.galaxy.com

The WWW Virtual Library（VL）　　http://www.vlib.org

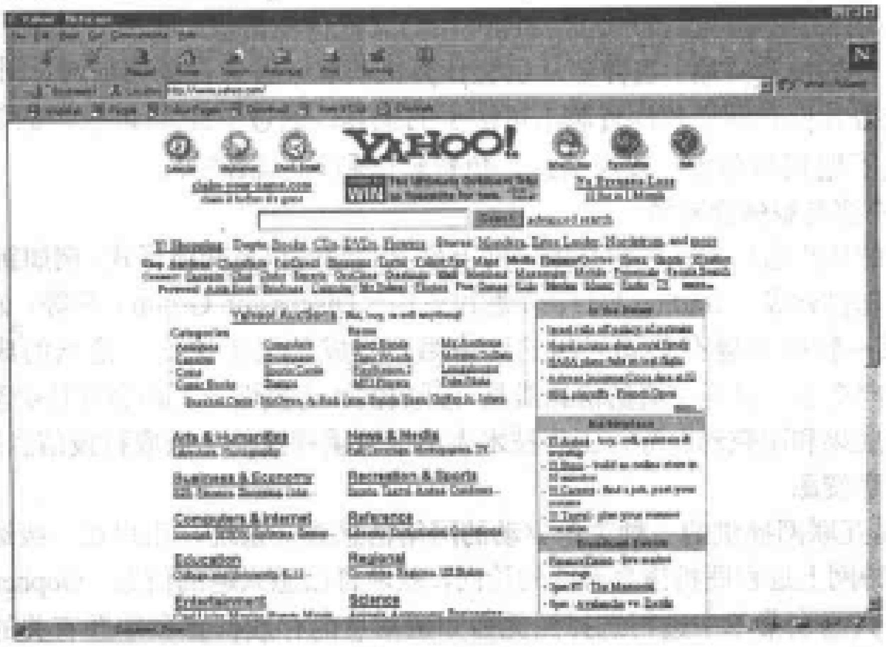

图 2.1　Yahoo!

2　搜索引擎（Search Engine）

搜索引擎利用网络索引软件搜集各网站信息并建立索引，写到自己的数据库中，供用户查询。搜索引擎具有突出的检索功能，又可称为面向关键词的搜索工具。

著名的搜索引擎有：

Alta Vista　　http://www.altavista.com（图 2.2）

Infoseek　　http://www.infoseek.com

http://infoseek.go.com

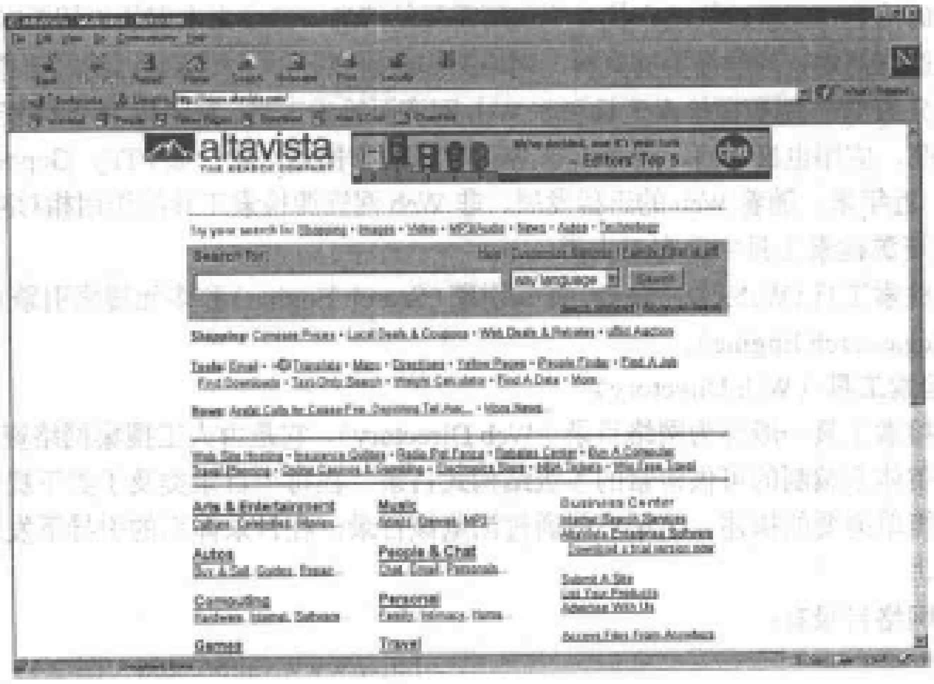

图 2.2　Alta Vista

目录型检索工具和搜索引擎之间的差别，用英文来表示：

A Web directory is

A pre-defined list of Web sites

Compiled by human editors

Categorised according to subject/topic

Search engines have three primary components

A "spider" that examines Web sites

An index/database of Web site listings

Interrogation/retrieval software

Search engine databases are primarily built up by "spiders"

值得注意的是，目录型检索工具和搜索引擎之间的界限越来越模糊，大多数流行的网络检索工具同时提供两种方式的检索。

3 多元搜索引擎

多元搜索引擎是将多个搜索引擎集成在一起，并提供统一的检索界面。它们又可分为搜索引擎目录和多元搜索引擎两种类型。

搜索引擎目录也可称为检索工具的检索工具，它将多个搜索引擎集成在一起，并按类型或检索问题等编排成目录，帮助和引导用户根据检索需求来选择适用的搜索引擎，当搜索引擎选中后，检索由所选的搜索引擎执行，检索的过程与普通的单一搜索引擎的检索一样。

常用的搜索引擎目录有：

ALL-in-one	http://www.allonesearch.com
CUSI	http://cusi.co.uk
iTools!	http://www.itools.com

和搜索引擎目录相似，多元搜索引擎也是将多个检索工具集成在一起，并提供统一的检索界面。但是在搜索时将同一个检索问题同时交给多个搜索引擎，同时检索多个数据库，所得的检索结果经整理之后输出给用户。

常用的多元搜索引擎有：

DOGPILE	http: //www.DOGPILE.com
INFERENCEFIND	http: //www.infind.com
MetaCrawler	http: //www.metacrawler.com
	http: //www.go2net.com/search.html

网络搜索仍在迅速发展，除了上述以网络服务器为基础的网络搜索工具之外，近来出现了以微机为基础的搜索工具，英文名称是 search utility。

PC-based search tools—Search utilities and intelligent agents

Meta-search sites such as Dogpile and Mamma have grown in popularity as they allow users to search across different search indexes simultaneously with duplicates removed and results reranked (depending on the meta search service used). Search utilities represent the logical evolution of this functionality. Unlike meta-search engines, where the processing power to refine results still remains on the server the user is interrogating, search utilities are programs that are installed on to the user's hard drive. By shifting processing power away from the server, and on to the user's own desktop, search utilities offer a much greater range of search and results analysis functionality.

Like several of the second-generation search technologies that have emerged (Electric Monk, Google) many of these search utilities incorporate intelligent agents (or bots). Indeed, many of the powerful features offered by search utilities, such as language independent searching, filtering, automatic refinement of results, and document summaries, active hyperlinking of query words and live highlighting are possible because of the nature of intelligent agents. Unlike a standard software program that will execute specific functions within clearly defined parameters, agents/bots:

are adaptive—they can interpret monitored events to make appropriate decisions;

are self-organising—they assimilate both information and experience;

can communicate with both the user and other bots.

Agents can search across a wide range of document types and formats. They can provide a uniform interface for search queries across different sources and are true "informediaries" in that they can identify and search appropriate resources that may or may not be known to the researcher. The adaptive element of intelligents is central to the functionality of many search products that incorporate agents. The following popular search utilities, which all contain agent technology, are available as free downloads and as more comprehensive paid versions:

Mata Hari (www.thewebtools.com) can learn one set of power search commands and then automatically translate these for each search service/database that it queries for the user.

BulleEye Pro (www.intelliseek.com) incorporates 11 different intelligent agents, including technology from Verity to conduct what it calls "Web mining". The different agents are used to target specfic types of information such as business news in over 450 sources on both the visible and invisible Web. It will automatically run searches, allows import/export of searches to other users, whilst users can choose to receive change alerts by HTML e-mail, pager or other hand-held data devices.

Copernic (www.copernic.com) can translate a search statement for different services and then simultaneously submit the query to these search engines, Web directories and databases. There are about 20 categories such as business and finance, science, etc., with predetermined Web sources to search in.

Recognising the advantages offered by search utilities, some search providers have released a variety of free basic search utility programs as "plug in". As the name suggests, once installed, they are incorporated within the user's browser and enable the search engine provider to offer more features. Search providers that have released search utilities include Infoseek, AltaVista, nd more recently Lycos.

A common function of agents is that they allow the user to specify a high-level goal instead of issuing explicit instructions, leaving the "how" and "when" decisions to the agent. This, combined with their ability to search across data in unstructured formats, to automatically learn and adapt to user preference and to identify patterns, is giving agent technology an ever increasing role in Web searching.

2.2.2 因特网图书与期刊信息检索

1 图书馆公共可检索目录（OPAC）

因特网的发展冲破了图书馆的目录只能在本馆范围内使用的限制。近年来世界各地的图书馆在建设数字图书馆系统的进程中，已将传统的图书馆的目录发展为"联机图书馆公共可检索目录"（Online Public Access Catalog—OPAC）。这是一个基于网络的书目检索系统，它在网上提供书目信息检索服务。网络用户可在自己终端检索世界各地图书馆的 OPAC。从清华大学图书馆的网页（URL　www.lib.tsinghua.edu.cn/chinese/otherlib）可以查到部分国内联网图书馆的 URL。另外在 Yahoo！的总目录中按路径 Reference—Library 向前，也可以连接到世界各地各类图书馆的主页，检索其 OPAC。另外已知某大学的 URL，一般可推测出其图书馆的 URL，例如: Oxford University 的 URL 是 http://www.ox.ac.uk/，则其图书馆的 URL 为：　http://www.lib.ox.ac.uk/。图 2.3 是康奈尔大学工程图书馆的主页。

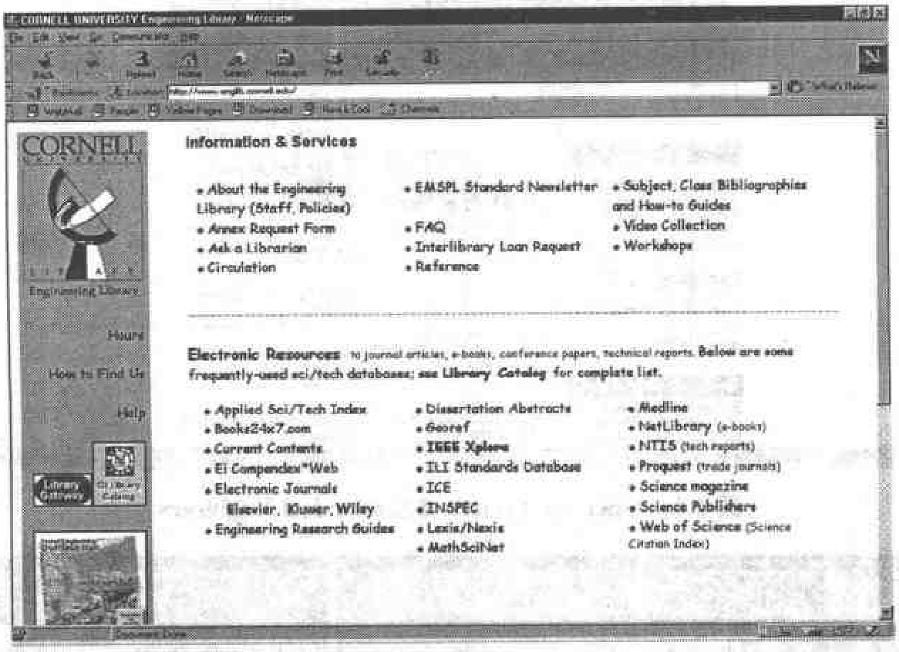

图 2.3　The Engineering Library of Cornell University

2 电子期刊

学术期刊是传递科技信息、交流学术思想最简便最基本的手段，也是科技工作者获取学术信息的最主要的渠道。随着因特网尤其是万维网的广泛应用，近年来电子期刊也大量出现。可以说电子期刊时代已经到来。据报道目前最大的电子期刊网站之一，Electronic Journal Access（URL　http://www.coalliance.org）收录了几千种网络电子期刊。很多电子期刊目前还只提供其印刷版本的目次和文摘。也有不少电子期刊提供全文。还有一些是纯粹的电子期刊，它们只有电子版本没有印刷版本。检索期刊信息的重要网站还有：

The Internet Directory of Publications	http: //www.publist.com
MediaFinder	http://www.mediafinder.com
Excite's Newstracker	http://www.chinainfo.gov.cn
Wiley InterScience	http://www/interscience.wiley.com
中国工程技术信息网	http://www.cetin.net.cn

3 机械工程专业信息检索

ASME（American Society of Mechanical Engineers），SAE（Society of Automobile Engineers），和 IMECHE（Institution of Mechanical Engineers）等机械工程学术组织也在网上发表学术期刊，公布学术活动信息，它们也提供信息服务。它们的网址分别是：

ASME	http://www.asme.org（图 2.4）
SAE	http://www.sae.org（图 2.5）
IMECHE	http://www.imeche.org.uk（图 2.6）

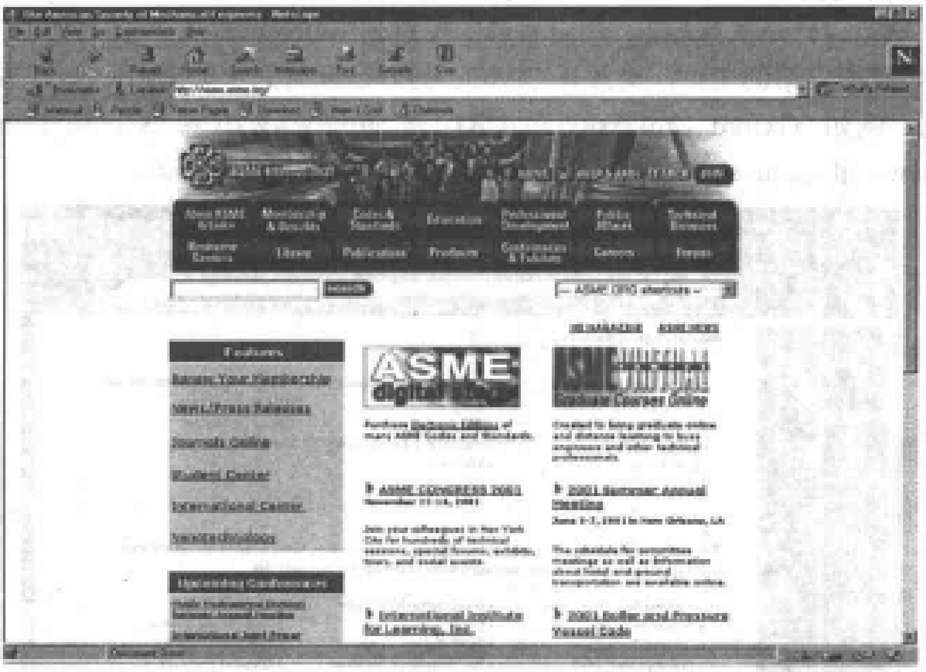

图 2.4　American Society of Mechanical Engineers

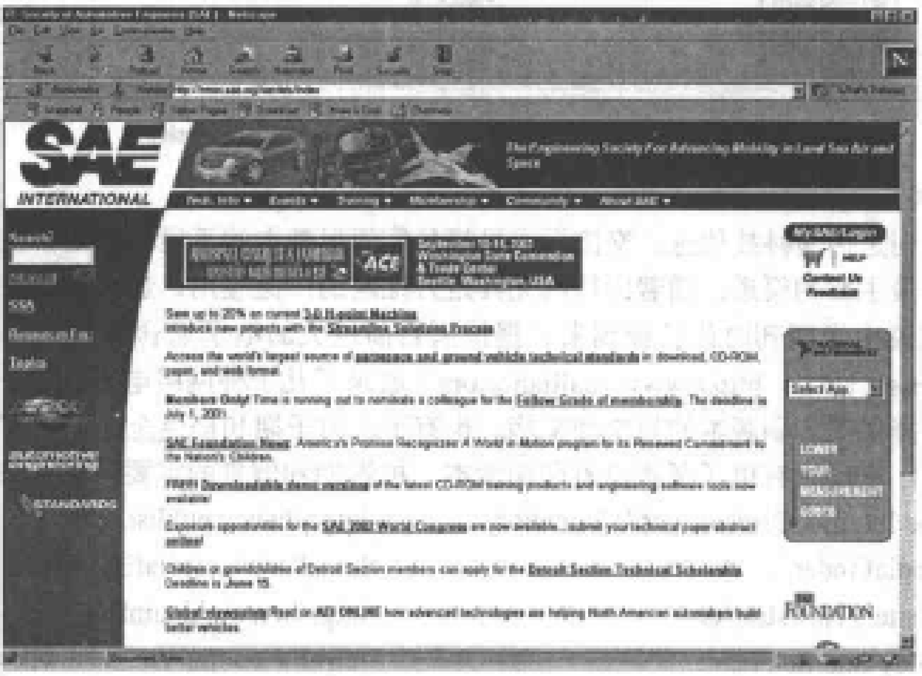

图 2.5　Society of Automobile Engineers

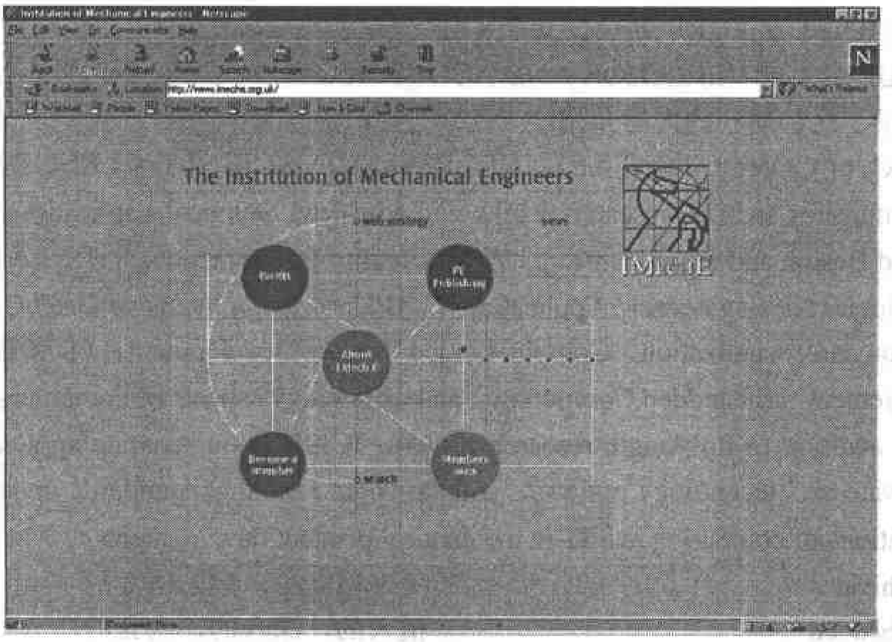

图 2.6 Institution of Mechanical Engineers

ASME 在网上提供的学术活动内容非常丰富，有电子期刊和学术会议的信息，有关于纳米技术 Nanotechnology 的讨论，还有 Virtual Campus， 它提供 Distance Learning，包括 Graduate Online Courses，及面向其他对象的 Continuing Education。对机械工程技术人员来说 ASME 是一个值得重视的网站。

ASME 出版的期刊主要有：

APPLIED MECHANICS REVIEW
HEAT TRANSFER RECENT CONTENTS
JOURNAL of APPLIED MECHANICS
JOURNAL of BIOMECHANICAL ENGINEERING
JOURNAL of COMPUTING AND INFORMATION SCIENCE IN ENGINEERING
JOURNAL of DYNAMIC SYSTEMS， MEASUREMENT， and CONTROL
JOURNAL of ELECTRONIC PACKAGING
JOURNAL of ENERGY RESOURCES TECHNOLOGY
JOURNAL of ENGINEERING FOR GAS TURBINES AND POWER
JOURNAL of ENGINEERING MATERIALS AND TECHNOLOGY
JOURNAL of FLUIDS ENGINEERING
JOURNAL of HEAT TRANSFER
JOURNAL of MANUFACTURING SCIENCE AND ENGINEERING
JOURNAL of MECHANICAL DESIGN
JOURNAL of OFFSHORE MECHANICS AND ARCTIC ENGINEERING
JOURNAL of PRESSURE VESSEL TECHNOLOGY
JOURNAL of SOLAR ENGINEERING
JOURNAL of TRIBOLOGY

JOURNAL of TURBOMACHINERY

JOURNAL of VIBRATION AND ACOUSTICS

下面摘录了几种期刊的内容介绍：

1 JOURNAL of COMPUTING AND INFORMATION SCIENCE IN ENGINEERING

JCISE publishes archival research results and advanced technical applications in the areas of Internet-Aided Design and Manufacturing, Virtual Reality Environments and Systems, Information Models/Ontologies for Engineering Applications, AI/Knowledge Intensive CAD/CAM, Engineering Simulation and Visualization, Computer aided Product Development, PDM/Enterprise Information management, Embedded Computing, and technology aspects of computers in engineering education. In addition to full-length research papers, JCISE has a separate application track that features software and technology reviews, software/data exchange standards updates, and innovative applications of computing and IT in mechanical product development.

archival	关于档案的，记人档案的
embedded	植人的，深人的，内含的
VR	abbr. Virtual Reality，虚拟现实
AI	abbr. Aritificial Intelligence，人工智能

2 JOURNAL OF TRIBOLOGY

One of the most respected archival journals in the field of tribology, the Journal of Tribology publishes over 100 outstanding technical articles of permanent interest to the tribology community annually, and attracts articles by tribologists from around the world. The journal features a mix of experimental, numerical, and theoretical articles dealing with all aspects of the field, including, but not limited to: friction and wear, fluid film lubrication, elastohydrodynamic lubrication, surface properties and characterization, contact mechanics, magnetic recordings, tribological systems, seals, bearing design and technology, gears, metalworking, lubricants, and artificial joints. In addition to being of interest to engineers and other scientists doing research in the field, the information published in the journal is also of great importance to engineers who design or use mechanical components such as bearings, gears, seals, magnetic recording heads and disks, or prosthetic joints, or who are involved with manufacturing processes.

Tribology	摩擦学
elastohydrodynamic lubrication	弹性流体动力润滑
gears	齿轮，传动装置调整，（使）适合，换挡
artificial joints	人造关节
prosthetic	弥补性的，置换的

3 JOURNAL OF ENERGY RESOURCES TECHNOLOGY

Addressing the wide-ranging topic areas of petroleum drilling, production, refining, processing, transportation, and equipment and vehicles for sea underwater usage, the Journal presents peer-reviewed technical papers as well as briefs which are an excellent way to present new computing algorithms, experience with new measurement devices, evaluation studies, etc. Specific areas of importance include (but are not limited to): offshore mechanics and technology;

ice-water-structure interactions; ocean engineering drilling and production; riser mechanics and transportation; rock and material mechanics for energy resources; emerging technologies in oil shale; advanced energy resources-systems-analyses; fundamental combustion of energy resources; energy resource recovery from bio-mass and solid wastes; petroleum equipment and design; and economics of energy resource exploitation.

petroleum	石油
drilling	钻井
refining	精炼
processing	加工，处理
offshore	离岸的，海面上的
peer	凝视，盯着看
algorithm	算法
oil shale	油页岩

4 JOURNAL OF DYNAMIC SYSTEMS, MEASUREMENT, AND CONTROL

The Journal of Dynamic Systems, Measurement, and Control publishes theoretical and applied original papers in the traditional areas implied by its name, as well as papers in interdisciplinary areas. Theoretical papers are expected to present new theoretical developments and knowledge for controls of dynamical systems together with clear engineering motivation for the new theory. "Application" is taken to include modeling, simulation, and corroboration of theory with emphasis on demonstrated practicality. Areas of interest include but are not limited to: adaptive and optimal control; uncertain systems and robust control; nonlinear systems and control; intelligent control; distributed parameter systems and control; energy systems and control; fluid control systems; instrumentation and components; manufacturing technology; aerospace systems; computer control; mechatronics; power systems; production systems; real time control; robotics; motion controls; transportation and biomedical systems.

interdisciplinary	学科间的，跨学科的
corroboration	使确实，确证的事实，确证
robust control	鲁棒控制
distributed parameter systems	分布参数系统
mechatronics	机械电子学
robotics	机器人学，机器人技术

5 Micro Electro Mechanical Systems（MEMS）

Author/Editor : IEEE/ASME

Sponsored By ; IEEE Robotics and Automation Society

MEMS is the first international forum focused on interdisciplinary research topics on design, modeling, fabrication, operation, and applications of microelectromechanical devices, machines, and systems constructed on the micrometer to millimeter scale.

forum	论坛，讨论会
micrometer scale	微米级

millimeter scale　　　　　　　　　　　　毫米级

SAE 是 Society of Automobile Engineers（美国汽车工程师协会）的缩写。当前 SAE 在网上推行一个关于智能车辆的开放型的研究项目，任何有兴趣的团体或个人都可参加，下面的一段短文介绍了发 展智能车辆需要解决的技术问题。

SAE Intelligent Vehicle Program（IV）

SAE has played and continues to play a critical role in the progress of the technological growth of the automotive industry. Our influences on the industry include such major developments as: the first engine oil viscosity standard; the closed-in automobile body; self-starting vehicles; automatic shifting; multiplexing standards for today's electronically laden cars; and recommendations for charging environmentally-friendly electric vehicles.

As more electronics are incorporated into the automobiles at higher rates, a new automotive market is developing: the Intelligent Vehicles market.

The Intelligent Vehicles market offers a new breed of automotive engineering and a whole new world of electronics, computers and software applications. These systems, applied to automobiles, will affect the vehicle in three basic functional areas: the basic vehicle, safety and security and telematics—information, communications and entertainment.

Intelligent Vehicles systems will help lessen traffic congestion; improve safety, driver comfort and convenience; and foster a cleaner environment. These are also the stated objectives of SAE's mission, and thus, SAE has committed its resources to be aligned with the Intelligent Vehicles market.

In this age of consumerism, SAE supports the Intelligent Vehicles market as it responds with the latest technologies to the consumer interests of safety, comfort and convenience. Consumer interests and the Intelligent Vehicles market have fostered the development of many new products. SAE is working with its corporate customers to speed the application of the technologies and reduce the time to market of these products. In order to accomplish this, SAE is working to educate and promote Intelligent Vehicles technologies/products to the consumer market as well as to the engineering community.

The following areas are included in the SAE Intelligent Vehicle program:

Basic Vehicle

Comfort and convenience（HVAC, adaptive displays, adaptive accommodations）

Low friction warning and control assist

Vehicle diagnostics and owner/dealer notification

Powertrain control

Braking assistance

Energy management（electric/hybrid vehicles）

Lighting control

Chassis control（stability enhancement, suspension-active, semi-active, and height-adjustable damping）

Smart restraints and occupant protection systems

Safety/Security

Collision warning/avoidance（forward，rearward，road departure，lane change/merge，intersection，railroad crossing，multiple vehicle）

Vision enhancement（night and inclement weather）

Location-specific alert and warning

Automatic collision and severity notification

Adaptive cruise control（throttle/transmission and/or braking intervention）

Lateral control（steering assist，lane keeping）

Driver condition monitoring/warning

Obstacle/pedestrian detection

Safety event recorder

Personal security（identification，mayday）

Vehicle security（tracking and recovery）

Telematics—Information/Entertainment

Navigation and route guidance

Real-time information（traffic，news，business directories，internet/email）

Entertainment（broadcast，onboard）

Automated transactions（tolls，purchases）

Position reporting

Communications（broadcast，two-way）

Stored onboard information databases

Services on demand（door lock，lights on/off，vehicle tracking and recovery）

viscosity	粘性
automatic shifting	自动变速，自动换挡
breed	品种，种类（使）繁殖，教养，抚养
traffic congestion	交通堵塞
foster	养育，抚育，培养，鼓励，抱（希望）养育者，鼓励者
mission	使命，任务
aligned with	与……结盟
diagnostics	诊断
inclement	险恶的，严酷的
throttle	节流阀
mayday	救难信号
tracking	跟踪
telematic	信息通讯业务，远程信息处理
transactions	处理者，办理人，办理，处理，处理事务
toll	（道路、港口的）通行费，过路税，费用，代价
laden	装满的，负载的，苦恼的

multiplexing	多路技术
chassis	汽车底盘
damping	阻尼，减振

IMECHE 的全称是 Institution of Mechanical Engineers，即英国机械工程师协会，它出版的主要期刊是 The Proceedings of the Institution of Mechanical Engineers，有 12 个分册：

Part A Journal of Power and Energy
Part B Journal of Engineering Manufacture
Part C Journal of Mechanical Engineering Science
Part D Journal of Automobile Engineering
Part E Journal of Process Mechanical Engineering
Part F Journal of Rail and Rapid Transit
Part G Journal of Aerospace Engineering
Part H Journal of Engineering in Medicine
Part I Journal of Systems and Control Engineering
Part J Journal of Engineering Tribology
Part K Journal of Multi-body Dynamics
Part L Journal of Materials: Design and Application

这些期刊可以通过下述网站在网上查阅：

ingentaJournals	http://www.ingenta.com
Eletronic Collections online from OCLC	http://www.oclc.org/oclc/menu/eco.htm
RoweCom Information Quest	http://www.informationquest.com
Swestsnet from Swets and Zeitlinger	http://www.swetsnet.nl
Ebsco online from EBSCO	http://www.ebsco.com

第 3 章　专业文献检索

及时了解并掌握本专业科技发展的现状和趋势是科技工作者的日常工作任务之一。为了跟踪最新科技成果和科技动态，科技工作者需要经常地检索和阅读本专业的文献或者其他有关专业的文献。按出版类型划分，专业文献可分为图书、期刊和特种文献三大类。

获取专业文献的途径有两种，一是直接阅读本专业的图书、期刊或会议文集等，另一种是通过查阅文摘类文献，找到有关文献的摘要，在阅读了摘要之后，根据需要来确定是否阅读全文。本章将介绍与机械工程关系密切的文摘类文献和如何使用它们来检索专业文献。

3.1　期刊和会议文献的检索

最重要的英文科技文献检索工具有以下四种

（1）Engineering Index, Ei

（2）Index to Scientific & Technical Proceedings, ISTP

（3）Science Abstracts, SA

（4）Science Citation Index, SCI

本书仅介绍 Ei 和 ISTP

3.1.1　美国工程索引

美国工程索引 Engineering Index（简称 Ei）是最具有影响力的工程技术文摘性期刊，它的内容广泛，所报道的内容遍及工程技术的各个领域，Ei 从五千多种国际性期刊和会议文集中收录文献和文摘，并且它所报道的文摘都是经过专家们精心挑选编撰的，具有很高的学术价值，深受广大工程技术人员的欢迎。近几年来，它每年报道的文摘超过十万条。

Ei 有年刊（The Engineering Index Annual）和月刊（Engineering Index Monthly），其中的内容可划分为摘要（Abstract），主题索引（Subject Index），作者索引（Author Index）等。Ei 还出版主题词表（Ei Thesaurus），它把 Ei 所用的主题词（Descriptor）分类编码分级列出，以方便读者查阅。一般来说，当对于所要查找的文献把握不准时，就先通过 Ei Thesaurus 查找到 descriptor，然后再按 descriptor 查找文摘。在阅读文摘之后，如感到有必要再去查阅原始文献。

下面一段摘要选自 Ei Annual 1999

Bolted joints（Descriptor　主题词）

（Ei Abstract Number　文摘号）013704　（Title 题目）**Stress analysis of bolted joints with plain washers.**

（Abstract 摘要）Bolted joints have been widely used in many kinds of industries, being used commonly. Recently the bolt strength has been improved and high strength bolts are usually used. As the bolt strength increases, bolt pre-load increases. In reliable design standpoint of bolted joints, the contact stress at the bearing surfaces between a bolt head and a clamped part must be examined in order to prevent the permanent set due to over stress at the bearing surfaces. Thus, flat washers have been used in bolted joints in order to enlarge the bearing area. In this paper the contact stress at the bearing surfaces between a plain washer and a clamped part is analyzed using the axisymmetric theory of elasticity as a contact problem, where clamped parts are finite hollow cylinders. In the analysis, the bolt head and bolt shaft are replaced by finite solid cylinders and a plain washer and the clamped parts by finite hollow cylinders. In the numerical calculations, the effects of the stiffness, the thickness and the outer diameter of plain washers on the contact stress distribution are examined. Furthermore, it is important to know the mechanical behaviors of bolted joints with plain washers subjected to external loads. When, an external load W is applied to a bolted joint with a plain washer, an increment of axial bolt force F_1 occurs in the bolt and the contact stress between the clamped parts is decreased. The ratio W/F_1 is knows as the load factor in designing bolted joints with plain washers. The analysis of the load factor is also done. In addition, the effects of the plain washer on the load factor of bolted joints are examined in the numerical calculations. The experiments to measure the load factor of bolted joints with plain washers are carried out. The results of the analysis are compared with the experimental results. (Author abstract) 4 Refs. English

（作者，作者单位，来源等信息）Sawa, Toshiyuki (Yamanashi Univ, Jpn); Yasui, Hajime. *Reliability, Stress Analysis, and Failure Prevention Aspects of Adltesive and bolted Joints, Rubber Components, Composite Springs, ASME Des Eng Div Publ DE* v 100 1998 Proceedings of the International Mechanical Engineering Congress and Exposition, Anaheim, CA, USA, ASAME, Fairfield, NJ USA, p125-131

除了上述常规期刊以外，Ei 还出版电子期刊，其中最重要的是 Ei Compendex 光盘。Ei 也在因特网上提供检索服务，其 URL 是 http://www.ei.org（图 3.1）。

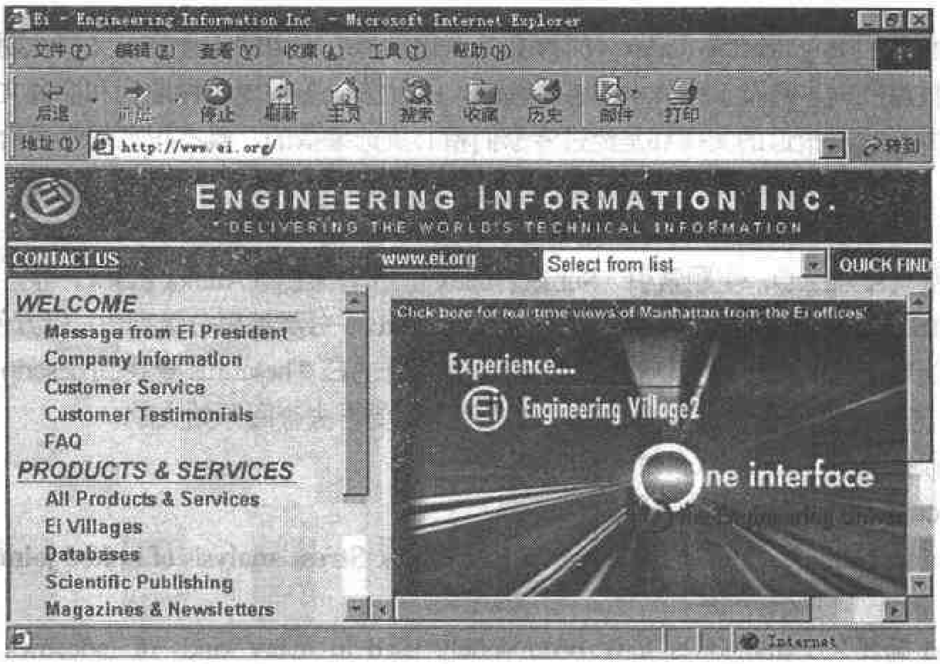

图 3.1 Engineering Information Inc.

下面一段摘要选自 Ei Compendex

（目录号）DIALOG No: 04924618　EI Monthly No: EIP98024039688

（题目）Title: Influence of filament winding parameters on composite vessel quality and strength

（作者）Author: Cohen, D.

（作者单位）Corporate Source: Alliant Techsystems, Inc, Magna, UT, USA

（来源）Source: Composites—Part A: Applied Science and Manufacturing v 28 n 12 1997. P 1035-1047

（出版时间）Publication Year: 1997

（出版号）CODEN: CASMFJ　ISSN: 1359-835X

（语言）Language: English

（文献类型）Document Type: JA; (Journal Article) Treatment Code: T; (Theoretical); X; (Experimental)

（摘要）Abstract: An experimental design investigation of manufacturing and design variables that affect composite vessel quality, strength，and stiffness was conducted. Eight 20-in. cylinders (with one additional cylinder as a replicate) were manufactured and tested for hoop strength, hoop stiffness, fiber and void volume fraction distribution through thickness, residual stress, and interlaminar shear strength. Material and processing variables were divided into five categories: (a) resin, (b) fiber, (c) fabrication process, (d) design, and (e) equipment. Five variables were selected (from a list of 12) for study using a 1/4 fractional factorial design of experiment setup. The five variables were: (a) winding tension, (b) stacking sequence, (c) winding-tension gradient, (d) winding time, and (e) cut-versus-uncut helicals. Statistical analysis of the data shows that the composite vessel strength was affected by the manufacturing and design variables. In general, it was found that composite strength was significantly affected by the laminate stacking sequence, winding tension, winding-tension gradient, winding time, and the interaction between winding-tension gradient and winding time. The mechanism that increased composite strength was related to the strong correlation between fiber volume in the composite and vessel strength. Cylinders with high fiber volume in the hoop layers tended to deliver high fiber strength. (Author abstract) 13 Refs.（参考文献 13 篇）

3.1.2　美国科技会议录索引

美国科技会议录索引 Index to Scientific & Technical Proceedings（简称 ISTP）以题录的形式报道在全世界范围内发表的重要的科技会议文献。大约有 75% 到 90% 重要的国际会议文献可以从 ISTP 查到。其内容分有 50 多个大类，几乎覆盖了所有自然科学和工程技术的重要领域。因此 ISTP 是查询科技会议文献的首选检索工具。

ISTP 有月刊和年刊，内容分为六个部分，主要部分是 Content of Proceedings，这里报道会议内容及有关检索信息，对收录的会议首先给出会议编号，会议名称，会议地点，会议日期以及其它获取原始文献的检索信息，然后列出会议论文的标题，论文作者以及第一作者的地址。ISTP 的其它部分是辅助性索引，包括 Category Index, Permuterm Subject Index, Sponsor Index, Author/Editor Index, Meeting Location Index 和 Corporate Index。利用辅助性索引可以查到会议的编号，然后再转到 Content of Proceedings 进一步查阅。

一般应用 ISTP 期刊查询会议文献时，首先用 Category Index 查找我们所关心的领域里有哪些会议，如果发现了感兴趣的会议，再根据会议编号，转到 Content of Proceedings 进一步查阅。

例如，假设我们想查找无损检测方面的会议情况，先找到 Category Index。在其中的 Engineering 类中，看到有两个与无损检测有关的会议：

2ND INTERNATIONAL CONFERENCE ON EMERGING TECHNOLOGIES IN NDT P88438

3RD INTERNATIONAL WORKSHOP ON NONDESTRUCTIVE TESTING AND COMPUTER SIMULATIONS IN SCIENCE AND ENGINEERING P88506

然后到 Content of Proceedings 部分，按会议编号查找 P88438

2ND INTERNATIONAL CONFERENCE ON EMERGING TECHNOLOGIES IN NDT, Athens, Greece, May 24-26, 1999

Sponsors:Free Univ Brussels, Dept Mech Struct & Mat/ Univ Patras, Dept Mech Engn &Aeronaut

EMERGING TECHNOLOGIES IN NDT

Eds: D.VANHEMELRIJCK, A.ANASTASSOPOULOS, T.PHILIPPIDS

A a Balkema, Rotterdam, 2000, 378pp., 50 chaps., N/A/hardbound, ISBN 90-5809-127-9

INDIVIDUAL PAPERS AVAILABLE THROUGH THE GENUINE ARTICLE; WHEN ORDERING USE ACCESSION NUMBER BP80X

A A BALKEMA PUBLISHERS OLD POST ROAD BROOKFIELD VT 05036 OR

A A BALKEMA PO BOX 1675 3000 BR ROTTERDAM NETHERLAND

THE EUROPEAN FEDERATION FOR NDT（EFNDT）—BACKGROUND, STRUCTURE, OBJE-CTIVES, AIMS.

D.Schnitger (Bundesanstalt Mat Forsch & Prufung, Bam Berlin Germany)··························3

THE HISTORY AND THE DRIVING FORCES OF NON DESTRUCTIVE TESTING TODAY AND BEYOND 2000. *S.Vahavioios*(Mistras Holdings Grp Princeton NJ)·······························11

……

RAPID MANUAL INSPECTION AND MAPPING USING INTERGRATED ULTRASONIC ARRAYS. *D.I.A. Lines, K.R.Dikson, G.Filippi*(Diagnost Sonar Ltd Livingston Scotland)··················7

……

APPLICATION OF THE EDDY-CURRENT METHOD IN FERRITIC WELD INSPECTION. *T.P.Theodoulidis, M.K.Kotouzas* (Technol & Qual Control Ctr Thessaloniki Greece)s··················357

……

在因特网上也可以查阅 ISTP。ISTP 由美国 Institute of Scientific Information（简称 ISI）公司出版，ISI 的 URL 是 http://www.isinet.com（图 3.2）。

在 Internet 上查询并阅读 ISTP 的有关信息之前，让我们先了解一下 ISI 的概况。在 ISI 的主页上依次链接 About ISI 和 Products 可以看到关于 ISI 的简介。

For over 40 years, ISI has been publishing scholarly bibliographic databases for the global research community. Founded in 1958 by Dr. Eugene Garfield, ISI maintains the most comprehensive bibliographic database of research information in the world.

ISI products are primarily distributed worldwide via the Internet/intranet. Our focus is on the ongoing development of access to essential research material published in the journal and proceedings

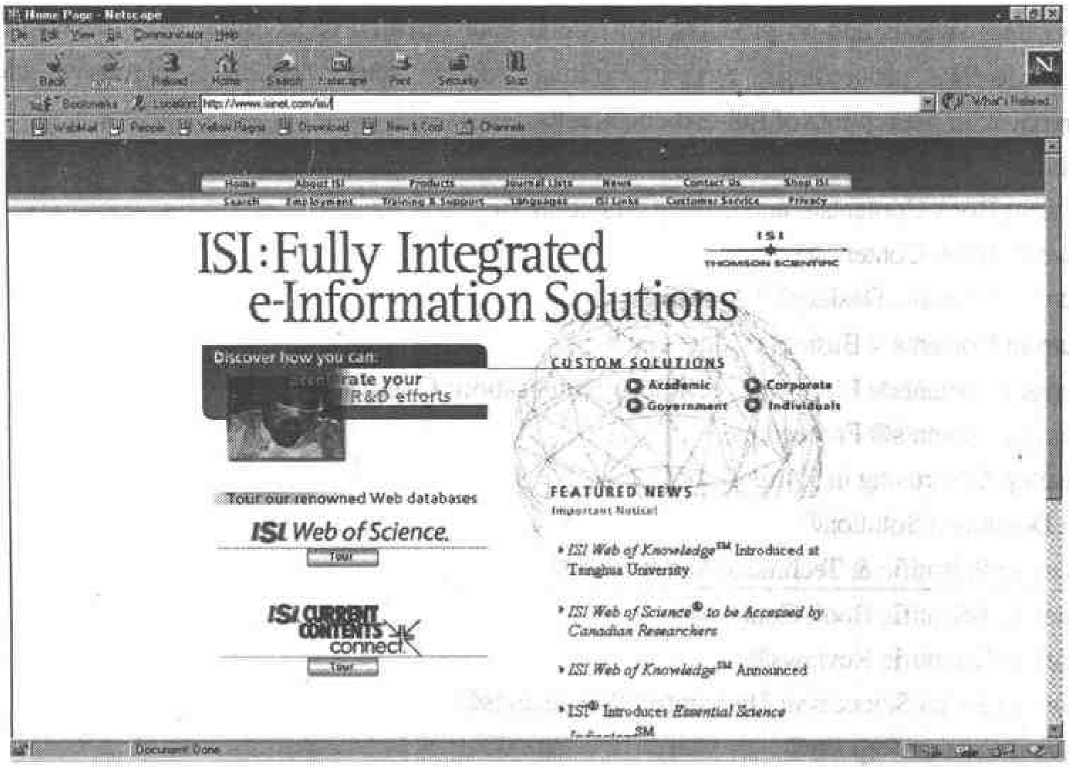

图 3.2 Institute of Scientific Information

literature with links to scholarly full-text journal articles, other databases, pre-print servers and Web sites.

ISI products include the ISI Web of Science®, a unique multidisciplinary bibliographic database that offers Web access to over a half century of the world's most influential information. It includes three Citation Databases: Science Citation Index ExpandedTM, Social Sciences Citation Index®, and Arts & Humanities Citation Index® and covers approximately 8 500 scholarly journals annually. The Web of Science also provides links to the full text of journals and chemical, patent, life science and proceedings literature. Released less than three years ago, this innovative Web-based resource is being used by over 3.5 million researchers and scientists worldwide.

ISI also publishes Current Contents Connect®, a current awareness database that is available via the World Wide Web and provides daily updates to over 8 000 scholarly journals and links to selected Web sites and pre-print servers. Other services include a line of bibliographic management tools, a document delivery service and other literature research tools in multiple formats including CD-ROM and diskette.

ISI Products & Services

Searchable Databases

Alerting Services

Patent Information Products

Chemical Information Products

Research Performance & Evaluation Tools

Complementary Products/Services

ISI offers various add-on products that extend your research capabilities. Add retrospective data; access conference proceedings; evaluate journal impact factors; organize references and create bibliographies; or get reprints of full-text documents.

Bibliographic Management Products

Current Book Contents® and Calling Attention To

Current Book Contents®

Current Contents Desktop™ Archive

Current Contents® Business Collection

Current Contents® Electronics & Telecommunications Collection

Current Contents® Proceedings

Display Advertising in Current Contents®

ISI Document Solution®

Index to Scientific & Technical Proceedings®

Index to Scientific Book Contents®

Index to Scientific Reviews®

Index to Social Sciences & Humanities Proceedings®

Journal Citation Reports®

Medical Documentation Services®

Reprint Request Cards®

Request-A-Print® Cards and Forms

Scientific Direct(TM) Customized Mailing

TermTracker®

Web of Science® Proceedings

读了这段文字之后，我们了解到，依次点击 Products，Complementary Products/Services 和 Index to Scientific & Technical Proceedings®即可进入 ISTP 网页（图 3.3），从而了解 ISTP 并进行检索。

进入 ISTP 后，就可以看到关于 ISTP 的介绍，从中可以了解到 ISTP 提供的检索服务。

Index to Scientific & Technical Proceedings

The ISI® Index to Scientific & Technical Proceedings provides comprehensive, multidisciplinary coverage of proceedings papers delivered at prestigious international scientific and technology conferences. It delivers complete bibliographic information and author abstracts from source publications that include monographs, series, preprints, and proceedings published in the journal and book literature. The ISTP covers the disciplines indexed by the Science Citation Index .

Key Advantages & Capabilities

Provides detailed conference information, article information, and publication information

Helps researchers stay up to date by giving them access to data that provides early indications of emerging and developing new ideas and concepts and, in fields such as engineering and materials science, often provides the only source of published information available.

Enables users to make progress in resolving research problems by letting them search a single resource for key information across multiple disciplines.

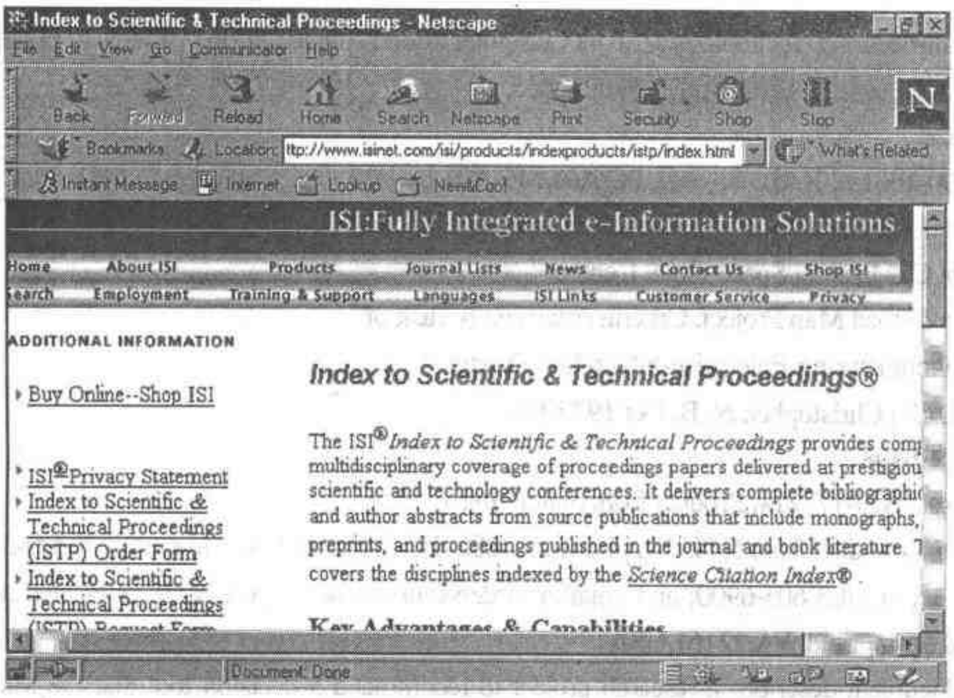

图 3.3 Index to Scientific & Technical Proceedings

Is ideal for subject searches, acquisitions planning, and current and retrospective searches

Formats & Delivery Options

CD-ROM — updated quarterly on a rolling five-year file; covers over 960 000 papers published since 1996 from 28 000 conference proceedings; each update adds approximately 53 000 papers from 2 500 recently published conference proceedings; networking options available.

FTP — updated weekly via Index to Scientific & Technical Proceedings Search; same coverage as CD-ROM version; abstracts from 1997 optional.

Online — updated weekly via Index to Scientific & Technical Proceedings Search; available with Index to Social Sciences & Humanities Proceedings® through DIMDI, 1978 to date.

3.2 科 技 报 告

每当一项研究工作完成时，研究人员都要向委托方提供科技报告，介绍研究工作过程、方法和成果。和其它类型科技文献相比，科技报告具有报道速度快、及时反映最新科技信息、内容丰富详细，可借鉴性强等优点，值得注意。在科技报告中，美国政府的 PB，AD，NASA 和 DOE 四大科技报告最具有影响力，一直受到科技工作者的重视。其中 PB 报告以民用技术为主，AD 报告侧重军用工程技术，NASA 报告由 National Aeronautics and Space Administration 发布，主要报道航空航天技术的研究，DOE 报告由 Department of Energy 发布，以能源技术为主。美国国家技术情报服务局（National Technical Information Service NTIS）出版的检索工具 Government Reports Announcement & Index — GRA&I 系统报道美国政府科技报告。

例：应用检索工具 Government Reports Announcement & Index—GRA&I 查找科技报告（Vol 100, No. 8 和 Vol 100, No. 9）

在 Manufacturing Technology 之下的 Computer Aided Manufacturing（CAM）栏目中可以看到下面有关计算机辅助制造的研究报告的概况。

8-00.826

PB2000-100132/XAB　　PC A04/MF A01

National Aeronautics and Space Administration, Huntsville, AL

George C. Marshall Space Flight Center.

Standard Road Map Project. Criteria Analysis: A Task of

The Manufacturing-Enterprise-Integration Project

Nell, J. G. ; Christopher, N. B. Oct 1999 38p

NISTIR-6408

See also PB99-177214. Product from digital image.

Order this product from NTIS by: phone at 1-800-553-NTIS(U.S. Customers); (703)605-6000(other countries); fax at (703)605-6900; and email at orders@ntis.fedword.gov. NTIS is located at 5285 Port Royal Road Springfield, VA,22161,USA

This document describes a research project to recommend a decision tool that the Manufacturing Systems Integration Division(MSID) could use during its strategic-planning process to evaluate which standard activities to support. This paper describes the criteria selected to give priority, in National Institute of Standard and Technology (NIST) and (MSID) terms，to the standards activities that NIST and MSID do or should support. There are criteria for judging the quality of the standard itself, independent of how applicable to the NIST mission. Other criteria are designed to help MSID decide whether or not to participate in a standard's development. A computer-aided, decision-analysis tool was used to show that computer assistance would be useful to make decisions when many variables impact that decision.

在 Manufacturing Technology 之下的 Tooling, Machinery, & Tools 栏目中有一条关于液力操纵装置的研究报告的介绍。

Hydraulic manipulator design, analysis, and control at Oak Ridge National Laboratory To meet the increased payload capacities demanded by present-day tasks, manipulator designers have turned to hydraulics as a means of actuation. Hydraulics have always been the actuator of choice when designing heavy-life construction and mining equipment such as bulldozers backhoes and tunneling device. In order to successfully design, build, and deploy a new hydraulic manipulator (or subsystem) sophisticated modeling, analysis and control experiments are usually needed. To support the development and deployment of new hydraulic manipulators, Oak Ridge National Laboratory (ORNL) has outfitted a significant experimental laboratory and has developed the software capability for research into hydraulic manipulators, hydraulic actuators, hydraulic systems, modeling of hydraulic systems and hydraulic controls. The hydraulic laboratory at ORNL has three different manipulators. First is a 6-Degree-of-Freedom (6-DoF), multi-planer, teleoperated, flexible controls test bed used for the development of waste tankclean-up manipulator controls, thermal studies, system characterization, and manipulator tracking. Finally is a human amplifier test bed used for the development of an entire new class of teleoperated systems. To compliment the hard ware in the hydraulic laboratory ORNL has developed a hydraulics simulation capability including a custom package to model the hydraulic systems and manipulators for performance studies and control development. This paper outlines the history of hydraulic manipulator developments at ORNL, describes the hydraulic laboratory, discusses the use of the equipment within the laboratory, and presents some of the initial results from experiments and modeling associated with these hydraulic manipulators. Included are some of the results from the development of the human amplifier/de-amplifier concepts, the characterization of the thermal sensitivity of hydraulic systems, and end-point tracking accuracy studies. Experimental and analytical results are included.

现在 NTIS 还在因特网上为用户提供这些报告的检索服务。

图 3.4 是美国国家技术情报服务局（URL　http://www.ntis.gov）的主页。选择 About NTIS 可以了解 NTIS 提供的服务。

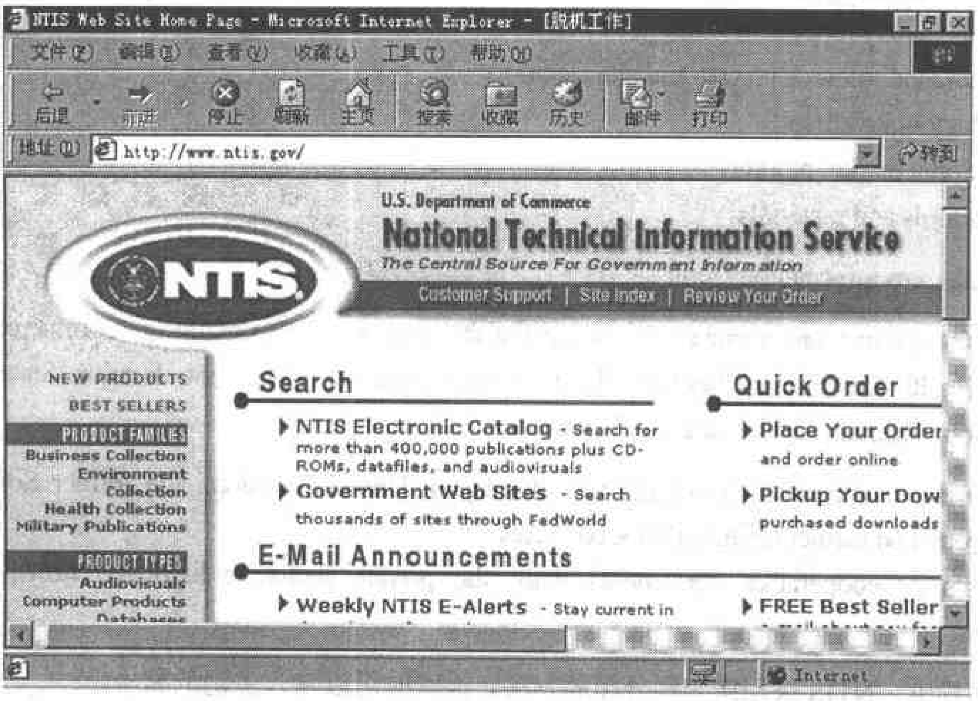

图 3.4　National Technical Information Service

How NTIS Helps You

Whether you are a research scientist, corporate librarian, or government engineer, NTIS can help you today and tomorrow through its mission as the central source for U.S. Government scientific, technical, and business information. For example, you can conduct detailed subject searches through the NTIS Government Research Center's online databases at http://grc.ntis.gov/. You also can use our Web site, http://www.ntis.gov/, to lookup any of the 400 000 documents in our collection since 1990. Perhaps you purchase annually the U.S. Statistical Abstract and need to know when it will be available for sale this year. You can locate that information from our Web site under our bestsellers list.

The NTIS customer comments collected over the last 50 years value the breadth and depth of the NTIS collection, and also praise the speed of locating and fulfilling product orders with friendly customer service. NTIS is known as the government's central source for the sale of scientific, technical, engineering, and related business information produced by or for the U.S. government and complementary material from international sources.

About NTIS' mission

For example you can:

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Learn how NTIS joint ventures with business

Quick facts:

The NTIS collection (by topic) contains nearly 3 million publications and other products covering:
business and management studies
health and safety reports
environmental research reports and site clean-up
technology innovations
international market reports
training tools and materials

NTIS acquires information from:

Over 200 government agencies, including the departments of: Agriculture, Commerce, Defense, Education, Health and Human Services, Housing and Urban Development, Interior, State, Treasury, Transportation, Veterans Affairs, and much more.

International contributors including: Canada, Japan, United Kingdom, the former Soviet Union, Western Europe and former Eastern Block countries.

Contracts or cooperative agreements with: the private sector, individuals, firms, and other organizations.

为方便检索，NTIS 采用按主题分类的方法，检索时可以输入主题的编号。

NTIS Standard Subject Topics

NTIS assigns every product's electronic catalog record with one or more standard subject topics to help you narrow your search.

Using a coding scheme comprised of 38 broad topics and more than 350 subtopics, NTIS has assigned at least one of its standard subject topics to each of the 400 000 electronic catalog records on this web site. These standard topics make it easier for you to quickly create subject subsets when you are looking for information.（下面只列出与机械工程关系密切的主题）

Combustion, Engines, & Propellants
Computers, Control & Information Theory
Energy
Environmental Pollution & Control
Industrial & Mechanical Engineering
Manufacturing Technology
Materials Sciences

Subject Topic List

Below, the broad topics are in bold. Their subtopics follow. Along with each standard topic phrase, is a corresponding subject topic code. You also may search using these codes by entering them in the keyword section on a search form .(只列出了 Manufacturing Technology 类的 subtopics)

Code　　　Topic name

ntiscat41 **Manufacturing Technology**
ntiscat41a Computer Aided Design (CAD)
ntiscat41b Computer Aided Manufacturing (CAM)
ntiscat41c Robotics/Robots
ntiscat41d Productivity
ntiscat41e Manufacturing, Planning, Processing & Control
ntiscat41f Joining
ntiscat41g Quality Control & Reliability
ntiscat41h Plant Design & Maintenance
ntiscat41i Job Environment
ntiscat41j Tooling, Machinery, & Tools
ntiscat41k Engineering Materials
ntiscat41l Tribology
ntiscat41m Optics & Lasers
ntiscat41n Computer Software
ntiscat41o Domestic Commerce, Marketing, & Economics
ntiscat41p Research Program Administration & Technology Transfer

下面列出以质量控制及可靠性为主题检索得到的部分结果。

Some Search Results on Quality Control & Reliability

Intelligent Tool Condition Monitoring in Milling Operation. [1998]
Low-Speed Mini-Motor Failure Recognition Using Fuzzy Theory. [Apr 96]
Failure of Components Although the Causes Are Simple & Well Documented. [1998]
Virtual Company/Distributed Manufacturing Demonstration Project. [3 Jul 97]
USSR Report, Machine Tools and Metalworking Equipment. [16 Mar 87]
In-Situ Nondestructive Examination of Weld Penetration. [9 Nov 98]

3.3 学 位 论 文

大学本科生，硕士研究生和博士研究生毕生时都要完成学位论文，其中硕士论文和博士论文选题一般有新意，并且对所研究的课题阐述详细，因而有较高的参考价值。

美国的 UMI 公司 http://www.umi.com（图 3.5）长期以来一直从事有关学位论文的信息服务。目前 UMI 在因特网上免费为用户提供学位论文的索引和文摘。通过定购可以得到全文。

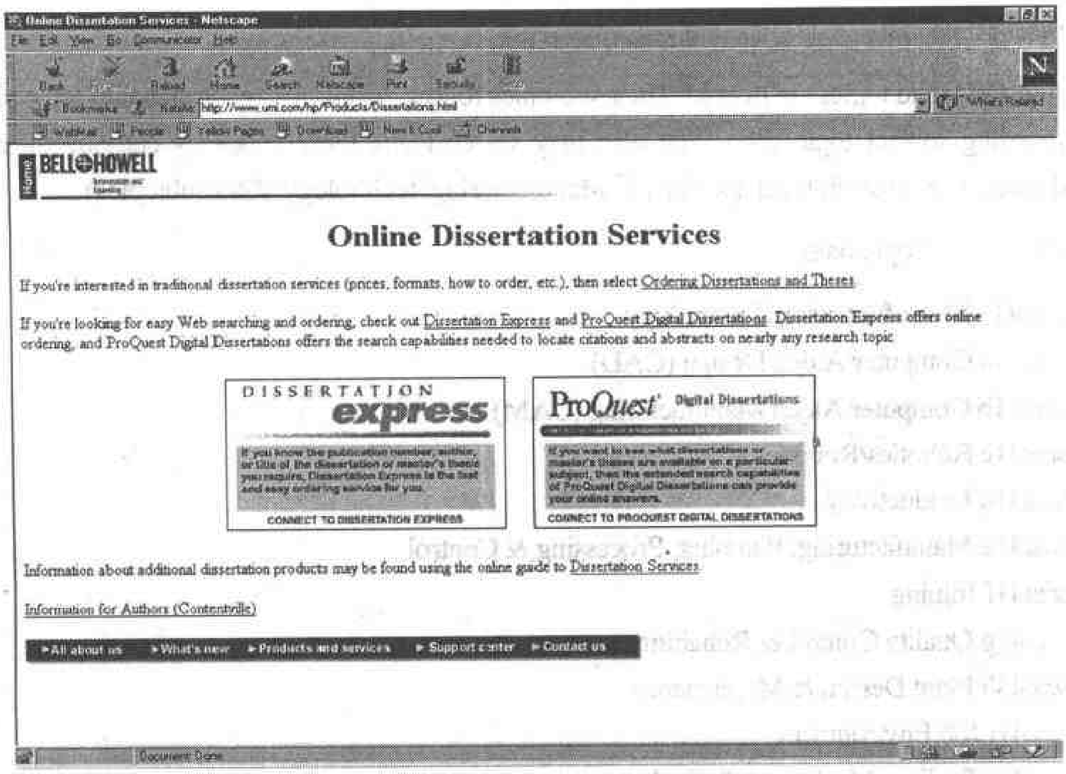

图 3.5 UMI Dissertation Service

下面是一篇有关激光测量技术的博士学位论文的索引和文摘。

Full Citation & Abstract

PUBLICATION NUMBER AAT 9972634

TITLE Laser-induced thermal acoustic velocimetry

AUTHOR Schlamp, Stefan

DEGREE PhD

SCHOOL CALIFORNIA INSTITUTE OF TECHNOLOGY

DATE 2000

PAGES 119

ADVISER Hornung, Hans G.

ISBN 0-599-77944-6

SOURCE DAI-B 61/05, p. 2633, Nov 2000

SUBJECT ENGINEERING, AEROSPACE (0538); PHYSICS, FLUID AND PLASMA (0759); PHYSICS, OPTICS (0752); REMOTE SENSING (0799)

DIGITAL FORMATS 5.01Mb image-only PDF

Laser-Induced Thermal Acoustics (LITA) is a non-intrusive, remote, four-wave mixing laser diagnostic technique for measurements of the speed of sound and of the thermal diffusivity in gases. If the gas composition is known, then its temperature and density can be inferred. Beam misalignments and bulk fluid velocities can influence the time history and intensity of LITA signals. A closed-form analytic expression for LITA signals incorporating these effects is derived. The magnitude of beam misalignment and the flow velocity can be inferred from the signal shape using a least-squares fit of this model to the experimental data. High-speed velocimetry using homodyne detection is demonstrated with NO_2-seeded air in a supersonic blow-down nozzle. The measured speed of sound deviates less than 2% from the theoretical value assuming isentropic quasi-1D flow. Boundary layer effects degrade the velocity measurements to errors of 20%. Heterodyne detection is used for low-speed velocimetry up to Mach number $M=0.1$. The uncertainty of the velocity measurements was & sim; 0.2 m/s. The sound speed measurements were repeatable to 0.5%. The agreement between theory and experiments is very good. A one-hidden-layer feed-forward neural network is trained using back-propagation learning and a steepest descent learning rule to extract the speed of sound and flow velocity from a heterodyne LITA signal. The effect of the network size on the performance is demonstrated. The accuracy is determined with a second set of LITA signals that were not used during the training phase. The accuracy is found to be better than that of a conventional frequency decomposition technique while being computationally as efficient. This data analysis method is robust with respect to noise, numerically stable, and fast enough for real-time data analysis. The accuracy and uncertainty of non-resonant LITA measurements is investigated. The error in measurements of the speed of sound and of the thermal diffusivity initially decreases with increasing signal intensity (excitation beam pulse energy) and increases again after passing a minimum. The location of the minimum error for the speed of sound and for the thermal diffusivity coincide. The errors at the minimum are 0.03% and 1%, respectively. The uncertainties for the speed of sound and the thermal diffusivity decrease monotonically to 0.25% and 5%, respectively. The increased error for high excitation beam pulse energies results from finite-strength waves that cannot be treated using the linearized equations of motion.

3.4 专利文献

3.4.1 专利简介

专利可以看作为国家和发明者之间的协议，国家授予发明者一定期限（一般是二十年）的专利权或独占权，作为条件，发明者应当公布他的发明。在专利的有效期限之内，其他人只有得到发明者的许可之后才能使用受专利保护的发明。但是当专利权到期之后，公众就可以免费使用该发明。专利一方面保护发明者的权益，另一方面也促进社会的技术进步。

当今全世界都普遍实行了专利制度，任何单位或个人，当他准备制造一种产品或实现一种加工方法或工艺过程时，都应该首先查阅专利文献，以确定这种产品或工艺是否受其他人的专利保护。一项发明必须具有创新和实用价值才能获得专利，为了保护自己的利益，发明者在申请专利之前都要保守他的技术秘密。关于发明的技术细节的报道往往都是首先出现在专利文献中。经常阅读专利文献，是及时了解最新的技术进展的有效方法。专利法规定发明者申请专利时必须充分地和详细地说明他的发明，使得同行的专家能再现这项发明。阅读这些技术细节很可能使我们得到启发而形成自己的创见。从产品开发和技术进步的角度看，工程技术人员应当重视专利文献。

重要的专利术语

Intellectual property

The general term for intangible property rights which are a result of intellectual effort. Patents, trademarks, designs and copyright are the main intellectual property rights.

Patent

A patent is an intellectual property right relating to inventions — that is, to advances made in a technical field. A patent for an invention is granted by the government to the applicant, and gives him the right for a limited period to stop others from making, using or selling the invention without permission. In return for this right, the applicant must disclose how his invention works in sufficient detail. When a patent is granted, the applicant becomes the owner of the patent. Like any other form of property, a patent can be bought, sold, licensed or mortgaged.

Patentability

The basic conditions of patentability, which an application must meet before it is granted, are that the invention must be novel, contain an inventive step, be capable of industrial application and not be in one of a number of excluded fields. Patents are not available for, amongst other things, discoveries and scientific theories, mathematical methods, computer software producing no technical effect, methods of doing business and aesthetic creations.

Abstract

A concise summary of the invention described in a patent application. It should include all the most important technical features of the invention.

Claims

A precise statement in English of the invention that the applicant wishes to protect. A main claim will define the invention in its broadest form, by including its essential technical features. Further "dependant" claims can then relate to additional features of the invention.

Description

A full and detailed explanation of the invention and how it works, filed at the Office to initiate a patent application. The description may be accompanied by one or more drawings.

Novelty

If an application for a patent is to be granted, the invention must be novel. This means that the invention must not have been publicly disclosed, anywhere in the world, before the date of filing of the patent application (or before the priority date, if the application has one).

Inventive step

If a patent for an invention is to be granted, the invention must contain an inventive step. This means that the invention must not be an obvious development of what has gone before, when considered by someone who is skilled in the area of technology to which the invention relates.

Specification

The term used to cover the description, drawings and claims contained in an application.

3.4.2 专利文献因特网检索

主要专利文献检索机构有：

世界知识产权组织 WIPO http://www.wipor.int（图 3.6）

美国专利局 USPTO http://www.uspto.gov（图 3.7）

德温特 DERWENT http://www.derwent.com（图 3.8）

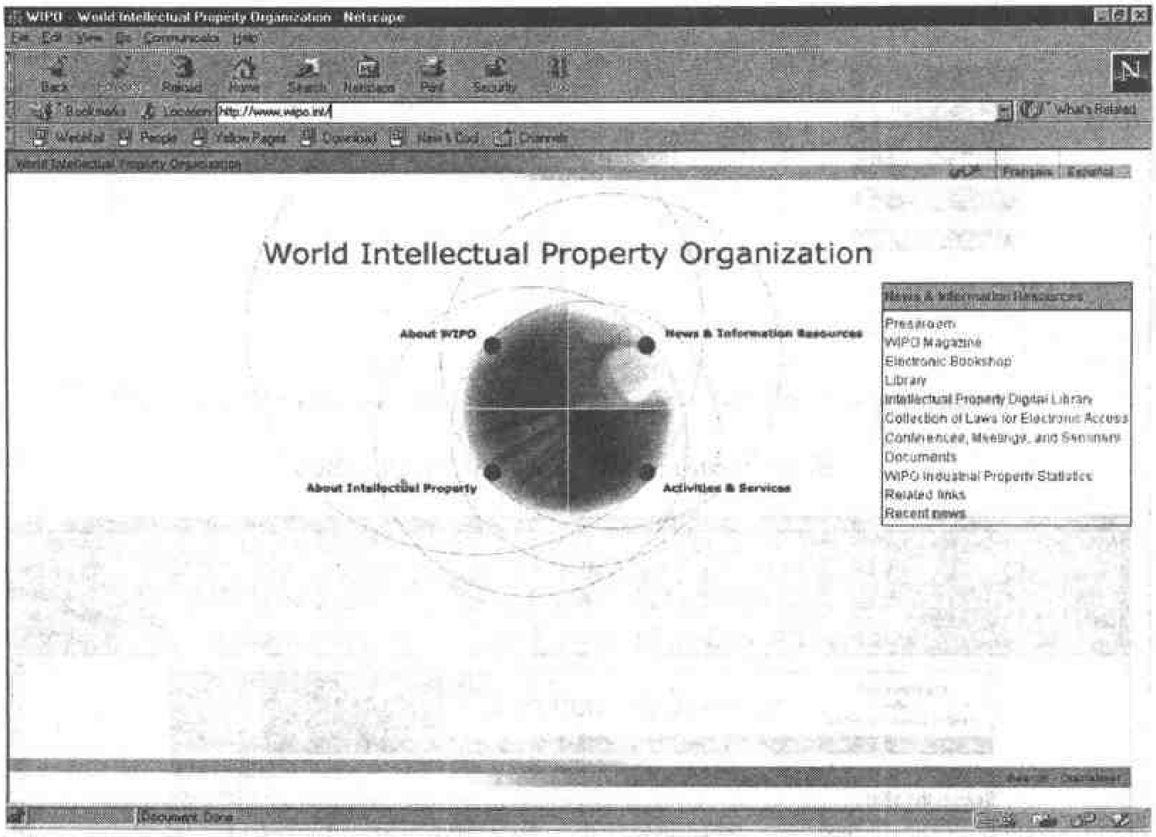

图 3.6 The World Intellectual Property Organization

WIPO 网上检索

在 WIPO 的主页上，链接 news and informationservice，可以看到关于 IPDL 的介绍，并且可了解到如何进行检索。

Intellectual Property Digital Library (IPDL)

The Intellectual Property Digital Library Web site provides access to various intellectual property data collections currently hosted by the World Intellectual Property Organization. These collections include Madrid, PCT and JOPAL (non-patent reference) data and support fully searchable information retrieval and display by users on demand. Access to the Digital Library is available to the general public free-of-charge. The services are operational and are updated on a daily, weekly and monthly basis respectively.

There are currently two levels of access available: Guest and Account. For users with accounts, a search query history is maintained across connections. For guest access, click on Search IPDL or Browse IPDL and, when prompted, enter:

Username: guest

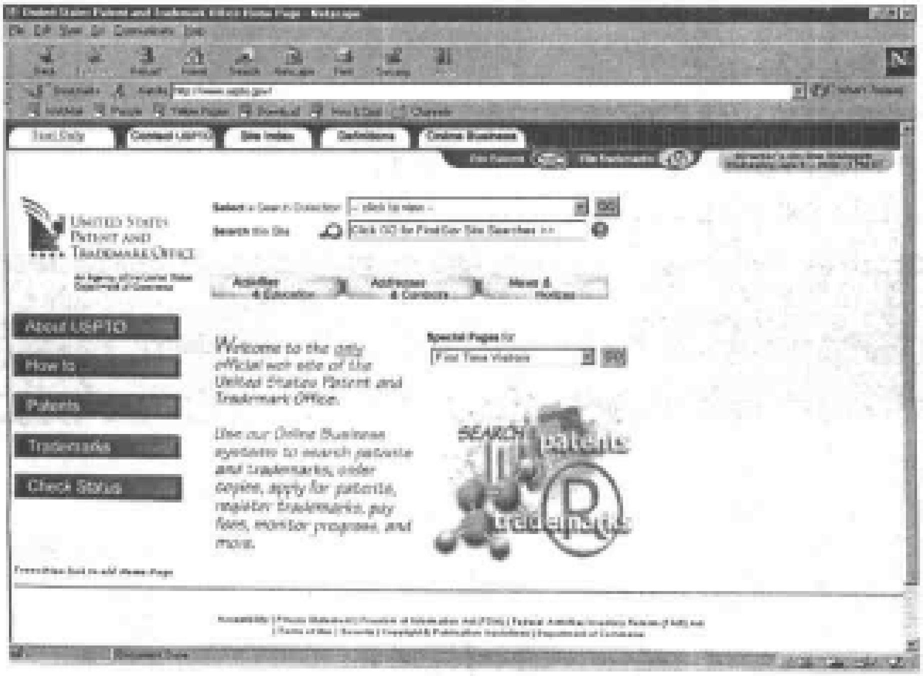

图 3.7 United States Patent & Trademark Office

图 3.8 Derwent Thomson Scientific

Password: guest

If you already have an account, simply click on Search IPDL or Browse IPDL and enter your name and password. To create a new (free) account, click here.

PCT Electronic Gazette

This database contains the first page data (bibliographic data, abstract and drawing) of PCT applications published since January 1997. The first page data of applications published each week in Section I of the Gazette are added to the database. The full-text (image format) of PCT pamphlets is accessible via the "View Images" button on the displayed front page of hit list cases. (Full-text data is available fourteen days after publication.)

Madrid Express

This database provides access to data relating to international applications and subsequent designations that have been received by the International Bureau but have not yet been recorded in the international register of marks, as well as data relating to international registrations and subsequent designations that have been recorded but not yet published in the WIPO Gazette of International Marks. With regard to the former, users are warned that the International Bureau has not yet made a decision on the international applications or subsequent designations concerned.

JOPAL

This database contains bibliographic details of articles published in leading scientific and technical periodicals since 1981. Each month, the latest set of data as provided by the offices is added to the database.

USPTO 网上检索

链接到USPTO的主页，然后选择Seaschable Databases，进入专利数据库首页，从这里可以了解到它提供的专利检索服务。

检索范围:

Patent Grants

Full-text of all US patents issued since 1976

Full-page images of all US patents issued since 1790

Patent Applications

Full-text of all US patent applications published since 15 March 2001

Full-page images of all US patent applications published since 15 March 2001

检索方法:

Quick Search (Two-term Boolean Searching)

Advanced Boolean Searching

Patent Number Searching

USPTO 的专利说明书包括下述内容：

United States Patent　　6 88 945 (美国专利号)

Graf , et al.　　February 13, 2001 (发明者)

Drive train control for a motor vehicle (专利名称)

Abstract (摘要)

Inventors: (发明者)
Assignee: (发明受让者)
Appl. No.: (申请号)
Filed: (申请日期)
Foreign Application Priority Data (国外优先权项目)

Current U.S. Class: (美国专利分类号)
Intern'l Class: (国际专利分类号)
Field of Search: (检索范围)

References Cited [Referenced By] (引用文献)
U.S. Patent Documents (美国专利)
Foreign Patent Documents (外国专利)
Other References (其他文献)
Primary Examiner: (审查者)
Attorney, Agent or Firm: (代理人，代理商或公司)

Claims (专利权项范围)

Description (说明)

BACKGROUND OF THE INVENTION (发明背景)
Field of the Invention (专业范围)
Background Art (技术背景)
SUMMARY OF THE INVENTION (发明摘要)
BRIEF DESCRIPTION OF THE DRAWINGS (附图简述)
DESCRIPTION OF THE PREFERRED EMBODIMENTS (最优实施方案说明)

下面是一个关于扭矩测量的专利说明，因原文较长，本书只摘录了部分内容。

United States Patent 6 202 028
Crane, et al. March 13, 2001

Variable torque rate simulated test joint

Abstract

A variable rate test joint comprises a housing and a shaft mounted within the housing. A hexagonal head is provided for coupling a tool to be tested to the shaft. In use a frictional braking torque is applied to the shaft. A computer controls the magnitude of the braking torque applied to the shaft as a function of time.

Inventors: Crane; David O. (Lutterworth, GB); Quinton; Hedley L. (Castle Donington, GB)

Assignee: Crane Electronics Ltd. (Leicestershire, GB)
Appl. No.: 261536
Filed: March 3, 1999
Foreign Application Priority Data
Sep 05, 1996[GB] 9618408
Jul 01, 1997[GB] 9713806

Current U.S. Class: 702/43; 702/41; 702/42; 73/862.08; 73/862.23
Intern'l Class: G01L 003/00
Field of Search: 702/33,41,42,43 73/862.08,862.12,862.21,862.23,862.24 303/141,155,167

References Cited [Referenced By]
U.S. Patent Documents
3981545 Sep., 1976 Eddy 303/139.
4062233 Dec., 1977 Bonomo 73/862.
4150559 Apr., 1979 Levy 73/862.
4669045 May., 1987 Kubo 702/141.
4762007 Aug., 1988 Gasperi et al. 73/862.
5624164 Apr., 1997 Tozu et al. 303/113.
Other References
PCT Written Opinion dated Jun. 10, 1998, Int'l. Appl. No. PCT/GB97/02375.
PCT Written Opinion dated Aug. 27, 1998, Int'l. Appl. No. PCT/GB97/02375.

Primary Examiner: Hoff; Marc S.
Assistant Examiner: Bui; Bryan
Attorney, Agent or Firm: Marshall, O'Toole, Gerstein, Murray & Borun

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Parent Case Text
This is a continuation of International Application No. PCT/GB97/02375, filed Sep. 5, 1997.

Claims
What is claimed is:

1. A variable rate test joint comprising:
a housing;
a shaft mounted within the housing;
means for coupling a tool to be tested to the shaft; and
brake means for applying a braking torque to the shaft;
wherein the brake means comprises

a brake shoe assembly actuable by electrohydraulic or electropneumatic means and being arranged to act in use directly on the outer cylindrical surface of the shaft to apply a frictional braking torque thereto; and

a computer for controlling the pressure applied to the electrohydraulic or electropneumatic means as a function of time, being arranged to vary in use the applied pressure from a preset threshold to a maximum value over a time period which is variable to reflect the hardness of the joint being simulated.

2. A variable rate test joint according to claim 1, further including means for measuring the braking torque (.tau.) applied to the shaft and the angle (.alpha.) through which the shaft rotates.

...

13. A method for testing torque application tools, the method including the steps of:

coupling the tool to a shaft;

applying a frictional braking torque to the shaft by the direct frictional contact of an electrohydraulically or electropneumatically actuable brake shoe assembly on the outer cylindrical surface of the shaft; and

controlling the magnitude of the hydraulic or pneumatic control pressure acting on the brake shoe assembly to generate the frictional braking torque, using a computer to raise the applied control pressure as a function of time from an initial threshold pressure to a maximum value over a time period which has been preselected to reflect the hardness of the joint being simulated.

...

Description

DESCRIPTION

1. Field of the Invention

The invention relates to calibration equipment for testing the accuracy and consistency of rotary power assembly tools for threaded fasteners, and provides a variable torque rate simulated test joint against which such rotary power assembly tools can be tested.

2. Background Art

...

THE INVENTION

The invention provides a variable rate test joint comprising:

a housing;

...

a shaft mounted within the housing;

...

a brake shoe assembly actuable by electrohydraulic or electropneumatic means and being arranged to act in use directly on the outer cylindrical surface of the shaft to apply a frictional braking torque thereto; and

...

a computer for controlling the pressure applied to the electrohydraulic or electropneumatic means as a function of time, being arranged to vary in use the applied pressure from a preset threshold to a maximum value over a time period which is variable to reflect the hardness of the joint being simulated.

3.5 标准文献

在市场经济环境中标准和质量认证具有重要的作用，工程技术人员必须具备这方面的知识。下面是国际标准化组织对这两个问题的概述。

1 标准和国际标准化组织

Standards and the International Organization for Standardization

What are standards?

Standards are documented agreements containing technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics, to ensure that materials, products, processes and services are fit for their purpose.

For example, the format of the credit cards, phone cards, and "smart" cards that have become commonplace is derived from an ISO International Standard. Adhering to the standard, which defines such features as an optimal thickness (0.76 mm), means that the cards can be used worldwide.

Types of standards

Four major types of standards can be cited:

Fundamental standards which concern terminology, metrology, conventions, signs and symbols, etc.

Test methods and analysis standards which measure characteristics; define the characteristics of a product (product standard) or of a specification standards which service (service activities standard) and the performance thresholds to be reached (fitness for use, interface and interchangeability, health, safety, environmental protection, standard contracts, documentation accompanying products or services, etc.).

Organization standards which deal with the description of the functions of the company and with their relationships, as well as with the modelling of the activities (quality management and assurance, maintenance, value analysis, logistics, quality management, project or systems management, production management, etc.).

Management system standards

Recent years have seen the development and application of what are known as "generic management system standards", where "generic" means that the standards' requirements can be applied to any organization, regardless of the product it makes (or whether the "product" is actually a service activity), and "management system" refers to what the organization does to manage its processes. Two of the most widely known series of international standards falling into this category are almost certainly the ISO 9000 series for managing quality systems, and the ISO 14000 series for environmental management systems. Wide ranging information and assistance related to these standards and their application is available from the ISO members, many of which give extensive information through their Web sites.

ISO (International Organization for Standardization)

Founded in 1947, (ISO) is a worldwide federation of national standards bodies. currently comprising over 125 members, one per country. The mission of ISO is to encourage the development of standardization and related activities in the world in order to facilitate international exchanges of goods and services and to achieve a mutual entente in the intellectual, scientific, technical and economic fields. Its work concerns all the fields of standardization, except electrical and electronic engineering standards, which fall within the scope of the IEC.

IEC (International Electrotechnical Commission)

Founded in 1906, the IEC is responsible for international standardization in the fields of electricity, electronics and related technologies. Its charter embraces all electrotechnologies including electronics, magnetics and electromagnetics, electroacoustics, telecommunication, and energy production and distribution, as well as associated general disciplines such as terminology and symbols, measurement and performance, dependability, design and development, and safety and the environment.

2 质量认证

Certification of Conformity to Standards and Quality Assurance

Definition of certification

Certification is a procedure by which a third party gives written assurance that a product, process or service conforms to specified requirements. (Definition: ISO/IEC Guide 2:1996)

It is distinct from the other systems of proof of conformity such as supplier declarations, laboratory test reports or inspection body reports. Certification is based on the results of tests, inspections and audits and gives confidence to the customer on account of the systematic intervention of a competent third body.

The role of certification

Certification is an asset and an advantage, both for the producer and for the purchaser, consumer or distributor. It gives an incontestable added value to the product or service bearing its mark.

For the manufacturer or service provider, it valorizes the goods or service, it opens up markets and simplifies relations.

For the user, it provides assurance that the product purchased meets defined characteristics or that an organization's processes meets specified requirements. Certain product certification marks may represent an assurance of safety and quality. Certification enables one to distinguish apparently identical products or services; it offers to everyone a possibility of appeal in the event of dissatisfaction.

Types of certification

Product certification attests that a product complies with the safety, fitness for use and/or interchangeability characteristics defined in standard(s), and in specification(s) supplementary to standards where they are requested by the market.

Organization certification demonstrates the conformity of, for example, an organization's quality or environmental management system to the relevant model of the ISO 9000 or ISO 14000 series of management system standards. The different systems of reference are not attached to the performance level of a product.

Accredited testing laboratories

Manufacturers may need the technical help of independent testing laboratories either for developing new products or at the marketing and export stage. Many industrialized countries have made substantial attempts to develop laboratory networks that provide assurance of the quality of testing services (mainly in terms of the quality of results on which they base their decisions).

At international level, this activity falls within the scope of the International Laboratory Accreditation Cooperation (ILAC). One of the objectives of this coordination is to provide companies with better access to the services of those laboratories which are most likely to meet their testing needs and optimize the use of these means.

At national level, there are a number of laboratory networks. The national standards bodies may be contacted for information relative to their countries.

国际标准可从 ISO 的网站 http://www.iso.ch（图 3.9）检索查询

其他提供标准检索查询的机构主要有:

欧洲标准委员会 CEN　http://www.cenorm.be

美国国家标准协会 ANSI　http://www.ansi.org

英国标准协会 BSI　http://www.bsi.org.uk

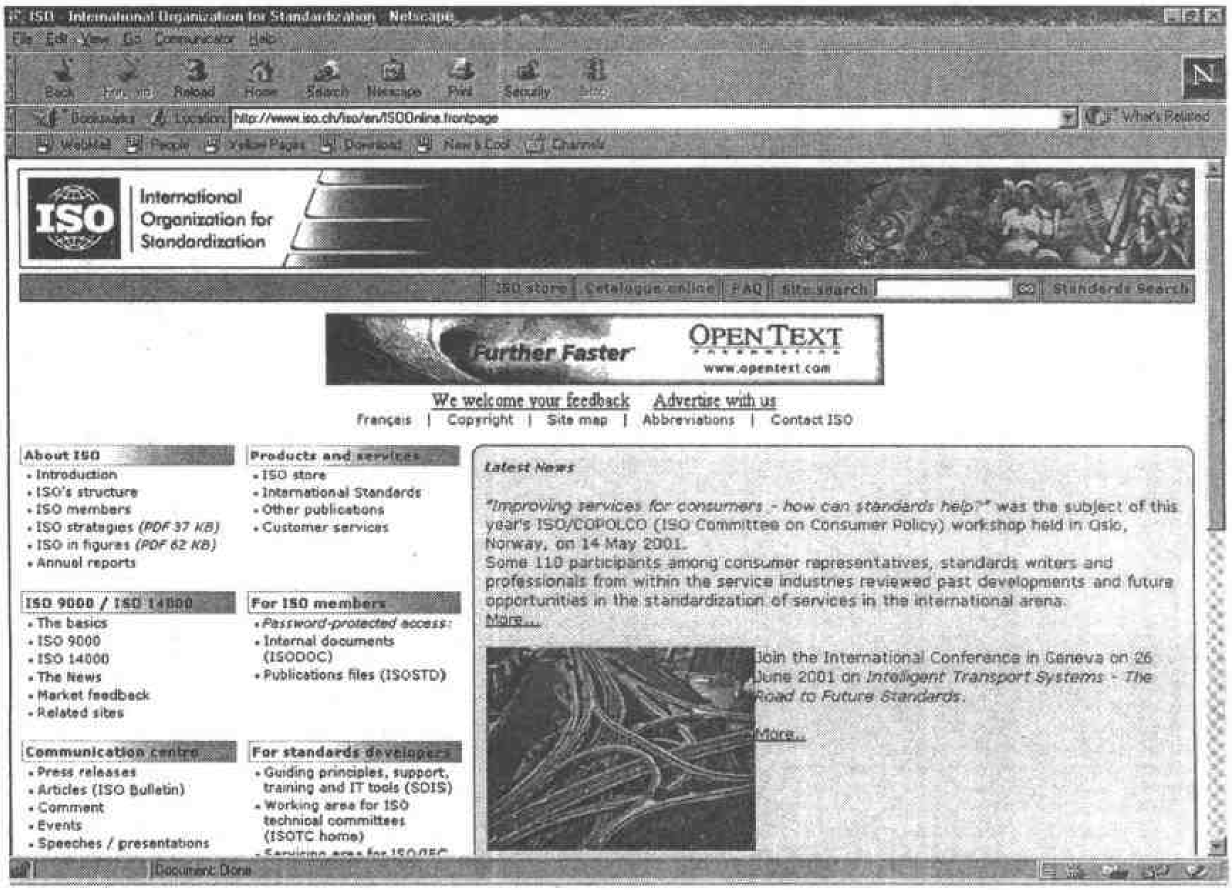

图 3.9　International Organization for Standardization

例：有关紧固件的国际标准目录

ISO 225:1983 Fasteners—Bolts, screws, studs and nuts—Symbols and designations of dimensions

ISO 885:2000 General purpose bolts and screws—Metric series—Radii under the head

ISO 888:1976 Bolts, screws and studs—Nominal lengths, and thread lengths for general purpose bolts

ISO 898-1:1999 Mechanical properties of fasteners made of carbon steel and alloy steel—Part 1: Bolts, screws and studs

ISO 898-5:1998 Mechanical properties of fasteners made of carbon steel and alloy steel—Part 5: Set screws and similar threaded fasteners not under tensile stresses

ISO 898-7:1992 Mechanical properties of fasteners—Part 7: Torsional test and minimum torques for bolts and screws with nominal diameters 1 mm to 10 mm

第 4 章　专业文献的翻译

翻译是把一种语言的信息用另一种语言表达出来，翻译的目的是使译文的读者能得到原作者所表达的思想，得到与原文读者大致相同的感受。翻译涉及到两种语言，而不同的语言各有不同的表达方式，所以翻译决不是从一种语言到一种语言的简单转换，它要求译者进行创造性的实践活动。为了提高翻译能力，不仅要提高外语水平和汉语水平，还必须掌握翻译理论和一些翻译技巧。但应当强调的是翻译是一门实践性极强的学问，仅仅学习翻译理论、翻译技巧是不够的，翻译能力的形成主要靠大量的翻译实践。翻译质量和译者的外语水平、汉语水平有密切的关系，还与译者的相关知识水平有关。从事专业英语翻译的人应该注意提高自己的外语水平、汉语水平和专业知识水平。

4.1 概　　论

4.1.1 翻译的标准

翻译的标准既是衡量译文质量的尺度，也是指导翻译实践的准则，因此翻译的标准一直是翻译工作者关注的问题，严复在 1898 年提出的“信达雅”的翻译标准对后世影响极大。

其中“信”指的是译文要忠实于原文，要把原文中所包含的内容和形式完整地、确切地表达出来，不得有增删和遗漏。“达”指的是译文语言必须符合规范，用词造句应该符合本民族语言的表达习惯，做到通顺易懂。“雅”指的是文字优美高雅。目前我国通用的翻译标准是准确和通顺，这实际上就是“信”与“达”的翻版。由于专业科技英语注重表现技术问题的科学性、逻辑性和严密性，所以专业英语翻译更注重“信”和“达”，即准确和通顺。

【例 1】Although the oil spills have happened repeatedly in the past，significant public concern does not appear to have been aroused until the Torrey Canyon tanker disaster occurred in March 1967.

虽然石油泄漏在过去反复发生，但是直到 1967 年 3 月灾难性的 Torrey Canyon 油轮事故发生之后才引起人们的严重关注。

翻译此句应注意“not…until”是双重否定，含义是“直到……才”，其意义肯定的。

【例 2】In the case of carbon burning in an oxygen bearing atmosphere，diffusion of oxygen to the carbon interface must occur before oxidation of carbon can take place.

可能会译为：当碳在含氧气的大气燃烧时，氧必须扩散到碳界面上，在碳氧化之前。

宜译为：当碳在含氧气氛中燃烧时，在碳氧化之前，氧必须扩散到碳界面上。

翻译此句时应注意 atmosphere 一词不仅有大气，空气的含义还有环境，气氛的含义。

【例 3】A major simplification in the refrigeration plant is achieved by dispensing with an expansion machine and using a simple throttle valve to obtain the reduction in pressure.

不采用膨胀机而采用节流阀使压力降低可使制冷设备得到显著的简化。

翻译此句时应注意 dispense 的含义是分配，发放而 dispensing with 的含义是免除。

【例 4】In the earlier days, for pressure measurement spatial resolutions as well as vibration isolation were significant problems; however, presently the availability of highly sensitive miniature pressure transducers with acceleration compensation have made the measurement task simpler and more reliable.

在早期，对于压力测量振动隔离和空间精度都是严重的问题。而现在，由于有了高灵敏度的具有加速度补偿功能的微型压力传感器，测量工作变得简单可靠多了。

一般情况下 resolution 的意思是决心，决定，决议，但是在讨论测量技术时 resolution 表示精度。

从上面的例子可以看到透彻地理解原文对翻译是非常重要的，而且理解和专业知识有密切关系。在下笔写出译文之前一定要在理解上下足够的功夫。

4.1.2 翻译的过程

当我们进行翻译时，首先要阅读原文，理解作者的思想，然后根据自己的理解，用汉语表达出来。可见翻译包括理解和表达两个过程。翻译是复杂的脑力劳动，一般说来不能一蹴而就，通常为了保证翻译的质量，还应该仔细地反复地校核和修改译文。因此也可以说翻译包括理解、表达和校核三个阶段。

1 阅读理解

阅读理解是翻译过程的第一步，透彻地理解原文是确切表达的前提。阅读理解必须从整体着眼，通过上下文联系，结合专业背景知识。在阅读过程中应注意两个方面，一是通过对词汇含义、语法结构的分析从语言方面理解原文，二是分析原文中的逻辑推理论证过程以理解原文中的逻辑关系。

2 汉语表达

表达是在理解的基础上进行的，然而理解正确并不意味着表达一定正确，要把原文的内容恰如其分地把表达出来，还需要认真地斟酌，选择适当的表达手段。

表达专业科技英语文献的内容时应注意用词简洁准确。专业术语的译名要特别注意，并在全文中始终保持一致，对已经通用的专业术语，应采用传统的译名。

3 检查校核

检查校核是对理解和表达的进一步深化，是一个使译文符合标准的必不可少的阶段，在这个阶段，一方面要对原文的内容进一步核实，另一方面，要对译文的语言进一步推敲。

4.2 英汉语言的对比

本节从翻译的角度分析英语和汉语在词汇和句法方面的特点。了解这些特点对于提高翻译质量有重要意义。

4.2.1 词法的对比

词义的对应关系

不论是在英语中和还是在汉语中绝大多数的词都是多义词，因此英语中的词和汉语中的词的

词义范围大都只是部分对等。两种语言中词义范围全部对等的词很少，一般只有专有名词和科技术语才可能。例如 ratio—比率，temperature—温度，velocity—速度等。

现在我们以 vehicle 为例，仔细地看一下词义范围部分对等的情况。

在英汉词典中可以看到和 vehicle 对应的汉语单词有：

交通工具，车辆，媒介物，传达手段等含义。

在英语词典中 vehicle 的意义为：

any kind of contrivance，on wheels or runners，used to carry people from one place to another over land (e.g. a carriage，a bicycle，a sleigh，etc) a means of transmission

例如 *matter is the vehicle of energy* 物质是能量的载体

a fluid used as a medium for a suspension of a pigment 载色剂

a substance with which the active agent of a medicine is compounded 赋形剂

any person or thing used as a medium to convey ideas，emotions etc.，

例如 *a newspaper is a powerful propaganda vehicle.* 报纸是威力强大的宣传工具。

注意这里把"vehicle"译成了"工具"，但"vehicle"和"工具"的词义范围是有差别的，在英语中表示"工具"的单词还有很多，如 tool，instrument，utility 等。Vehicle 有车辆的含义，汉语中车辆显然不包括雪橇，但是在英语中 sleigh 却属于 vehicle。Vehicle 和车辆、工具等汉语单词在词义范围方面都只是部分地对等。另外我们也看到在化工、制药业 vehicle 还有特定的含义。从这里我们可以感到翻译时应当根据具体情况慎重地选择词义，对于不熟悉的英语单词不能仅仅依靠英汉词典，而应该通过查阅英语词典掌握英语单词在不同场合的含义，并结合上下文和专业知识来确定词义。

词序的差异

汉语是分析性语言，依靠词序表示各成分之间的关系，词序是严格的，而英语的词序比较灵活。英语和汉语的句子中主语、谓语、宾语和表语的词序大体一致，但是定语和状语的位置有时相同，有时不同。在翻译时应该注意汉语的习惯。

定语的位置

英语中可作定语的有单词、短语和定语从句，以单词作定语一般前置，以短语和从句作定语一般后置。汉语的定语一般都在被修饰词之前。

【例 1】Bronze is a very useful metal.

青铜是一种非常有用的金属。

【例 2】There are two types of heat treatment applicable to aluminium alloys.

适合于铝合金的热处理方法有两种。

【例 3】Materials with micropores of <2 nm dia can absorb quite large amount of natural gas.

含有直径在 2 纳米以下微孔的材料能吸附相当大量的天然气。

状语的位置

汉语中状语一般是前置，而英语中状语可前置也可后置。

【例 4】When ignited，the exothermic reaction reaches the welding temperature within a few seconds.

一旦点燃，放热反应就在几秒钟之内达到焊接温度。

【例 5】In operation the temperature of the rotor，the surrounding case and the liquid inside remains in equilibrium as the process temperature changes.

运行时，当过程温度变化时，转子和环绕它的壳体以及其中的液体的温度都处在平衡状态。

【例 6】Although metals are crystalline solids，this is not immediately apparent when they are examined under a microscope.

虽然金属都是晶体组成的固体，但是在显微镜下观察时，这并不是一目了然的。

【例 7】Residual tensile stress develops in such local，compressively deformed metal because the adjacent sound metal does not suffer such plastic deformations.

因为邻近处的完好金属没有受到那样的塑性变形，在受到压缩变形的局部金属中就形成了残余拉伸应力。

4.2.2 句法的对比

1 句子结构转换

从句子结构方面看，英语句子和汉语句子不完全对等。汉语的复合句分为联合复合句、偏正复合句、多重复合句、紧缩复合句。英语的复合句分为并列复合句和主从复合句两类。英语的主从复合句和汉语的偏正复合句大致相当。英语的并列复合句和汉语的联合复合句不完全对等，而且英语没有紧缩复合句。反过来汉语没有名词性从句、定语从句等。因此把英语句子翻译成汉语句子时为了表达通顺，应视需要转换句子结构。句子结构转换大致有以下五种情况：

（1）英语简单句转换成汉语复合句。

（2）英语复合句转换成汉语简单句。

（3）英语复合句转换成汉语复合句。

（4）英语被动结构转换成汉语主动结构，或英语主动结构转换成汉语被动结构。

（5）英语倒装句转换成汉语正常句序。

【例 8】The WP valve ensures a smooth，laminar airflow over its surface，allowing more air into the engine.

WP 阀能使空气以层流状态平顺地流过其表面，从而使更多的空气进入发动机。

【例 9】Much of the pollution caused by cars happens when they change speed.

汽车引起的污染大部分都发生在汽车变速时。

【例 10】Surface ships operate at the interface between two media of differing density (water and air), and are therefore subject to the interaction between them-determination of the most suitable shape is therefore a complex matter for which there is no comprehensive theory.

水面船舶运行在密度不同的两种介质（水和空气）的交界面间，因而受到二者之间的相互作用，所以确定船舶的最适当形状是一个非常复杂的问题，在这方面还没有综合性的理论。

【例 11】A plug-and-play version of the valve，in which electrical and pneumatic connections are achieved by simply sliding the valve into position and looking it，will be seen next year.

明年就会见到这种阀门的即插即用型产品。在新产品中只要把阀门滑动到位并锁紧就可实现电气和气动连接。

【例 12】Then comes the analysis (or computation) of internal forces.

接下来进行内力分析（或计算）。

2 主句和从句的顺序

英语的复合句中表示时间和因果关系的从句的位置比较灵活，但是汉语的表达习惯是按时间

顺序叙述，先发生的事件先说，后发生的事件后说，谈到因果关系时，先说明原因，后叙述结果。因此在翻译有时间和因果关系的复合句时，要注意按照汉语的习惯表达。

【例 13】Although metals are crystalline solids, this is not immediately apparent when they are examined under a microscope.

虽然金属都是晶体组成的固体，但是在显微镜下观察时，这并不是一目了然的。

【例 14】Residual tensile stress develops in such local, compressively deformed metal because the adjacent sound metal does not suffer such plastic deformations.

因为邻近处的完好金属没有发生那些塑性变形，受到压缩变形的局部金属区域中就形成了残余拉伸应力。

4.3 英译汉词汇翻译

本节介绍英译汉时经常采用词汇翻译的方法，主要讨论词义的选择、引申、转换以及增减词等。

4.3.1 词义的确定或选择

翻译时遇到的第一个问题就是如何选择词义。在专业英语文献中，有一些词汇只有一种特定的专业含义。翻译时要注意采用传统的译法。

【例 1】The ferrous metals can be classified into steels, cast irons, and wrought irons.

黑色金属可分为钢，铸铁和熟铁。

【例 2】Since pig iron and scrap are cheap, and because there is no expensive refinement process, cast iron is a low cost material compared with steel.

由于生铁和废钢铁都便宜，又因为不需要昂贵的精炼过程，和钢相比铸铁是一种廉价材料。

英语中有很多词汇本身是多义的，并且英语词汇和汉语词汇大多不是一一对应的。在专业科技英语文献中出现的词汇中，有些词汇在不同专业领域有不同的含义，所以词义的选择或确定应从词的类别、词的搭配、上下文联系和专业知识等方面着手。

例如：在科技英语中 term 有条款，术语，项，称为等含义。

【例 3】Each term of the Bernoulli equation has the dimension of force per unit area.

伯努利方程中的每一项的量纲都是单位面积上的力。

【例 4】The second term $\rho v^2/2$ in the Bernoulli equation is termed the dynamic pressure.

伯努利方程中的第二项 $\rho v^2/2$ 称为动压。

又例如："power" 一词在科技文献中出现频繁，在不同专业范围和不同的词搭配时有不同含义。

【例 5】Power can be transmitted over a long distance.

电力可远距离输送。

【例 6】Friction causes a loss of power in machines.

摩擦引起机器的功率损耗。

【例 7】Knowledge is power.

知识就是力量。

还有："differential" 在数学中有微分的含义，而在机械中有差速器的含义。

【例 8】Fluid flows are described by sets of non-linear partial differential equations.

流体的流动可用非线性偏微分方程组来描述。

【例 9】The drive train uses two differentials，with one to produce forward and reverse motion and the other to produce a difference in speed between the two sides.

传动装置有两个差速器，一个用于产生向前和向后的运动，另一个在两侧形成速度差。

4.3.2 词义引申

翻译时有时会遇到一些词在词典里找不到恰当的词义。这时，应该从词的基本含义出发，根据上下文联系引申词义。

【例 10】Rather than the proposed 20-cell design，a smaller 10-cell version was manufactured to keep development cost down without compromising technical evaluations.

为了降低研究开发成本而又不影响技术评价，没有实施原来拟定 20 单元方案，而制造了一个更小的 10 单元的样品。

【例 11】Each uranium isotope is part of a decay series; when U-238 decays，the daughter element is also radioactive and decays，producing another radioactive daughter，and so on，until a stable element is reached.

铀的每一种同位素都是一个衰变系列，U—238 衰变时，其子代元素也是放射性的并继续衰变，生成下一代放射性元素，就这样继续下去，直到得到稳定的元素为止。

【例 12】Carbon dioxide，methane，and gas molecules that have a similar structure may influence the global climate by the following mechanism: Internal molecular vibration and rotation cause these molecules to absorb infrared radiation.

二氧化碳，甲烷，以及一些有相似结构的气体分子通过下述作用影响全球气候：内部分子的振动和旋转使得这些分子吸收红外辐射。

4.3.3 词性转换

英语和汉语在结构和表达习惯上都有很大差别。因此，在英译汉时，有时把英语名词译成汉语动词，有时把英语动词译成汉语名词等等。

1 转译成汉语动词

一个英语句子只能有一个谓语动词，而汉语中动词使用的较多，可以几个动词连用。汉语中使用动词的场合，英语常用名词、形容词、介词或副词等来表达。在英译汉时应按照汉语的习惯把它们转译成汉语动词。

【例 13】The application of mathematical analysis to the solutions of complex technical problems is almost impossible.

用数学分析来解决复杂的技术问题几乎是不可能的。(英语名词转译成汉语动词)

【例 14】Paper filters are used to separate out oil and capture solid particles from hydrocarbon combustion.

纸质过滤器用分离机油和捕获碳氢化合物燃烧生成的固体粒子。（英语介词转译成汉语动词）

【例 15】Weather patterns determine how air contaminants are dispersed and move through the troposphere.

天气类型决定了气体污染物在对流层中如何扩散和运动的。（英语形容词转译成汉语动词）

【例 16】The construction of the dam was two months behind.

这座大坝的工期耽误了两个月。（英语副词转译成汉语动词）

2 转译成汉语名词

【例 17】The two stage turbine features air cooled first stage rotor and nozzle blading.

这种双级透平的特点是第一转子和喷嘴叶片采用气冷。（英语动词转译成汉语名词）

【例 18】This book aims at giving a general outline of the subject.

本书的目的是给出本学科的梗概。（英语动词转译成汉语名词）

【例 19】Water is at a maximum density at 4°C; water both colder and warmer than this is less dense, and therefore ice floats.

水在 4°C 时的密度最大，不论是再冷点的水还是再热点的水，其密度都要低些，因此冰浮在水上面.（英语形容词转译成汉语名词）

【例 20】A standard method for measuring atmosphere SO_2 may be represented schematically as in Fig.18.1.

图 18.1 给出一种测量大气中 SO_2 的标准方法的简图。（英语副词转译成汉语名词）

4.3.4 句子成分的转换

由于英语和汉语的句子结构不尽相同，翻译时为了使译文通顺，有时需要将原文中的某一语法成分译成另一种语法成分。

【例 21】When traces of metal magnesium or cerium are added to ordinary grey cast iron, the graphite flakes become redistributed throughout the mass of the metal as fine spheroids of graphite.

当把微量的镁或铈加到普通灰铸铁中时，片状石墨就以细小的石墨球的形式在金属母体中重新分布。（表语转换成谓语）

【例 22】A large number of parameters affect the drag or flow around an obstacle.

影响障碍物的阻力或其周围流动的参数有很多。（主语转换成表语）

【例 23】There are three states of matter: solid, liquid and gas.

物质有三态：固体，液态和气态。（定语转换成主语）

【例 24】The more carbon the steel contains, the harder and stronger it is.

钢的含碳量越高，就越硬，强度也就越高。（表语转换成主语）

4.3.5 增词和减词

由于英语和汉语在遣词造句方面的差别，翻译时应注意在词量上有所增减。有时需要在译文中增加原文中无其形而有其意的词。有时原文中的有些词在译文中不译出来，因为译文中虽无其词，但已有其意。

1 增词译法

增词译法主要用于英语省略结构、短语结构、有指代关系的结构和有动作意义的名词。

【例 25】Creep is defined as the gradual extension of a material under a constant applied load.

蠕变是指材料在不变的载荷作用下逐渐伸长的现象。

【例 26】A lubricant is any substance which，when inserted between the moving surfaces，can reduce the friction，wear，and heating of machine parts.

任何物质，只要当把它置于两运动表面之间时，能减少摩擦、磨损和机器零件的发热，就可称为润滑剂。

【例 27】The material selected for the components is IN 939，chosen for its good corrosion resistance and creep strength.

制造这种零件的材料是 IN 939，选用它的原因是这种材料具有良好的抗腐蚀性能和高的蠕变强度。

【例 28】This form of construction enables close quality control of the component parts and therefore of the whole assembly.

采用这种结构形式能够实现对组成零件的质量进行严格地控制，从而实现对装配总成的质量控制。

【例 29】Traffic on roads，even when they are complete paved，is also a major source of dust，smoke，and aerosol emissions.

道路上的交通，甚至当道路是完全铺盖的情况下，也是灰尘、烟和悬浮质的主要排放源。

【例 30】The simplest representation of viscoelasticity is the combined feature of Hookean solid and Newtonian liquid. The former provides an elastic compent，and the latter a viscous component.

表述粘弹性最简单的方法是综合胡克固体弹性定律和牛顿流体粘性定律的特点，前者提供了弹性分量，后者提供了粘性分量。

【例 31】With all these tentative decision made，a lubricant can be selected and the hydrodynamic analysis made as already presented.

当把这些试探性的决定确定之后，就可选定润滑剂，并可按前述的方法进行流体动力学分析。

2 减词译法

很多情况下英语原文中一些词如冠词、代词和介词等在译成汉语时可省略不译。

【例 32】An atom is the smallest particle of an element.

原子是元素的最小粒子。

【例 33】Flexible machine elements，such as belts，ropes，or chains，are used for the transmission of power over comparatively long distance.

柔性零件，例如皮带，绳索，或者链条，用于向较远距离传递动力的场合。

【例 34】Ventilation is one way of reducing emissions in the workshop，however，you cannot depend on this alone to solve your dust problem.

通风是一种降低车间内污染排放的方法，但不能只依靠它解决粉尘问题。

【例 35】Naturally occurring composite materials include examples such as wood，bone and corn which are based upon naturally occurring fibres of cellulose，collagen and keratin respectively.

天然的复合材料包括诸如木材、骨头和角等，它们分别由纤维素，胶原质以及角蛋白组成。

【例 36】Water treatment is often necessary if surface water supplies are to be available for human use.

当把地表水供人使用时，通常需要处理。(supplies ***n. pl*** 供给物供应品)

4.4 被动语态和否定句的翻译

4.4.1 被动语态的翻译

英语中被动语态使用得很广泛，在科技英语中使用得更多，而汉语中被动语态的使用范围要窄得多。因此英语被动语态应尽量翻译成汉语主动语态

【例 1】Metals are widely used in industry.

金属广泛地应用在工业上。

【例 2】All bodies are known to possess mass.

大家都知道所有的物体都有质量。

【例 3】It is generally recognized that light has a vast capacity for transmitting information.

一般认为，光传播信息的容量极大。

【例 4】The mechanical energy can be changed back into electrical energy by a generator.

采用发电机可以把机械能再转换回去成为电能。

【例 5】The raw material is introduced at the higher end and moves steadily down the kiln to the burning zone.

原料从窑的较高端进入并稳定地向下运动，到达燃烧区。

当英语被动句强调主语时，翻译时用原文的主语作译文的主语构成汉语被动句，以体现这种强调。

【例 6】The direction of a force can be indicated by an arrow.

力的方向可用箭头表示。

【例 7】Heavy metal pollution，including lead，zinc，and cooper may be caused by corrosion of the very pipes that carry water from its source to the consumer.

重金属污染，包括铅、锌和铜的污染可能正是由于把水从水源输送到用户的管道本身的腐蚀而引起的。

科技英语中有很多以“It”作形式主语，以被动语态作谓语的习惯用法，其中有些着重于强调状态和性质。

常见的句型如下：

It is assumed that	假设，假定
It is expected that	预期，人们希望
It is found that	人们发现
It is hypothesized	假设
It is known that	众所周知
It is proposed that	一般认为，有人提出
It is suggested that	有人建议
It is supposed that	据推测

4.4.2 否定句型

英语中表示否定概念的形式有多种，其中部分否定和否定转移与汉语的表达差别甚大，容易引起误解，应该特别注意。

1 部分否定

英语中 all，both，each，every，many，much，always，often 等词与 not 搭配表示部分否定。

【例 8】All metals are not good conductors.

金属并非都是良导体。

【例 9】Every machine here is not produced in our factory.

这里的机器并不全是我厂制造的。

2 否定转移

否定转移指的是否定对象的转移，不是否定紧跟其后的动词，而是否定后面的从句或从句中的谓语。

【例 10】I do not believe that percentage humidity and relative humidity are the same.

我确信湿度百分率和相对湿度不是一回事。

3 意义否定

英语中有一些词或词组本身具有否定的意义，含有这些词的句子形式上是肯定句，但意义上是否定句。

常见的具有否定意义的词汇和词组有：

deny，fail，lack，miss，free from，hardly，seldom，in vain，too…to，until，without 等。

【例 11】Flame-hardening is used on small lots because of its adaptability and freedom from special tooling and setup.

由于适应性好以及不需要专用工具和装备，火焰硬化工艺用于小批量产品。

【例 12】This equation is far from being complicated.

这个方程一点也不复杂。

4 双重否定

两个否定意义的词出现在同一个句子中形成双重否定。双重否定表达的意思是肯定的，翻译成汉语时可译成双重否定形式，也可译成肯定形式。

常见构成双重否定的搭配有：

can't…without，never…without，no…unless，no…but，not(none)…the less，not…until 等。

【例 13】There is no grammatical rule that has no exceptions.

没有一条语法规则没有例外。

【例 14】The fractures were not discovered until the machine parts were sectioned while searching for the cause of service failures.

直到为寻找失效原因而把这些机器零件剖开时才发现了这些裂纹。

4.5 长句的翻译

科技英语在表达复杂概念时，为了说理清楚、思路连贯和逻辑严密，常用多重复合句，句子长，结构复杂。翻译这种句子时，先要弄清楚原文的语法结构和逻辑关系。然后按汉语的表达习惯，用短句分层次逐步译出。翻译英语长句通常采用的方法有顺序译法、逆序译法和分译法，而且有时往往需要同时使用几种方法。

1 顺序译法

对专业英语翻译而言，只要不大违反汉语的行文习惯和表达方式，一般应尽量采用顺序译法。

【例 1】In some mechanical systems there may be internal forces which are proportional to the velocity with which their points of application move and which oppose the motion as in viscous dampers; such forces dissipate energy as heat.

在某些机械系统中可能存在着一些内力，这些内力的大小和它们的作用点的速度成比例，并且这些内力像粘性阻尼一样阻碍运动，把能量耗散为热。

2 逆序译法

当英语句子的表述层次和逻辑顺序和汉语相反时，需要按汉语的习惯表达方式将英语句子全部或局部逆序译出。

【例 2】The simplification of assuming the fluid to be inviscid may not be made when analysis of heat convection are undertaken，because the process of convection of heat away from the wall is intimately concerned with thermal conduction and energy transport due to motion in the fluid layers in the immediate vicinity of the wall.

因为从壁面带走热量的对流过程与热传导和壁面直接邻近区域内由流体层运动所产生的能量传递密切相关，所以进行热对流分析时，不能简单地假设流体为无粘性的。（because 和 when 引起的两个状语从句用逆序法逆序译法）

3 分译法

英语句子中，有些句子成分与其他部分关系松弛，具有意义上的独立性，需要分出来译成分句。

【例 3】This book is a practical guide aimed at those thousands of practicing engineers who may have a general understanding of the concept of reliability，but who lack，or have forgotten，the precise understanding of the language of Reliability Engineering to be able to confidently make effective practical use of the technique involved.

本书的目的是为众多的实际工作的工程师提供关于可靠性的实用性指导，他们可能对可靠性的概念有一般性的了解，但是他们或是对可靠性工程术语缺乏确切的理解，或是忘记了，因而对在实际中有效地使用有关的技术信心不足。（由两个 who 引起的两个定语从句译成分句）

4.6 定语从句的翻译

1 限制性定语从句

限制性定语从句通常译为前置定语，但当限制性定语从句本身过长或与被修饰词关系松弛时需要把它单独译成一个分句。

【例 1】Polymers which conduct electricity like metals，and new methods of making them，are set to revolutionize materials technology.

能像金属那样导电的高分子聚合物和生产它们的新方法将在材料技术领域引起革命性的变化。

【例 2】The balance is essentially a pendulum which can tilt in any direction.

平衡机实质上是一个可向任何方向倾斜的摆。

【例 3】The cam is driven by a known input motion, usually a shaft which rotates at constant speed, and it is intended to produce a certain desired output motion for the follower.

凸轮由一个已知的输入运动驱动，通常是一个等速转动的轴，从而使从动件产生预期的输出运动。

【例 4】An interesting feature of the new unit is that it uses a patented method of heating based on high frequency induction which provides high level of efficiency.

新设备有吸引力的特点是它采用了有专利权的高效率的高频感应加热方法。

【例 5】Fuel consumption on two-stroke engines can be cut by up to 50 per cent with a new low cost fuel injector which uses the kinetic energy in a column of liquid as its power source.

采用一种新型低成本的喷油器，可使二冲程发动机的燃油耗降低百分之五十。这种喷油器利用液柱的动能作为其动力。

2 非限制性定语从句

非限制性定语从句与其所修饰的名词关系不密切并有逗号与之隔开，这种从句一般译成并列句或独立句。

【例 6】Some 200 year ago, an unknown engineer invented the Oldham coupling, which allows two parallel but misaligned shafts to be efficiently coupled.

大约 200 年前，有一个不知名的工程师发明了 Oldham 联轴器，这种联轴器能把两个互相平行但又未对中的轴有效地联结起来。

【例 7】When a rigid body has a motion of pure translation, the resulting inertial force and the resulting external force have the same line of action, which passes through the mass center of the body.

当刚体做纯平移运动时，惯性力的合力和外力的合力作用在同一条线上，此线通过物体的质量中心。

【例 8】The high performance fans located inside the alternator body at each end of the rotor coil help to keep the unit cooler than previous generations, which only had a single external fans.

位于交流发电机机体内，转子线两端的两台高性能风机有助于使电机的冷却效果优于老产品，老产品只在机体外面配了一台风机。

有时定语从句含有原因、让步、条件等意义，这时应将其译成状语。

【例 9】These polymer chains when coiled exhibit plasticity, but some, when they are cross-linked, loss plasticity and become elastic.

这些高聚合物链在卷曲时呈塑性，但有些在交联时失去塑性呈现出弹性。

【例 10】Vibrating systems, whether lumped or distributed, are described by differential equations, and like them can be classified as linear or non-linear.

不论振动系统是集总式还是分布式，它们都可用微分方程来描述，和振动系统相似这些方程也可分为线性方程和非线性方程两类。

3 由 which 或 as 引导的特种定语从句

由 which 或 as 引导的特种定语从句并不修饰某一名词，而是补充说明整个主句，其中的 which 或 as 代表主句。这种从句翻译成单独的句子，which 或 as 译成“这”。

【例 11】Nowadays external treatment of water involves the principle of ion-exchange, which ensures water of virtually zero hardness.

如今水的外部处理涉及离子交换原理，这确保水的硬度几乎为零。

【例 12】The increased stress reduces the velocity of sound in the metal，which further increases the echo time.

应力的增大使得声波在金属中的传播速度降低，这进一步延长了回声到达的时间。

【例 13】As has been previously stated，there are certain cases，such as cylinders，discs，curved bars，in which it is rather more convenient to use cylindrical co-ordinates.

如前所述，在有些场合，如圆柱体，圆盘，曲杆等，应用圆柱坐标系更方便。

【例 14】As will be shown by test data，the surface strength of steel specimens may be as low as one-half that of the subsurface material.

试验数据将表明，钢试件表面的强度可能只有表面底下材料强度的一半。

4.7 数量增减的译法

表示数量和倍数的增加有两个概念：净增加的数量和倍数和增加后的数量和倍数（包括基数），翻译时要注意分清“增加了……”和“增加到……”的区别。表示数量减少也有两个概念：净减少值和减少后的数值，译为“减少了……”和“减少到……”。例如：

increase N times 译为“增加到原来的 N 倍”或“增加了 $N-1$ 倍”。

reduce N times 译为“减少到原来的 $1/N$”或“减少了$(N-1)/N$”。

在表示增减意义的谓语之后跟

to+数字或倍数：表示增加到或减少到。

by+数字或倍数：表示净增减数或净增加的倍数。

by a factor of N：表示增加到原来的 N 倍或减少到原来的 $1/N$，（即增加了 $N-1$ 倍或减少了 $N-1/N$）。

【例 1】The cost was reduced to 30%.

成本减少到 30%。

【例 2】The cost was cut down by 30%.

成本减少了 30%。

【例 3】The price was increased by a factor of 2.

价格提高到（原来的）2 倍。（即提高了 1 倍）。

【例 4】The new device will reduce the error probability by a factor of 5.

新设备将使误差概率降低 4/5。[即降低到（原来的）1/5]

【例 5】Suppose a cylindrical tube of the type discussed above is to have its second moment of area increased by a factor of ρ while the area remains constant. Then，since $I=\pi r^3t=AK^2=2\pi rt(r^2/2)$ this requires that r be increased by a factor of $\sqrt{\rho}$ whilst simultaneously the thickness of the tube must be reduced by a factor of $\sqrt{\rho}$.

如果要把上述的圆柱形管的面积二阶矩增大 ρ 倍，并保持面积不变，则由等式

$$I=\pi r^3t=AK^2=2\pi rt(r^2/2)$$

可知，r 应增大 $\sqrt{\rho}$ 倍，同时管壁厚度应减少到原来的 $1/\sqrt{\rho}$。

专业科技英语文献中还会遇到一些表示数量近似的习惯短语，如：

Order of magnitude　数量级，
of the order of　约为
within a factor of ten　在一个数量级范围内

【例 6】Either the inertial force or the viscous force，or both，must be of the same order of magnitude as the buoyancy force.

或者是惯性力或者是粘性力，或者是它们二者，其大小都必定和浮力是一个数量级。

英 译 汉 练 习

1. Assumptions and approximations

Exact solutions for stress，displacements，etc.，in real engineering problems are not always mathematically possible and even those that are possible can involve lengthy computation and advanced mathematical techniques which are not necessarily justifiable. This is because we seldom know the exact conditions of applied loading on a component or structure for its expected working life，and the materials used are not wholly predictable in behavior. It therefore becomes necessary and desirable in most engineering problems to make some simplifying approximations and assumptions，while not changing the basic nature of the problem，will allow a simple solution and an answer which is not too far from the truth. It is important，however，that any approximations or assumptions are clearly stated at the start so that the reader may assess the validity of the answer in respect of what might be the exact solution.

Some of the problems to follow are in general not statically determinate but，with some realistic geometrical limitations，they can be solved purely from equilibrium conditions to give answers which although not exact，are reasonably accurate for the purposes of engineering design.

2. Stress relieving

Most iron castings have internal stresses when they are released from the mould. These stress not only reduce the strength of the casting，they may also cause it to warp and distort during machining. Traditionally，machine beds and frames which were required to be dimensionally and geometrically stable were "weathered"；that is they were rough machined and left out of doors for a period of time varying from months to years. The continual changes in temperature caused diffusion of the internal structure coupled with continual expansion and contraction. This resulted in the release of the internal stresses and allowed the casting to warp to their final shape so that，after finish machining no further distortion took place.

Nowadays，castings are more like to be relieved by soaking them in furnace at (approxi mately) 550℃ for a period ranging from several hours to several days，depending upon the size of the casting. Very slow cooling follows the heating. Thus the temperature for the stress relief of iron castings is very much lower than that for the whole annealing of steel castings and forgings.

weather 时效
annealing 退火

3. LearnIT system

We describe LearnIT, a computer program that can observe an iterative solution to parametric design problem and learn the strategy employed. When the design requirements change, the program uses the learned strategy to automatically generate a new solution in the "style" of the original. The program uses a specialized instance–based learning method based on observation the iterative design is often a form of debugging–each iteration is an attempt t repair a particular flaw in the design. Thus the program learns the design strategy by observing what actions are taken in response to each kind of flaw.

第5章　科技论文写作

学术交流是促进科学技术发展的重要因素，撰写科技论文是科技工作者必须完成的工作之一。随着我国科学技术的迅速发展，我国的科技工作者参与国际交流的机会越来越多，学习用英语写作科技论文已经成为科技工作者的迫切需要。本章将简要地介绍英语科技论文的写作方法和写作的注意事项。

5.1　论文的组成部分

国际标准化组织，美国和英国的标准化组织都对科技论文的写作作出了规定。一些重要的学术期刊对所刊登的论文也有具体的要求。但是，一般说来期刊类科技论文主要由标题、摘要、正文、致谢、参考文献和附录等部分组成。

例如 The Proceedings of the Institution of Mechanical Engineers 对论文的内容和顺序要求如下：

The preferred order of contents is as follows:

1. Title of paper.
2. Author (s) name (s) and business address (es).
3. Synopsis of not more than 200 words: covering the aim of the work, methods used, results obtained and conclusions reached, keywords for information retrieval purposes should be indicated.
4. List of notation in alphabetical order, defining all the symbols used in the paper.
5. Body of the paper: organized into logical sections sequentially, numbered with no more than two grades of subheadings.
6. Acknowledgements.
7. References in the order to which they have been referred in the text.
8. Appendices.
9. Tables: these should be numbered consecutively throughout the text.
10. List of captions for the illustrations, which should be numbered consecutively throughout the text; both line drawings and photographs must be included in the same numbering sequence.

5.2　标题和摘要

标　题

标题是一篇论文给读者的第一印象，标题应该引人注目以吸引读者，但最重要的是标

题要反映论文的主要内容。写标题时要选用：（1）The most precise words possible.（2）Words that indicate the main point of the paper.（3）Words that lend themselves to indexing the subject.

CBE Style Manual 对标题的写作提出了下述建议：

The title should be as informative as possible within the limit of length，which should be stipulated by the journal in its information-for-authors page. A title should be straightforwardly descriptive and eschew hyperbolic rhethoric. The title should start with a word or term representing the most important aspect of the article，with the following terms in descending order of importance，if possible. Standard terms for formal scientific nomenclatures should generally be preferred to common or nonstandard terms.

摘　要

摘要的作用是：（1）To show the reader very quickly whether the full report is valuable for further study.（2）To be extracted（abstracted）from the full report for separate publication.（3）To furnish terminology to help in literature searches by individuals or by literature retrieval specialists for indexes and computer banks.

为达到这些目的，The abstract must be a short，concise，but self-explanatory report on a scientific investigation.

摘要的内容 The abstract must include（1）The research objective and basic justification for conducting the investigation.（2）The basic methods used.（3）The results and significant conclusions that can be drawn.

摘要的长度 Most journals specify that the abstract should not exceed 200 to 250 words or 3 to 5% of the length of the paper itself and the form should be one paragraph.

CBE Style Manual 对摘要的写作提出下述建议：

Abstract

The content and sequence should accurately and objectively represent the text and include the major elements of the method，findings，and conclusions. Abstracts of research reports should be informative（ANSI 1979），giving specific summaries of all elements of contents. For reviews and other similarly long and wide-scope articles，abstracts have to be indicative（ANSI 1979），simply sketching out the topics of the article and not summarizing evidence and conclusions. Abbreviations should not be used unless they are understood when standing alone. Abstracts should not include bibliographic reference or tabulated data.

In general，abstracts should be single paragraphs and carry no subheadings. It should be no longer than the length limit stipulated in the journal's information-for-authors sheet.

摘要实例：

【例 1】这是一篇研究圆柱形薄壳固有振动频率论文的摘要。

Prediction of natural frequencies for thin circular cylindrical shells

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Abstract：In this paper an analytical procedure is given to study the free-vibration characteristics of thin circular cylindrical shells. Ritz polynomial functions are assumed to model the axial modal dependence and the Rayleigh-Ritz variational approach is employed to formulate the general eigenvalue problem. Influence of some commonly used boundary conditions, viz. simply supported-simply supported, clamped-clamped and clamped-free, and also the effects of variations of shell parameters on the vibration frequencies are examined. Natural frequencies for a number of particular cases are evaluated and compared with some available experimental and other analytical results in the literature on this topic. These results are given in the form of tables and figures. A very good agreement between these results of the present analysis and the corresponding experimental and analytical results available in the literature is obtained to confirm the validity and accuracy as well as the efficiency of the method.

Keywords: cylindrical shells, variations, boundary conditions, Rayleigh-Ritz method, Ritz polynomial functions, natural frequencies

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参考译文

圆柱形薄壳固有振动频率的预测

摘要：本文给出一种研究圆柱形薄壳自由振动特性的分析方法，本文用里兹多项式函数模拟轴向模式的依赖关系，用瑞利里兹变分法构造一般特征值问题。文中研究了一些常用的边界条件，即简支—简支，固定端—固定端，固定端—自由端，以及壳体参数变化对振动频率的影响。对一些特定情况下的固有振动频率作了计算，并与试验结果以及有关本问题的文献中的其他分析结果作了对比。这些结果都用图表形式给出。本文的结果和相应的试验结果以及其他分析结果吻合得很好，表明本文的方法既有效又准确可靠。

关键词：圆柱形壳体，振动，边界条件，瑞利—里兹方法，里兹多项式函数，固有频率

5.3 正文的组成和写作

反映科研进展的科技论文可称为研究报告型论文（research report）。

它的正文包括 Introduction，Methods and Materials，Results，Discussion 等部分。各部分的功能如下：

Introduction

Describes the state of the knowledge that gives rise to the question examined by, or the hypothesis posed for, the research. State the question or hypothesis.

Methods and Materials

Describe the research design, the methods and materials used in the research (subjects, their selection, equipment, laboratory or field procedures), and how the findings were analyzed.

Results

Findings in the described research. Tables and figures supporting the text.

Discussion

Brief summary of the decisive findings and tentative conclusions. Examination of other evidence supporting or contradicting the tentative conclusions. Final answer. Implications for further research.

科技论文的目的是介绍作者的研究成果或研究进展，其内容反映作者对科学技术的发展所作出的贡献。对论文的读者来说，一篇科技论文的参考价值有三方面，一是论文的结论，二是研究的方法，三是论文提供的数据资料。撰写科技论文最重要的是论证是否正确，论点能否成立。因此正文部分的写作应该特别注意论证过程的严谨，作到论点明确，概念准确，论据充分，推理过程符合逻辑。

为了达到这些要求，在写作时应注意以下几点：

（1）按逻辑关系组织文章的结构和段落，每段都用一个主题句开头。常见的段落展开形式有：从一般到特殊，从问题到解答，从原因到结果和按时间顺序。

（2）段落不要过长，每一段只述及一个问题。

（3）每一句只述及一个论点。不要把过多的内容塞到一个句子里，使读者不得要领。

（4）尽量使用简单的单词和短语，当有两个或更多的同义词可选择时，选用普通的、使用频率高的词。例如表示期待可用 expect，也可用 anticipate，但以采用 expect 为好。

（5）缩写词在文中第一次出现时应给出其全称，以便于读者理解。

（6）对文中的重要概念，要自始至终用同一个词表示，在科技论文中不必苛求文采。

（7）用连接词或副词等清楚地指示出句子间的逻辑关系，参见下表。

指示逻辑关系的单词和词组表

关　系	单　词　和　词　组
并　列	also, and, apart from, as well, besides, equally, finally, first (second, etc.), firstly, in addition, in the same way, last, lastly, next, such as
因　果	as, as a result, because, consequently, for this reason, since, so, therefore, thus, then
结　论	briefly, finally, in brief, in conclusion, in short, in summary, to conclude, to summarise
对比或让步	again, alternatively, although, at the same time, but, compared with, contrary to, even though, even if, however, in any case, in contrast to, in spite of, instead, on the contrary, on the other hand, regardless of, still, whereas, while, yet
示　例	for example, for instance, in other words, to illustrate, that is, such as

5.4 常用语法

动词时态

在科技英语写作中最常用的时态是一般现在时，表示客观事实和真理。阐述某项研究现状时也会用现在完成时。

【例 1】A fatigue failure begins with a small crack.

【例 2】A great deal of research has been devoted to a study of the mechanism of fatigue, and yet there is still not a complete understanding of the phenomenon.

分析和推理在科技论文中占有重要地位，在推理过程中，经常要用到条件语句或祁使语句以表示条件、假设、设想、建议等。

条件语句

最常用的条件语句是 if 语句，其他表示条件的单词和词组有：

unless (=if not)，providing (that)，suppose (that)，assume (that)，only if，with，without，so (as) long as，等。

【例 3】If a bar is subjected to longitudinal tensile stress，it will extend in the direction of the stress and contract in the transverse direction.

【例 4】Lead is virtually unaffected by air and moisture and so is pure aluminium providing it has been correctly pretreated and is regularly washed clean.

【例 5】Hydraulic systems have many advantages，such as high power density，but are difficulty to control without considerable loss of energy.

【例 6】In this book the values of the thermal conductivity will be given in SI units unless noted otherwise.

【例 7】Only after the liquid has been heated sufficiently will the vapor bubble travel all the way to the liquid surface.

祈使语句

【例 8】Let's refer to Fig. 5.6 in order to understand the reasons for this increase in hardness.

【例 9】Remember that thermoplastics is that group of polymeric materials that can be softened every time they are heated.

【例 10】Note that the act of holding x constant means that $C1$ and $C2$ can be functions of y.

【例 11】Suppose that the flow in the non-turbulent region is irrotational，as is usually the case in the examples that have been mentioned.

It 作形式主语的结构

科技英语著作注重反映客观现实，有不少期刊还要求：Papers should be written in the third person in an objective，formal and impersonal style. 因此以 It 作形式主语的结构使用的比较频繁。

It＋is＋表语＋to 不定式

It＋is＋表语＋that 从句

常用的系词还有 seem，appear，become，prove.

【例 12】It is necessary to be familiar with the assumptions used in any analysis.

【例 13】It is very important for the designer to develop a "feel" for stress concentration so that he will know intuitively when it exists and what to do about it.

省略形式

语言简练是科技论文的特点，在不影响内容准确的情况下，科技论文写作时常常采用省略形式，下面列举了一些常用的省略形式。

1　用独立分词结构代替从句

【例 14】By adupting a radically different geometry,a new, low cost sensor is able to measure yawing—twisting about a vertical axis—to an accuracy of 0.2°/s.

【例 15】Before writing the equation of motion of the linear system，it is necessary to investgate the preloading of the retaining spring.

【例 16】When the temperature of a piece of material is changed，its size will also change，and when expressed non-dimensionally this is termed thermal strain.

2 用过去分词作后置定语代替定语从句

【例 17】Stress concentrations caused by sharp corners，sudden changes of section，or undercuts are all classified as "incipient cracks" from which a fatigue crack may spread.

【例 18】However，in dynamic applications the low component cost is often offset by the high maintenance and repair costs caused by the material's static and dynamic friction properties，coupled with a wide difference between the two values.

3 并列复合句的省略

并列复合句的第二个句中与第一个分句相同的句子成分，可以省略。

【例 19】With all these tentative decisions made，a lubricant can be selected and the hydrodynamic analysis made as already presented.

【例 20】Not only can base elastomers be treated，but also fabric and fibre-reinforced，metal-caged and bounded components.

4 状语从句的省略

当状语从句的主语与主句的主语相同并且谓语含有动词 be 时，从句中的 be 可省略。

【例 21】Although primarily researched as a solution to the problem of repairing subsea oil installations，the core technology could be applied in many other industries.

【例 22】Already proven in the telecommunications industry，the technique now looks set to revolutionise electronics and electrical circuitry in cars.

5 名词作定语

英语名词可以放在名词的前面作定语，这和汉语的习惯相同，但是当连续有两个以上的名词作定语时往往很难理解，例如：isotope dilution assay results; angle steel pylon system 等，为避免误解，用名词作定语时要谨慎，要避免名词串（Avoid noun clusters）。

5.5 常用句型

科技论文正文由 Introduction，Methods and Materials，Results，Discussion 组成，各部分内容不同，写作方法也有所不同，本节针对各部分的特点介绍一 些适用的句型。

引 论

在 Introduction 中要说明研究的背景，引起研究要求的现实情况。这就需要评述他人的工作。通常采用现代完成时态。

【例 1】Attempts have been made to simulate polymer structure and its creep and recovery responses by mechanical type modelling using two principal elements.

【例 2】To date many technologies have been developed to reduce the surface friction of elastomeric components，all with their own set of disadvantages.

【例 3】During the last few decades the theory of dynamical system has experienced extremely rapid progress.

定 义

对于论文中出现的概念，应该使读者明确其内涵是什么，这就需要给出它的定义。常用的句型有：

… is …

… is defined as …

… is called …

【例 4】A power screw is a device used in machinery to change angular motion into linear motion and, usually, to transmit power.

【例 5】The critical cooling rate is defined as the slowest cooling rate (quenching rate) which will produce a martensitic structure throughout the mass of the steel.

分类与比较

阐明事物特点，予以归纳或比较，有助于加深对事物的认识。常用的句型有：

There are … types of …

There are … kinds of …

There are … sorts of …

There are … classes of …

… can be classified into …

… can be divided into …

… can be categorized into …

… can be grouped into …

【例 6】The Curies classified the radiation form radium and polonium into three types, according to the direction of deflection in a magnetic field. These three types of radiation were called alpha (α), beta (β), and gamma (γ).

表示比较的句型很多，常用的有：

as … as …

not as … as …

比较级＋than

… (be) superior to …

… (be) inferior to …

【例 7】Large components do not cool as quickly as small components and may not achieve the critical cooling rate necessary for maximum hardness.

方式和方法

表示方式和方法的结构很多，一般用副词或介词短语，例如：

by …

with …

theoretically

statistically

empirically

【例 8】Materials selection for high-temperature applications is aided by deformation mechanism diagrams since they provide creep information plainly and succinctly.

【例 9】Flow is measured by pressure drop across an orifice and the pressure drop is measured by a silicon diaphragm differential transducer.

数量和度量

提供数据资料是科技论文的任务之一，定量分析时不仅应给出有关物理量的具体的值，还应对测量或计算的误差作出估计。定性分析时要对有关物理量的值作出估计。论文中物理量的度量单位应采用 System International（SI）units. 参见下表。

Table 5.1 SI Units for Mechanical/Electrical Systems

Quantity	*Symbol*	*Unit*	*Abbreviation*
Length	l	meter	m
Mass	m	kilogram	kg
Time	t	second	sec
Energy	e	joule	J
Force	F	Newton	N
Power	P	watt	W
Charge	Q	coulomb	C
Current	I or i	ampere	A
Voltage	V or v	volt	V
Resistance	R	ohm	Ω
Capacitance	C	farad	F
Inductance	L	henry	H
Temperature	T	Kelvin	K

【例 10】All aluminium alloys lose strength rapidly at temperature above 150°C and the speed of Concord, the civil supersonic transport, is therefore limited to Mach 2.2. This corresponds to saturation skin temperature of about 125°C.

【例 11】A reduction in vehicle weight results in fuel savings of about 7% in the city and 4% on longer journeys.

【例 12】Recent trends in pressure sensors include the development for an array of 100 pressure sensors on a single chip of the size of 0.5mm×0.5mm.

图表和公式

在科技论文中为了直观和简洁常常用图表的形式表示数据资料。

下面是一幅插图及其说明的例子。

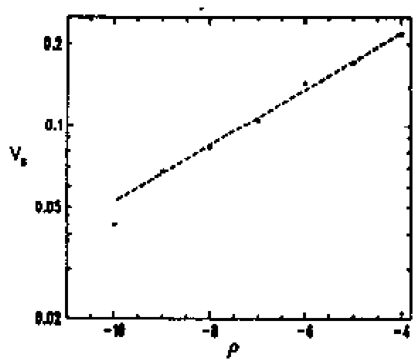

Fig.5.1 Spreading Velocity v, as Function of ρ Found from the Exponents λ (v).
The dashed line is a fit with $\ln v = a\rho - b$ with $a = 0.24$ and $b = 0.56$
[van de Wâter and Bohr 1993]

【例 13】表及其说明

Table 5.2 Typical Gray Cast irons

Compositions (%)					*Applications*
C	*Si*	*Mn*	*S*	*P*	
3.30	1.90	0.65	0.08	0.15	Motor vehicle brake drums
3.25	2.25	0.65	0.10	0.15	Motor vehicle cylinder blocks
3.25	1.75	0.50	0.10	0.35	Medium machine castings
3.25	1.25	0.50	0.10	0.35	Heavy machine castings
3.60	1.75	0.50	0.10	0.80	Light and medium spun cast water pipes
3.50	2.75	0.50	0.10	0.9	Ornamental castings requiring maximum fluidity but only low strength

公　式

科技论文几乎离不开公式和方程，有时还要叙述其推导过程。此时常用到的词汇有下列四类：

表示假设的常用词汇：

suppose，assume

表示结果的常用词汇：

find，follow get，give，obtain，produce，result in，yield.

表示形式和方法的常用词汇：

form，manner，means，method，way.

表示推导过程的常用词汇：

rearranging

by analogy to

with respect to

下面的一段课文，讲述厚壁圆筒应力分布公式的推导过程，阅读时请注意上面提到词汇的如何应用。

The equations of equilibrium for an element of materials are

$$\frac{d\sigma_r}{dr}+\frac{\sigma_r-\sigma_\theta}{r}=0 \tag{5—1}$$

and since σ_z is constant

$$\frac{d\sigma_z}{dr}=0 \tag{5—2}$$

The strain-displacement equations are

$$\varepsilon_r=\frac{du}{dr} \tag{5—3}$$

$$\varepsilon_\theta=\frac{u}{r} \tag{5—4}$$

$$\varepsilon_z = \frac{dw}{dz} \tag{5—5}$$

The stress-strain relationships are

$$\varepsilon_r = \frac{\sigma_r}{E} - \frac{\nu}{E}(\sigma_\theta + \sigma_z) = \frac{du}{dr} \tag{5—6}$$

$$\varepsilon_\theta = \frac{\sigma_\theta}{E} - \frac{\nu}{E}(\sigma_z + \sigma_r) = \frac{u}{r} \tag{5—7}$$

$$\varepsilon_z = \frac{\sigma_z}{E} + \frac{\nu}{E}(\sigma_r + \sigma_\theta) = \frac{dw}{dz} \tag{5—8}$$

differentiating eqn（5—7）with respect to r gives

$$\frac{E}{r}\left(\frac{du}{dr} - \frac{u}{r}\right) = \frac{d\sigma_\theta}{dr} - \nu\frac{d\sigma_z}{dr} - \nu\frac{d\sigma_r}{dr}$$

Substituting for du/dr and u/r from eqns（5—6）and（5—7）and symplying，

$$\frac{1+\nu}{r}(\sigma_r - \sigma_\theta) = \frac{d\sigma_\theta}{dr} - \nu\frac{d\sigma_z}{dr} - \nu\frac{d\sigma_r}{dr} \tag{5—9}$$

Now，since ε_z=constant, $d\varepsilon_z/dr=0$ and differentiating eqn.（5—8）gives

$$\frac{d\sigma_z}{dr} = \nu\left(\frac{d\sigma_r}{dr} + \frac{d\sigma_\theta}{dr}\right) \tag{5—10}$$

Substituting into eqn.（5—9）for $d\sigma_z/dr$ from eqn.（5—10）and $(\sigma_r - \sigma_\theta)/r$ from eqn.（5—1）and simplying gives

$$(1-\nu^2)\left(\frac{d\sigma_\theta}{dr} + \frac{d\sigma_r}{dr}\right) = 0 \tag{5—11}$$

From eqns (5—11) and (5—12) we see that $d\sigma_z/dr=0$ and therefore σ_z is cnstant through the wall thickness. Integrting eqn.（5—11）shows that

$$(\sigma_\theta + \sigma_r) = \text{constant} = 2A \tag{5—12}$$

Eliminating σ_θ between eqns（5—12）and（5—1）gives

$$\frac{d\sigma_r}{dr} + \frac{2\sigma_r - 2A}{r} = 0 \tag{5—13}$$

From which，multiplying by r^2，

$$\sigma_r = A - \frac{B}{r^2} \tag{5—14}$$

and from eqn.（5—12)，

$$\sigma_\theta = A + \frac{B}{r^2} \tag{5—15}$$

Where A and B are constants which may be found using the boundary conditions. It will be noted that these equations are the same as equations in the previous chapter，which confirms that they satisfy the equilibrium and compatibility conditions.

5.6 致谢和参考文献

致谢（Acknowledgements）

致谢放在正文之后，向论文所述研究提供资助的机构表示感谢，向对论文提供帮助的个人表示感谢等。

CBE Style Manual 指出：

An acknowledgements section can carry notices of permission to cite unpublished work, identification of grants and other kinds of finacial support, and credits for contributions to the reported work that did not justify authorship.

可用的句型有：

The research effort was partially sponsored by …

The authors would like to acknowledge the financial support of …

The authors are thankful to … for …

参考文献（References）

在论文中凡是引用他人著作中的数据、资料、方法、观点或结论的都应该标明，并在参考文献中列出来源。这一方面是对别人劳动成果的尊重，另一方面是提供研究工作的依据，便于读者全面地了解问题的起源和前人的研究工作。ASME *Journal of Heat Transfer* 对文献引用的标示和参考文献的书写格式规定如下：

Text Citation. Within the text, reference should be sited in numerical order according to their order of appearance. The numbered citation should be enclosed in brackets.

Example:

It was shown by Prisa [1] that the width of the plume decreases under these conditions.

In the case of two citations, the numbers should be separated by a comma [1, 2]. In the case of more than two references citations, the numbers should be separated by a dash [5-7].

List of references. References to original sources for cited materials should be listed together at the end for this purpose. References should be arranged in numerical order according to their order of appearance within the text.

（1）References to journal articles, papers in conference proceedings, or any collection of works by numerous authors should include:

last name of each author followed by their initials

year of publication

full title of the cited article

full name of the publication in which it appears

volume number（if any）in boldface（Do not include the abbreviation "vol." within the reference.）

inclusive page numbers of the cited article

（2）References to textbooks, monographs, theses, and technical reports should include:

last name of each author followed by their initials year of publication

full title of the the publication (in italic or underlined)

publisher

city of publication

inclusive page numbers of the work being cited

In all cases, the titles of books, periodicals, and conference proceedings should be underlined or in italic. A sample list of references follows.

Sample References

[1] Kwon, O. K., and Pletcher, R. H., 1981, "Prediction of the Incompressible Flow Over a Rearward-Facing Step," Technical Report No HTL-26, CFD-4, Iowa State Univ., Ames, IA.

[2] Lee, Y., Korpela, S. A., and Horne, R. N., 1982, "Structure of Multi-Cellular Natural Convection in a Tall Vertical Annulus," *Proc. 7th International Heat Transfer Conference*, U. Grigul et al eds., Hemisphere Publishing Corp., Washington, DC, 2, pp. 221-226.

[3] Sparrow, E. M., 1980, "Fluid-to-Fluid Conjugate Heat Transferfor a Vertical Pipe-Internal Forced onvection and External Natural Convection," ASME *Journal of Heat Transfer*, 102. pp. 402-407.

[4] Sparrow, E. M., 1980, "Forced-Convection Heat Transfer in a Duct Having Spanwise-Periodic Rectanglar Protuberances," *Numerical Heat transfer*, 3. pp. 149-167.

[5] Tung, C. Y., 1982, "Evaporative Heat Transfer in the Contact Line of a Mixture, "Ph.D these, Rensselaer Polytechnic Institute, Troy, NY.

[6] Amon, A., Jr., 1995, Electronic *Packaging*, Wiley, New York.

5.7 论文实例

为了对科技论文整体有一个感性认识，下面给出一篇论文的框架，论文的内容是关于一种用于快速提取物体几何信息并将其传递给虚拟制造系统的方法。

An image-based fast three-dimensional modeling method for virtual manufacturing

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Abstract: This paper fouses on a quick way to extract geometric information from an object and transfer the information into a virtual reality (VR) system. Considering the problems associated with

The MS was received on 25 August 1998 and was accepted after revision for publication on 17 November 1999.

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the construction of VR environments, different three-dimensional modeling methods are analysed in this paper, and the authors report an effective methodology to construct virtual manufacturing environments. A three-dimensional surface reconstruction system, based on image analysis, forms a new approach to data acquisition and promises to be a competitive technique for VR applications. This three-dimensional surface reconstruction system integrates the binocular stereo principle and the shape from shading technique. Experimental results are encouraging and the performance of the system has been evaluated by simulation procedures.
Keywords: virtual manufacturing, CAD, reverse engineering

NOTATION

b	displacement between two cameras used for obtaining the image pair
f	focal length of the camera
I_n	incident intensity of the point light source
I_{co}	image coordinate system
k_d	constant diffuse reflectivity
$\mathbf{N}$	surface normal
p, q	parital derivatives of height Z with respect to image coordinates
p_s, q_s	partial derivatives of the light direction
$r_{W_{co}} = (X, Y, Z)^T$	coordinate vector of a point relative to the world coordinate system
$r_{Ico} = (x, y, z)^T$	coordinate vector of a point relative to the image coordinate system
R_{Ico}	roatation matrices between the image coordinate and the world coordinate
T_{Ico}	translation matrices between the image coordinate and the world coordinate
W_{co}	world coordinate system
$x_l - x_r$	pixel shift at a point between two corresponding images
$z = \zeta(x, y)$	surface funcition of the object
$\Theta(x)$	Heaviside function
λ	Lagrangian multiplier used to enforce the constraint of surface smoothness
$\xi(x, y)$	reflection coefficient
Ω, ω	thresholds

1 INTRODUCTION

The exciting new technology of virtual reality (VR) is being increasingly employed to improve and the reduce the costs in design and manufacturing. The great potential of VR is that it can provide a virtual environment in which a user can experiment with different design and manufacturing techniques. Unlike most simulation systems, which replay a predetermined sequence of the design or manufacturing process, the VR system allows the user to follow their instinctive idea to complete a design or manufacturing process, and allows the operations to be performed on a workpiece in real time. In a VR system, for example, components of a product to be designed can be merged or split, and workpieces to be cut can be fixtured on the work-table of the machine tool. Therefore, rather than being just a simulation of the process, VR can provide much more support for the design and manufacturing process. However, this places a heavy demand on the geometric modelling task in the virtual design and manufacturing system, and building an environment around a particular system continues to prove one of the most difficult development problems. For instance, a replica of a factory floor with its machine tools and supporting equipment could be modelled on a computer aided design (CAD) package. Each item would have to be individually created as a three-dimensional model and merged together to form the whole manufacturing environment. This accounts for a significant portion of the overall process.

Therefore, it is a challenging task to create a completely new virtual environment and it needs support from efficient three-dimensional modeling methods. Most of the current virtual CAD/CAM (computer aided design/manufacture) systems use a "synthetic" virtual world that is based on advanced computer graphics and realtime simulation techaology [1-4] as their virtual environment. The first step to set up a virtual "synthetic" environment is to make a copy of the real world. The process of building a virtual environment is shown in Fig.5.2 In each loop, the system gathers information about the environment from sensors, such as a mouse, spaceball or camera, and processes the input data to form the shape of the object and update the VR environment.

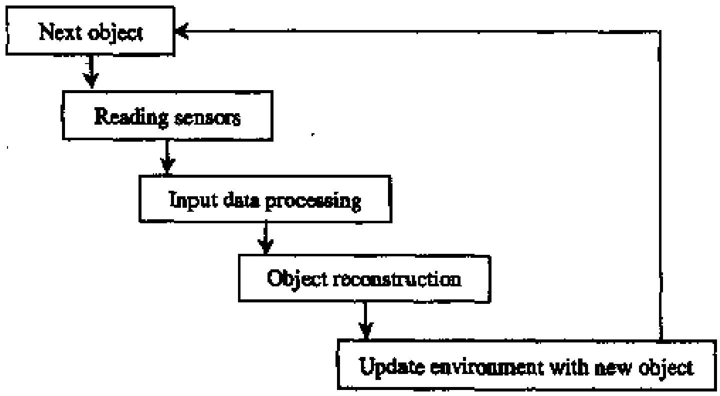

Fig.5.2 A Virtual Environment Building Process

Current commercial VR software provides powerful VR functionality but may fall short of creating the new VR environment. The shape information of a new object has to be built by other CAD software, such as Pro/Engineer or AutoCAD, in a standard CAD format and then translated into a virtual object in a VR system. An alternative method is to use virtual reality modelling language (VRML) to download existing three-dimensional object models from three-dimensional shape libraries by Internet. Using a CAD system to define the required three-dimensional shape can substantially reduce the shape building work, but building a virtual world still requires significant time, especially when CAD libraries are not available. The most general demand of a VR system is to make users feel that they are a part of the environment and can easily interact with it, i.e. provide an immersive capability.

The approach to building a VR environment should ideally be:

1. Fast. It should catch and build the object quickly and meet the real-time requirement.

2. Automatic. The process should be able to extract all the shape information without input from an operator.

3. Versatile. The method should not be limited to simple geometries but should be able to handle complex items.

4. Accurate and efficient.

Different three-dimensional modeling methods, such as CAD/CAM system-based methods, three-dimensional scanner-based approaches, magnetic sensor-based methods and image-based approaches are analysed in this paper, and the authors report an effective methodology to construct virtual manufacturing environments. The main aim of the methodology is to extract the geometric information from a three-dimensional object and transfer this information into the VR system. The new three-dimensional surface construction approach integrates the binocular stereo principle and the shape from image information technique. The experimental results are encouraging and support the development of VR technology and its applications into the manufacturing environments.

2 THREE-DIMENSIONAL SHAPE CAPTURING METHODS

Several methods which can provide a quick means to construct VR environments are being considered.

2.1 CAD/CAM system-based methods

An integrated CAD/CAM system allows users to design the manufacturing process as a unified model representation that supports the transfer of the model between software systems. Feature-based methods are used by most of the current CAD systems. The feature extraction and recognition method analyses the geometry and topology of the existing CAD model and attempt to classify geometric features of the model as different manufacturing entities [5]. This method is limited to the existing CAD model. Starting with a simple shape, features are added or modified to refine the model. This approach speeds up the model creation process because previous designs can be used as the basis for new models. However, this restricts the user using new features to define the model. It will also take a long time to build a new VR environment from the start if an existing CAD database is not available. This has forced researchers to look to other emerging technologies when forming an immersive three-dimensional environment [6, 7].

2.2 Three-dimensional scanner-based methods

The three-dimensional laser scanner is a popular and accurate method of recovering three-dimensional data from an object. However, its capturing process is slow, because it scans the surface line-by-line and point-to-point. The high energy light source also needs to be treated with care.

An alternative approach to three-dimensional shape capture is to use tactile methods that measure the surface of an object by the touch of mechanical arms. The relative corrdinate positions are determined by the sensors in the joints of the arm, which can be supported by robotic devices. This method is accurate and reliable but the slow speed is a disadvantage [8].

2.3 The magnetic sensor-based technique

In the magnetic sensor system, a transmitter is driven by a pulsed d.c. signal, as shown in Fig.5.3. The sensor measures the transmitted magnetic-field pulse referenced to the magnetic transmitter. An electronics card controls the transmitting and receiving elements and converts the received signals into three-dimensional position and orientation measurements. This method supports realtime measurement with high accuracy, but its disadvantages include the touch measuring process with wire and sensor, limited captured points from the sensors and the limitations of the magnetic-field that is applied.

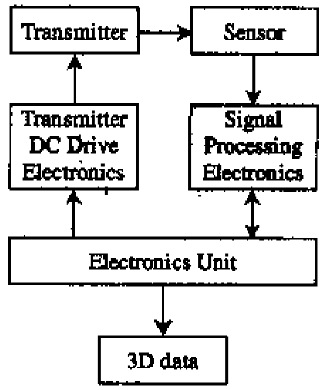

Fig.5.3 Magnetic Sensor-Based Technique

2.4 Image-based approaches

Inage-based methods have the special features of noncontact measurement, low energy and capturing all the surface data at the same time. An ultrasonic image-based method is shown in Fig.5.4. The ultrasonic imaging system consists of a transmitter, an ultrasonic receiver array, and an object to be recovered. The three-dimensional surface of the object is defined by

$$f(x,y,z)=\xi(x,y)\Theta(\xi(x,y)-z)$$

Therefore, the three-dimensional shape of the object can be reconstructed from the observed pressure of the scattered wave at specific locations and time [9].

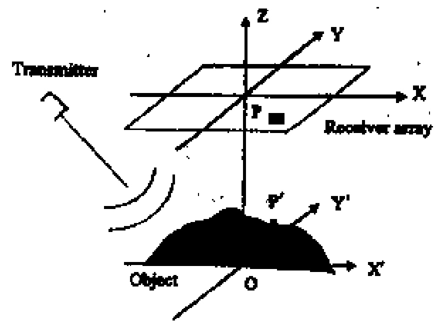

Fig.5.4 Ultrasonic Image Reconstruction

Even in dark environments, the images of an object can be obtained by the ultrasonic system. However, it has seldom been used for surface reconstruction because the following factors lower the resolution: long wavelength, limited number of receivers, attenuation due to propagation through air, and the non-linear response of the ultrasonic receiver. An alternative way is to use charge coupled devices (CCDs) or digital cameras as the sensors to capture the image, and apply the approaches of image processing to recover the object information.

The methods of three-dimensional shape reconstruction, based on vision information from a CCD or a digital camera, have received considerable attention and various methods have been used to capture the three-dimensional depth information of objects from their two-dimensional digital images [10-13]. These methods can be divided imto two groups: photometric stereo-based and binocular stereo-based. The photometric stereo-based techniques use images of the same scene with different light source directions. If the surface reflectance properties of the object are known, the local surface orientation and the height of illuminated points can be computed by the techniques of shape from shading. One of the important advantages of this method is that it does not suffer from the correspondence problem, which is referred to later in this paper. It has been used effectively by the authors in reverse engineering applications [14]. Unfortunately, as the images are captured at different times, this approach cannot meet the needs of real time in a VR system. The binocular stereo-based techniques extract the depth information from intensity images acquired by two cameras at the same time; the two cameras being displaced from each other by a known distance.

The key to this method is to determine the point in one image which corresponds to a given point in the other image, namely the correspondence problem. A significant amount of work has been carried out to solve this challenging problem, but the results have not been satisfactory [11], because time delays hinder real-time applications. The technique is also limited by the sparse (feature points) depth information which it can provide.

This paper outlines an approach to overcome these problems by integrating the information from the shape from shading process with the binocular stereo-based technique. The three-dimensional shape information of an object is recovered from the key feature points extracted by the binocular stereo-based method and the shape from shading method reconstructs the surface of the object.

3 THE SHAPE FROM SHADING METHOD

In order to describe the difficulties in recovering a three-dimensional shape from an image, it is necessary to understand the nature of reflection from an object and the associated image information process. Most implementations of the shape from shading module assume a Lambertian surface, which only considers diffuse reflection from materials with a distance point source.

Given a Lambertian image, the image irradiance equation relates the intensity of an image point (x, y) with the surface normal **N**, as follows [10]:

$$I(x, y) = R(p, q) = k_d I_n \mathbf{L} \cdot \mathbf{N} = k_d I_n \frac{1 + pp_s + qq_s}{\sqrt{1+P^2+q^2}\sqrt{1+p_s^2+q_s^2}} \qquad (5\text{—}16)$$

Shape from shading by a single image does not produce accurate results. The surface normal at each point is represented by two numbers, p and q, the two variables representing the surface normal direction at each point cannot be computed by using one equation. Boundary conditions and local constraints based on reasonable assumptions support the most common reported solutions.

A direct formulation of the shape from shading problem, with a smoothness condition on the surface, is stated in the following minimization problem:

$$\iint_{\Omega} \left\{ \left[I(x, y) - k_d I_n \frac{1 + pp_s + qq_s}{\sqrt{1+P^2+q^2}\sqrt{1+p_s^2+q_s^2}} \right]^2 + \lambda (p_y - q_x)^2 \right\} \mathrm{d}x\mathrm{d}y \to \min \qquad (5\text{—}17)$$

where $p_y = q_x$. Therefore, p and q can be computed by the iterative scheme from equation (5—17), as follows [10]:

$$p_{ij}^{n+1} = \overline{p}_{ij}^n + \lambda \left[I_{ij} - R(p_{ij}^n, q_{ij}^n) \right] R_p(p_{ij}^n, q_{ij}^n) \qquad (5\text{—}18)$$

$$q_{ij}^{n+1} = \overline{q}_{ij}^n + \lambda \left[I_{ij} - R(p_{ij}^n, q_{ij}^n) \right] R_q(p_{ij}^n, q_{ij}^n) \qquad (5\text{—}19)$$

where

$$\overline{p} = \frac{1}{2}(p_{ij+1} + p_{ij-1}), \qquad \overline{q} = \frac{1}{2}(q_{i+1j} + q_{i-1j}),$$

$$R_p = \frac{\partial R}{\partial p}, \qquad R_q = \frac{\partial R}{\partial q},$$

Unfortunately, even for ideal Lambertian diffuse reflectance, this model has practical difficulties in achieving an accurate solution for three-dimensional shape recovery. However, the shape from shading process can converge to a unique solution when the boundary condition is available. The binocular stereo-based method can be used to find this information.

4 THE SHAPE FROM BINOCULAR STEREO METHOD

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5 THE INTEGRATION OF THE BINOCULAR STEREO AND SHAPE FROM SHADING METHODS

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6 THREE-DIMENSIONAL ENVIRONMENT CAPTURING AND ACCURACY ANALYSIS

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7 CONCLUSIONS

Many of the ideas and technologies of VR are still being researched, but progress suggests that VR technologies will play a key role in future design and manufacturing application. The initial results from the suggested method are encouraging and support VR environments to be constructed with little expense and effort. The approach described in this paper is still under development in the following directions:

1. To develop an automatic process system to link a group of images in order to form a whole recovery shape of an object, because the pictures taken from one angle can only be used to recover the visible surface of the object.

2. A fast calibration system is needed to cooperate with the camera system in order to build three-dimensional model rapidly and efficiently.

3. Colour image information is to be used to improve the recovery accuracy.

ACKNOWLEDGEMENT

The authors acknowledge the support given by the CVCP for the ORS award and the School of Manufacturing and Mechanical Engineering at the University of Birmingham for additional assistance.

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第6章 机械工程专业文献选读

1 Design Process

Engineering is defined by ABET (the Accreditation Board for Engineering and Technology) as:

… that profession in which knowledge of the mathematical and natural sciences gained by study, experience and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind.

What differentiates engineering from many other fields is that it attempts to go from theory into practice for the purpose of developing products and processes instead of merely observing the phenomena of that science or art. For example, a physicist studies and records findings in order to understand better some phenomenon or physical process. On the other hand, an engineer utilizes scientific information to make a particular process or product for use by consumers. ABET further defines the design portion of engineering activity as follows:

Fundamentally, design is the process of problem solving. Problem solving is used by professionals from many different fields in the normal course of their work. In this chapter, we will look at the definition of design and how it fits into the overall scheme of problem solving. We will also look at the process one uses in implementing a design task. We will then discuss the computational tools that are helpful to the design analysis process. Finally, we will take a brief look at where one goes to acquire technical information to augment the design process.

Problem Solving and Design

The organization of problem solving is a hierarchical domain. One way to think of this is to consider the nested circles shown in Fig.6.1.1 below. What becomes obvious from this diagram is that many subfields are a part of the domain of problem solving. It is easy to think of problem solving that is not design because it is not oriented toward developing a product or process. For example, when one solves a legal problem it is likely not design. In much the same way, one can follow the hierarchical structure to see that there are types of design that do not involve the use of engineering fundamentals. A good example of this would be interior design, which draws heavily on art rather than on scientific or engineering knowledge. Within the domain of engineering design there are many subdomains that relate to the different disciplines of the engineering profession. In this text we are more interested in the discipline of mechanical engineering, but it is safe to conclude that there are excellent design activities in other engineering fields such as electrical, civil, chemical, etc.

The smallest two domains presented in Fig 6.1.1 are those of mechanical design and machine design. The reason for the distinction between these two is that the field of mechanical engineering is divided into two stems. These are the (1) energy stem and the (2) structures and motion stem. The term **mechanical design** applies to design in mechanical engineering systems where both stems can be involved. The Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation.

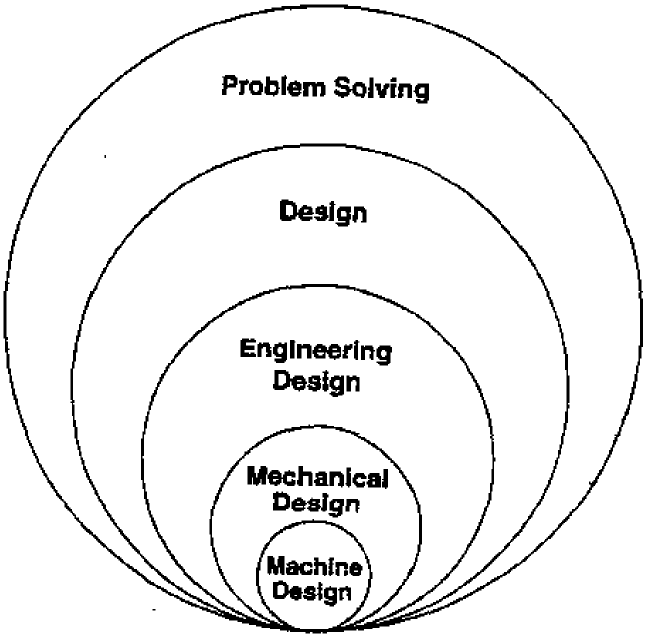

Fig.6.1.1 The Hierarchy of Problem Solving

The Design Process

It is important that a rational method of design be understood by engineers. There are two reasons for this. The first is that a rational method of design helps engineers to manage their task when confronted with a vast amount of input information. The second reason is that the use of a common procedure for design greatly facilitates interaction among engineers. Although the content of each engineering design problem is unique, the methodology for solving these problems is universal and can be described in a specific way. Although a number of authorities on the methodology of design have presented descriptions of the process, most of these descriptions tend to be similar. The design process, as we will describe it, involves the six-step procedure diagrammed in Fig.6.1.2. We will now look at the activity that takes place during each of these steps.

Step 1: Recognize the need—Some people mistakenly believe that engineers create need. This is, of course, no more true than the notion that physicians create illness or farmers create hunger. The products and processes created by engineering design are a direct response to specific

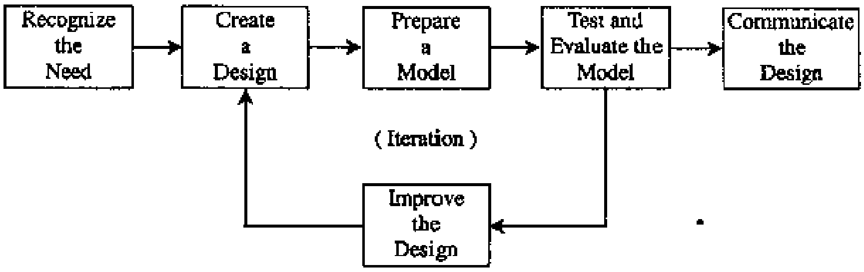

Fig.6.1.2 The Six-Step Process of Design

needs of society. The first step in the design process is probably the single most important part of the overall process. Yet it is frequently given inadequate treatment in the design process. A carefully formulated statement of need can often save considerable time and energy later in the design cycle. Implied in any statement of need is an understanding of the real constraints on the problem. Once a statement of need has been established, the designer would be well advised to review this statement periodically during the design process so that it can be revised if necessary.

Step 2: Create a design—Once the need has been clearly recognized and stated in a succinct way, the next step is to begin creating design ideas that will satisfy this need. Of all of the steps in the design process, this one requires the most ingenuity and imagination.

Step 3: Prepare a model—Once an idea has been created, it becomes necessary to find a Means to evaluate the quality of that idea in satisfying the need requirements. One way to do this, of course, would be to build the suggested design idea. This procedure is usually impractical for reasons of cost, time, and effort. In order to conserve cost, time, and effort, engineers frequently make use of a simplified model to evaluate a design idea. A model may be real or abstract and may be anything from a simple mental image of the idea to a complex mathematical or physical reproduction of the proposed concept. A frequently used model is a mathematical equation that describes the physical performance of the part. Much of this book will be devoted to developing such mathematical relationships. A designer must understand that all models are only approximations of a physical phenomenon. It is thus important to know when a model is robust enough to give meaningful results. An understanding of significant figures in calculations is also highly important to performing design analysis.

Step 4: Test and evaluate the model—Once the model has been prepared, it is time to evaluate the proposed design idea by exercising the model. The testing usually involves judgment. In the case of a mathematical model of a physical phenomenon, the engineer will put values into the equations and look at the results. What becomes obvious as a result of this type of model is that it is important for the designer to become proficient in the manipulation of mathematical models and that a good system of documenting the solution process is highly desirable. It is for this reason that this book makes use of spreadsheet calculations to solve problems in machine design.

Step 5: Improve the design—As a result of the tests performed on the model, the engineer should have a quantitative measure of the success or failure of the idea. The engineer will likely know whether the ideas should be abandoned or whether it should be retained for further improvement. One of the fortunate results of testing and evaluation is that this process often provides considerable insight into where improvements can and should be made. Thus, this step leads back to the creation step. Since a number of different design ideas may be tried, modified, and improved before a final design choice is made, the process shown in Fig.6.1.2 is quite iterative. What is important to realize is that the design process may yield many workable solutions or no solutions at all. This charâcteristic is one that makes design problem solving quite different from most engineering science problems, where there is often only one right answer.

Step 6: Communicate the design—No matter how well a design may satisfy a particular human need, it cannot be converted into a useful product or process if the details of the design are not communicated to those who will implement its use. Thus, the communication step is a very important part of the design process. Communication of engineering design ideas may be by written words, spoken words, or by pictures, graphs, or drawings.

As we think about applying the engineering design method diagram, several important facts are worth keeping in mind. First, the human mind is capable of handling straightforward design decisions with remarkable speed. The complete process of making a good design choice need not take excessive time for routine problems. Second, the human mind often has difficulty defining boundaries between the steps in the process. The designer may combine one or more of the blocks in the diagram into what seems like a single activity. While this procedure is not wrong, it should be avoided if it results in inadequate treatment of each important step.

Stages of Design

The design process, as described in the previous section, is a thought module that can be applied over and over again in engineering practice. In the industrial environment, design is frequently accomplished through a progressive series of four operational stages. These stages carry the design through from inception to completion. Each of these stages involves a complete design cycle. The four stages are presented in Fig.6.1.3. Each of these stages is connected in series with the next so that the communications output of the first stage will provide a statement of need for the second stage and so on. The diagram also provides for the possibility of returning to a previous stage if the outcome of a particular stage suggests that this is prudent. A close inspection of Fig.6.3.1-3shows that the stages are: "feasibility stage," "preliminary stage," "detail stage" and "revision stage." The characteristics of each of these stages will now be discussed.

Stage 1: Feasibility stage—The first stage determines whether it is both possible and profitable to undertake a given engineering project. For this reason, the need statement will often be phrased "to consider the desirability of ···" or "to consider the economic feasibility of ··· ".

The ideas generated during this stage of the design process generally consist of general statements about overall concepts rather than specific descriptions of hardware. The models for this stage tend to be based on economic theories, market surveys, and the opinions of authorities. For this reason, people who are experts from disciplines other than engineering are often part of the design team during this stage. The output of this stage will generally be a recommendation either to proceed or to abandon the project.

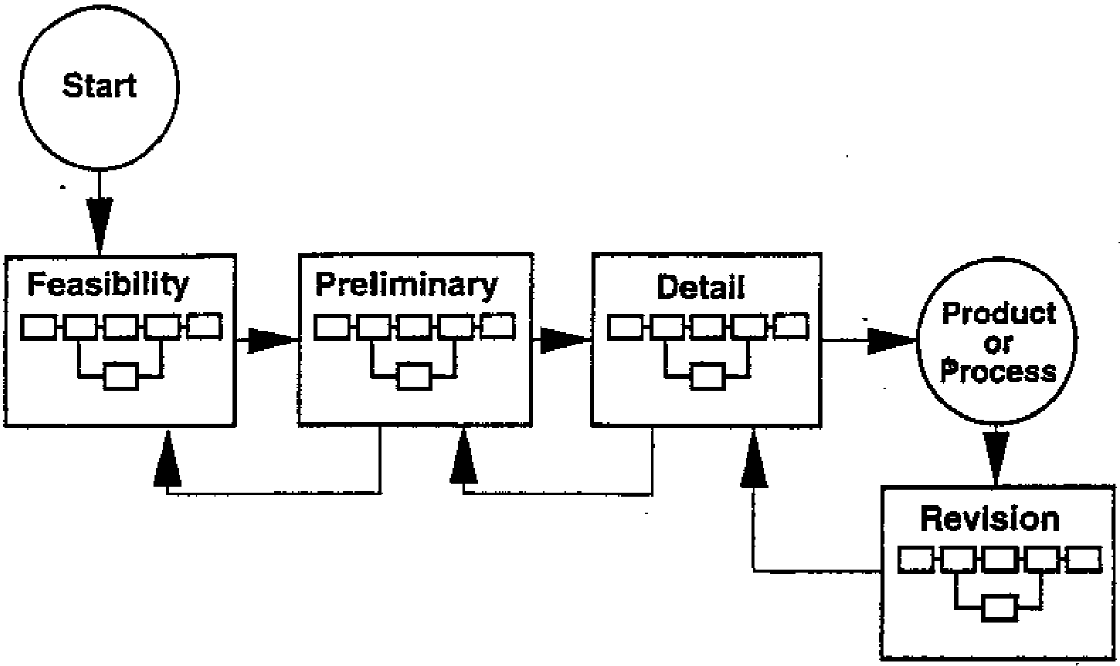

Fig.6.1.3 The Four Stages of Design

Stage 2: Preliminary stage—The purpose of the preliminary stage is to make qualitative judgments about the types of components and resources to use in meeting the conceptual need identified by the feasibility study. The statement of need for this stage usually calls for the designer to select the kinds of components that will be used to make the process or product. The selection process involves studying the tradeoffs between alternative types of component hardware and raw materials. It is beyond the scope of this stage to select quantitative things such as dimensional size, critical geometry, color, weight, etc.

Stage 3: Detail stage—The communication output of the preliminary stage will form the basis for a statement of need that requires the complete, detailed specification of the elements recommended for the final product or process. This is called the detail stage. The tasks required for the completion of this stage of design will involve making quantitative design selections with respect to size, shape, orientation, color, etc. The modeling and testing parts of this stage often involve extensive calculations and experiments. Much of what we will develop in this text will be appropriate to making decisions in the detail design stage. The output of this stage usually results in the manufacture of the product.

Stage 4: Revision stage—Once the detail stage has been completed and the product or process has been placed in service, it may be found desirable to use field experience as a basis for further improvement of the product. This process is called the revision stage. Since the final product is available, it often becomes the model for evaluation during the revision stage. The revision stage is not always used in the design process.

Word and Phrases

1. accreditation 评审，认证

2. carburetor 汽化器
3. facilitate 使容易
4. authority 权威
5. notion 观念，想法
6. constrain 约束
7. succinct 简洁的
8. ingenuity 独创性
9. robust 健壮，鲁棒
10. manipulation 处理，操作
11. spreadsheet 数据表
12. iterative 重复的，反复的
13. implement 实现
14. module 模块
15. inception 初始
16. revision 修改
17. conceptual 观念上的
18. tradeoff 交易，折衷，权衡

2 Finding and Using Information in Machine Design

Although the chapters in this book will enable you to design your own machine parts, it should be noted that often the design process involves specifying and using standard parts that are designed and sold by companies who specialize in the manufacture of machine parts. Usually, parts acquired in this way are of high quality and allow the designer to utilize the knowledge and experience of specialists who have based their entire careers on producing optimum parts for a very reasonable cost. Frequently these vendors will be able to provide you with highly detailed technical information on the optimum application of their products. This might even include on-site help or free consulting recommendations about the application of their products and parts. Many vendors also supply very good design handbooks that enable you to choose the right product for an application you have in mind. The information in this text will enable you to utilize and understand the terminology of standard parts. It will acquaint you with the modes of failure as well as the critical parameters that need to be considered when utilizing such standard parts. The issue then is how to obtain information about the availability of standard parts and the vendors that supply these. There are several excellent sources of this type of information.

Libraries of Catalogs and Specifications

Most companies that are engaged in machine design maintain their own product catalog library. Even though vendors of standard parts may be located far away from your place of business, most use 800 toll-free numbers for information and for orders. Many also have local representatives in your community who are knowledgeable and willing to assist you with information. For thosestandard parts that you find yourself using repeatedly, you may want to develop your own mini-library of catalogs and specifications.

Catalog Services on Microfilm/Microfiche and CD Rom

Some companies make a business of compiling catalogs and specification sheets of machine parts and then making these available on some type of media that enables the user to quickly access the information that he or she needs. These information organizations often provide regular updates of their materials so that you can be reasonably sure that you are getting the most recent information about standard parts. Although information on media is much easier to use than a paper library, the services of such information companies can be expensive. Thus, the size of your company and the extent to which they use standard parts will determine if the use of an information service is economically justified.

The Internet

More and more manufacturers of standard machine parts are beginning to place home pages on the Internet. Almost any type of web browser can be used to search for gears, bearings, roller chains, etc. Most web pages now have telephone numbers to call to obtain further information and catalogs. Some companies are even putting their entire catalogs on-line.

Special Yellow Pages of Suppliers

Although your local yellow pages will likely provide you with sources of standard machine parts, many communities now have special yellow pages that are designed for use by industrial organizations. These can be an extremely valuable source of information and contacts.

Trade Publications and Magazines

Most trade publications and magazines that deal with topics relating to machine design have extensive advertisements that will give you the names of companies that manufacture and sell standard parts. Many of these magazines have reader service cards that you can use to request information. The most often read trade magazines by machine designers are **Machine Design, Chilton's Product Design and Development, and Design News.** One of the best things about the use of trade magazines is that the extensive advertisements that they contain enables the publisher to provide these to you for a very low cost or even for free.

Trade Shows

Trade shows either at the regional or national level are an excellent opportunity for you to collect catalogs and to talk face-to-face with sales representatives of those companies that provide the standard parts that you may need to use. The largest and best-known trade show for machine design is the ASME Design Show that is held every spring in Chicago, IL. The show is often combined with workshops and seminars that should be well worth a trip to this event even if yourorganization is not located in the middle part of the country.

Product Registers

Product registers, such as Thomas Register or Sweet's Catalog, provide an encyclopedia-like library reference that lists companies that manufacture and sell standard parts. These publications are often found in company libraries, university libraries as well as public libraries, and are updated on an annual basis. As an example of what one of these references might include, consider the three-part Thomas Register. The first part, consisting of 16 volumes, provides a listing of over 50 000 products and services. These are listed alphabetically by product name and the listings are organized by state in order to allow you to identify those that do business near to where you work. The second part, consisting of two additional volumes, provides profiles on 145 000 U.S. companies that includes their name, address, phone number, and asset rating. The second part also includes and additional volume that lists the name and owner company for trademarks and brand names. The third and final part of the Thomas Register consists of 8 volumes containing 11 000 pages of recent catalogs from 2 000 companies.

Recognized Standards for Design

As one undertakes the design of machine parts, it is not uncommon to encounter codes and standards that are in place to assist the designer as well as the consuming public. It would be well advised for engineers to become acquainted with the use of standards and to incorporate this information into their professional activities. Two questions come to mind.

1. Who sets the standards?

2. Where can information be obtained about these standards?

The most logical groups to set standards are the two closest to the products-the manufacturers and the users. Engineers from the user community have a strong interest in seeing that the standard specifications for design of engineering products are written in a way that will provide maximum utility and maximum safety for the consuming public. In like manner, engineers from the manufacturing companies have a strong economic interest in seeing that their products have the widest possible use in the engineering marketplace. For this reason, national committees of engineers are often brought together under the auspices of engineering professional societies or trade organizations to establish and to document national standards that are acceptable to all sectors. The national standards system is presently administered by ANSI (the American National Standards Institute) in New York. Companies may subscribe to membership in ANSI and may purchase copies of standards from this organization or from other organizations that provide standards. These standards specify factors of safety and provide design guidelines for safe practice particularly in the case of designs where public safety is at stake. For example, the American Society of Mechanical Engineers provides standards for the design of elevators and pressure vessels. In many cases, standards developed through ANSI and through professional organizations have actually become part of the legal codes for design in the U.S. and throughout the world. Some of the sponsoring organizations of ANSI are listed in Table 6.2.1. ANSI provides a valuable service both for the engineering community and for the consuming public. ANSI publishes a **Catalog of American National Standards** which alphabetically lists the titles of available standards. This catalog is available on the Internet at http://www.ansi.org/cat_top.html for those who care to use this on-line resource.

Table 6.2.1 Selected Ansi Accredited Standards Developers (DECEMBER, 1996)

(*List selected by the author as appropriate to machine design. For a complete list of ANSI standard developers, contact the American National Standards Institute at* 11 *W.* 42*nd St., New York, NY* 10036)

Air-Conditioning and Refrigeration Institute
Aluminum Association
American Architectural Manufacturers Association
American Association of Textile Chemists and Colorists
American Concrete Institute
American Dental Association
American Foundrymen's Society
American Gear Manufacturers Association
American Institute of Aeronautics and Astronautics
American Institute of Steel Construction
American Institute of Timber Construction
American Nuclear Society
American Petroleum Institute
American Society for Quality Control
American Society for Testing and Materials
American Society of Agricultural Engineers
American Society of Civil Engineers
American Society of Heating, Refrigeration and Air-Conditioning Engineers
American Society of Mechanical Engineers
American Society of Non-Destructive Testing
American Society of Sanitary Engineers
American Water Works Association
American Welding Society
American Wind Energy Association
American Wire Cloth Institute
Builders Hardware Manufacturers Association
Compressed Air and Gas Institute
Compressed Gas Association
Concrete Reinforcing Steel Institute
Consortium for Advanced Manufacturing International
Conveyor Equipment Manufactures Association

Table 6.2.1 (cont.)

Cooling Tower Institute
Electronics Industries Association
Federal Highway Administration
Fluid Controls Institute
Human Factors & Ergonomics Society
Hydraulic Institute
Illuminating Engineering Society of North America
Industrial Safety Equipment Association
Institute of Electrical and Electronics Engineers
Instrument Society of America
International Electrical Testing Association
Material Handling Institute
National Association of Architectural Metal Manufacturers
National Association of Corrosion Engineers
National Board of Boiler and Pressure Vessel Inspectors
National Conference of States on Building Codes and Standards
National Electrical Manufacturers Association
National Fire Protection Association
National Information Standards Organization
National Safety Council
North American Die Casting Association
NSF international
Nuclear Information and Records Management Association
Packaging Machinery Manufacturers Institute
Plastic Drum Institute
Power Tool Institute
Recreational Vehicle Industries Association
Robotics Industries Association
Rubber Manufacturers Association
Society of Automotive Engineers
Society of Cable Telecommunications Engineers
Society of the Plastics Industry
Standards Engineering Society
Steel Tank Institute
Toy Manufacturers of America
Truss Plate Institute
Tubular Rivet and Machine Institute
U.S. Product Data Association
Underwriters Laboratories
Uniform Code Council
Water Quality Association

Computational Tools for Machine Design

It goes without saying that the process of machine design relies heavily on calculations and experiments. The principles of design are, of course, universal. The same theory or equations may be applied to a very small part, as in an instrument, or to a larger but similar part used in a piece of heavy equipment. In no case, however, should mathematical calculations be looked upon as absolute and final. They are all subject to the accuracy of the various assumptions which must necessarily be made in engineering work. Sometimes only a portion of the total number of parts in a machine are designed on the basis of analytic calculations. The form and size of the remaining parts are then usually determined by practical considerations. One the other hand, if the machine is very expensive, or if weight is a factor, as in airplanes, design computation may then be made for almost all the parts.

The purpose of the design calculations is, of course, to attempt to predict the stress or deformation in a part in order that it may safely carry the loads which will be imposed upon it, and that it may last for the expected life of the machine. All calculations are, of course, dependent on the physical properties of the construction materials as determined by laboratory tests. A rational method of design attempts to take the results of relatively simple and fundamental tests and apply them to all the complicated and involved situations encountered in present-day machinery.

Training in rapid and accurate numerical work is invaluable to the designer. The designer should keep accurate work records, as it is frequently necessary to refer to work done in the past. It goes without saying that all data, assumptions, equations, and calculations should be documented in full in order to be intelligible when referred to at a later date. The student should start forming such habits, and it is recommended that the problems in this book be worked out and preserved as reference material.

A variety of computational tools can be applied to design calculations with success. Even at a low level of cost, a notebook and a quality scientific calculator can be used to solve most of the problems in this text. Other special-purpose computational tools are emerging in the fields of engineering that have particular merit for particular computational tasks. Among these are softwarepackages like Mathematica, MATLAB, TK Solver, and Math Cad. Because they are so widely used, spreadsheet programs like Excel, Lotus 1-2-3, and Quattro Pro have especially high promise for engineering problem solving. These packages have the advantage of allowing the user to document and save completed work in a highly detailed fashion.

Conclusions

The practice of design can be one of the most exciting and fulfilling activities that an engineer can undertake. There is a strong sense of satisfaction and pride in seeing the results of one's creative efforts emerge into actual products and processes that benefit people. To do design well requires a number of characteristics. The design engineer should not only have adequate technical training, but must also be a person of sound judgment and wide experience, qualities which are usually acquired only after considerable time has been spent in actual professional work. A start in this direction can be made with a good teacher while the student is still at the university. However, the beginning designer must expect to get a substantial portion of this training after leaving school through further reading and study, and especially by being associated with other competent engineers.

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Word and Phrases

1. vendor	销售商
2. toll	费，税
3. update	更新
4. yellow pages	电话号码簿
5. workshop	（学术专题）讨论会
6. seminar	研究讨论会
7. encyclopedia-like	百科全书型的，综合的
8. alphabetically	按字母顺序地
9. profile	概况
10. asset	资产
11. incorporate	结合，体现
12. auspices	赞助，主办
13. at stake	在危险中，（生死）攸关
14. intelligible	可以理解的，易于了解的，明白的
15. interpolation	添写，插补

3 The Formalization of Selection Procedures

In selecting a material for a given application the materials engineer is faced with an almost endless number of possibilities. If the choice is to be made with economy of time and effort, but also with the assurance that no possibility is overlooked, some systematization of procedures is essential.

The basis for inaterials selection is a shopping list of design requirements and, as stated in the Introduction, the selection procedure should be as numerate as possible. The extent to which thiscan be achieved, however, varies from one design requirement to another, extending from attempts to quantify the aesthetics of design and current fashion to the considerable precision attainable in some property parameters.

A useful reduction in the initial number of candidate materials can be obtained by establishing at the outset upper and lower bounds for the various design requirements. On the basis that every design requirement must be present to an acceptable degree, but that costs must inevitably increase if it is present to a greater extent than is strictly necessary, a table can be drawn up (Table 6.3.1) summarizing the merits and demerits of the contenders so as to permit early elimination of unsuitable materials. Materials M1 to M6 represent generic types of material for this initial materials selection step, for example, cast aluminium alloys, austenitic stainless steels, polyamides, polyacetals etc. Analysis of individual materials at this stage, e.g. PA6, 6%-30% glass fibre filled, is dangerous, as other families of material may be missed; what is needed is a broad sweep of all genetic materials' families.

Table 6.3.1

Materials	Design requirements					Cost	Decision
	Primary			Secondary			
	DR1	DR2	DR3	DR4	DR5		
M1	A	O	A	A	A	E	Reject
M2	A	A	A	O	A	A	
M3	U	A	A	A	A	A	Reject
M4	A	O	A	A	O	A	
M5	A	A	A	A	A	E	Reject
M6	A	A	A	U	A	A	

U=Underprovision; O=Over-provision; E=Excessive; A=Acceptable.

Considerable knowledge and experience are required to reject a material at this stage, because materials properties can be varied widely during manufacture and processing, and so also can costs. A material would not necessarily be rejected because it was unsatisfactory in respect of a single secondary design requirement, or even a primary one, if there were scope for ameliorating the disadvantage during design and manufacture. Whether or not over-provision of some property is cause for rejection depends upon the effect upon cost. Excessive cost is always cause for rejection but cost is also a function of processing. Clearly, any version of basically expensive material, such as titanium, will be costly but whereas steels are mostly cheap they become expensive when highly alloyed or manufactured to tight tolerances or compositional limits. It is likely that any class of material which passes this initial stage of selection will produce three or more competing variants of the same material to be considered at a later stage.

Table 6.3.1 can be refined by replacing the simple go/no-go criteria of satisfactory and unsatisfactory by varying degrees of merit. For properties that are not reliably quantifiable, more-or-less vague terms such as poor, fair, excellent, etc. are best abandoned in favour of numerical ratings of, say, 1 to 5 in ascending order of merit. The individual merit ratings can then be totalled to give an overall numerical rating as in Table 6.3.2.

Table 6.3.2

Material	Heat resistance	Rigidity	Resistance to Stress cracking	Mouldability	Overall rating (Max = 20)
M1	4	3	3	3	13/20 = 0.65
M2	2	3	4	3	12/20 = 0.60
M3	5	4	1	1	11/20 = 0.55
M4	1	1	4	3	9/20 = 0.45
M5	4	5	1	3	13/20 = 0.65
M6	3	2	5	5	15/20 = 0.75

Clearly, the overall superiority of M6 derives from its maximum ratings in respect of stress cracking and mouldability, but what if heat resistance and rigidity were the properties more urgently required? This might well be so, since although the life of the component could be determined by its resistance to stress cracking, its resistance to heat and its rigidity could determine whether or not it can do the job at all. (Mouldability is important mainly through its influence on costs.) The relative importance of the various properties therefore depend upon the nature of the application and this can only be assessed by the designer using the tools of function analysis and quality function deployment, as discussed in earlier chapters. For example, he can exercise his judgement in this respect by assigning weighting factors to the various properties, as in Table 6.3.3.

Table 6.3.3

Material	Heat resistance ×5	Rigidity ×5	Resistance to stress cracking ×2	Mouldability ×3	Overall rating (Max = 75)
M1	20	15	6	9	50/75 = 0.67
M2	10	15	8	9	42/75 = 0.56
M3	25	20	2	3	50/75 = 0.67
M4	5	5	8	9	27/75 = 0.36
M5	20	25	2	9	55/75 = 0.73
M6	15	10	10	15	50/75 = 0.67

The choice now moves to M5, which means that a short-life material has been preferred to a long-life material. This emphasizes that weighting factors must be used cautiously, since by their use small changes in heavily weighted properties can mask the effects of large changes in more lightly weighted properties. However, the next stage will be to examine specific materials within the M5 family in more detail, although for the example shown, families M1, M3 and M6 should not be ruled out.

As always, materials selection is more effective when it can be carried out in terms of precisely defined quantitative property parameters. A method of dealing with this may be exemplified by means of the data given in Table 6.3.4, in which are listed materials which might be considered for use in an aeroplane wing. These materials could have been arrived at following a "sweeping" exercise as illustrated above. The values of cost/tonne given are illustrative only, and must not be taken as definitive. Price instability will bring change of magnitude and possibly, even, relationships.

Table 6.3.4

Material	σYS (MPa)	K_C (MPa m$^{1/2}$)	ρ (tonnes/m^3)	E (Gpa)	Cost (£/tonne)
Aluminium alloy 1	350	45	2.7	70	590
Aluminium alloy 2	550	25	2.7	70	700
Titanium alloy	880	60	4.5	110	5 500
Stainless steel	900	100	7.8	200	500
Unidirectional high strength carbon fibre epoxy laminate (60% carbon)	1 300	50	1.8	130	15 000

These data cannot be used in raw from, first, because the significance of the individual properties varies from one part of the structure to another, and second, because the units are variegated. The first point can be dealt with by combining units into so-called "merit parameters", formulated by consideration of the target function, as discussed in previous chapters; the second by expressing the data in each column as proportions of the largest figure appearing in that column (see Table 6.3.5).

Table 6.3.5

Material	$\sigma_{YS}^{1/2}/\rho$		$K_C^{1/2}/\rho$		$E^{1/3}/\rho$		Cost (£/tonne)		Overall rating $\frac{A+B+C+(1-D)}{4}$
	Abs.	Rel. (= A)	Abs.	Rel. (= B)	Abs.	Rel. (= C)	Abs.	Rel. (= D)	
Aluminium alloy 1	6.93	0.35	2.48	0.63	1.53	0.54	590	0.04	0.62
Aluminium alloy 2	8.69	0.43	1.85	0.47	1.53	0.54	700	0.05	0.60
Titanium alloy	6.59	0.33	1.72	0.44	1.06	0.38	5 500	0.37	0.45
Stainless steel	3.85	0.19	1.28	0.33	0.75	0.27	500	0.03	0.44
Unidirectional high strength carbon fibre epoxy laminate (60% carbon)	20.03	1.00	3.93	1.00	2.81	1.00	15 000	1.00	0.75

Abs=Absolute value; Rel.=Value relative to largest quantity.

The values of the three merit parameters listed in Table 6.3.5 should be maximized to provide the minimum weight of a flat panel, loaded in bending where the thickness is free. Where strength is important, $\sigma^{1/2}/\rho$ is important; where stiffness is important, $E^{1/3}/\rho$ is important; where toughness is important, $K_C^{1/2}/\rho$ is important. These are all reasonable parameters to apply to aircraft wing skin materials. Despite its high price, the overall rating of the composite is the highest. There is apparently little to choose between the aluminium alloys or, at the bottom of the five candidate materials, titanium alloy and stainless steel. It is hardly surprising that where cost is relatively insignificant, which is generally the case for military supersonic aircraft, composite materials are used. Even in civil aircraft, the use of composites is increasing. However, aluminium alloys remain a good choice, partly for conservative reasons because their processing and behaviour is well characterized. The use of stainless steels in wing structures is limited, despite their corrosion resistance, but some titanium alloys have been developed for selected aircraft skin applications, despite the low overall rating shown in Table 6.3.5, and the reasons are explored in Chapter 15. Illustrating, perhaps, that while merit parameters are useful, in the real world the situation is often more complicated.

Word and Phrases

1. aesthetics	美学，审美学
2. merit	优点
3. ameliorating	改善，改进
4. contender	竞争对手
5. generic	类别的，一般的
6. austenitic stainless steel	奥氏体不锈钢
7. polyamides	聚酰胺
8. polyacetal	聚缩醛
9. ameliorate	改善，改良，变好
10. excessive	过度的，极端的
11. titanium	钛
12. tolerance	允许误差
13. quantifiable	量化的
14. vague	含糊的，笼统的
15. ascending	下降的
16. asses	评估
17. cautiously	谨慎地，小心地
18. mask	掩盖
19. variegated	多样化的
20. stiffness	刚度
21. composite	复合材料

4 Materials Databases

The importance of integrating materials selection and manufacturing method with the design process has been highlighted in Chapter 2, as has the role of computer-aided design and computer-aided manufacture. Therefore, it is logical that the materials selection should also be computerized. Also, the computer is able to sort through masses of data rapidly, which is invaluable given the ever expanding number of available engineering materials, making a manual search of data very laborious if not impossible. Much of the available materials data does now exist in computerized form, and several information networks now exist. However, hardcopy databases should not be ignored, and the relationship between the different database forms is illustrated in Fig.6.4.1. The different types of database available are shown in Fig.6.4.2.

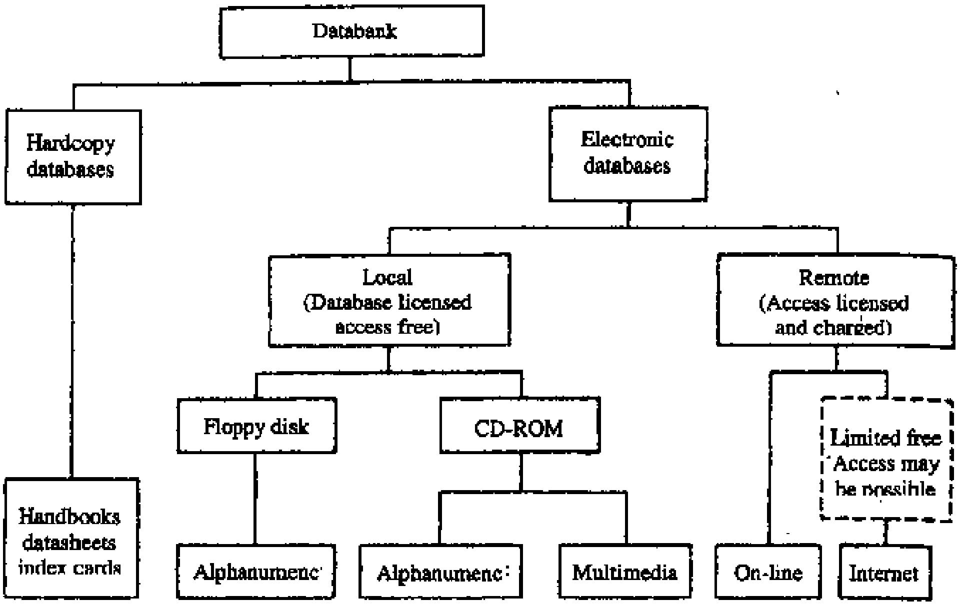

Fig.6.4.1 Database Forms (from Maier)

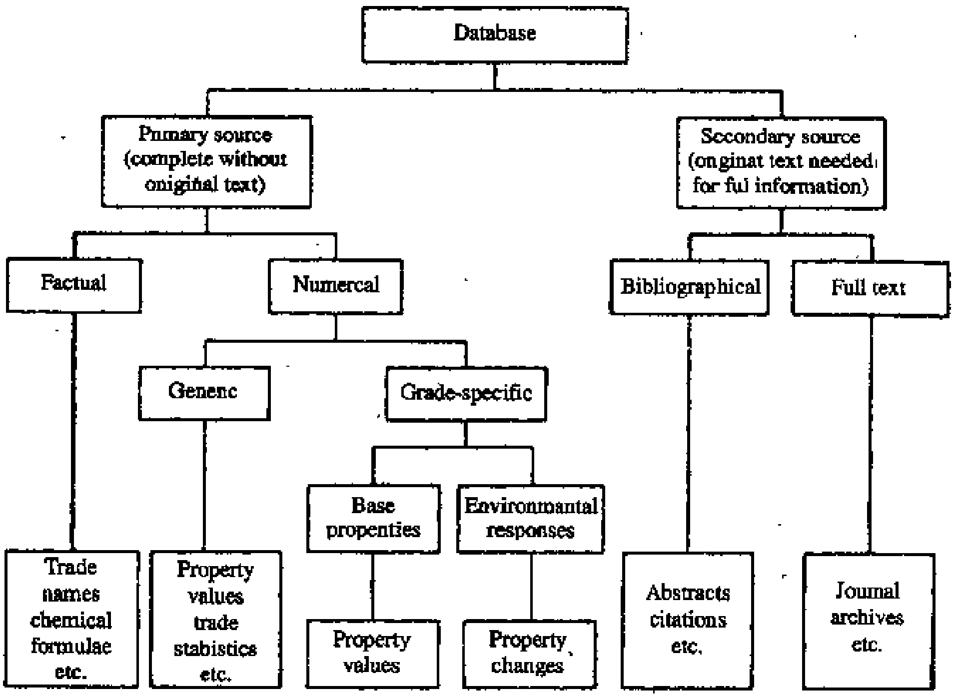

Fig.6.4.2 Database Types

The use of a database with a particular selection methodology was an idea developed many years ago by Waterman and further discussed by Appoo and Alexander. Gillam also discussed some aspects of computer selection, and Reid and Greenberg described, as an example, how a simple computer program could aid optimal materials selection for a compound beam. The apprcach has now become wellestablished, with several systems available commercially.

Generic Databases

Generic databases are concerned with materials at the "family" level. Property values are those considered typical for specific grades within the family, although the materials are often subdivided into a reasonably narrow band of materials, generally suitable for the conceptual design stage.

The **Cambridge Materials Selector** is a generic database that builds on the graphical methods described by Ashby, which are user-friendly and very effective in the initial; sorting stages. The selection philosophy involves first identifying the design requirements. These are then expressed in terms of a merit parameter. The merit parameter can be plotted as a straight line onto the Ashby map, where on logarithmic scales, the properties under consideration are displayed along the axes. Two examples are shown as Fig.6.4.3 and 6.4.4, where Young's modulus is plotted against density and Young's modulus is plotted against strength, respectively. The range of properties displayed by each family of materials is described by a "balloon" on the map. In Fig.6.4.3, the lines for E/ρ, $E^{1/2}/\rho$ and $E^{1/3}/\rho = C$, where C is a constant, are drawn. For minimum weight design, the value of C should be maximized, which represents moving the lines from right to left. As already noted, when selecting materials for a light, stiff column, $E^{1/2}/\rho$ should be maximized, and, as can be seen from Fig.6.4.3, wood and composite CFRP are good candidate materials, residing in the unshaded portion of the graph.

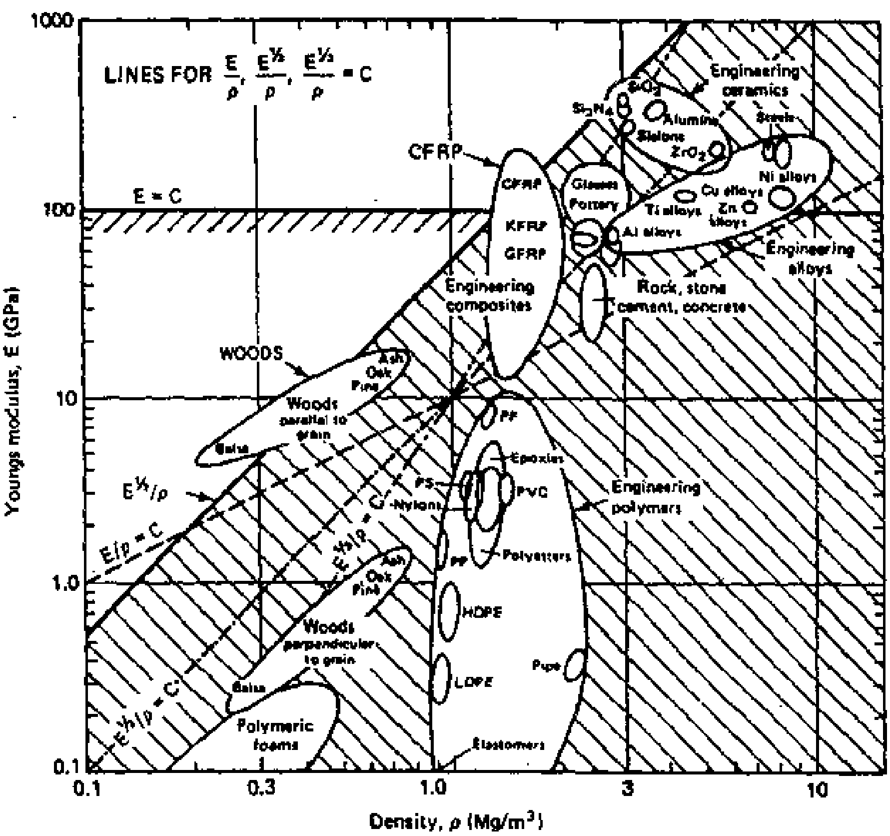

Fig.6.4.3 Materials Selection Chart: Young's Modulus/Density Indicating Relationships of Specific Stiffness

In Fig.6.4.4, the lines for σ_y/E and $\sigma_y^2/E = C$ are drawn. To minimize the volume of a spring with a specified energy storage value, for example, the parameter σ_y^2/E should be maximized, regardless of spring shape or loading method. Moving the line for σ_y^2/E to increase C (N.B left to right), materials with maximum C values include rubber and spring steels, which might have been anticipated. Note, however, that CFRP and glass make excellent springs in the right circumstances, hence the use of glass galvanometer suspensions and CFRP vehicle springs.

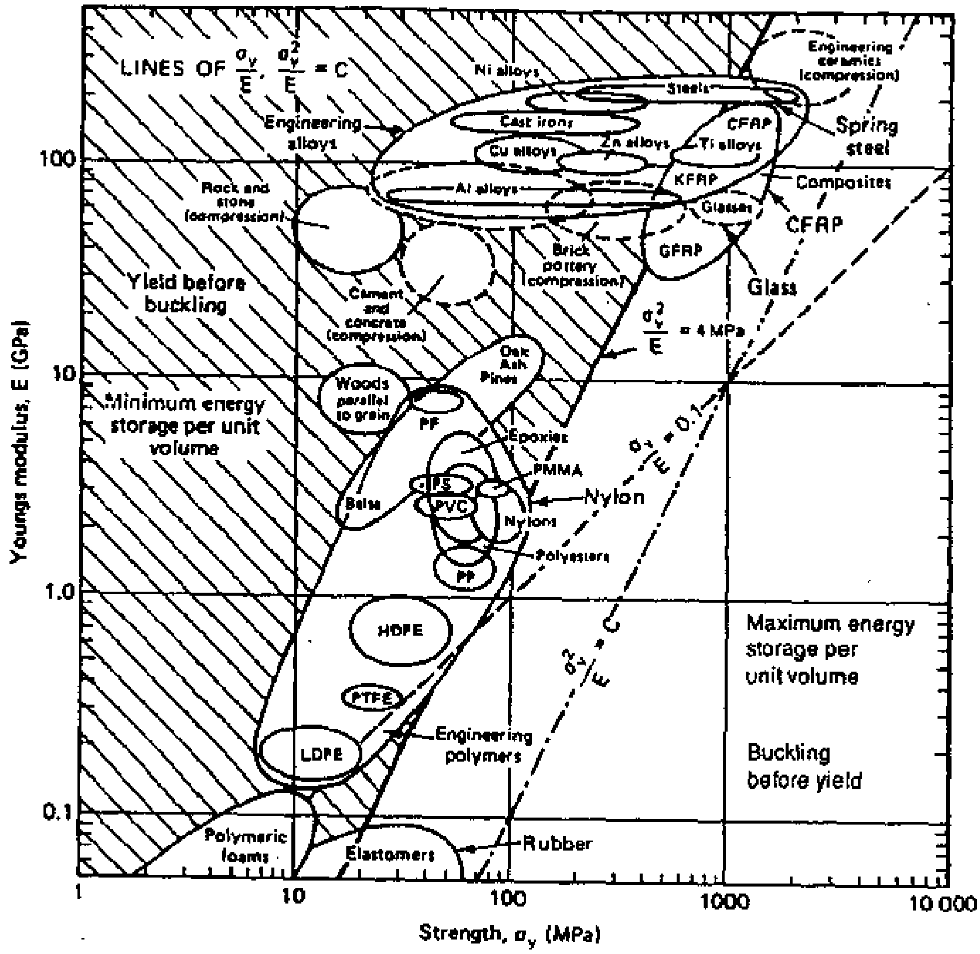

Fig.6.4.4 Materials Selection Chart: Young's Modulus/Strength Indicating Relationships for Consideration as Springs

The method is very powerful and makes it possible to sweep across the properties of each of the generic materials families, useful in design innovation exercises. The **Cambridge Materials Selector (CMS)** allows these maps to be plotted from the comprehensive database, with continuous properties such as strength plotted as shown above; discontinuous properties such as corrosion resistance in certain environments are ranked on a scale of 1 to 5. After the design requirements are finalized, it is possible to perform several sequential selection steps as well as combine properties on one axis (e.g. cost multiplied by density) and the materials passing each and all of the steps can be displayed. Although included in the generic databases, CMS uses several specific databases as well as a front-end generic database, including polymers, light alloys and metal matrix composites. Once the generic database has highlighted, for example, that a number of polymer families are candidate materials, it is possible to refine the selection further by interrogating the polymers database, although there is no data on specific commercial grades, and the selection of "short fibre reinforced polymers" with the generic database may be refined only to "polyamide 6/6-30% short glass fibre reinforced" using the polymers database. The generic database contains 143 materials (15 of which are thermoplastics), the polymers database contains 178 materials (54 of these are thermoplastics).

Plascams is a generic database for plastics, with 351 material types included, arranged under 84 generic family titles. The search philosophy is more basic than the approach used in CMS. Initially, an elimination search is conducted to ascertain those materials meeting certain essential design criteria, e.g. "tensile strength greater than 60 MPa". Materials passing these elimination searches are then ranked by a combined weighting search of desirable properties. Each of the 351 materials has been given an "expert" ranking between 0 and 9 for each property. These rankings are simply multiplied by the weightings assigned to the property by the designer. There can be a danger in using the weightings to arrive at the answer that might have been anticipated from past experience. **Rubacams** is a sister database to **Plascams**, containing data on 38 generic types of rubbers and elastomers, utilizing a broadly similar selection philosophy to **Plascams**. The producers of **Plascams** and **Rubacams** have used this software in recently released knowledge-based systems for plastics and rubbers. Using CD-ROM technology, the producers have been able to combine several software programs and databases into one system. This enables it to cut across the boundaries shown in Fig.6.4.2, containing abstracts, encyclopaedic information, materials processing analysis software as well as materials selection systems. The knowledge-base allows all of these components to be "hot-linked" so that a line of enquiry can be followed through the system.

Grade-Specific Databases

These databases hold property values for identified commercially available material grades, so they work well in conjunction with a generic database, refining the materials selection to specific grades and suppliers. For plastics, **Campus** is the world-leader in grade-specific databases and emerged from an initiative by the major materials producers. Now more than 30 materials suppliers produce **Campus** disks, holding data on their own material grades. Compatibility of data between suppliers is ensured by utilizing the ISO standards for single and multi-point data. It is possible to search the grades of all suppliers simultaneously using a program developed by the producers of the database engine, M-Base. This allows access to more than 6 000 grades of plastic materials. Materials selection is made by defining upper and lower bounds to the desired property.

Other grade-specific database for plastics include **Selector** II, giving a total coverage of some 21 500 grades of thermoplastic and thermoset. **Plaspec** contains data on more than 11 000 grades. The selector program can be enhanced with the purchase of other database modules containing bibliographic information. For metals, a number of disks are available in the UK that originated from a recent government initiative. Databases for copper alloys, magnesium alloys, stainless steels and titanium alloys have been produced to run under DOS. The Aluminium

Federation produce a database of aluminium alloys, **Aluselect.**

There are also a number of databases providing grade-specific information on a range of materials. **Mat. DB** is a modular database that can be built to suit the user. Ten modules are currently available, including thermoplastics, composites and steels. The data are derived largely from standards and critical assessment of the scientific literature. It is, however, expensive and somewhat cumbersome to use. **Cen BASE/Materials** is another grade-specific database covering about 30 000 plastics, metals, composites and other materials. All property fields are searchable and the data are backed-up by full-text descriptions and supplier contact details. In a recent development, **CenBASE/Materials**, has become available on the Internet, with unlimited access for a small annual subscription (<http://www.icentor.com>, see below). **M-Vision** is an expensive system, primarily containing data for aerospace alloys and composites, but the selection procedures are very flexible, although it needs a workstation to operate.

The Plastics Design Library have developed **Rover PDL Electronic Handbooks**, which are a modular database system, building on the PDL hardcopy data on the environmental properties of plastics, and will include data on metals and ceramics.

Bibliographical Databases

Bibliographical databases are designed to rapidly assemble a series of references relevant to a particular enquiry. They normally comprise abstracts but sometimes include numerical data and statistical information. **Rapra Abstracts** is the world's biggest store of plastics information, containing over 400 000 references, all classified by keywords. **Engineered Materials Abstracts** is a bibliographical database of over 75 000 references concerned with plastics, ceramics and composites. The abstracts are derived from technical journals, books, patents, conference proceedings and suppliers' literature. **Metadex** is the equivalent database for metals. Each of these bibliographical systems is available on-line or via CD-ROM.

The Internet

The Internet population is growing rapidly and most information providers now have a presence on the world-wide web. There is a good deal of information made available without charge, but several sites are used to act as "tasters" for a subscription service, although the charges for these can be modest. Useful Internet addresses are listed below at the end of this chapter.

Data Quality

In all these selection systems, whether computerized or not, much hinges on the current recognition of the service requirements and correct instructions in terms of weightings given to various factors and the significance of constraints. Several important properties are not easily quantifiable and data may not be obtainable, particularly in relation to wear and various forms of corrosion. The GIGO principle applies, namely garbage in-garbage out. And no database has been developed to truly deal with synergistics, making the testing of materials in their anticipated service conditions just as essential before final selection.

The quality of the data held in computerized and hard copy systems is always of concern and it is important to ensure that data used for comparative purposes results not only from equivalent testing but that its accuracy is also validated.

At an advanced stage in the selection process, whether or not computerized handling of the data is envisaged, it becomes convenient to combine cost and property parameters because processing accounts for a large part of final costs, and it may happen that the properties exhibited by a material processed in one way are different from the properties of the same material processed in another way. It is best then to employ compound parameters such as $(C_R)_p / \sigma_{YS}$, where (C_R) is the price per unit mass, and where the parameter takes different values for different materials variants and different manufacturing processes. An overall rating can then be obtained in terms of these parameters in the manner previously described, using weighting factors and lower bounds, as appropriate. A list of compound parameters of this sort is given in the Introduction.

It may be noted that where space-filling is the major requirement, as applies for example to a pressure-activated device, then the only criteria of choice are surface stability and price per unit volume since mechanical properties are irrelevant.

PC-Based Materials Databases

Cambridge Materials Selector

Granta Design Ltd
20 Trumpington Street
Cambridge CB2 1QA, UK
Tel: +44(0) 1223 334755
Fax: +44(0) 1223 332797
WWW: http://www.granta.co.uk

Plascams, Rubacams, Rapra Abstracts, Plastics and Rubber Knowledge-Based Systems

Rapra Technology Ltd
Shawbury
Shrewsbury
Shropshire SY4 4NR, UK
Tel: +44(0) 1939 250383
Fax: +44(0) 1939 251118
WWW: http://www.rapra.net

Campus (disks available from plastics material manufacturers)

M-Base GmbH
Dennewart Strasse 27
DS-2068 Aachen, Germany

Tel: +49 241 963 1450
Fax: +49 241 963 1469
WWW: http//www.m-base.de

Selector II

Data Business Publishing
15 Inverness Way East
PO Box 6510
Englewood
CO 801556510, USA
Tel: +1 303 799 0381
Fax: +1 303 799 4082

Aluselect

Aluminium Federation
Broadway House
Calthorpe, Fiveways
Birmingham B15 1TW, UK
Tel: +44(0) 121 456 1103
Fax: +44(0) 121 456 2274

Mat. DB, Engineered Materials Abstracts, Metadex

ASM International
Materials Park
OH 44073, USA
Tel: +1 216 338 5151
Fax: +1 216 338 4634
WWW: http://www.asm-intl.org

CenBASE/Materials

Infodex
12782 Valley View Street
Garden Grove
CA 92645, USA
Tel: +1 714 893 2471
Fax: +1 714 893 4856
WWW: http://www.centor.com/cbmat/index.html

M-Vision

PDA Engineering
2975 Redhill Avenue

Costa Mesa
CA 92626, USA
Tel: +1 714 540 8900
Fax: +1 714 979 2990

PDL Electronic Handbooks

Plastics Design Library
13 Eaton Avenue
Norwich
NY 13815, USA
Tel: +1 607 337 5000
Fax: +1 607 337 5090
WWW: http://www.norwich.net/~wai001

On-Line Materials Databases

Plaspec

D & S Data Resources, Inc
PO Box H
Yardley
PA 19067, USA
Tel: +1 215 428 1060
Fax: +1 215 428 1069

Engineered Materials Abstracts, Metadex ASM International
as above

Rapra Abstracts
as above

On-Line Service Providers

ERA-IRS Dialtech
British Library
25 Southampton Buildings
London WC2A IAW, UK
Tel: +44(0) 171 323 7951
Fax: +44(0) 171 323 7954

Datastar Dialog Europe
Knight-Ridder Information Ltd
Haymarket House

1 Oxenden Street
London SWIY 4EE, UK
Tel: +44(0) 171 930 7646
Fax: +44(0) 171 930 2581

Questel Orbit
18 Parkshot
Richmond
Surrey TW9 2RG, UK
Tel: +44(0) 181 332 7888
Fax: +44(0) 181 332 7449

STN International
FIZ Karlsruhe
PO Box 2465
76012 Karlsruhe
Germany
Tel: +49 7247 808555
Fax: +49 7247 808131

Internet Sites General Materials

Cen BASE/Materials
as above

Cambridge Materials Selector
as above

The Institute of Materials
http://www.instmat.co.uk

University of Cambridge, Department of Materials Science and Metallurgy
http://www.msm.cam.ac.uk

Index to WWW Materials Engineering
http://www.materials.drexel.edn/others/industry.html

Metals

The Copper page
http://www.copper.org

The Aluminum Industry WWW Server
http://www.euro.net/concepts/industry.html

Metal Powder Industries Federation
http://www.well.com/user/css/mpif.htm

Ceramics

Technical ceramics-WWW virtual library
http://www.ikts.fhg.de/ceramics.html

Plastics

Rapra Technology Ltd
as above

PDL/Plastics Design Library
as above

Polymer DotCom
http://www.polymers.com/dotcom/subscribe.html

Plastics News
http://www.plasticsnews.com

Allied Signal Plastics
http://www.asresin.com

BASF
http://www.basf.de/basf/html/e/home.htm

GE Plastics
http://www.ge.com/plastics/index.htm

Hoescht
http://www.hoescht.com

IDES Databases
http://www.odesinc.com

IRC in Polymer Science
University of Leeds
http://www.irc.leeds.ac.uk

Composites

Turner Moss Co
http://www.advmat.com/links.html

Word and Phrases

1. selection philosophy 选择策略
2. logarithmic 对数的
3. Young's modulus 杨氏模量
4. interrogating 询问

5. encyclopaedic　百科全书的，包含各种学科的，广博的
6. thermoplastic　热塑性
7. thermoset　热固性
8. cumbersome　麻烦的，笨重的
9. bibliographic　加书目提要的
10. Magnesium　镁
11. hinge on　取决于
12. envisage　考虑，设想

5 Graphical Analysis

Graphicai Position Analysis

Regardless of what procedure is used for a linkage analysis, it is necessary to determine the angular positions of the links before it is possible to perform a velocity analysis. Likewise, it is necessary to know the link angular velocities before an acceleration analysis can be performed. That is, the kinematic analysis of a linkage must **always** proceed in this sequence: position analysis, then velocity analysis, then acceleration analysis. If the linkage has one degree of freedom and the driver is a crank, it is necessary that the angular position, angular velocity, and angular acceleration of a driving link be specified for a solution to be possible. If the driving member is connected to the hase by a prismatic joint, the linear position, velocity, and acceleration of any point in that link must be specified.

When working graphically, the position analysis consists of simply drawing the linkage to scale. Usually this is to straightforward that it tends to be forgotten as an important step in the solution process. The representation used is a geometric skeleton of the linkage: links connected by revolute joints are represented by the line, or lines, joining the joint axes. Prismatic joints are represented by lines in ths direction of sliding. Revolute joints are usually represented only by the points that are the intersections of their axes with the plane of motion. The way the method works in the analysis of a simple linkage is illustrated in the examples.

As will be shown in Chapter 3, the position equations for mechanisms are inherently nonlinear. In many cases, the mechanism can be assembled (or drawn) in two possible configurations. It is necessary to know before the analysis is conducted which solution is desired. This will be illustrated in the examples that will be discussed after the equations for velocity and acceleration are developed.

We will begin the analysis of velocities and accelerations with a relatively simple case involving two points fixed to the same rigid link. The equations for this case are commonly developed in courses in mechanics using the procedure we shall use here. The equations developed will be directly applicable to mechanisms with revolute joints and/or sliders on fixed lines. We will illustrate the use of the procedure with several examples.

For more complex joints, a more rigorous and general approach will be used to develop the velocity and acceleration equations. This will entail identifying the coordinate systems relative to which each of the vectors is described and relative to which the time derivatives are desired. It will be shown that the velocity and acceleration equations developed for the case of two points on a rigid link are special cases of the more general equations.

Planar Velocity Polygons

Velocity analysis is the determination of the angular velocities of different links in a mechanism and of the velocities of points on the links, given either the angular velocity of some member or the velocity of some point on the link designated as the input. The vector polygon technique will be used here to solve the velocity and acceleration equations. The method facilitates the solution of a large variety of velocity and acceleration problems and also has the advantage that the acceleration polygon solution has a strong similarity to that of the velocity polygon, which makes it relatively straightforward to learn and remember. Almost all practical problems can be solved by this approach.

In theory, however, the technique is not general. It is possible to formulate problems that cannot be solved by the methods presented here. Special techniques have been developed that allow treatment of some of the simpler cases that are not amenable to the vector polygon method; however, it is possible to formulate problems that cannot be solved by even these embellished techniques. The reader is referred to books by Hirschhorn,[1] Hall,[2] and Holowenko[3] for the auxiliary-point technique and other methods of handling more general mechanisms. It should be emphasized, however, that problems that cannot be solved by the methods presented in this chapter are rarely encountered in practice.

The key to the graphical velocity analysis of most linkages is the relationship between the velocities of any two points embedded in a rigid body. This relationship is

$$v_B = v_A + \omega \times r_{B/A} \tag{6.5—1}$$

where A and B are points fixed in a moving lamina (rigid body) as shown in Fig.6.5.1, v_A and v_B are

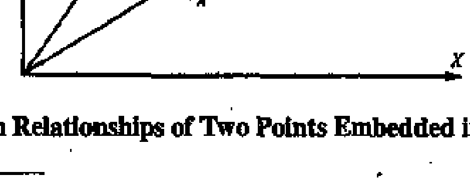

Fig.6.5.1 Position Relationships of Two Points Embedded in a Moving Lamina

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1 Hirschhorn, J., *Kinematics and Dynamics of Plane Mechanisms*, McGraw Hill Book Co., New York, 1962
2 Hall, A., *Kinematics and Linkage Design*, Balt Publishers, West Lafayette, IN, 1966
3 Holowenko, A. R., *Dynamics of Machinery*, John Wiley & Sons, Inc., New York, 1955

the respective velocities relative to the frame of those points, $r_{B/A}$ is the vector $\overline{AB}$, and ω is the angular velocity of the lamina relative to the frame.

To prove this relationship, consider the two points A and B fixed in the lamina shown in Fig.6.5.1. The lamina is moving with general planar motion. Let the position of point A relative to a fixed reference frame be r_A and that of point B be r_B. The vector $\overline{AB}$ is $r_{B/A}$ and is pointed from A to B. Therefore

$$r_B = r_A + r_{B/A} \tag{6.5—2}$$

Differentiating Eq.(6.5—2) with respect to time gives

$$v_B = v_A + \mathrm{d}r_{B/A}/\mathrm{d}t$$

Now, since points A and B are fixed in the moving lamina, vector $r_{B/A}$ is fixed in that lamina and moves with it. It has constant length, so only its direction changes. Let the change in direction in a small time interval δt be $\delta\theta$ as shown in Fig.6.5.2. The magnitude of the change in $r_{B/A}$ is

$$\delta r = r_{B/A}\delta\theta$$

As δt and hence $\delta\theta$ approach zero, the angle between vectors $\delta r_{B/A}$ and $r_{B/A}$ approaches 90°. If ω is the magnitude of the angular velocity of the lamina,

$$\delta\theta = \omega\,\delta t$$

Therefore

$$\delta r/\delta t = r\omega$$

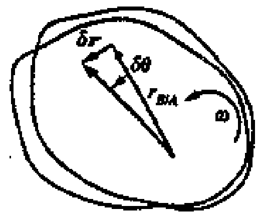


Fig.6.5.2 Successive Positions of the Lamina Separated by a Small Time Interval, δt

so, in the limit as δt approaches zero,

$$\left|\mathrm{d}r_{B/A}/\mathrm{d}t\right| = r_{B/A}\omega$$

If ω is considered to be a vector normal to the plane of motion, clockwise (CW) if directed away from the observer and counterclockwise (CCW) if directed toward the observer, the direction of $\mathrm{d}r_{BA}/\mathrm{d}t$ is normal to ω and to $r_{B/A}$ and obeys the right-hand screw rule with respect to those vectors. Therefore $\mathrm{d}_{rB/A}/\mathrm{d}t$ can be represented by the expression

$$\mathrm{d}r_{B/A}/\mathrm{d}t = \omega\times r_{B/A}$$

Thus

$$v_B = v_A + \omega\times r_{B/A} \tag{6.5—1}$$

As will be shown later, this expression is actually valid for general, spatial motion, although the derivation above applies only to planar motion.

It is convenient to write Eq.(6.5—1) in the from

$$v_B = v_A + v_{B/A} \tag{6.5—3}$$

where

$$v_{B/A} = \omega\times r_{B/A} \tag{6.5—4}$$

The vector $v_{B/A}$ is usually called the velocity of B relative to A, although, strictly speaking, it is meaningless to talk of a velocity relative to a point. Velocities are vectors and are measured relative to reference frames. Therefore, $v_{B/A}$ would be the velocity of point B relative to a reference frame which has its origin at point A. The reference frame moves so as to be always parallel to the fixed frame.

The basic technique used in a graphical linkage analysis is to work from one or more points with known velocity to one of unknown velocity using the relationship in Eq.(6.5—1) between the velocities of two points fixed in the same lamina. The intersections of the axes of revolute joints with the plane of motion form transfer points because they are actually coincident points fixed in two different links. Thus, the velocity of a revolute point can be obtained by considering it to be a point in one of the links it connects. That information can then be used by considering it to be fixed in the other link.

Eq. (6.5—3) can be represented graphically as the vector triangle shown in Fig.6.5.3. This triangle can always be solved given the direction and magnitude of one of the three vectors and the directions of the remaining two. This is the normal situation in planar velocity analysis. Again, the way in which this works will be illustrated in several examples after all of the necessary equations have been developed.

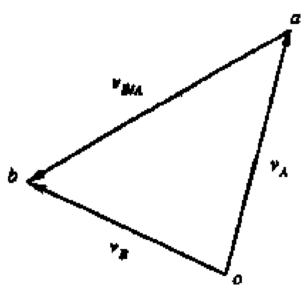


Fig.6.5.3 Velocities of Two Points Embedded in a Lamina

Based on Eq.(6.5—3), to find the angular velocity, ω, for a given link, we must compute the relative velocity between two points on the link, and the velocity must be given relative to the desired reference frame. For example, the relative velocity relationship for points B and A can be written as

$$v_{B/A} = \omega \times r_{B/A} \tag{6.5—5}$$

The vectors will be mutually orthogonal as indicated schematically in Fig.6.5.4. Because we will know the lines along which each of the vectors must lie, the main problem is to determine the directions along the lines and the magnitudes of each of the vectors. Given any two of the vector directions, we can find the direction of the third by observing the directions given by the right-hand screw rule. Two examples are shown in Fig.6.5.4.

Fig.6.5.4 The Direction Relationship Among the Vectors $v_{B/A}$, ω, and $r_{B/A}$ for Planar Motion

Notice that $v_{B/A}$ and $r_{B/A}$ are always perpendicular to each other. Also, visually, we can determine the direction of $v_{B/A}$ by rotating $r_{B/A}$ 90° in the direction of ω. Similarly, if we know the directions of $r_{B/A}$ and $v_{B/A}$, we can determine the direction of ω by visualizing the direction in which we must rotate $r_{B/A}$ to obtain the direction of $v_{B/A}$.

Because the three vectors in Eq.(6.5—4) are orthogonal, their magnitudes are related by

$$|v_{B/A}| = |\omega||r_{B/A}| \qquad (6.5—6)$$

Given any two of the three magnitudes in Eq.(6.5—6) we can easily solve for the third magnitude.

Graphical Acceleration Analysis

Just as was the case for velocity analysis, the key to most graphical acceleration analysis is the relationship between the accelerations of two points fixed in the same rigid lamina or link. This relationship can be derived by differentiating the velocity relationship with respect to time. Rewriting Eq.(6.5—1)

$$v_B = v_A + \omega \times r_{B/A} \qquad (6.5—1)$$

Differentiating

$$a_B = a_A + \mathrm{d}\omega/\mathrm{d}t \times r_{B/A} + \omega \times \mathrm{d}r_{B/A}/\mathrm{d}t$$

As was shown above,

$$\mathrm{d}r_{B/A}/\mathrm{d}t = \omega \times r_{B/A}$$

Also, α is defined to be $\mathrm{d}\omega/\mathrm{d}t$. Hence

$$a_B = a_A + \alpha \times r_{B/A} + \omega \times (\omega \times r_{B/A}) \qquad (6.5—7)$$

As will be demonstrated later, this expression is generally valid for three-dimensional motion, although it has been derived here only in the planar motion context. For planar motion, it is possible to simplify the expression by noting that, in this case, ω and $r_{B/A}$ are orthogonal ,as shown in Fig.6.5.5. Also, $\omega \times r_{B/A}$ has the magnitude $\omega r_{B/A}$ and is normal to both ω and $r_{B/A}$ in the sense given by the right-hand screw rule. Then $\omega \times (\omega \times r_{B/A})$ has the magnitude $\omega^2 r_{B/A}$ and is orthogonal to both ω and $\omega \times r_{B/A}$. Applying the right-hand screw rule, it can be seen that this vector $\omega \times (\omega \times r_{B/A})$ is always in the negative $r_{B/A}$ direction. Therefore it can be written as $-\omega^2 r_{B/A}$, and the relationship between the accelerations of points A and B is

$$a_B = a_A + \alpha \times r_{B/A} - \omega^2 r_{B/A} \qquad (6.5—8)$$

It is usual to write

$$a^r_{B/A} = -\omega^2 r_{B/A} \quad \text{and} \quad a^t_{B/A} = \alpha \times r_{B/A} \qquad (6.5—9)$$

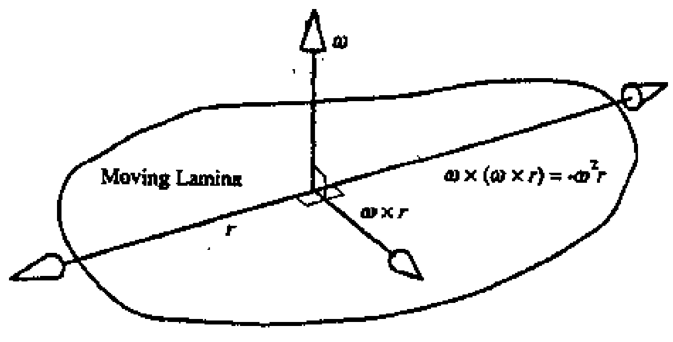


Fig.6.5.5 The Derivation of the Relationship $\omega(\omega \times r) = -\omega^2 r$ which is Valid for Planar Motion

with $a^r_{B/A}$ called the radial component of the acceleration of B relative to A and $a^t_{B/A}$ called the transverse component of the acceleration of B relative to A. As was noted in the case of velocities, it is not really proper to talk about the velocity or acceleration of one point relative to another point. The vector $a_{B/A}$ is really the acceleration of point B relative to a reference frame with origin at A. The reference frame moves so that it is always parallel to the fixed frame.

The vector polygon corresponding to Eq.(6.5—7) is shown in Fig.6.5.6. If a velocity analysis of the linkage has been performed, the angular velocities of all the links are known, and so the radial component $a^r_{B/A} = -\omega^2 r_{B/A}$ can always be calculated and plotted. Hence, if one of the other vectors is known, and the directions of the remaining two are also known, the polygon can be solved in very much the same way as the vector triangle was used in velocity analysis. This is the normal procedure for a graphical acceleration analysis.

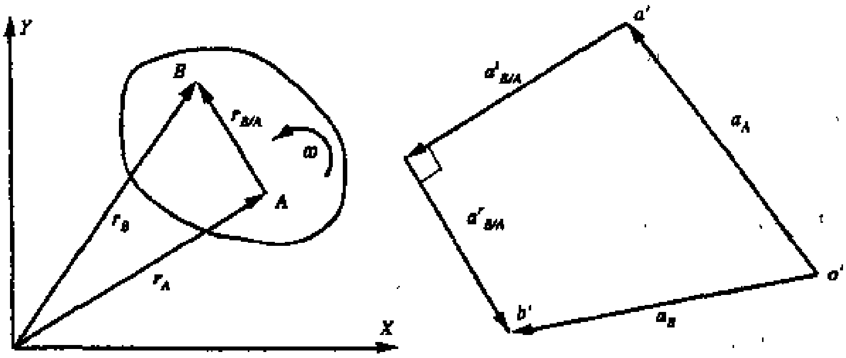


Fig.6.5.6 Accelerations of Two Points Embedded in a Moving Lamina

The angular acceleration for a given link is obtained in the same manner as the angular velocity except that the **tangential** component of relative acceleration is used instead of the linear velocity. To find a value of α, we must know the tangential component of the relative acceleration between any two points on the link. That tangential component of acceleration must be given relative to the desired reference frame. For example, the relative tangential acceleration relationship for points B and A can be written as

$$a^t_{B/A} = \alpha \times r_{B/A}$$

Because we will know the lines along which the vectors must lie, the main problem again is to determine the directions along the lines and the magnitude of each of the vectors. Given any two of the vector directions, we can find the direction of the third by observing the directions given by the right-hand screw rule. Two examples are shown schematically in Fig.6.5.7.

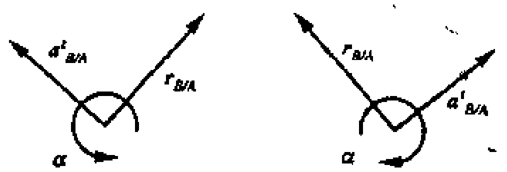


Fig.6.5.7 The Direction Relationship Among the Vectors $a^t_{B/A}$, α, $r_{B/A}$ for Planar Motion

Notice that these relationships are exactly the same as for the velocity expressions if ω is replaced by α and $v_{B/A}$ is replaced by $a^t_{B/A}$. In particular, notice that $a^t_{B/A}$ and $r_{B/A}$ are always perpendicular to each other. Also, we can determine the direction of $a^t_{B/A}$ by visually rotating $r_{B/A}$ 90° in the direction of α. Similarly, if we know the directions of $r_{B/A}$ and $a^t_{B/A}$, we can determine the direction of α by visualizing the direction in which we must rotate $r_{B/A}$ to obtain the direction of $a^t_{B/A}$.

Because the three vectors in Eq.(6.5—9) are orthogonal, their magnitudes are related by

$$\left|\alpha^t_{B/A}\right| = \left|\alpha\right| \left|r_{B/A}\right| \qquad (6.5—10)$$

Given any two of the three magnitudes in Eq.(6.5—10), we can easily solve for the third magnitude.

Word and Phrases

1. constraint	约束
2. ingenuity	独创性，设计新颖
3. robust	健壮，鲁棒
4. iterative	反复，迭代
5. kinematic	运动学的
6. linkage	连杆机构
7. degree of freedom	自由度
8. driver	驱动件
9. crank	曲柄
10. prismatic joint	移动副
11. revolute joint	转动副
12. inherently	内在的，固有的
13. slider	滑块
14. entail	需要
15. derivative	导数
16. polygon	多边形
17. rigid body	刚体
18. lamina	平面构件
19. amenable to	适合于
20. embellish	修饰
21. coincident	一致的，符合的
22. transverse component	切向分量
23. tangential component	切向分量

6 Ball and Roller Bearings

Ball and roller bearings have been brought to their present state of perfection only after a long period of research and development. The benefits of such specialized research can be obtained when it is possible to use a standardized bearing of the proper size and type. Ball bearings are used in almost every kind of machine and device with rotating parts. However, such bearings cannot be used indiscriminately without a careful study of the loads and operating conditions. In addition, the bearing must be provided with adequate mounting, lubrication, and sealing.

Pillow blocks, incorporating ball or roller bearings, are available from stock, and are very convenient as the mounting and sealing of the bearing has already been done.

Construction and Types of Ball Bearings

A ball bearing usually consists of four parts: an inner ring, an outer ring, the balls, and the cage or separator. To increase the contact area and permit larger loads to be carried, the balls run in curvilinear grooves in the rings. The radius of the groove is slightly larger than the radius of the ball, and a very slight amount of radial play must be provided. The bearing is thus permitted to adjust itself to small amounts of angular misalignment in the assembled shaft and mounting. The separator keeps the balls evenly spaced and prevents them from touching each other on the sides, where their relative velocities are the greatest.

Ball bearings are made in a wide variety of types and sizes. Single-row radial bearings are made in four series, "extra light, light, medium, and heavy," for each bore, as illustrated in Fig.6.6.1(a), (b), and (c). The heavy series of bearings is designated by 400. Most manufacturers use a numbering system so devised that if the last two digits are multiplied by 5, the result will be the bore in millimeters. The digit in the third place from the right indicates the series number. Thus, bearing 307 signifies a medium-series bearing of 30 mm bore. Additional digits, which may be present in the catalog number of a bearing, refer to the manufacturer's details. Some makers list deep groove bearings and bearings with two rows of balls.

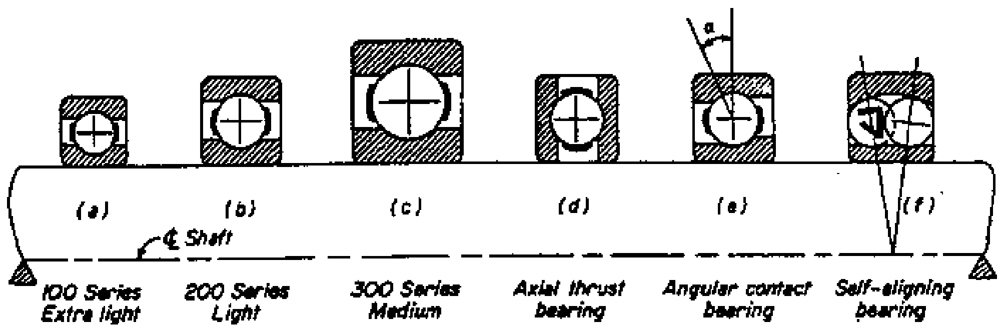
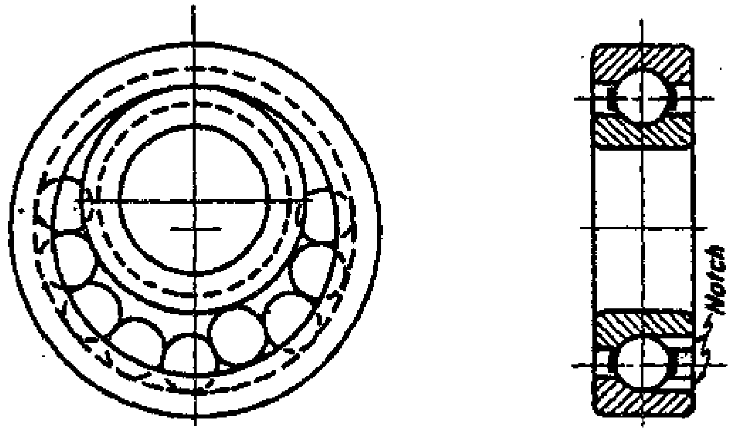


Fig.6.6.1 Types of Ball Bearings

The radial bearing is able to carry a considerable amount of axial thrust. However, when the load is directed entirely along the axis, the thrust type of bearing should be used. The angular contact bearing will take care of both radial and axial loads. The self-aligning ball bearing will take care of large amounts of angular misalignment. An increase in radial capacity may be secured by using rings with deep grooves, or by employing a double-row radial bearing.

Radial bearing are divided into two general classes depending on the method of assembly. These are the Conrad, or nonfilling-notch type, and the maximum, or filling-notch type. In the

Conrad bearing, the balls are placed between the rings as shown in Fig.6.6.2(a). Then they are evenly spaced and the separator is riveted in place. In the maximum-type bearing, the balls are inserted through a filling notch ground into each ring, as shown in Fig.6.6.2(b). Because more balls can be placed in such bearings, their load capacity is greater than that of the Conrad type. However, the presence of the notches limits the load-carrying ability of these bearings in the axial direction.



(a) Conrad or non-filling notch type (b) Maximum or filling notch type

Fig.6.6.2 Methods of Assembly for Ball Bearings

High-carbon chromium steel 52100 is used for balls and rings. It is heat treated to high strength and hardness, and the surfaces are smoothly ground and polished. The dimensional tolerances are very small; the balls must be very uniform in size. The stresses are extremely high because of the small contact areas, and the yield point of the material may be exceeded at certain points. Because of the high values of the fluctuating stresses, antifriction bearings are not designed for unlimited life, but for some finite period of service determined by the fatigue strength of the materials. A specified speed and number of hours of expected service must therefore accompany the given load values for these bearings.

Roller Bearings

When shock and impact loads are present, or when a large bearing is needed, cylindrical and tapered roller bearings are usually used. A roller bearing, in general, consists of the same for elements as a ball bearing: the two rings, the cage, and the rollers. Some typical examples of roller bearings are shown in Fig.6.6.3.

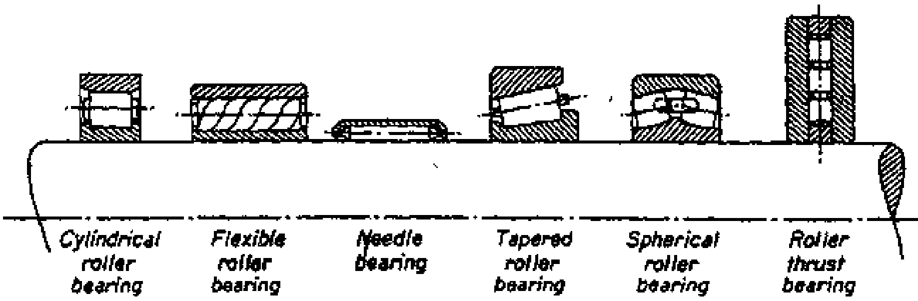


Fig.6.6.3 Types of Roller Bearings

In the cylindrical roller bearing, the flanges on the rings serve to guide the rollers in the proper direction. When the flanges are omitted from one of the rings, as shown in Fig.6.6.3, the rings can then be displaced axially with respect to each other, and no thrust component can be carried.

In addition to the radial load, the tapered roller bearing can carry a large axial component whose magnitude depends on the angularity of the rollers. The radial load will also produce a thrust component. The outer ring is separable from the remainder of the bearing. In this type of bearing, it is possible to make adjustment for the radial clearance: Two bearings are usually mounted opposed to each other, and the clearance is controlled by adjusting one bearing against the other. Doublerow tapered roller bearing are also available.

Roller bearings, in general, can be applied only where the angular misalignment caused by shaft deflection is very slight. This deficiency is not present in the spherical roller bearing. It has excellent load capacity and can carry a thrust component in either direction.

In the flexible roller bearing, the rollers are wound from strips of spring steel, and afterwards are hardened and ground to size. If desired, the rollers can bear directly on the shaft without an inner ring, particularly if the shaft surface has been locally hardened. This bearing has been successfully applied under conditions of dirty environment.

The needle bearing has rollers that are very long as compared to their diameters. Cages are frequently not used, and the inner ring may or may not be present. The outer ring may consist of hardened thin-walled metal as shown in Fig.6.6.3; the housing in which the bearing is mounted must have sufficient thickness to give adequate support. The friction of needle bearings is several times as great as for ordinary cylindrical roller bearings. Because of the tendency of the unguided rollers to skew, needle bearings are particularly adapted to oscillating loads as in wrist pins, rocker arms, and universal joints. For continuous rotation, needle bearings are usually suitable where the loading is intermittent and variable so that the needles will be frequently unloaded and thus tend to return to their proper locations. When the application involves angular misalignment of the shaft, two short bearings end to end are usually better than one bearing with long rollers. The needle bearing is lowpriced and requires very little radial space.

Spherical roller bearings, Fig.6.6.3, can be used when the shaft has angular misalignment.

Thrust bearings can be constructed by the use of straight or tapered rollers.

Roller bearings are selected by a process similar to that used for ball bearings. They must be chosen, however, in accordance with the recommendations given in the catalog of the manufacturer of the particular type of bearing under consideration.

Contact Stress Between Spheres and Cylinders[1]

When two bodies having surfaces of different curvatures are pressed together, an area of contact develops because there is no such thing as line or point contact. This area is usually very small, and the resulting stress can attain a very high value. In addition to rolling contact bearings,

1 Formulas in this section are from *Roark's Formulas for Stress & Strain*, 6th Edition, by Warren C. Young, McGraw Hill Book Co. 1989

the problem is of importance in the design of cams and gear teeth. The resulting contact stresses are often referred to as "Hertz" stresses after the German engineer H. Hertz who first studied their behavior in 1881. The stress patterns that result from contact between bodies pressed together are triaxial states of stress that are concentrated in highly local regions. This suggests that surface treatment of the bodies can be highly important. We will consider three different types of loading.

Contact between two spheres. For the case of two spheres pressed into contact, the area of contact will be a circle of radius a. The normal stress at the surface will be maximum along the center of the circle and will diminish to zero at the edges of this footprint, as shown in Fig.6.6.4. The radius of the contact area will increase as the load is increased, and its value will depend on the relative softness of the material according to the relationship:

$$a = \sqrt[3]{\frac{3FC_E K_D}{8}}$$

where:

$$C_E = \frac{1-\mu_1^2}{E_1} + \frac{1-\mu_2^2}{E_2}$$

$$K_D = \frac{d_1 d_2}{d_1 + d_2}$$

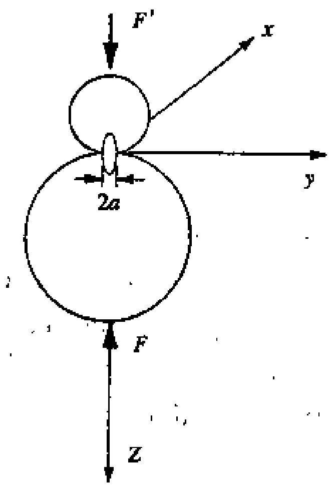


Fig.6.6.4 Contact Between Two Spheres

where μ_1 and μ_2 are the Poisson ratios for the material of sphere 1and sphere 2, and E_1 and E_2 are the elastic modulus values for each of the spheres. If the concavity of either of the two spheres is changed, as would be the case of a ball bearing rolling on the inside surface of the outer race of a bearing, the sign on the d_i values should be changed. Thus, for a sphere contacting the inside of another sphere, the value of K_D would be:

$$K_D = \frac{d_1 d_2}{d_1 - d_2}$$

If one of the surfaces of the spheres is flat, as would be the case of a sphere that is resting on a flat surface, then $1/d = 0$ for this particular surface. Thus, if a sphere rests on a flat plane, the value of K_D would be:

$$K_D = d_2$$

The maximum normal stress will be on the surface of the spheres at the center of the circle of contact and will be:

$$\sigma_{z0} = \frac{-3F}{2\pi a^2}$$

As the sign suggests, this stress is compression. The state of stress at points within the spheres is triaxial. This means that there are two other normal stresses at this point that are somewhat smaller than this value. Thus, the value of this maximum compressive stress σ_{z0} can be used in the maximum normal stress theory of failure to determine if a design is safe. If the designer wishes to use another design equation, he or she will need to know the other stress components in the spheres and some information about how they change as the distance from the point of contact changes. Although it is beyond the scope of this text to develop these equations, the theories predict that the point of maximum shear stress will be at a location along the line of contact at a distance of about 0.5 a below the surface. At this location, the maximum shear stress is:

$$\tau_{max} \approx \frac{1}{3}\sigma_{z0}$$

This value could be used together with the maximum shear stress theory of failure to determine if the design is safe.

The relationship between load and deflection for the two spheres in contact will be:

$$\delta = 1.040\sqrt[3]{\frac{F^2 C_E^2}{K_D}}$$

This is a nonlinear relationship that stiffens.

Contact between two cylinders with parallel axes. For the case of contact between two cylinders pressed together with parallel axes as shown in Fig.6.6.5, the area of contact will be a rectangle of width $2b$ and length l. The stresses will be distributed elliptically over this rectangular footprint, with the maximum normal stress being along the center of the rectangle. The half width of the rectangle "b" can be found from:

$$b = \sqrt{\frac{2F}{\pi l} C_E K_D}$$

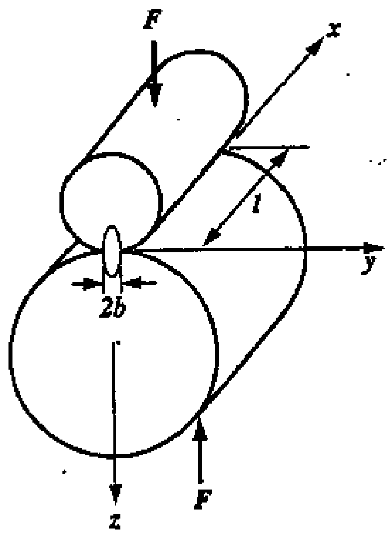


Fig.6.6.5 Contact Between Two Cylinders with Parallel Axes

In this expression, the value of l is the length of the cylinders and

$$C_E = \frac{1-\mu_1^2}{E_1} + \frac{1-\mu_2^2}{E_2}$$

$$K_D = \frac{d_1 d_2}{d_1 + d_2}$$

As before, if the concavity of either of the cylinders is changed, the sign on the d term for that cylinder should be changed. If one of the surfaces is flat, the value of $1/d=0$. The maximum normal stress will be on the surface of contact along the center line of the contact rectangle and will be:

$$\sigma_{z0} = \frac{-2F}{\pi bl}$$

This maximum normal stress component can be used in the max normal stress theory of failure to determine if the design is safe from failure. Since the state of stress between the two cylinders is triaxial, there will be normal stress components at the point of contact in the x and y directions. Thus, if one wishes to apply some other failure theory, these components will need to be known. Although it is beyond the scope of this text to develop these equations, the interested reader should consult the work of Timoshenko and Goodier or Boresi and Sidebottom listed as references at the end of this chapter. For the designer interested in applying the maximum shear stress theory of failure, the maximum shear stress arising from the contact of these two cylinders will be at a location about $0.8b$ below the surface. At this location, the maximum shear stress will be:

$$\tau_{max} \approx \frac{1}{3}\sigma_{z0}$$

Roark reports that the deflection for two cylinders having the same material properties will be of the following form:

$$\delta = \frac{2F(1-\mu^2)}{l\pi E}\left(\frac{2}{3} + \ln\frac{d_1}{b} + \ln\frac{d_2}{b}\right)$$

Since the value of b is related to the applied force F, this relationship is nonlinear.

Contact between two cylinders with axes at right angles. Contact between two cylinders at right angles, as shown in Fig.6.6.6, will result in an area of contact that is an ellipse with c as the major semiaxis and d as the minor semiaxis. These two semiaxes are reported by Young to be:

$$c = \alpha\sqrt[3]{FK_D C_E}$$
$$d = \beta\sqrt[3]{FK_D C_E}$$

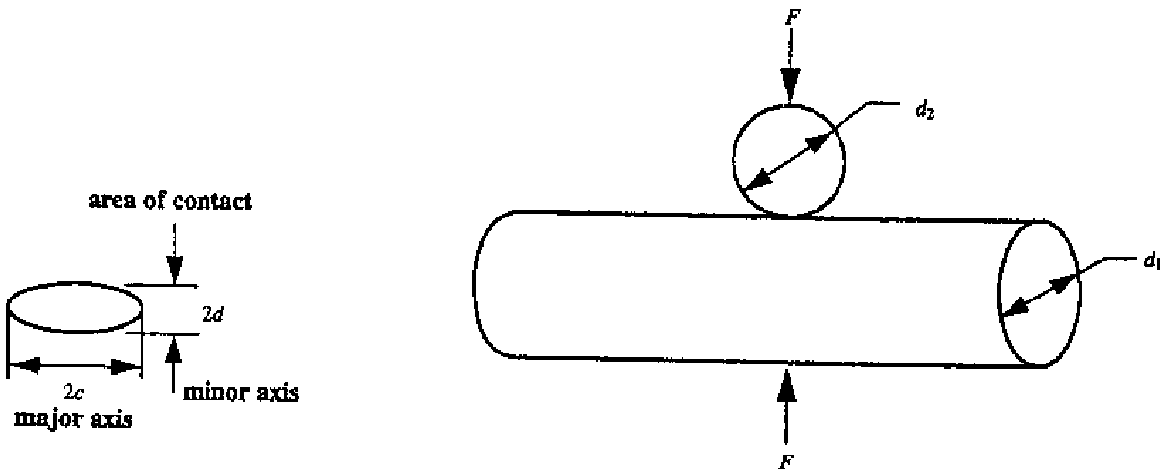


Fig.6.6.6 Contact Between Two Cylinders with Axes at Right Angles

where:

$$C_E = \frac{1-\mu_1^2}{E_1} + \frac{1-\mu_2^2}{E_2}$$

$$K_D = \frac{d_1 d_2}{d_1 + d_2}$$

and the values of α and β depend on the ratio d_1/d_2 and are found from Table 6.6.1.

Table 6.6.1 Coefficients Needed for the Analysis of Cylinders in Contact with Axes at Right Angles

d_1/d_2	1	1.5	2	3	4	6	10
α	0.908	1.045	1.158	1.350	1.515	1.767	2.175
β	0.908	0.799	0.734	0.651	0.602	0.544	0.481
λ	0.825	0.818	0.804	0.774	0.747	0.702	0.641

For this loading case, the maximum normal stress at the surface will be:

$$\sigma_{z0} = \frac{-1.5F}{\pi cd}$$

The maximum shear stress will be:

$$\tau_{max} \approx \frac{1}{3}\sigma_{z0}$$

Roark reports that the deflection can be found from the relationship:

$$\delta = \lambda \sqrt[3]{\frac{F^2 C_E^2}{K_D}}$$

Each of these three cases of contact stress have been implemented as speadsheet modules to facilitate the use of the equations in this section.

Word and Phrases

1. pillow block 轴承座
2. curvilinear 曲线的
3. groove 凹槽
4. bore 内径，孔
5. radial play 径向间隙
6. misalignment 未对准
7. designate 指定
8. thrust 推力
9. notch 槽口，凹口
10. rivet 铆钉联接
11. chromium 铬
12. grind（ground） 磨

13. polish　　抛光
14. shock　　震动
15. impact　　冲击
16. tapered　　锥形的
17. flange　　法兰，凸缘
18. clearance　　间隙
19. deficiency　　缺乏，不足，不完善
20. flexible　　柔性的
21. wind（wound）　　缠，绕
22. skew　　歪斜的
23. wrist pin　　活塞销，曲柄销，偏心轮销
24. cam　　凸轮
25. concavity　　凹度
26. elliptically　　椭圆形地
27. rocker　　摇杆

7 Defining Reliability

Intent

We learned that the discipline known as reliability was developed to provide methods for assuring that a product or service will function when it is required to do so by its user. These methods consist of techniques for determining what can go wrong, how we can prevent it from going wrong, and, if something does go wrong, how we can quickly recover and minimize the consequences. This chapter presents the definitions of common terminology applied to the techniques and provides an understanding of how reliability is regarded under various circumstances.

System

In this text, we shall regard any product or service that is used by a consumer as a system. Accordingly, let us consider a system to be an arrangement of related material or nonmaterial items that behave as a whole body, a body whose purpose is to perform some functions or services. Under this definition a system can be a physical assemblage of items (parts) to form a functional piece of equipment or it can be an established sequence of items (that is, a procedure) for performing a service. Hence, as a product a system can be anything from a tape dispenser to a personal computer or a power plant, any product from which a consumer has usage demands. As a service, a system can be a medical procedure, a process for having a restaurant meal served, or the Internal Revenue Service.

Reliability

We can now define **reliability** in terms of a generic item.

> **The *RELIABILITY* of an item is the *probability* that the item will**
> **perform a *specified function***
> **under *specified operational* and *environmental conditions*,**
> ***at* and *throughout a* specified *time***

The first thing to notice in this definition is that reliability is a *probability*, so we are dealing with the laws of random chance as they appear in nature. Indeed, occurrences of inopportune interruptions in functionability or service in a system are random events, the expected frequencies of which we aim to reduce.

The next thing to notice is that the definition depends on a *specified* function, operating conditions, environment, and time. So before we can deal with reliability, the producer (or provider) and the user must reach formal agreements on what the product or service is to do, how the user is to use the product or service (that is, how he or she will operate the product or receive or apply the service), the range of environments under which the product of service is expected to perform satisfactorily, and the instant or duration in time that the performance of the product or service is demanded.

Demand Time

The definition of reliability allows for the specification of demand time to be either an instant in time or a time interval. In actuality, the demand time may be a sequence of instances (or periods of cycles) or it may be a series of intervals. That depends, of course, on the type of system or service. How we apply the definition of reliability to an actual product or service depends heavily upon the nature of the demand time. Fig.6.7.1 illustrates the four types of demand times that can be applied to an item's performance. Each of these suggest a different way of regarding the reliability of an item.

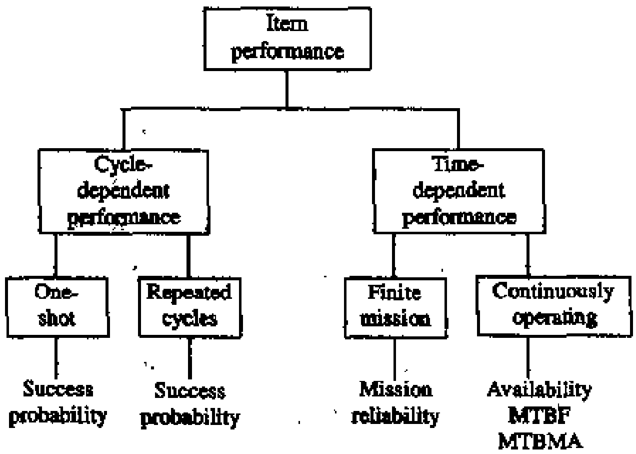


Fig.6.7.1 Reliability Parameters

When the demand time of an item's performance is either a discrete instant in time or a series of instances, we shall use the term **cycle-dependent performance.** A cycle-dependent performance may be **one-shot** or **repeated cycles.** Examples of one-shot items are a mouse trap, the cancellation of a postage stamp, or a match. The one-shot item (product or service) is expected to operate just once and at one instance in time, the demand time. A postage stamp needs to be canceled just once, at the point in time that the piece of mail is being processed at the post office. A mouse trap also needs to operate once, at the time the mouse arrives. A one-shot item is absolutely useless if it functions at any time other than the demand time. A toggle switch is an example of a repeated cycle item. It has a series of demand instances, and it must function every time it is demanded for, say, turning on a light.

If the demand time of an item's performance is a time interval or is continuous, we describe the performance as **time dependent.** A time-dependent performance may be for a *specified mission* or may be *continuously operating*. Examples of a specifiedmission operation are the launching of a satellite or a haircut. Examples of a continuously operating item are a refrigerator, a power-generating station, or the telephone company's directory assistance service. Time-dependent items are expected to operate throughout their demand intervals without interruption or, in the case of continuously operating items, all the time.

One-Shot Items

The reliability of a one-shot item is best described as its success probability—that is, the probability that the item will perform as expected (as specified, under specified operating and environmental conditions) at the specific instance of the item's demand. Consider, as an example, a wooden match. If you, the user, strike the match and it lights, *success* has been achieved. On the other hand, if it fails to light (that is, it is incapable of lighting no matter how many times you strike it), a *failure* occurs.

Regarding the definition of reliability in this example, the *item* is the wooden match, the *specified function* is the lighting of the match, the *specified environmental conditions* consist of typical ambient conditions (dry, no wind, etc.), the *specified operating conditions* consist of the accepted methods for striking a match, and the *specified time* is your demand time (that is, the point in time that you choose to strike the match).

The reliability of the wooden match is its success probability under the specified environmental and operating conditions, and it can be expressed as

$$R = P(S) = \frac{S}{N} = \frac{S}{S+F} \qquad (6.7\text{—}1)$$

where $P(S)$ = success probability

N = number of sequential trials of match strikes

S = number of successes

F = number of failures

In other words, if we struck millions of similar types of matches, matches that were produced through the same process, the ratio of successful lightings to total trials would estimate the success probability.

Repeated Cycles

As with one-shot items, the reliability of an item that functions through repeated cycles is also its success probability. As an example, if you, the user, drop a coin into a postage stamp machine, the reliability of that stamp machine is the probability that the machine provides the expected stamp for you.

To examine the elements of the definition of reliability through our stamp machine example, the specified function is that the machine produces the stamp that it indicates it will—that is, the proper denomination or a specific commemorative stamp as pictured on the face of the machine. A further specified function may be that the machine advertises that it will make change, in which case the correct amount of change is also expected.

The specified operational conditions would be presented as instructions for operating the machine; for example, pennies may be restricted or the machine may or may not take paper money. If you, the user, violate the specified operating conditions by, say, dropping in a penny or by inserting a $10 bill into the paper money slot when the machine is specified to make change for only $1 and $5 bills, then the machine is not expeated to perform. Further operating conditions may be that the machine is not to be used if it indicates that it is out of stamps or that only correct change is to be used if tha machine indicates that it is out of change.

Specified environmental conditions may include maintenance or reloading (of stamps or change) instructions and restrictions for the location of the machine (e.g., indoors only). It would be up to the maintainer of the stamp machine (the post office or store) to provide the specified environmental conditions. Finally, the specified time is that instant in time when you choose to insert your coin(s) or bill into the machine.

The response to your inserting of the coin(s) or bill will be either a success or failure. If the machine provides the stamp you ordered and the correct change, if applicable, the functioning is considered a success. In other words, you got what you wanted when you wanted it. If, on the other hand, you fail to get a stamp, or you get the wrong stamp, or you get the wrong change, it is a failure. If you fail to get the right stamp or change but specified operating or environmental conditions were violated, the function cannot be considered a success or failure.

For millions of transactions with our postage stamp machine leading to success or failure, the machine's success probability can be estimated by the number of successes divided by the number of trials. So the reliability is

$$R = P(S) = \frac{S}{N} = \frac{S}{S+F} \qquad (6.7\text{—}2)$$

where $P(S)$ = success probability

N = number of trials (either success or failure)

S = number of successes

F = number of failures

Time-Dependent Items of Specified Mission

When an item's function is time dependent and it is needed throughout a time interval—but only throughout that specified time interval—its reliability is known as **mission reliability**, expresed as

$$R = R(t) \tag{6.7—3}$$

where $R(t)$=reliability defined as a function of time t, (i.e., the reliability for the specified duration t)

t=specified mission time duration

An example is a satellite launching rocket, which must operate long enough to launch the satellite but need not operate beyond that. So if the time to launch is, say, 30 min, the rocket must operate without any failures during that 30 min mission, after which time we do not care about it. Hence, its mission reliability is $R=R(t)=R(30\text{ min})$. We deal with determining mission reliability in the next chapter.

As another example, consider having dinner at a restaurant. The mission in this case is the interval from the time you enter the restaurant until you leave for your next activity (or, possibly, until your body has satisfactorily digested all the restaurant's food). The reliability is then the probability that your restaurant experience is failure free throughout the defined mission. Reliability in this example is certainly a function of the systems within the restaurant. But it is concerned only with results during your demand interval, not before it and not after it.

For some types of services, such as a paint job, the mission time may be defined by the agreed-upon warrantee period. The painter may guarantee that the exterior paint job on your house will be effective for 3 years, and that becomes the mission time.

Continuously Operating Items

Now let us consider the type of item that is required to operate continuously, forever or for the duration of a long, extended service life. Here we are talking about products such as a personal computer or your home's heating system and services such as electric power or the postal system. Because there are no finite missions associated with the operation of such items, mission reliability is not the best way to define or specify reliability requirements. Nevertheless duration reliability, $R(t)$, values are sometimes used, regardless of the fact that $R(t)$ is relatively meaningless in such situations. For example, we may consider the probability that electric power is provided without incident during the hours of 5:00 p.m. to 8:00 p.m.—in other words, the interval reliability for a fictitious mission within our infinite demand time.

More useful reliability parameters for continuously operating items are the **mean time between failures (MTBF)** and the **availability.** The MTBF tells us how frequently, on the average, we can expect our item to experience an outage. The availability tells us the proportion of the time that we can expect our item to be operating. Associated with these characteristics are the **mean downtime (MDT)**, the average time that it takes to return to an operating state after an outage has occurred, and the **outage rate**, the complement of availability, or the portion of the time that we can expect our item to be down.

Availability and outage rate are related as follows.

$$\text{availability} = 1 - \text{outage rate} \tag{6.7—4}$$

In the simplest possible situation an item's availability is

$$A = \frac{\text{MTBF}}{\text{MTBF} + \text{MDT}} \tag{6.7—5}$$

and an item's outage rate (OR) is

$$\text{OR} = \frac{\text{MDT}}{\text{MTBF} + \text{MDT}} \tag{6.7—6}$$

In later chapters you will see that for complex items, Eq.6.7—5 and 6.7—6 are not necessarily true.

Associated with continuously operating items are the **mean time between maintenance actions (MTBMA)** and the **mean time to restore (MTTR).** The MTBMA is the average frequency of (preventive or corrective) maintenance actions upon the item, whether or not the maintenance actions impose or are in response to an outage. The MTTR is the average time taken up by maintenance activities, whether or not the item is inoperable during the maintenance activities. If the item is always out during maintenance, then MTBMA=MTBF and MTTR=MDT. You will see in later chapters, however, that the MDT may be composed of a logistics delay time and an administrative downtime in addition to maintenance downtime.

Word and Phrases

1. assemblage	集合
2. pulse	脉冲
3. spindle	轴，心轴
4. screw	螺旋
5. milling machine	铣床
6. lathe	车床
7. turret	刀架（车床）
8. key in	键入
9. servomotor	伺服马达
10. torque	扭矩，转矩
11. feedback	反馈
12. discrepancy	差异
13. transducer	传感器
14. tool magazine	刀具库
15. sequential	顺序的

8 Construction of CNC Machines

CNC machine tools are complex assemblies, and a more detailed study is a topic for a separate book. However, in general, any CNC machine tool consists of the following units:

1. Computers
2. Control systems
3. Drive motors
4. Tool changers

According to the construction of CNC machine tools, CNC machines work in the following (simplified) manner:

1. The CNC machine control computer reads a prepared program and translates it into machine language, which is a programming language of binary notation used on computers, not on CNC machines.

2. When the operator starts the execution cycle, the computer translates binary codes into electronic pulses which are automatically sent to the machine's power units. The control units compare the number of pulses sent and received.

3. When the motors receive each pulse, they automatically transform the pulses into rotations that drive the spindle and lead screw, causing the spindle rotation and slide or table movement. The part on the milling machine table or the tool in the lathe turret is driven to the position specified by the program.

Computers

The first NC machines relied on electronic hardware based on the digital circuit technology available at that time. These machines had no memory and were not able to store programs. To produce a new part, the NC machine had to reread the program one statement at a time and execute each statement before proceeding. CNC machines, introduced in the late 1970s, are less dependent on hardware and more dependent on software. These machines store a program into memory when it is first read in. This provides for faster operation when producing a number of identical parts, since the program can be recalled from memory repeatedly without having to read it again. CNC machines use an on-board computer that allows the operator to read, analyze, and edit programmed information, while NC machines require operators to make a new tape to alter a program. In essence, the computer is what distinguishes CNC from NC.

As with all computers, the CNC machine computer works on a binary principle using only two characters, 1 and 0, for information processing. The computer reacts on precise time impulses from the circuit. There are two states, a state with voltage, 1, and a state without voltage, 0. Series of ones and zeroes are the only states that the computer distinguishes. Called *machine language*, it is the only language the computer understands. When creating the program, the programmer does not care about the machine language; he or she simply uses a list of codes and keys in the meaningful information. Special built-in software compiles the program into machine language and the machine moves the tool by its servomotors. However, the programmability of the machine is dependent on whether there is a computer in the machine's control. If there is a minicomputer programming, say, a radius (which is a rather simple task), the computer will calculate all the points on the tool path. On the machine without a minicomputer, this may prove to be a tedious task, since the programmer must calculate all the points of intersection on the tool path.

Modern CNC machines use 32-bit processors in their computers that allow fast and accurate processing of information. This results in a savings of machining time.

Drive Motors

The drive motors control the machine slide movement on NC/CNC equipment.

They come in four basic types:

1. Stepper motors
2. DC servomotors
3. AC servomotors
4. Fluid servomotors

Stepper Motors convert a digital pulse, generated by the microcomputer unit (MCU), into a small step rotation. Stepper motors have a certain number of steps that they can travel. The number of pulses that the MCU sends to the stepper motor controls the amount of the rotation of the motor. Stepper motors are mostly used in applications where low torque is required.

Stepper motors are used in open-loop control systems, while AC, DC, or hydraulic servomotors are used in closed-loop control systems. (Control systems are discussed in the next section.)

Direct Current (DC) servomotors are variable speed motors that rotate in response to the applied voltage. They are used to drive a lead screw and gear mechanism. DC servos provide higher-torque output than stepper motors.

Alternative Current (AC) servomotors are controlled by varying the voltage frequency to control speed. They can develop more power than a DC servo. They are also used to drive a lead screw and gear mechanism.

Fluid, or hydraulic, servomotors are also variable speed motors. They are able to produce more power, or more speed in the case of pneumatic motors, than electric servomotors. They hydraulic pump provides energy to valves that are controlled by the MCU.

Control Systems

There are two types of control systems on NC/CNC machines: open loop and closed loop. The overall accuracy of the machine is determined by the type of control loop used.

The **open-loop control system** does not provide positioning feedback to the control unit. The movement pulses are sent out by the control and they are received by a special type of servomotor called a stepper motor. The number of pulses that the control sends to the stepper motor controls the amount of the rotation of the motor. The stepper motor then proceeds with the next movement command. Since this control system only counts pulses and cannot identify discrepancies in positioning, the control has no way of knowing that the tool did not reach the proper location. The machine will continue this inaccuracy until somebody finds the error.

The open-loop control can be used in applications in which there is no change in load conditions, such as the NC drilling machine. The advantage of the open-loop control system is that it is less expensive, since it does not require the additional hardware and electronics needed for positioning feedback. The disadvantage is the difficulty of detecting a positioning error.

In the **closed-loop control system**, the electronic movement pulses are sent from the control to the servomotor, enabling the motor to rotate with each pulse. The movements are detected and counted by a feedback device called a *transducer*. With each step of movement, a transducer sends a signal back to the control, which compares the current position of the driven axis with the programmed position. When the number of pulses sent and received match, the control starts sending out pulses for the next movement.

Closed-loop systems are very accurate. Most have an automatic compensation for error, since the feedback device indicates the error and the control makes the necessary adjustments to bring the slide back to the position. They use AC, DC, or hydraulic servomotors.

Tool Changers

Most of the time, several different cutting tools are used to produce a part. The tools must be replaced quickly for the next machining operation. For this reason, the majority of NC/CNC machine tools are equipped with **automatic tool changers**, such as magazines on machining centers and turrets on turning centers (Fig.6.8.1). They allow tool changing without the intervention of the operator. Typically, an automatic tool changer grips the tool in the spindle, pulls it out, and replaces it with another tool. On most machines with automatic tool changers, the turret or magazine can rotate in either direction, forward or reverse.

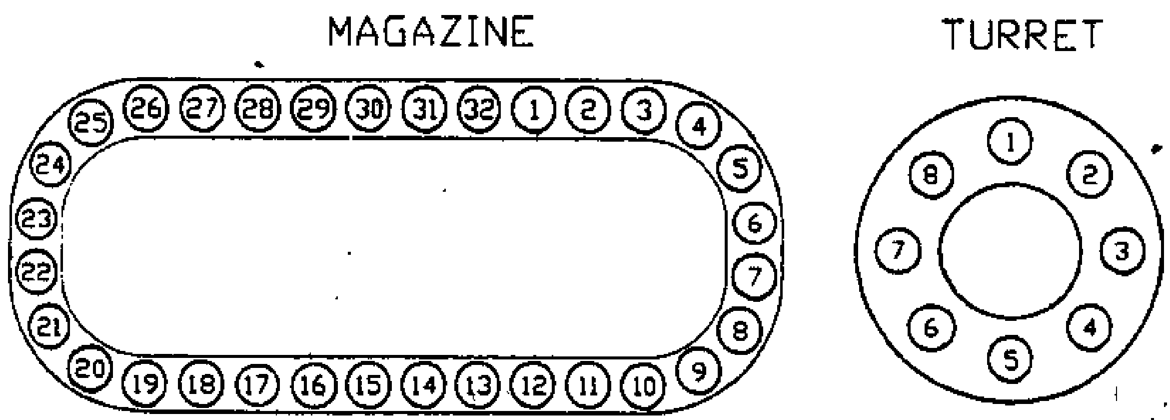


Fig.6.8.1 The Automatic Tool Changers Used Most Often

Tool changers may be equipped for either random or sequential selection. In **random tool**

selection, there is no specific pattern of tool selection. On the machining center, when the program calls for the tool, it is automatically indexed into waiting position, where it can be retrieved by the tool handling device. On the turning center, the turret automatically rotates, bringing the tool into position.

In random tool selection, the tools do not have to be loaded into the magazine or turret in the order in which they are called for in the program. The machine control knows where to find a particular tool as many times as it appears in the program. For instance, in one program, tools are called for in the following order: 1-2-3-4-5. However, they may be loaded in the magazine in any order, such as 5-1-3-4-2. This is illustrated in Fig.6.8.2.

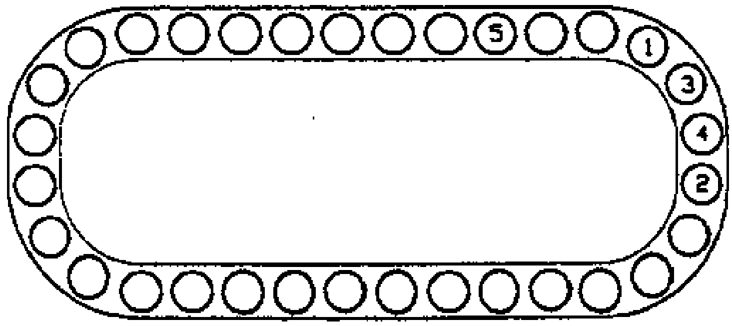


Fig.6.8.2 Random Tool Selection

In sequential tool selection, the tools must be loaded in the exact order in which they are called for in the program (Fig.6.8.3). Even if the tools are not in the correct order, the next tool is automatically selected, whether or not it is suitable for the next machining operation. When it is necessary to use a tool twice, the operator must load another tool with the same purpose.

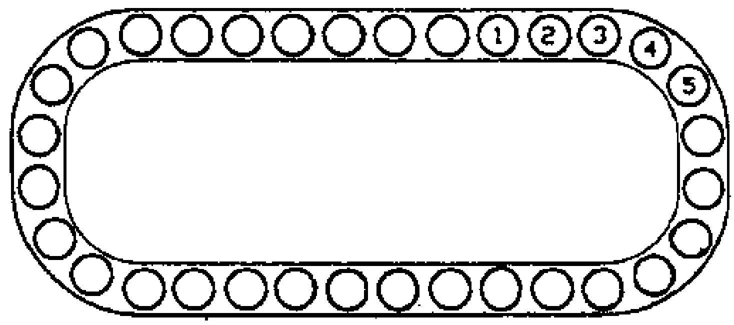


Fig.6.8.3 Sequential Tool Selection

The advantage of sequential tool selection is that less time is needed for indexing the tool into waiting position. The disadvantage is that more time is needed for setup when switching to a job with a different order of tools. This means that although the same tools are to be used, they have to be preloaded (rearranged) because of a different order in the program. The majority of modern machines are able to return the tool in the magazine and to search for the next tool during the program execution. This eliminates the time advantage of sequential tool selection, making random tool selection a standard feature on today's CNC machine tools.

Word and Phrases

1. assembly	集合，装配
2. inopportune	不合适的
3. fictitious	假想的，习惯上假定的
4. toggle switch	切换开关
5. denomination	命名
6. commemorative stamp	纪念邮票
7. transaction	交易
8. warrantee	被保证人，被担保人
9. outage	(自来水，电力，燃用气)断供期
10. complement	补助，补足
11. deactivates	使无效，撤消，停用

9 Accelerometer Designs

An accelerometer is an electromechanical transducer which generates an electrical output when subjected to mechanical shock or vibration. Accelerometers are inertial sensors which make measurements by virtue of Newton's second law. Unlike displacement and velocity, which are usually determined with respect to an arbitrary reference point, acceleration can be measured on an absolute basis.

Shock and vibration measurements are vital to the development, testing and operation of structures and machines in all fields of engineering. Accelerometers are widely used because of their accuracy, robustness, wide frequency response, and sensitivity. In general accelerometers are smaller, lighter, and easier to install than other types of vibration sensor.

In this section the design characteristics, operating principles, and limitations of the most common forms of accelerometer are described. The underlying mathematics are discussed in section 4.2. Clearly, few if any users will wish to design their own accelerometer. However, understanding how a sensor operates is an essential prerequisite to its intelligent selection and use.

Piezoresistive Accelerometers

The piezoresistive effect occurs in silicon and other materials, and is used in the fabrication of miniature accelerometers. As the name implies, a change in electrical resistance occurs in response to changes in the applied stress. Piezoresistive (PR) vibration sensors are formed by placing stress-sensitive resistors on highly stressed parts of a suitable mechanical structure. The PR transducers are usually attached to cantilevers, or other beam configurations, and are connected in a Wheatstone bridge circuit. The beam may carry a seismic mass or may utilize its own self-weight. Under acceleration the beam deflects due to the inertial forces and undergoes stress changes. These stress variations are converted into an electrical output, which is proportional to acceleration, by the PR transducers.

PR accelerometers are relatively easy to construct, provide a low frequency response extending to DC, and work well over a relatively large temperature range (−50°C to+150°C). A further feature which makes them valuable is their ability to include signal processing and communication functions within the sensor package at little extra cost.

The drawbacks of PR devices are that the output signal level is moderate (typically 100 mV full scale for a 10 V bridge excitation), the sensitivity can be temperature dependent, and the usable bandwidth is not as large as that which may be obtained from a PE sensor.

Before considering the design of PR accelerometers in detail, we need to understand the phenomenon of piezoresistance.

Analysis of Piezoresistance

If a rectilinear resistor has length l, width w, thickness t and a bulk resistivity ρ, its resistance R will be:

$$R = \frac{\rho l}{wt} \tag{6.9—13}$$

The gauge factor or strain sensitivity is defined as k, where:

$$k = \frac{\mathrm{d}R/R}{\varepsilon} \tag{6.9—14}$$

ε is the relative change in length of the resistor (the strain) due to a stress, σ, applied to the substrate parallel to its length. Fig.6.9.1 shows the consequences of the applied stress. The length increases by an amount dl, while the width and thickness decrease by dw and dt due to Poisson's ratio ν. It is clear that $\mathrm{d}w = -\nu w\varepsilon$ and $\mathrm{d}t = -\nu t\varepsilon$

The original cross-section was:

$$A = wt$$

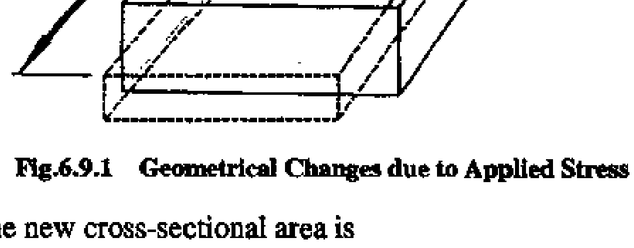


Fig.6.9.1 Geometrical Changes due to Applied Stress

Owing to the strain ε, the new cross-sectional area is

$$A' = (w - \mathrm{d}w)(t - \mathrm{d}t) = wt + 2\nu wt\varepsilon + \nu^2 wt\varepsilon$$

The term ($\nu^2 wt\varepsilon$) is very small compared with the other two terms in the equation and can be neglected. We can therefore write the change in cross-sectional area as

$$A - A' = dA = -2\nu\varepsilon A$$

giving

$$\frac{dA}{A} = -2\nu\varepsilon$$

Differentiating Eq. (6.9—13) gives

$$\frac{dR}{R} = \frac{d\rho}{\rho} + \frac{dl}{l} - \frac{dA}{A}$$

hence the gauge factor k is:

$$k = \frac{d\rho/\rho}{\varepsilon} + (1 + 2\nu) \qquad (6.9\text{—}15)$$

Typically ν will be between 0.2 and 0.3. Eq. (6.9—15) therefore shows that the longitudinal gauge factor is a function of changes in both longitudinal resistivity and geometry. In a conventional foil or wire strain gauges the piezoresistive effects are negligible, and the variations in resistance are mainly a function of dimensional changes. For a foil gauge k is approximately 2. For PR strain gauges the first term in Eq. (9.6—15) is significant, and higher gauge factors (typically around 10) can be achieved, giving enhanced sensitivity. It should be noted however that the resistivity of most PR materials is strongly temperature dependent, and that as a result PR strain gauges generally have a higher thermal sensitivity than other types.

Silicon Piezoresistive (PR) Accelerometers

One of the first silicon accelerometers was demonstrated in 1976. It consisted of a single cantilever carrying PR strain gauges near its root. The device was fragile and required the inclusion of a liquid-filled cell for damping. Improved designs have since appeared.

Three types of silicon PR accelerometer have since evolved, as shown in Fig.6.9.2. These are the *single cantilever*, the *doubly supported* structure, and the "*top hat*" design. It will be noted that, despite its name, the single cantilever design can have one, two or more supporting beams carrying the seismic mass. The distinguishing feature of this type is that the support beams are all placed along one edge. The doubly supported cantilever of Fig.6.9.2(b) uses four supporting beams, and

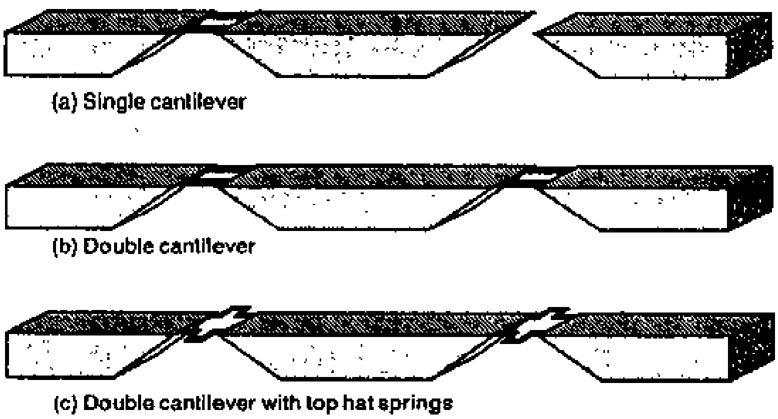


Fig.6.9.2 Three Types of Silicon PR Accelerometer

for this reason is sometimes referred to as a quad cantilever. The top hat approach is implemented when a device capable of undergoing large displacements is required. If the supports are folded as shown in Fig.6.9.2(c) the effective length can be increased, while the package size is kept constant.

In all three types viscous damping is provided by the inclusion of a small volume of air.

The single cantilever type has the highest gain, but can also have a large transverse sensitivity. The doubly supported and top hat designs provide good off-axis cancellation and are reasonably robust. They are consequently the most common configuration for PR silicon accelerometers.

Resonance Frequency

The resonance frequency of a silicon PR accelerometer is determined by the stiffness of the support structure and the seismic mass as discussed previously. Typical resonance frequencies for silicon PR accelerometers are in the range 500-5 000 Hz. Thus the bandwidth is considerably lower than that of a typical PE device. For comparison, thick film devices (see later) usually have resonance frequencies between 300 and 2 000 Hz.

Sensitivity of Silicon Accelerometers

The sensitivity increases with seismic mass m_s, decreases with support stiffness K, and is modulated by a transduction efficiency term b:

$$\text{sensitivity} = b \cdot \frac{m_s}{K}$$

The main parameters which determine b are the position of the PR transducers, the number of PR transducers, and the transduction efficiency of the transducers, which is a function of their geometry and chemical constitution.

The sensitivity is also inversely proportional to the square of the resonance frequency f_r:

$$\text{sensitivity} = \frac{(2\pi)^2 b}{f_r^2} \qquad (6.9—16)$$

Eq. (6.9—16) shows that if a sensitive accelerometer is required the resonance frequency should be as low as possible. Thus the sensitivity requirement is in conflict with the need for a large bandwidth. A typical doubly supported design with an output of 5 mV/g per volt of bridge excitation will have a resonance around 500 Hz, implying the useful bandwidth extends from DC to around 150 Hz. If the design is modified so that the resonance moves to 37 kHz, which is approaching the practical limit for this type of accelerometer, the sensitivity decreases to 5 μV/g per volt of bridge excitation.

Off-Axis Modes and Transverse Sensitivity

A major advantage of the doubly supported type is a substantial reduction in transverse sensitivity and unwanted resonant modes compared with the single cantilever. The three principal modes of vibration for a doubly supported cantilever are shown in Fig.6.9.3. The intended axis of sensitivity is vertical, and therefore only the mode shown in Fig.6.9.3(a) is desired. However, for the modes shown in Fig.6.9.3(b) and (c), which are excited by off-axis acceleration, opposite sides of the structure undergo opposite forms of bending. Careful positioning of the PR transducers and the use of a bridge circuit can therefore be used to give a high degree of immunity to outputs originating from these modes. No such symmetry exists in the case of a single cantilever. The maximum transverse sensitivity of a doubly supported PR silicon accelerometer is comparable with that of a PE device, and is typically 5% of the main axis sensitivity.

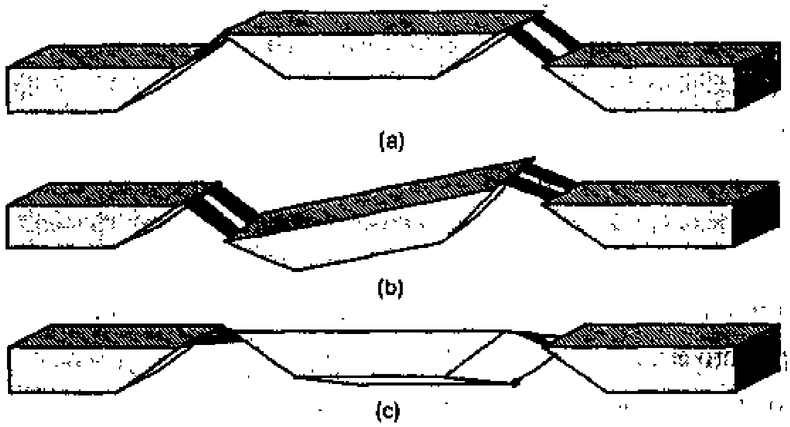


Fig.6.9.3 Three Principal Modes of Vibration for Doubly-Supported Cantilever

Word and Phrases

1. transducer	传感器
2. underlying	基础的
3. piezoresistive	压阻
4. miniature	小型，微小
5. cantilever	悬臂梁
6. Wheatstone bridge	惠斯敦电桥
7. rectilinear	直线的
8. Poisson's ratio	泊松比
9. longitudinal	纵向的
10. transverse	横向的
11. seismic	地震的
12. resonance	共振
13. stiffness	刚度
14. chemical constitution	化学成分
15. immune	免疫的
16. adhesive	粘合剂
17. amplifier	放大器
18. preamplifier	前置放大器
19. impedance	阻抗
20. spurious	欺骗性的，乱真的

10 Sigma-Delta One-Bit Converters

Sigma-delta converters are difficult to categorize. For starters, they are symmetric in the sense that the same structure can be used to create either an A/D or a D/A converter. In the speed range, they usually overlap with successive-approximation converters. In operating principle, however, they look most like pulse-width modulation. Developments in sigma-delta converters have been driven by the need for low-cost, high-precision converters. The lowest cost can be achieved in high-production devices by incorporating the converter onto the same integrated circuit as the other functions needed for system operation. Since converters by nature have both analog and digital information, the IC chips that include them must be *hybrid* designs (i.e., have a mixture of analog and digital circuitry on the same chip). There is a strong premium in hybrid chips to minimize the amount of analog circuitry since it is more difficult to manufacture reliably and also occupies more space than digital circuitry. The sigma-delta converter fills this need by increasing the reliance on digital circuits and minimizing both the amount and the sensitivity of analog circuitry needed for a given conversion performance.

The best known example of sigma-delta converters is in compact-disk players that are advertised as having "one-bit" converters. These are sigma-delta D/A converters. In broad terms, they have no advantage over other types of D/A converters, except for lower cost, but the term has been seized on by the advertising industry as a distinguishing characteristic.

Delta Modulation

The delta modulator serves as the basis for sigma-delta converters. The key idea behind this modulation scheme is to "track" the incoming analog signal in an average sense and produce a digital waveform that can be used to represent the analog signal. The demodulation process recovers an analog signal from the digital waveform by filtering. As with any modulated signal, the modulation (or carrier) frequency must be much higher than the highest frequencies of interest in the original signal in order for the representation to have a high degree of fidelity.

Fig.6.10.1 on the next page shows a delta modulator and a delta demodulator. As shown, the

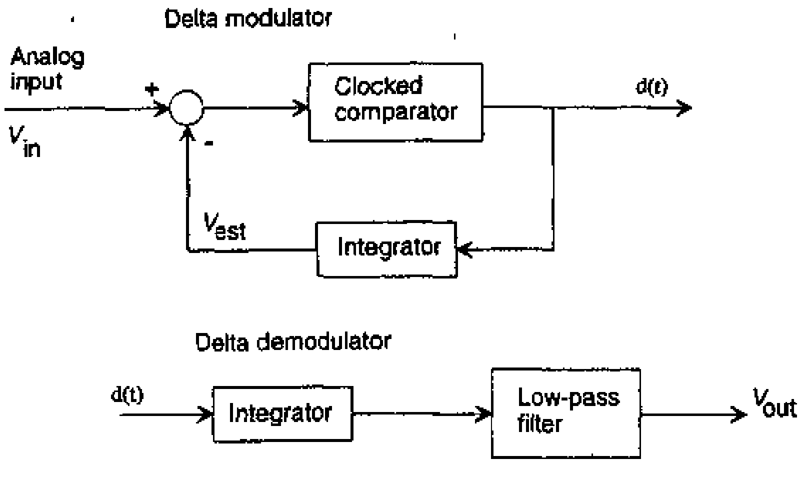


Fig.6.10.1 Delta Modulator/Demodulator

output of the modulator, d(*t*), is fed directly into the demodulator. This is done to show how the modulated signal is created and interpreted; in practical applications, some form of digital processing would normally take place on d(*t*) before putting it through the demodulator. The output of the modulator, d(*t*), is a digital signal, since it is the output of a comparator. The input signal, V_{in}, and the internal (estimated 'signal, V_{est}, are analog signals. By summing the modulated signalthrough the integrator an estimate of the input is produced. The feedback comparison then produces an error signal that is then used to create d(*t*). As the sign of the error changes, d(*t*) switches from one digital value to the other. The carrier frequency of this process is determined by the clock frequency used for the clocked comparator.

The top graph of Fig.6.10.2 shows the input (solid) and estimated (dashed) signals; the middle graph shows the modulated signal, d(*t*). The comparator used outputs of -1 and $+1$. A lower-than-normal clock frequency is used so that the nature of the signals can be seen clearly on the graph. In practice, the clock frequency must be high enough so that the error in V_{est} is within the project specifications. The demodulation process first passes the modulated signal through an integrater, then filters out the high-frequency (carrier) part of the signal in a low-pass filter. The input (solid) and the demodulated signal (dashed), V_{out}, is shown in the lower graph of Fig.6.10.2. The phase and amplitude differences are due to the action of the low-pass filter, which was only first order for this simulation.

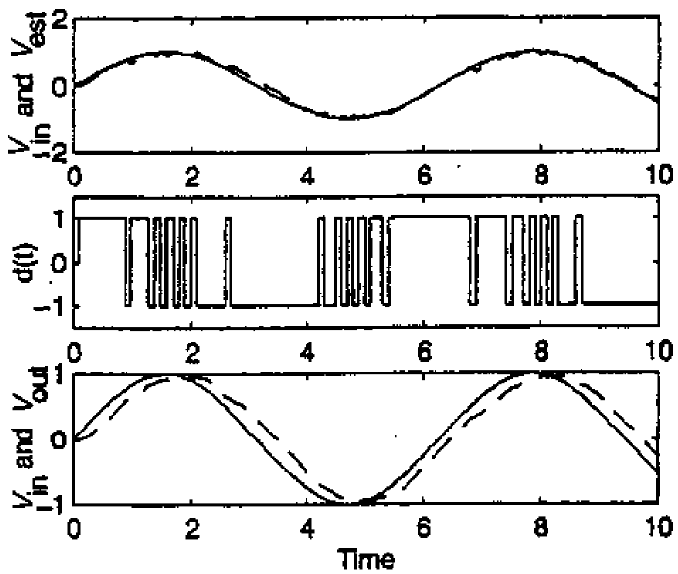


Fig.6.10.2 Simulation of Delta Modulation/Demodulation

Sigma-Delta Modulation

Sigma-delta converters use a feedback structure similar to that of the delta modulator to produce a modulated one-bit digital signal at the output of the comparator (Fig.6.10.3). This same basic structure applies to both analog-to-digital and digital-to-analog converters. The modulation process, which is a generalization of the delta modulator shown in Fig.6.10.2 is the heart of the converter and the reason why so little analog circuitry is needed. The output of the converter is at the output of the filter. This block diagram shows generalized signal domains, so it can represent either an A/D or D/A converter.

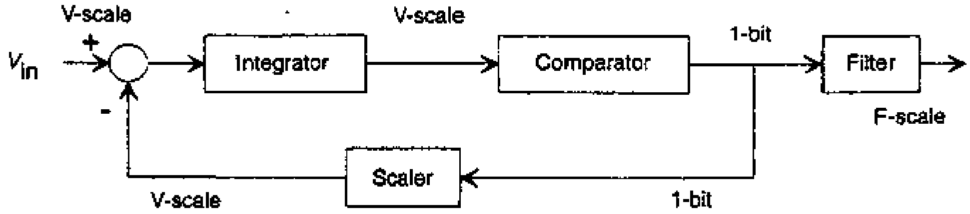


Fig.6.10.3 Sigma-Delta Converter Structure

Three scale domains are shown in the figure. The V-scale domain indicates signals in the same units as the input signal, V_{in}; the one-bit domain consists of signals that are one-bit digital values; and the F-scale domain is scaled to the output units. Note that, as pictured, this is a generic sigma-delta converter—it can be implemented as either a D/A or an A/D converter. The feedback loop is constructed in such a way that *on average* the output of the scaler will be equal to the input value, V_{in}. The input to the scaler is a one-bit signal, so its output will be either the minimum or maximum of the V-scale range. If it is the high limit value, it will generally be larger than V_{in}, so the output of the subtraction will be negative. This causes the integrator to start integrating down; when its output crosses zero, the comparator switches, the scaler's output switches to the low V-scale limit, and the integrator starts integrating up. Since the *scaler* can only produce extremevalued outputs, there will be constant switching going on in the comparator. The result is that the output of the comparator is a modulated one-bit signal such that its average value corresponds to the converter's input value. The filter does the averaging necessary to turn the modulated signal into a scaled representation of the input. This is illustrated below with an example, but first this generic converter will be turned into an A/D, then a D/A converter.

This sigma-delta structure is specifically designed for use as a converter, as compared to the more general modulation structure of the delta modulator. As such, it has some advantages over the delta modulator shown in the Delta Modulation Section. First, it requires only one integrator. Second, the designer of the converter has more control of how quantization noise will influence the device and therefore, can tailor it to the intended application. Third, the sigma-delta structure is better at dealing with rapidly changing input signals.

Sigma-Delta Analog-to-Digital Converter

In an A/D converter the V-scale domain is analog. The input signal is the unknown analog voltage; the subtractor and integrator are analog components; the comparator is, in effect, a one-bit A/D converter; the scaler is a one-bit D/A converter; and the filter is a digital filter. Although the D/A converter is only one bit, it still plays an important role. Whereas its input is a digital signal whose actual voltage value can fall anywhere in the acceptable range for the logic family involved, its output is analog and must conform to the proper voltage within the noise tolerances on the analog side.

• The F-scale domain is an n-bit digital domain, where the n-bit value is the output of the analog-to-digital conversion. The digital filter is often implemented with a digital signal processor (DSP). This structure is shown in a relabeled version of the converter structure (Fig.6.10.4). The one-bit domain is assumed to be synchronous, so that the operation of the one-bit ADC (comparator) and the digital are synchronized by a common clock.

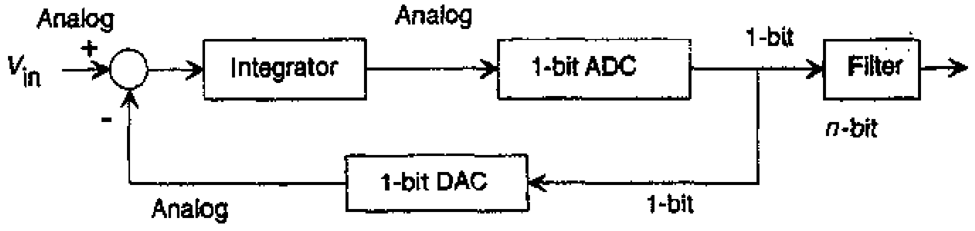


Fig.6.10.4 Sigma-Delta A/D Converter

An example of the output from a simple operating A/D converter is shown in Fig.6.10.5, which shows the output of the integrator and the comparator, and Fig.6.10.6, which shows the output of the filter. The input domain is analog, with a range of -1.0 to $+1.0$. The input signal is a constant voltage of 0.3. The output range is 0.0 to 1.0. The simple design, in both the converter and the digital filter, is used so that the operating principles can be demonstrated in a short simulated record.

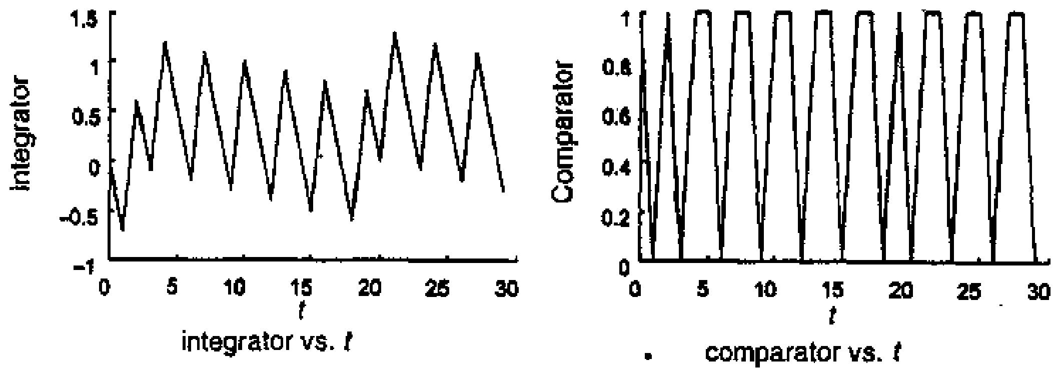


Fig.6.10.5 Sigma-Delta Converter Operation: Integrator and Comparator

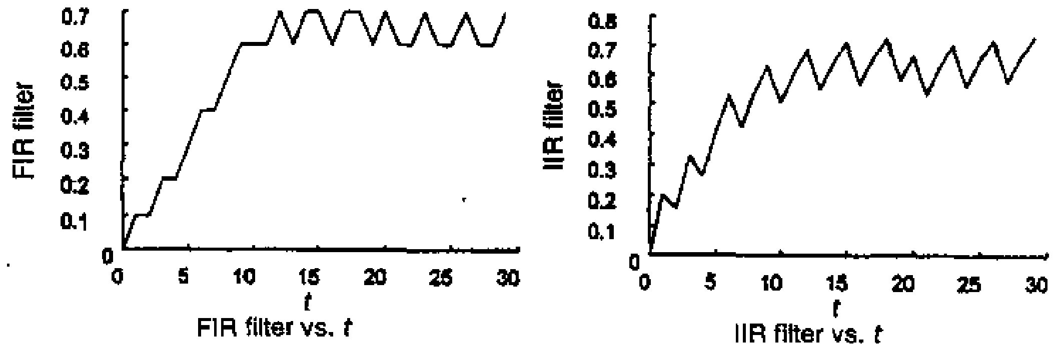


Fig.6.10.6 Sigma-Delta Operation: Filter Output

Looking first at the comparator (one-bit ADC) output, it takes on only the digital values of 0 or 1 (the time scale is in number of time steps; sloped lines are interpolated from point to point by the drawing program). Consistent with the fact that the input value is in the top half of the input domain's range (1.3out of 2.0), the comparator has a value of 1 for more of the time than the value is 0. The integrator, on the other hand, crosses back and forth across zero, causing the comparator to switch each time it crosses zero. Again, consistent with the input value, the integrator is above zero for more time than it is below. The integrator is in the V-scale domain and takes on arbitrary values between -1.0 and 1.0.

Output signals are shown for two types of filters, a FIR (finite impulse response) filter and an IIR (infinite impulse response) filter. The IIR filter is a digital version of a standard analog filter. In this case, the first-order filter implemented is described by the input-output relation,

$$y_k = (1-C)y_{k-1} + Cu_k \tag{6.10—2}$$

where u is the input to the filter and y is its output. This type of filter has a theoretically infinite tail. That is, if u is a constant, y will approach that constant value exponentially. The resulting signal takes about 15 time steps to reach its final value, then varies around its final value with an amplitude of about 0.1. This variation is what determines the precision of a sigma-delta converter. In this case the variation is about 1 part in 20, giving a converter with about four-bit precision.

A FIR filter differs from an IIR filter in that the right-hand side of the filter equation has values of the input, u, and its past values, but the previous values of the output, y, do not appear,

$$y_k = C_0u_k + C_1u_{k-1} + C_2u_{k-2} + \cdots \tag{6.10—3}$$

The simplest form of this filter is when all the coefficients have the same value, $1/n$, where n is the number of terms. This is also called a *boxcar filter*; it is a moving average of the most recent n points. The IIR filter shown in the figure is of the boxcar type, with $n = 10$. It has roughly the same rise time as the FIR filter and about the same amount of variation—but many more terms. There is a major advantage of using a FIR filter with a sigma-delta converter, however. Because the inputs are all 0's and 1's, no multiplications are necessary; if an input is 1, the corresponding coefficient is added into the sum. Otherwise, the term is skipped.

The FIR filter is also more sensitive to patterns in the input. In Fig.6.10.7, for example, all parameters are the same as in the previous case, except that the input, V_{in}, is zero. This is exactly at the midpoint of the V-scale range, so the modulation pattern is completed within the 10 samples of the filter, so no output variation appears after the filter has settled. In this case, the IIR filter shows its characteristic variation, but the FIR filter does not. Another advantage of the FIR-based sigma-delta converter is that it handles oversampling effectively (another advertising buzzword for CD players).

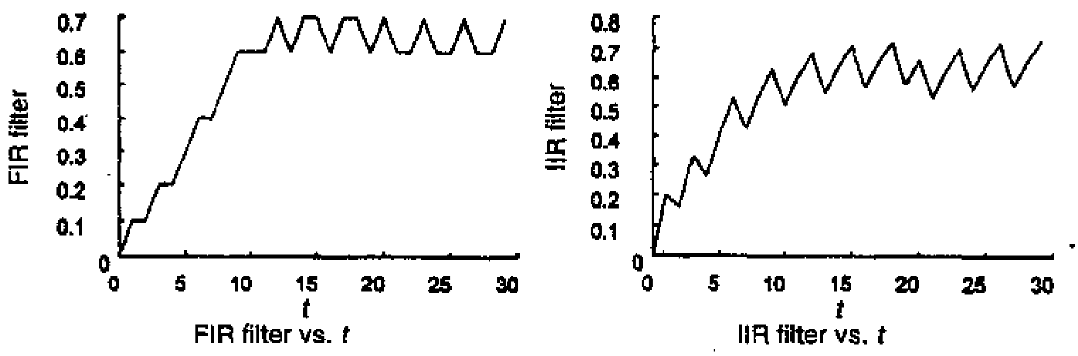


Fig.6.10.7 Filter Output for $V_{in} = 0$

Sigma-Delta Digital-to-Analog Converters

The D/A sigma-delta structure is shown in Fig.6.10.8. The input value is the digital number to be converted, the accumulator is a digital summation element, and the comparator and scaler are also fully digital components. The filter is an analog filter. Because it is analog, the filter will of necessity be of the IIR type. The performance curves given above can just as easily be interpreted as D/A performance as they were for A/D, except that the FIR filter outputs should be ignored since they cannot be realized in analog form. This system is a version of the one-bit DAC of CD fame.

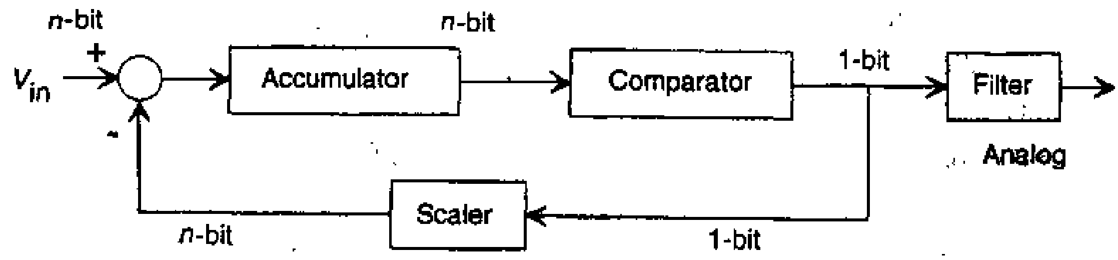


Fig.6.10.8 Sigma-Delta Digital-to-Analog Converter Structure

Sigma-Delta Design Considerations

Design of practical sigma-delta converters focuses on three aspects of the design: the modulator, the filter, and cost. The structures shown previously are first-order modulators Higher-order modulators can be used to improve noise rejection and to increase the dynamic range of a converter. Multiorder feedback or feedforward structures can be used. The feedback structures are simpler but harder to design. Because of the feedback structure used for all sigma-delta converters, there are possibilities of instabilities caused from loop closure. It is more difficult to assure stability for higher-order feedback structures because the comparator and scaler are nonlinear elements and make the stability analysis difficult or impossible. Stability cannot be guaranteed for higher-than-second-order sigma-delta structures. Higher-order feedforward structures, on the other hand, have guaranteed stability since they use cascaded first-order elements that are guaranteed to be stable. However, they use more components for the same performance.

Filter design is a major course of study in itself. For sigma-delta DACs, the output filter is analog, so the design decisions involve standard filter design parameters. For the ADC, however, it is possible to use either FIR or IIR filter structures. IIR filters achieve similar performance with fewer terms (as in the previous example) but are more difficult to design. FIR filters also have linear phase response (which is of particular importance in audio applications) and can be used directly in decimation configurations.

Cost is often more of a consideration in sigma-delta converters than in other types because they are peculiarly applicable to incorporation in high-volume integrated circuits. Extremely careful specification of input and noise signal characteristics and realistic specification of performance constraints are critical to arriving at the most cost-effective design.

Word and Phrases

1. contvertor=converter 转换器
2. categorize 分类
3. pulse-width modulation 脉冲宽度调制
4. integrated circuit 集成电路
5. IC chips 集成电路芯片
6. hybrid 混合的
7. premium 重视
8. digital waveform 数字波形
9. demodulation 解调器
10. fidelity 保真
11. specifications 规格，说明书，规范
12. scaler 计数器，定标器
13. quantization 量化
14. subtractor 减法器
15. integrator 积分器
16. synchronous 同步的

11 Exergy（Availability）Analysis

Defining Exergy

The basis for the exergy concept is present in the introduction to the second law. A principal conclusion is that an opportunity exists for doing work whenever two sytems at different states are brought into communication, for in principle work can be developed as the systems are allowed to come into equilibrium. When one of the two systems is a suitably idealized system called an *exergy reference environment* or simply, an *environment*, and the other is some system of interest, *exergy* is the *maximum theoretical work* obtainable as they interact to equilibrium.

The definition of exergy will not be complete, however, until we define the reference environment and show how numerical values for exergy can be determined. These tasks are closely related because the numerical value of exergy depends on the state of a system of interest, as well as the condition of the environment.

Exergy Reference Environment

Any system, whether a component of a larger system such as a steam turbine in a power plant or the larger system itself (power plant), operates within surroundings of some kind. It is important to distinguish between the environment used for calculating exergy and a system's surroundings. Strictly speaking, the term surroundings refers to everything not included in the system. However, when considering the exergy concept, we distinguish between the *immediate* surroundings, where intensive properties may vary during interactions with the system, and the larger portion of the surroundings at a distance, where the intensive properties are unaffected by any process involving the system and its immediate surroundings. The term *environment* identifies this larger portion of the surroundings.

Modeling the Environment

The physical world is complicated, and to include every detail in an analysis is not practical. Accordingly, in describing the environment, simplifications are made and a model results. The validity and utility of an analysis using any model are, of course, restricted by the idealizations made in formulating the model. In this book the environment is regarded to be a simple compressible system that is *large* in extent and *uniform* in temperature, T_0, and pressure, p_0. In keeping with the idea that the environment represents a portion of the physical world, the values for both p_0 and T_0 used throughout a particular analysis are normally taken as typical environmental conditions, such as 1 atm and 25°C (77°F). The intensive properties of each phase of the environment are uniform and do not change significantly as a result of any process under consideration. The environment is also regarded as free of irreversibilities. All significant irreversibilities are located within the system and its immediate surroundings.

Although its intensive properties do not change, the environment can experience changes in its extensive properties as a result of interactions with other systems. Changes in the extensive properties internal energy U_e, entropy S_e, and volume V_e of the environment are related through the *first* $T\,dS$ equation, Since T_0 and p_0 are constant, The eguation takes the form

$$\Delta U_e = T_0 \Delta S_e - p_0 \Delta V_e \qquad (6.11\text{—}1)$$

In this chapter kinetic and potential energies are evaluated relative to the environment, all parts of which are considered to be at rest with respect to one another. Accordingly, as indicated by the foregoing equation, a change in the energy of the environment can be a change in its internal energy only. Eq. (6.11—1) is used below to develop an expression for evaluating exergy. Later the environment concept is extended to allow for the possibility of chemical reactions, which are excluded from the present considerations.

Dend State

Let us consider next the concept of the *dead state*, which is also important in completing our understanding of the property exergy.

If the state of a fixed quantity of matter, a closed system, departs from that of the environment, an opportunity exists for developing work. However, as the system changes state toward that of the environment, the opportunity diminishes, ceasing to exist when the two are in equilibrium with one another. This state of the system is called the *dead state*. At the dead state, the fixed quantity of matter under consideration is imagined to be sealed in an envelope impervious to mass flow, at rest relative to the environment, and internally in equilibrium at the temperature T_0 and pressure p_0 of the environment. At the dead state, both the system and environment possess energy, but the value of exergy is zero because there is no possibility of a spontaneous change within the system or the environment, nor can there be an interaction between them.

With the introduction of the concepts of environment and dead state, we are in a position to show how a numerical value can be determined for exergy. This is considered next.

Evaluating Exergy

The *exergy of a system*, E, at a specified state is given by the expression

$$\mathrm{E}=(E-U_0)+p_0(V-V_0)-T_0(S-S_0) \tag{6.11—2}$$

where $E(=U+\mathrm{KE}+\mathrm{PE})$, V, and S denote, respectively, the energy, volume, and entropy of the system, and U_0, V_0 and S_0 are the values of the same properties if the system were at the dead state. By inspection of Eq. (6.11—2), the units of exergy are seen to be the same as those of energy.

In this book, E and e are used for exergy and specific exergy, respectively, while E and e denote energy and specific energy, respectively. Such notation is in keeping with standard practice. The appropriate concept, exergy or energy, will be clear in context. Still, care is required to avoid mistaking the symbols for these concepts.

Eq.(6.11—2) can be derived by applying energy and entropy balances to the *combined system* shown in Fig.6.11.1, which consists of a closed system and an environment. Exergy is the maximum theoretical work that could be done by the combined system if the closed system were to come into equilibrium with the environment — that is, if the closed system passed to the dead state. Since the objective is to evaluate the maximum work that could be developed by the combined system, the boundary of the combined system is located so that the only energy transfers across it are work transfers of energy. This ensures that the work developed by the combined system is not affected by heat transfer to or from it. Moreover, although the volumes of the closed system and the environment can vary, the boundary of the combined system is located so that the total volume of the combined system remains constant. This ensures that the work developed by the combined system is fully available for lifting a weight in its surroundings, say, and is not expended in merely displacing the surroundings of the combined system. Let us now apply an energy balance evaluate the work developed by the combined system.

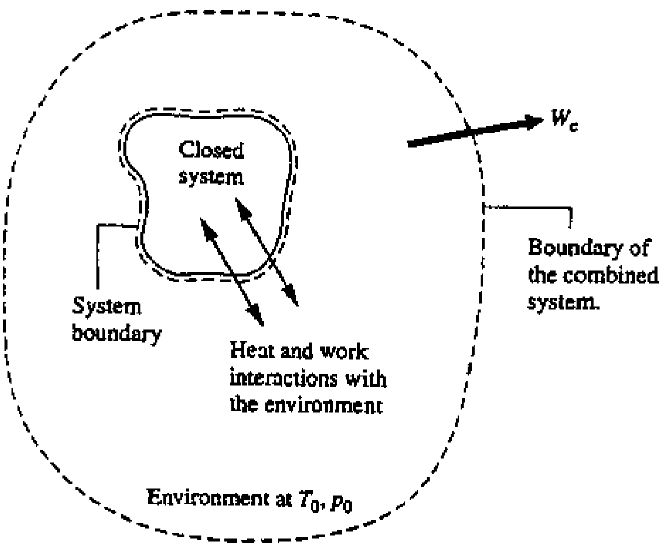


Fig.6.11.1 Combined System of Closed System and Environment

Energy Balance. An energy balance for the combined system reduces to

$$\Delta E_c = Q_c^0 - W_c \tag{6.11—3}$$

where W_c is the work developed by the combined system, and ΔE_c is the energy change of the combined system, equal to the sum of the energy changes of the closed system and the environment. The energy of the closed system initially is denoted by E, which includes the kinetic energy, potential energy, and internal energy of the system. Since the kinetic energy and potential energy are evaluated relative to the environment, the energy of the closed system when at the dead state would be just its internal energy, U_0. Accordingly, ΔE_c can be expressed as

$$\Delta E_c = (U_0 - E) + \Delta U_e$$

Using Eq.(6.11—1) to replace ΔU_e, the expression becomes

$$\Delta E_c = (U_0 - E) + (T_0 \Delta S_e - p_0 \Delta V_e) \tag{6.11—4}$$

Substituting Eq. (6.11—4) into Eq. (6.11—3) and solving for W_c gives

$$W_c = (E - U_0) - (T_0 \Delta S_e - p_0 \Delta V_e)$$

As noted previously, the total volume of the combined system is constant. Hence, the change in volume of the environment is equal in magnitude but opposite in sign to the volume change of the closed system: $\Delta V_e = -(V_0 - V)$. With this substitution, the above expression for work becomes

$$W_c = (E - U_0) + p_0(V - V_0) - T_0 \Delta S_e \tag{6.11—5}$$

This equation gives the work developed by the combined system as the closed system passes to the dead state while interacting only with the environment. The maximum theoretical value for the work is determined using the entropy balance as follows.

Entropy Balance. The entropy balance for the combined system reduces to give

$$\Delta S_c = \sigma_c$$

where the entropy transfer term is omitted because no heat transfer takes place across the boundary of the combined system, and σ_c accounts for entropy production due to irreversibilities as the closed system comes into equilibrium with the environment. ΔS_c is the entropy change of the combined system, equal to the sum of the entropy changes for the closed system and environment, respectively

$$\Delta S_c = (S_0 - S) + \Delta S_e$$

where S and S_0 denote the entropy of the closed system at the given state and the dead state, respectively. Combining the last two equations

$$(S_0 - S) + \Delta S_e = \sigma_c \qquad (6.11\text{—}6)$$

Eliminating ΔS_e between Eqs. (6.11—5) and (6.11—6) results in

$$W_c = \underline{(E - U_0) + p_0(V - V_0) - T_0(S - S_0)} - T_0\sigma_c \qquad (6.11\text{—}7)$$

The value of the underlined term in Eq. (6.11—7) is determined by the two end states of the closed system—the given state and the dead state—and is independent of the details of the process linking these states. However, the value of the term $T_0\sigma_c$ depends on the nature of the process as the closed system passes to the dead state. In accordance with the second law, $T_0\sigma_c$ is positive when irreversibilities are present and vanishes in the limiting case where there are no irreversibilities. The value of $T_0\sigma_c$ cannot be negative. Hence, the **maximum** theoretical value for the work of the combined system is obtained by setting $T_0\sigma_c$ to zero in Eq. (6.11—7). By definition, the extensive property exergy, E, is this maximum value. Accordingly, Eq. (6.11—2) is seen to be the appropriate expression for evaluating exergy.

Exergy Aspects

In this section, we consider several important aspects of the exergy concept, beginning with the following:

• Exergy is a measure of the departure of the state of a system from that of the environment. It is therefore an attribute of the system and environment together. However, once the environment is epecified, a value can be assigned to exergy in terms of property values for the system only, so exergy can be regarded as a property of the system.

• The value of exergy cannot be negative. If a system were at any state other than the dead state, the system would be able to change its condition **spontaneously** toward the dead state; this tendency would cease when the dead state was reached. No work must be done to effect such a spontaneous change. Accordingly, any change in state of the system to the dead state can be accomplished with **at least zero** work being developed, and thus the **maximum** work (exergy) cannot be negative.

•.Exergy is not conserved but is destroyed by irreversibilities. A limiting case is when exergy is completely destroyed, as would occur if a system were permitted to undergo a spontaneous change to the dead state with no provision to obtain work. The potential to develop work that existed originally would be completely wasted in such a spontaneous process.

• Exergy has been viewed thus far as the **maximum** theoretical work obtainable from the combined system of system **plus** environment as a system passes **from** a given state **to** the dead state while interacting with the environment only. Alternatively, exergy can be regarded as the magnitude of the **minimum** theoretical work **input** required to bring the system **from** the dead state *to* the given state. Using energy and entropy balances as above, we can readily develop Eq. (6.11—2) from this viewpoint. This is left as an exercise.

Although exergy is an extensive property, it is often convenient to work with it on a unit mass or molar basis. The specific exergy on a unit mass basis, e, is given by

$$\mathrm{e} = (e - u_0) + p_0(v - v_0) - T_0(s - s_0) \qquad (6.11\text{—}8)$$

where, e, v, and s are the specific energy, volume, and entropy, respectively, at a given state; u_0, v_0, and s_0 are the same specific properties evaluated at the dead state. With $e = u + V^2/2 + gz$,

$$\mathrm{e} = [(u + V^2/2 + gz) - u_0] + p_0(v - v_0) - T_0(s - s_0)$$

and the expression for the **specific exergy** becomes

$$\mathrm{e} = (u - u_0) + p_0(v - v_0) - T_0(s - s_0) + V^2/2 + gz \qquad (6.11\text{—}9)$$

By inspection, the units of specific exergy are the same as those of specific energy. Also note that the kinetic and potential energies measured relative to the environment contribute their full values to the exergy magnitude, for in principle each could be completely converted to work were the system brought to rest at zero elevation relative to the environment.

Using Eq. (6.11—2), we can determine the **change in exergy** between two states of a closed system as the difference

$$\mathrm{E}_2 - \mathrm{E}_1 = (E_2 - E_1) + p_0(V_2 - V_1) - T_0(S_2 - S_1) \qquad (6.11\text{—}10)$$

where the values of p_0 and T_0 are determined by the state of the environment.

When a system is at the dead state, it is in *thermal* and *mechanical* equilibrium with the environment, and the value of exergy is zero. We might say more precisely that the *thermomechanical* contribution to exergy is zero. This modifying term distinguishes the exergy concept of the present chapter from a more general concept introduced later where the contents of a system at the dead state are permitted to enter into chemical reaction with environmental components and in so doing develop additional work. As illustrated by subsequent discussions, the thermomechanical exergy concept suffices for a wide range of thermodynamic evaluations.

Word and Phrases

1. exergy	可用能
2. depicting	描写，叙述
3. intrinsically	本质地，固有地
4. impervious	密封的，不受影响的
5. spontaneous	自发的，自然产生的
6. vanish	消失，突然不见，[数]成为零
7. equilibrium	平衡
8. entropy	熵
9. magnitude	大小，数量
10. substitution	代换

11. irreversibility　　不可逆性
12. attribute　　属性，特征

12 Otto Cycle and Real Air-Fuel Engine Cycles

Otto Cycle

The cycle of a four-stroke, SI, naturally aspirated engine is the cycle of most automobile engines and other four-stroke SI engines. For analysis, this cycle is approximated by the air-standard cycle shown in Fig.6.12.1. This ideal air-standard cycle is called on **Otto cycle**, named after one of the early developers of this type of engine.

The intake stroke of the Otto cycle starts with the piston at TDC and is a constant-pressure process at an inlet pressure of one atmosphere (process 6-1 in Fig.6.12.1). This is a good approximation to the inlet process of a real engine at WOT, which will actually be at a pressure slightly less than atmospheric due to pressure losses in the inlet air flow. The temperature of the air during the inlet stroke is increased as the air passes through the hot intake manifold. The temperature at point 1 will generally be on the order of 25° to 35°C hotter than the surrounding air temperature.

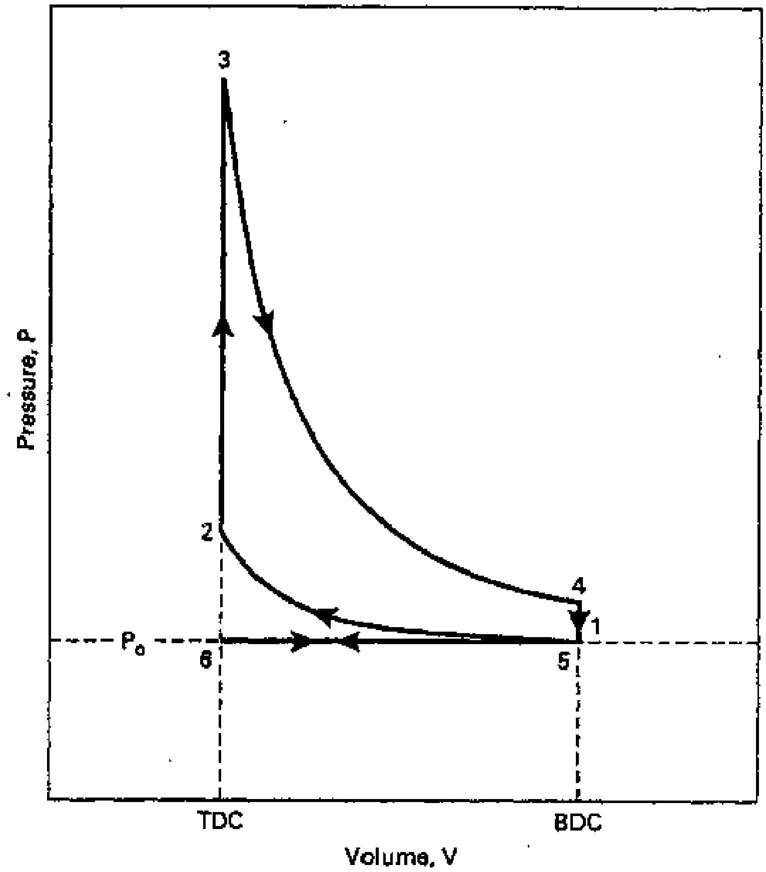


Fig.6.12.1 Ideal Air-Standard Otto cycle, 6-1-2-3-4-5-6, Which Approximates the Four-Stroke Cycle of a SI Engine on P-V Coordinates

The second stroke of the cycle is the compression stroke, which in the Otto cycle is an isentropic compression from BDC to TDC (process 1-2). This is a good approximation to compression in a real engine, except for the very beginning and the very end of the stroke. In a real engine, the beginning of the stroke is affected by the intake valve not being fully closed until slightly after BDC. The end of compression is affected by the firing of the spark plug before TDC. Not only is there an increase in pressure during the compression stroke, but the temperature within the cylinder is increased substantially due to compressive heating.

The compression stroke is followed by a constant-volume heat input process 2-3 at TDC. This replaces the combustion process of the real engine cycle, which occurs at close to constant-volume conditions. In a real engine combustion is started slightly bTDC, reaches its maximum speed near TDC, and is terminated a little aTDC. During combustion or heat input, a large amount of energy is added to the air within the cylinder. This energy raises the temperature of the air to very high values, giving peak cycle temperature at point 3. This increase in temperature during a closed constant-volume process results in a large pressure rise also. Thus, peak cycle pressure is also reached at point 3.

The very high pressure and enthalpy values within the system at TDC generate the power stroke (or expansion stroke) which follows combustion (process 3-4). High pressure on the piston face forces the piston back towards BDC and produces the work and power output of the engine. The power stroke of the real engine cycle is approximated with an isentropic process in the Otto cycle. This is a good approximation, subject to the same arguments as the compression stroke on being frictionless and adiabatic. In a real engine, the beginning of the power stroke is affected by the last part of the combustion process. The end of the power stroke is affected by the exhaust valve being opened before BDC. During the power stroke, values of both the temperature and pressure within the cylinder decrease as volume increases from TDC to BDC.

Near the end of the power stroke of a real engine cycle, the exhaust valve is opened and the cylinder experiences exhaust blowdown. A large amount of exhaust gas is expelled from the cylinder, reducing the pressure to that of the exhaust manifold. The exhaust valve is opened bBDC to allow for the finite time of blowdown to occur. It is desirable for blowdown to be complete by BDC so that there is no high pressure in the cylinder to resist the piston in the following exhaust stroke. Blowdown in a real engine is therefore almost, but not quite, constant volume. A large quantity of enthalpy is carried away with the exhaust gases, limiting the thermal efficiency of the engine. The Otto cycle replaces the exhaust blowdown open-system process of the real cycle with a constant-volume pressure reduction, closed-system process 4-5. Enthalpy loss during this process is replaced with heat rejection in the engine analysis. Pressure within the cylinder at the end of exhaust blowdown has been reduced to about one atmosphere, and the temperature has been substantially reduced by expansion cooling.

The last stroke of the four-stroke cycle now occurs as the piston travels from BDC to TDC. Process 5-6 is the exhaust stroke that occurs at a constant pressure of one atmosphere due to the open exhaust valve. This is a good approximation to the real exhaust stroke, which occurs at a pressure slightly higher than the surrounding pressure due to the small pressure drop across the exhaust valve and in the exhaust system.

At the end of the exhaust stroke the engine has experienced two revolutions, the piston is again at TDC, the exhaust valve closes, the intake valve opens, and a new cycle begins.

When analyzing an Otto cycle, it is more convenient to work with specific properties by dividing by the mass within the cylinder. It is not uncommon to find the Otto cycle shown with processes 6-1 and 5-6 left off the figure. The reasoning to justify this is that these two processes cancel each other thermodynamically and are not needed in analyzing the cycle.

Real Air-Fuel Engine Cycles

The actual cycle experienced by an internal combustion engine is not, in the true sense, a thermodynamic cycle. An ideal air-standard thermodynamic cycle occurs on a closed system of constant composition. This is not what actually happens in an IC engine, and for this reason air-standard analysis gives, at best, only approximations to actual conditions and output. Major differences include:

1. Real engines operate on an open cycle with changing composition. Not only does the inlet gas composition differ from what exits, but often the mass flow rate is not the same. Those engines which add fuel into the cylinders after air induction is complete (CI engines and some SI engines) change the amount of mass in the gas composition part way through the cycle. There is a greater gaseous mass exiting the engine in the exhaust than what entered in the induction process. This can be on the order of several percent. Other engines carry liquid fuel droplets with the inlet air which are idealized as part of the gaseous mass in air-standard analysis. During combustion, total mass remains about the same but molar quantity changes. Finally, there is a loss of mass during the cycle due to crevice flow and blowby past the pistons. Most of crevice flow is a temporary loss of mass from the cylinder, but because it is greatest at the start of the power stroke, some output work is lost during expansion. Blowby can decrease the amount of mass in the cylinders by as much as 1% during compression and combustion.

2. Air-standard analysis treats the fluid flow through the entire engine as air and approximates air as an ideal gas. In a real engine inlet flow may be all air, or it may be air mixed with up to 7% fuel, either gaseous or as liquid droplets, or both. During combustion the composition is then changed to a gas mixture of mostly CO_2, H_2O, and N_2, with lesser amounts of CO and hydrocarbon vapor. In CI engines there will also be solid carbon particles in the combustion products gas mixture. Approximating exhaust products as air simplifies analysis but introduces some error.

Even if all fluid in an engine cycle were air, some error would be introduced by assuming it to be an ideal gas with constant specific heats in air-standard analysis. At the low pressures of inlet exhaust, air can accurately be treated as an ideal gas, but at the higher pressures during combustion, air will deviate from ideal gas behavior. A more serious error is introduced by assuming constant specific heats for the analysis. Specific heats of a gas have a fairly strong dependency on temper-ature and can vary as much as 30% in the temperature range of an engine (for air, $c_p=$

1.004 kJ/kg-K at 300 K and $c_p = 1.292$ kJ/kg-K at 3 000 K.

3. There are heat losses during the cycle of a real engine which are neglected in air-standard analysis. Heat loss during combustion lowers actual peak temperature and pressure from what is predicted. The actual power stroke, therefore, starts at a lower pressure, and work output during expansion is decreased. Heat transfer continues during expansion, and this lowers the temperature and pressure below the ideal isentropic process towards the end of the power stroke. The result of heat transfer is a lower indicated thermal efficiency than predicted by air-standard analysis. Heat transfer is also present during compression, which deviates the process from isentropic. However, this is less than during the expansion stroke due to the lower temperatures at this time.

4. Combustion requires a short but finite time to occur, and heat addition is not instantaneous at TDC, as approximated in an Otto cycle. A fast but finite flame speed is desirable in an engine. This results in a finite rate of pressure rise in the cylinders, a steady force increase on the piston face, and a smooth engine cycle. A supersonic detonation would give almost instantaneous heat addition to a cycle, but would result in a rough cycle and quick engine destruction. Because of the finite time required, combustion is started before TDC and ends after TDC, not at constant volume as in air-standard analysis. By starting combustion bTDC, cylinder pressure increases late in the compression stroke, requiring greater negative work in that stroke. Because combustion is not completed until aTDC, some power is lost at the start of the expansion stroke. Another loss in the combustion process of an actual engine occurs because combustion efficiency is less than 100%. This happens because of less than perfect mixing, local variations in temperature and air-fuel due to turbulence, flame quenching, ect. SI engines will generally have a combustion efficiency of about 95%, while CI engines are generally about 98% efficient.

5. The blowdown process requires a finite real time and a finite cycle time, and does not occur at constant volume as in air-standard analysis. For this reason, the exhaust valve must open 40° to 60° bBDC, and output work at the latter end of expansion is lost.

6. In an actual engine, the intake valve is not closed until after bottom-dead-center at the end of the intake stroke. Because of the flow restriction of the valve, air is still entering the cylinder at BDC, and volumetric efficiency would be lower if the valve closed here. Because of this, however, actual compression does not start at BDC but only after the inlet valve closes. With ignition then occurring before top-dead-center, temperature and pressure rise before combustion is less than predicted by air-standard analysis.

7. Engine valves require a finite time to actuate. Ideally, valves would open and close instantaneously, but this is not possible when using a camshaft. Cam profiles must allow for smooth interaction with the cam follower, and this results in fast but finite valve actuation. To assure that the intake valve is fully open at the start of the induction stroke, it must start to open before TDC. Likewise, the exhaust valve must remain fully open until the end of the exhaust stroke, with final closure occurring after TDC. The resulting valve overlap period causes a deviation from the ideal cycle.

Because of these differences which real air-fuel cycles have from the ideal cycles, results from air-standard analysis will have errors and will deviate from actual conditions. Interestingly, however, the errors are not great, and property values of temperature and pressure are very representative of actual engine values, depending on the geometry and operating conditions of the real engine. By changing operating variables such as inlet temperature and/or pressure, compression ratio, peak temperature, etc., in Otto cycle analysis, good approximations can be obtained for output changes that will occur in a real engine as these variables are changed. Good approximation of power output, thermal efficiency, and mep can be expected.

Indicated thermal efficiency of a real four-stroke SI engine is always somewhat less than what air-standard Otto cycle analysis predicts. This is caused by the heat losses, friction, ignition timing, valve timing, finite time of combustion and blowdown, and deviation from ideal gas behavior of the real engine. Researches show that over a large range of operating variables the indicated thermal efficiency of an actual SI four-stroke engine can be approximated by:

$$(\eta_t)_{actual} \approx 0.85(\eta_t)_{OTTO}$$

This will be correct to within a few percent for large ranges of air-fuel equivalence ratio, ignition timing, engine speed, compression ratio, inlet pressure, exhaust pressure, and valve timing.

Word and Phrases

1. aspirate 吸气
2. cycle 循环
3. thermodynamic 热力学的
4. composition 成份
5. molar quantity 摩尔量
6. crevice 裂缝
7. blowby 窜漏
8. specific heat 比热
9. deviate 偏离
10. stroke 冲程
11. isentropic 等熵的
12. instantaneous 瞬时的
13. detonation 爆震
14. flame quenching 熄火
15. indicated thermal efficiency 指示热效率
16. camshaft 凸轮轴
17. exhaust stroke 排气冲程
18. piston 活塞
19. cylinder 汽缸
20. molar 摩尔的
21. mep（mean effective pressure） 平均有效压力

13 Emissions and Air Pollution

This chapter explores the undesirable emissions generated in the combustion process of automobile and other IC engines. These emissions pollute the environment and contribute to global warming, acid rain, smog, odors, and respiratory and other health problems. The major causes of these emissions are non-stoichiometric combustion, dissociation of nitrogen, and impurities in the fuel and air. The emissions of concern are hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_X), sulfur, and solid carbon particulates. Ideally, engines and fuels could be developed such that very few harmful emissions are generated, and these could be exhausted to the surroundings without a major impact on the environment. With present technology this is not possible, and aftertreatment of the exhaust gases to reduce emissions is very important. This consists mainly of the use of thermal or catalytic converters and particulate traps.

Air Pollution

Until the middle of the 20th century the number of IC engines in the world was small enough that the pollution they emitted was tolerable, and the environment, with the help of sunlight, stayed relatively clean. As world population grew, power plants, factories and an ever-increasing number of automobiles began to pollute the air to the extent that it was no longer acceptable. During the 1940s, air pollution as a problem was first recognized in the Los Angeles basin in California. Two causes of this were the large population density and the natural weather conditions of the area. The large population created many factories and power plants, as well as one of the largest automobile densities in the world. Smoke and other pollutants from the many factories and automobiles combined with fog that was common in this ocean area, and *smog* resulted. During the 1950s, the smog problem increased along with the increase in population density and automobile density. It was recognized that the automobile was one of the major contributors to the problem, and by the 1960s emission standards were beginning to be enforced in California. During the next decades, emission standards were adopted in the rest of the United States and in Europe and Japan. By making engines more fuel efficient, and with the use of exhaust aftertreatment, emissions per vehicle of HC, CO, and NO_X were reduced by about 95% during the 1970s and 1980s. Lead, one of the major air pollutants, was phased out as a fuel additive during the 1980s. More fuel-efficient engines were developed, and by the 1990s the average automobile consumed less than half the fuel used in 1970. However, during this time the number of automobiles greatly increased, resulting in no overall decrease in fuel usage.

Additional reduction will be difficult and costly. As world population grows, emission standards become more stringent out of necessity. The strictest laws are generally initiated in California, with the rest of the United States and world following. Although air pollution is a global problem, some regions of the world still have no emission standards or laws.

Hydrocarbona (HC)

Exhaust gases leaving the combustion chamber of an SI engine contain up to 6 000 ppm of hydrocarbon components, the equivalent of 1%-1.5% of the fuel. About 40% of this is unburned gasoline fuel components. The other 60% consists of partially reacted components that were not present in the original fuel. These consist of small nonequilibrium molecules which are formed when large fuel molecules break up (thermal cracking) during the combustion reaction. It is often convenient to treat these molecules as if they contained one carbon atom, as CH_1.

The makeup of HC emissions will be different for each gasoline blend, depending on the original fuel components. Combustion chamber geometry and engine operating parameters also influence the HC component spectrum.

When hydrocarbon emissions get into the atmosphere, they act as irritants and odorants, some are carcinogenic. All components except CH_4 react with atmospheric gases to form photochemical smog.

Causes of HC Emissions

Nonstoichiometric Air-Fuel Ratio. Fig.6.13.1 shows that HC emission levels are a strong function of AF. With a fuel-rich mixture there is not enough oxygen to react with all the carbon,

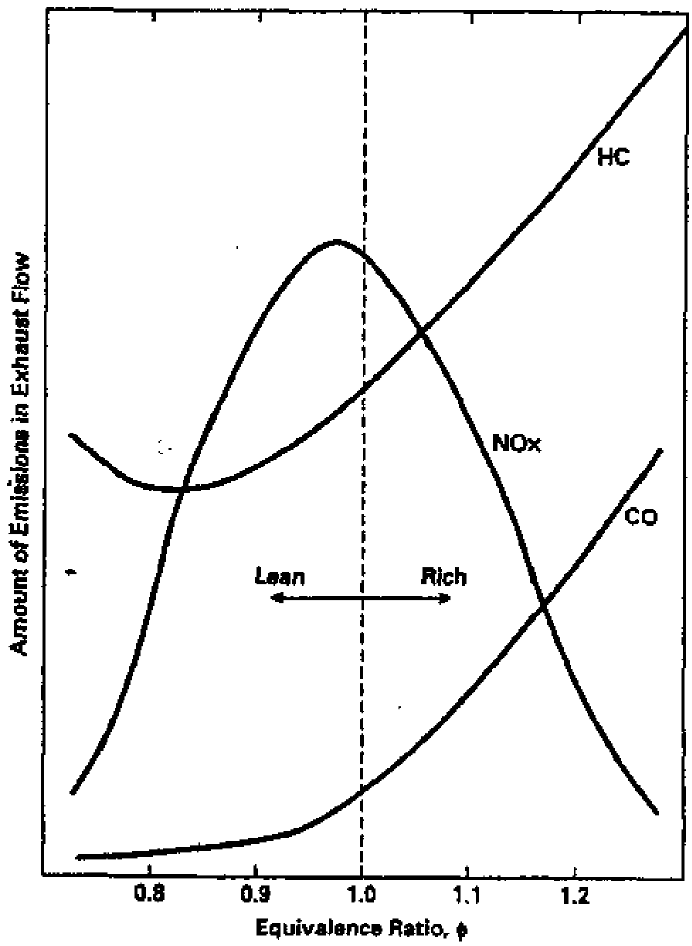


Fig.6.13.1 Emissions from an SI Engine as a Function of Equivalence Ratio

resulting in high levels of HC and CO in the exhaust products. This is particularly true in engine startup. When the air-fuel mixture is purposely made very rich. It is also true to a lesser extent during rapid acceleration under load. If AF is too lean poorer combustion occurs, again resulting in HC emissions. The extreme of poor combustion for a cycle is total misfire. This occurs more often as AF is made more lean. One misfire out of 1 000 cycles gives exhaust emissions of 1 gm/kg of fuel used.

Incomplete Combustion. Even when the fuel and air entering an engine are at the ideal stoichiometric mixture, perfect combustion does not occur and some HC ends up in the exhaust. There are several causes of this. Incomplete mixing of the air and fuel results in some fuel particles not finding oxygen to react with. Flame quenching at the walls leaves a small volume of unreacted air and fuel mixture. The thickness of this unburned layer is on the order of tenths of a mm. Some of this mixture, near the wall that does not originally get burned as the flame front passes, will burn later in the combustion process as additional mixing occurs due to swirl and trubulence.

Another cause of flame quenching is the expansion which occurs during combustion and power stroke. As the piston moves away from TDC, expansion of the gases lowers both temperature and pressure within the cylinder. This slows combustion and finally quenches the flame somewhere late in the power stroke. This leaves some fuel particles unreacted.

High exhaust residual causes poor combustion and a greater likelihood of expansion quenching. This is experienced at low load and idle conditions. High levels of EGR will also cause this.

It has been found that HC emissions can be reduced if a second spark plug is added to an engine combustion chamber. By starting combustion at two points, the flame travel distance and total reaction time are both reduced, and less expansion quenching results.

Crevice Volumes. During the compression stroke and early part of the combustion process, air and fuel are compressed into the crevice volume of the combustion chamber at high pressure. As much as 3% of the fuel in the chamber can be forced into this crevice volume. Later in the cycle during the expansion stroke, pressure in the cylinder is reduced below crevice volume pressure, and reverse blowby occurs. Fuel and air flow back into the combustion chamber, where most of the mixture is consumed in the flame reaction. However, by the time the last elements of reverse blowby flow occur, flame reaction has been quenched and unreacted fuel particles remain in the exhaust. Location of the spark plug relative to the top compression ring gap will affect the amount of HC in engine exhaust, the ring gap being a large percent of crevice volume. The farther the spark plug is from the ring gap, the greater is the HC in the exhaust. This is because more fuel will be forced into gap before the flame front passes.

Crevice volume around the piston rings is greatest when the engine is cold, due to the differences in thermal expansion of the various materials. Up to 80% of all HC emissions can come from this source.

Leak Past the Exhaust Valve. As pressure increases during compression and combustion, some air-fuel is forced into the crevice volume around the edges of the exhaust valve and between the valve and valve seat. A small amount even leaks past the valve into the exhaust manifold. When the exhaust valve opens, the air-fuel which is still in this crevice volume gets carried into the exhaust manifold, and there is a momentary peak in HC concentration at the start of blowdown.

Valve Overlap. During valve overlap, both the exhaust and intake valves are open, creating a path where air-fuel intake can flow directly into the exhaust. A well-designed engine minimizes this flow, but a small amount can occur. The worst condition for this is at idle and low speed, when real time of overlap is greatest.

Deposits on Combustion Chamber Walls. Gas particles, including those of fuel vapor, are absorbed by the deposits on the walls of the combustion chamber. The amount of absorption is a function of gas pressure, so the maximum occurs during compression and combustion. Later in the cycle, when the exhaust valve opens and cylinder pressure is reduced, absorption capacity of the deposit material is lowered and gas particles are desorbed back into the cylinder. These particles, including some HC, are then expelled from the cylinder during the exhaust stroke. This problem is greater in engines with higher compression ratios due to the higher pressure these engines generate. More gas absorption occurs as pressure goes up. Clean combustion chamber walls with minimum deposits will reduce HC emissions in the exhaust. Most gasoline blends include additives to reduce deposit buildup in engines.

Older engines will typically have a greater amount of wall deposit buildup and a corresponding increase of HC emissions. This is due both to age and to less swirl that was generally found in earlier engine design. High swirl helps to keep wall deposits to a minimum. When lead was eliminated as gasoline additive, HC emissions from wall deposits became more severe. When laded gasoline is burned the lead treats the metal wall surfaces, making them harder and less porous to gas absorption.

Oil on Combustion Chamber Walls. A very thin layer of oil is deposited on the cylinder wall of an engine to provide lubrication between them and the moving piston. During the intake and compression strokes, the incoming air and fuel comes in contact with this oil film. In much the same way as wall deposits, this oil film absorbs and desorbs gas particles, depending on gas pressure. During compression and combustion, when cylinder pressure is high, gas particles, including fuel vapor, are absorbed into the oil film. When pressure is later reduced during expansion and blowdown, the absorption capability of the oil is reduced and fuel particles are desorbed back into the cylinder. Some of this fuel ends up in the exhaust.

Propane is not soluble in oil, so in propance-fueled engines the absorption-desorption mechanism adds very little to HC emissions.

As an engine ages, the clearance between piston rings and cylinder walls becomes greater, and a thicker film of oil is left on the walls. Some of this oil film is scraped off the walls during the compression stroke and ends up being burned during combstion. Oil is a high-molecular-weight hydrocarbon compound that does not burn as readily as gasoline. Some of it ends up as HC emissions. This happens at a very slow rate with a new engine but increases with engine age and wear. Oil consumption also increases as the piston rings and cylinder walls wear. In older engines, oil being burned in the combustion chamber is a major source of HC emissions. Fig.6.13.2 shows how HC emissions go up as oil consumption increases. Often as an engine, ages clearance between the pistons and cylinder walls increases due to wear. This increases oil consumption and contributes to an increase in HC emissions in three ways: There is added crevice volume, there is added absorption-desorption of fuel in the thicker oil film on cylinder walls, and there is more oil burned in the combustion process.

In addition to oil consumption going up as piston rings wear, blowby and reverse blowby also increase. The increase in HC emissions is therefore both from combustion of oil and from the added crevice volume flow.

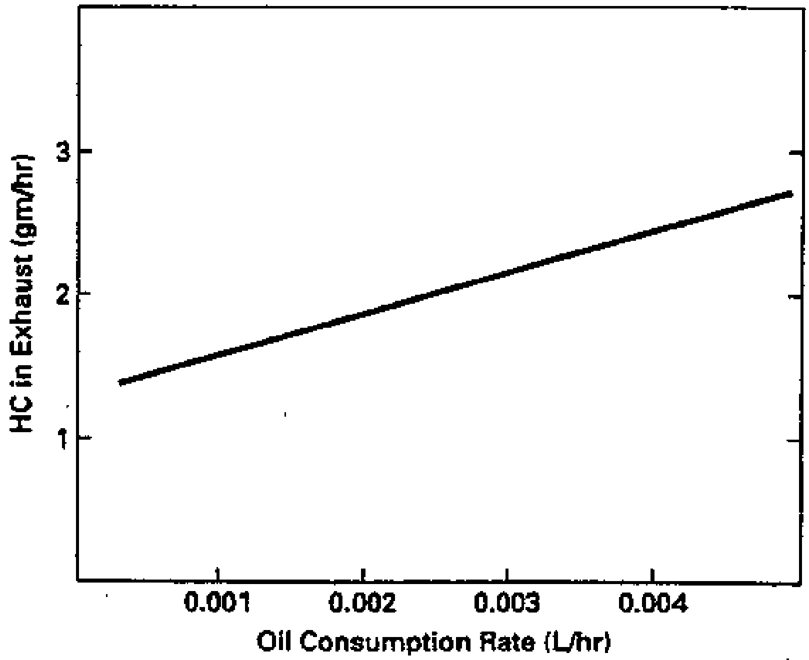


Fig.6.13.2 HC Exhaust Emissions as a Function of Engine Oil Consumption

Carbon Monoxide (CO)

Carbon monoxide, a colorless, odorless, poisonous gas, is generated in an engine when it is operated with a fuel-rich equivalence ratio, as shown in Fig.6.13.1. When there is not enough oxygen to convert all carbon to CO_2, some fuel does not get burned and some carbon ends up as CO. Typically the exhaust of an SI engine will be about 0.2% to 5% carbon monoxide. Not only is CO considered an undesirable emission, but it also represents lost chemical energy that was not fully utilized in the engine. CO is a fuel that can be combusted to supply additional thermal energy:

$$CO+\frac{1}{2}O_2 \rightarrow CO_2 + \text{heat} \qquad (6.13\text{—}1)$$

Maximum CO is generated when an engine runs rich, such as when starting or when accelerating under load. Even when the intake air-fuel mixture is stoichiometric or lean, some CO will be generated in the engine. Poor mixing, local rich regions, and incomplete combustion will create some CO.

A well-designed SI engine operating under ideal conditions can have an exhaust mole fraction of CO as low as 10^{-3}. CI engines that operate overall lean generally have very low CO emissions (see Fig.6.13.1).

Oxides of Nitrogne (NO_X)

Exhaust gases of an engine can have up to 2 000 ppm of oxides of nitrogen. Most of this will be nitrogen oxide (NO), with a small amount of nitrogen dioxide (NO_2), and traces of other nitrogen-oxygen combinations. These are all grouped together as NO_X (or NO_x), with x representing some suitable number. NO_X is a very undesirable emission, and regulations that restrict the allowable amount continue to become more stringent . Released NO_X reacts in the atmosphere to form ozone and is one of the major causes of photochemical smog.

NO_X is created mostly from nitrogen in the air. Nitrogen can also be found in fuel blends, which may contain trace amounts of NH_3, NC, and HCN, but this would contribute only to a minor degree. There are a number of possible reactions that form NO, all of which are probably occurring during the combustion process and immediately after. These include but are not limited to:

$$O + N_2 \rightarrow NO + N \tag{6.13—2}$$

$$N + O_2 \rightarrow NO + O \tag{6.13—3}$$

$$N + OH \rightarrow NO + H \tag{6.13—4}$$

NO, in turn, can then further react to form NO_2 by various means, including

$$NO + H_2O \rightarrow NO_2 + H_2 \tag{6.13—5}$$

$$NO + O_2 \rightarrow NO_2 + O \tag{6.13—6}$$

Atmospheric nitrogen exists as a stable diatomic molecule at low temperatures, and only very small trace amounts of oxides of nitrogen are found. However, at the very high temperatures that occur in the combustion chamber of an engine, some diatomic nitrogen (N_2) breaks down to monatomic nitrogen (N) which is reactive:

$$N_2 \rightarrow 2N \tag{6.13—7}$$

It is known that the chemical equilibrium constant for Eq.(6.13—7) is highly dependent on temperature, with a much more significant amount of N generated in the 2 500-3 000 K temperature range that can exist in an engine. Other gases that are stable at low temperatures but become reactive and contribute to the formation of NO_X at high temperatures include oxygen and water vapor, which break down as follows:

$$O_2 \rightarrow 2O \tag{6.13—8}$$

$$H_2O \rightarrow OH + \frac{1}{2}H_2 \tag{6.13—9}$$

Examination of more elaborate chemical equilibrium constant tables found in chemistry handbooks show that chemical Eq. (6.13—7)~(6.13—9) all react much further to the right as high combustion chamber temperatures are reached. The higher the combustion reaction temperature, the more diatomic nitrogen, N_2, will dissociate to monatomic nitrogen, N, and the more NO_X will be froned. At low temperatures very little NO_X is created.

Although maximum flame temperature will occur at a stoichiometric air-fuel ratio ($\phi=1$), Fig.6.13.1 shows that maximum NO_X is formed at a slightly lean equivalence ratio of about $\phi=0.95$. At this condition flame temperature is still very high, and in addition, there is an excess of oxygen that can combine with the nitrogen to form various oxides.

In addition to temperature, the formation of NO_X depends on pressure, air-fuel ratio, and combustion time within the cylinder, chemical reactions not being instantaneous. Fig.6.13.3 shows the NO_X-versus-time relationship and supports the fact that NO_X is reduced in modern engines with fast-burn combustion chambers. The amount of NO_X generated also depends on the location within the combustion chamber. The highest concentration is formed around the spark plug, where the highest temperatures occur. Because they generally have higher compression ratios and higher temperatures and pressure, CI engines with divided combustion chambers and indirect injection (IDI) tend to generate higher levels of NO_X.

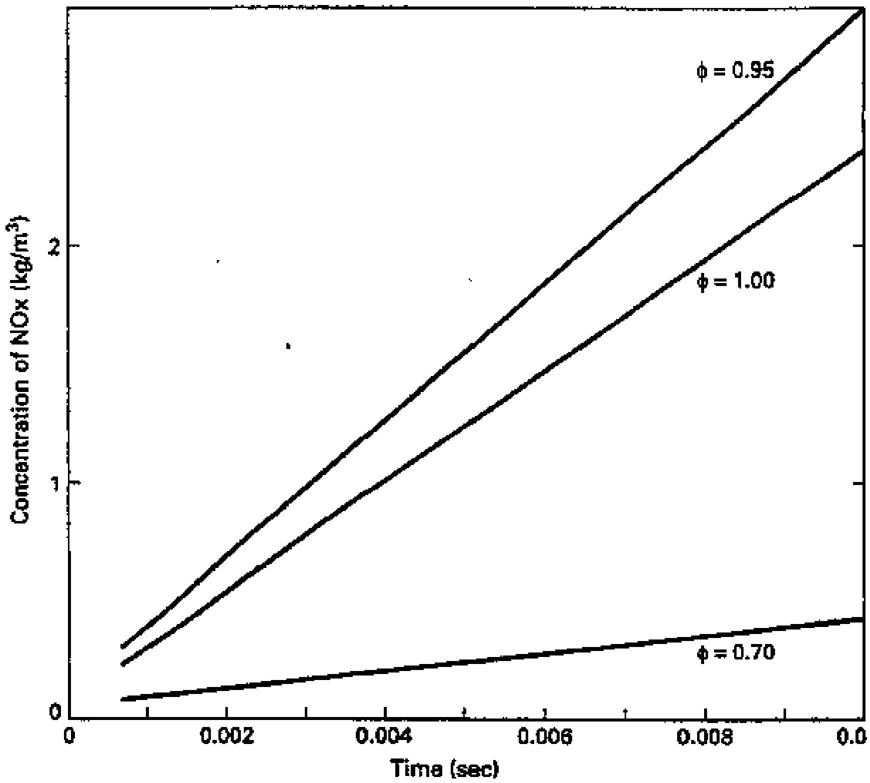


Fig.6.13.3 Generation of NO_X in an Engine as a Function of Combustion Time

NO_X can be correlated with ignition timing. If ignition spark is advanced, the cylinder temperature will be increased and more NO_X will be created.

Photochemical Smog. NO_X is one of the primary causes of photochemical smog, which has become a major problem in many large cities of the world. Smog is formed by the photochemical reaction of automobile exhaust and atmospheric air in the presence of sunlight. NO_2 decomposes into NO and monatomic oxygen:

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reaction of automobile exhaust and atmospheric air in the presence of sunlight. NO_2 decomposes into NO and monatomic oxygen:

$$NO_2 + \text{energy from sunlight} \rightarrow NO + O + \text{smog} \quad (6.13\text{—}10)$$

Monatomic oxygen is highly reactive and initiates a number of different reactions, one of which is the formation of ozone:

$$O + O_2 \rightarrow O_3 \quad (6.13\text{—}11)$$

Ground-level ozone is harmful to lungs and other biological tissue. It is harmful to trees and causes billions of dollars of crop loss each year. Damage is also caused through reaction with rubber, plastics, and other materials. Ozone also results from atmospheric reactions with other engine emissions such as HC, aldehydes, and other oxides of nitrogen.

Word and Phrases

1. emission	散发，排放
2. IC engine	内燃机
3. SI engine	点燃式内燃机
4. CI engine	压燃式内燃机
5. smog	烟雾
6. odors	气味
7. exhaust	排气
8. phase out	使逐步淘汰，逐渐停止
9. additive	添加剂
10. strigent	严格的，严厉的
11. respiratory	呼吸的
12. stoicbiometric	化学成份比例适当的
13. dissociation	分裂
14. sulfur	硫
15. catalytic converter	催化转换器
16. blend	牌号
17. irritant	刺激物，刺激的
18. carcinogenic	致癌的
19. photochemical	光化学的
20. trace amount	微量
21. ozone	臭氧
22. aldehydes	醛
23. soluble	可溶解的
24. phosphorus	磷
25. zinc	锌

14 Natural Convection

Introduction

Natural-convection heat transfer occurs whenever a body is placed in a fluid at a higher or a lower temperature than that of the body. As a result of the temperature difference, heat flows between the fluid and the body and causes a change in the density of the fluid in the vicinity of the surface. The difference in density leads to downward flow of the heavier fluid and upward flow of the lighter one. If the motion of the fluid is caused solely by differences in density resulting from temperature gradients and is not aided by a pump or a fan, the associated heat transfer mechanism is called **natural convection**. Natural convection currents transfer internal energy stored in the fluid in essentially the same manner as forced-convection currents. However, the intensity of the mixing motion is generally less in natural convection, and consequently the heat transfer coefficients are lower than in forced convection.

Although natural-convection heat transfer coefficients are relatively small, many devices depend largely on this mode of heat transfer for cooling. In the electrical engineering field, transmission lines, transformers, rectifiers, electronic devices, and electrically heated wires such as the heating elements of an electric furnace are cooled in part by natural convection. The temperatures of these bodies rise above that of the surroundings as a result of the heat generated internally. As the temperature difference increases, the rate of heat flow also increases until a state of equilibrium in which the rate of heat generation is equal to the rate of heat dissipation is reached.

Natural convection is the dominant heat flow mechanism from steam radiators, the walls of buildings, or the stationary human body in a quiescent atmosphere. The determination of the heat load on heating and air-conditioning equipment and computers requires, therefore, a knowledge of natural-convection heat transfer coefficients. Natural convection is also responsible for heat losses from pipes carrying steam or other heated fluids. Natural convection has been proposed in nuclear power applications for cooling the surfaces of bodies in which heat is generated by fission. The importance of natural-convection heat transfer has led to the publication of a texthook devoted entirely to the subject.

In all of the aforementioned examples gravitational attraction is the body force responsible for the convection currents. Gravity, however, is not the only body force that can produce natural convection. In certain aircraft applications there are components such as the blades of gas turbines and helicopter ramjets that rotate at high speeds. Associated with these rotative speeds are large centrifugal forces whose magnitudes, like the gravitational force, are also proportional to the fluid density and hence can generate strong natural-convection currents. Cooling of rotating components by natural convection is therefore feasible even at high heat fluxes.

The fluid velocities in natural-convection currents, especially those generated by gravity, are generally low, but the characteristics of the flow in the vicinity of the heat transfer surface are similar to those in forced convection. A boundary layer forms near the surface, and the fluid velocity at the interface is zero. Fig.6.14.1 shows the velocity and temperature distributions near a heated flat plate placed in a vertical position in air. At a given distance from the bottom of the plate, the local upward velocity increases with increasing distance from the surface to reach a maximum value close to the surface, then decreases and approaches zero again as shown in Fig.6.14.1. Although the velccity profile is different from that observed in forced convection over a flat plate, where the velocity approaches the free-stream velocity asymptotically, in the vicinity of the surface the characteristics of both types of boundary layers are similar. In natural convection, as in forced convection, the flow may be laminar or turbulent, depending on the distance from the leading edge, the fluid properties, the body force, and the temperature difference between the surface and the fluid.

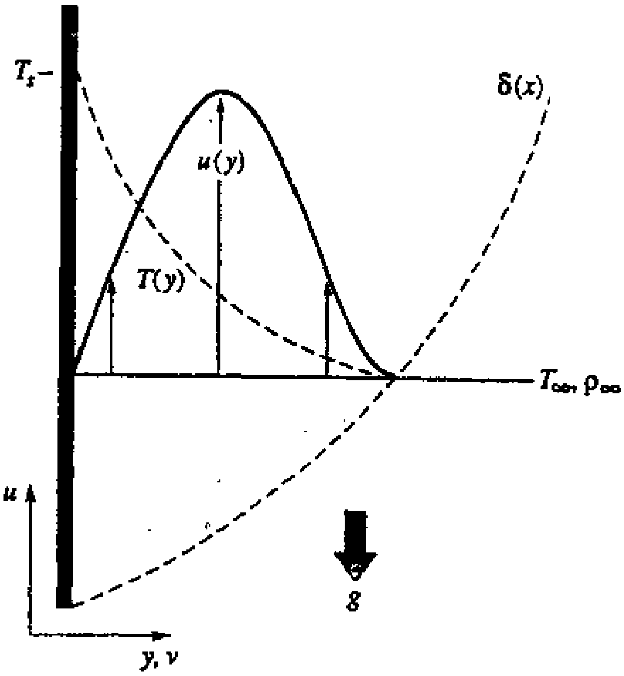

Fig.6.14.1 Temperature and Velocity Distributions in the Vicinity of a Heated Flat Plate Placed Vertically in Still Air (after E. Schmidt and W. Beckmann).

The temperature field in natural convection (Fig.6.14.1) is similar to that observed in forced convection. Hence, the physical interpretation of the Nusselt number applies. For practical applications, however, Newton's equation,

$$dq = h_c dA(T_s - T_\infty)$$

is generally used. The equation is written for a differential area dA because in natural convection, the heat transfer coefficient h_c is not uniform over a surface. As in forced convection over a flat plate, we shall therefore distinguish between a local value of h_c and an average value $\bar{h}_c$ obtained by averaging h_c over the entire surface. The temperature T_∞ refers to a point in the fluid sufficiently removed from the body that the temperature of the fluid is not affected by the presence of a heating (or cooling) source in the body.

Exact evaluation of the heat transfer coefficient for natural convection from the boundary layer is very difficult. The problem has been solved only for simple geometries such as a vertical flat plate and a horizontal cylinder. We shall not discuss these specialized solutions here. Instead, we shall set up the differential equations for natural convection from a vertical flat plate by using only fundamental physical principles. From these equations, without actually solving them, we shall determine the similarity conditions and associated dimensionless parameters that correlate experimental data. In section 6.14—3 pertinent experimental data for various shapes of practical interest will be presented in terms of these dimensionless parameters, and their physical significance will be discussed. Section 6.14—4 treats natural convection from rotating objects, in which the body force due to centrifugal acceleration may be more important which the body force due to centrifugal acceleration may be more important than the gravitational body force. Section 6.14—5 deals with problems in which natural convection and forced convection act at the same time—that is, mixed convection. Section 6.14—6 treats heat transfer to and from finned surfaces in natural convection.

Simil Parameters for Natural Convection

In the analysis of natural convection we shall make use of a phenomenon observed by the Greeks over two thousand years ago and phrased by Archimedes somewhat as follows: A body immersed in a fluid experiences a buoyant or lifting force equal to the mass of the displaced fluid. Hence, a submerged body rises when its density is less than that of the surrounding fluid and sinks when its density is greater. The buoyant effect is the driving force in natural convection.

For the purposes of our analysis, consider a domestic heating panel. The panel can be idealized as a vertical flat plate, very long and very wide in the plane perpendicular to the floor, so that the flow is two-dimensional (Fig.6.14.2). When the heater is turned off, the panel is at the same temperature as the surrounding air. The gravitational or body force acting on each fluid element is

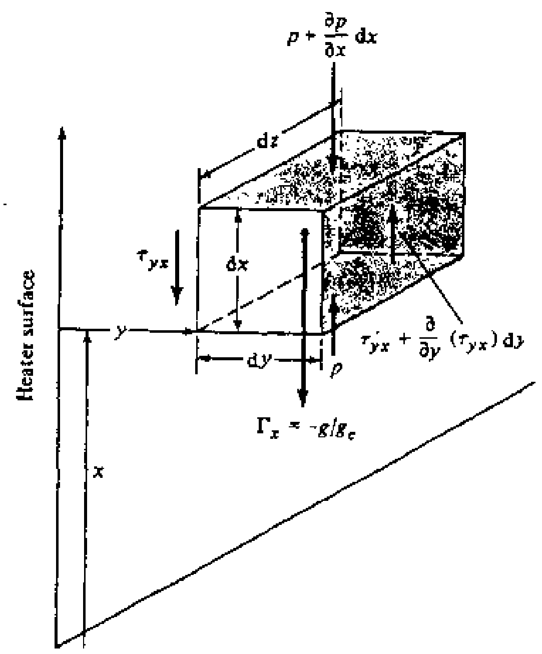

Fig.6.14.2 Forces Acting on a Fluid Element in Natural Convection Flow

in equilibrium with the hydrostatic pressure gradient, and the air is motionless. When the heater is turned on, the fluid in the vicinity of the panel will be heated and its density will decrease. Hence, the body force (defined as the force per unit mass) on a unit volume in the heated portion of the fluid is less than in the unheated fluid. This imbalance causes the heated fluid to rise, a phenomenon that is well known from experience. In addition to the buoyant force, there are pressure forces and also frictional forces that act when the air is in motion. Once steady-state conditions have been established, the total force on a volume element $dx\ dy\ dz$ in the positive x direction perpendicular to the floor consists of the following:

1. The force due to the pressure gradient

$$p\mathrm{d}y\mathrm{d}z-\left(p+\frac{\partial p}{\partial x}\mathrm{d}x\right)\mathrm{d}y\mathrm{d}z=-\frac{\partial p}{\partial x}(\mathrm{d}x\mathrm{d}y\mathrm{d}z)$$

2. The body force $\Gamma_x\rho(\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z)$, where $\Gamma_x=-g/g_c$, since gravity alone is active.*

3. The frictional shearing forces due to the velocity gradient

$$(-\tau_{yx})\mathrm{d}x\mathrm{d}z+\left(\tau_{yx}+\frac{\partial\tau_{yx}}{\partial y}\mathrm{d}y\right)\mathrm{d}x\mathrm{d}z$$

Since $\tau_{yx}=\mu(\partial u/\partial y)/g_c$ in laminar flow, the net frictional force is

$$\left(\frac{\mu}{g_c}\frac{\partial^2 u}{\partial y^2}\right)\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z$$

Forces due to the deformation of the fluid element will be neglected in view of the low velocity. Ostrach has shown that the effects of compression work and frictional heat may be important in natural-convection problems when very large temperature differences exist, very large length scales are involved, or very high body forces occur, such as in high-speed rotating machinery.

The rate of change of momentum of the fluid element is $\rho\,\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\times[u(\partial u/\partial x)+v(\partial u/\partial y)]$, as shown in section 4.4. Applying Newton's second law to the elemental volume yields

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-g_c\frac{\partial p}{\partial x}-\rho g+\mu\frac{\partial^2 u}{\partial y^2} \qquad (6.14\text{—}1)$$

after canceling $\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z$. The unheated fluid far removed from the plate is in hydrostatic equilibrium, or $g_c(\partial p_e/\partial x)=-\rho_e g$, where the subscript e denotes equilibrium conditions. At any elevation, the pressure is uniform and therefore $\partial p/\partial x=\partial p_e/\partial x$. Substituting $\rho_e g$ for $-(\partial p/\partial x)$ in Eq.(6.14—1) gives

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=(\rho_e-\rho)g+\mu\frac{\partial^2 u}{\partial y^2} \qquad (6.14\text{—}2)$$

A further simplification can be made by assuming that the density ρ depends only on the temperature and not on the pressure. For an incompressible fluid this is self-evident, but for a gas it implies that the vertical dimension of the body is small enough that the hydrostatic density ρ_e is constant. This simplification is referred to as the **Boussinesq approximation**. With these assumptions, the buoyant term can be written

* g_c is the gravitational constant, equal to 1 kg m/Ns^2 in the SI system.

$$g(\rho_e - \rho) = g(\rho_\infty - \rho) = -g\rho\beta(T_\infty - T) \tag{6.14—3}$$

where β is the coefficient of thermal expansion, defined as

$$\beta = -\frac{1}{\rho}\frac{\partial \rho}{\partial T}\bigg|_p \approx \frac{\rho_\infty - \rho}{\rho(T - T_\infty)} \tag{6.14—4}$$

For an ideal gas (i.e., $\rho = p/RT$) the coefficient of thermal expansion is

$$\beta = \frac{1}{T_\infty} \tag{6.14—5}$$

where the temperature T_∞ is absolute temperature far from the plate.

The equation of motion for natural convection is obtained by substituting the buoyant term, Eq.(6.14—3), into Eq.(6.14—2), yielding

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = g\beta(T - T_\infty) + v\frac{\partial^2 u}{\partial y^2} \tag{6.14—6}$$

In deriving the conservation of energy equation for the flow near the plate, we follow the same steps used in chapter 4 to derive the conservation of energy equation for the forced flow near a flat plate. This leads to the following equation, which also describes the temperature field for the natural-convection problem:

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2}$$

Word and Phrases

1. natural convection	自然对流
2. density	密度
3. gradient	梯度
4. transmission line	输电线
5. transformer	变压器
6. rectifier	整流器
7. quiescent	静止的
8. fission	裂变
9. gravity	重力
10. ramjet	冲压式喷气发动机
11. vicinity	邻近，接近
12. asymptotically	渐进地
13. correlate	使相互关联
14. pertinent	有关的
15. perpendicular	垂直的
16. deformation	变形
17. phrase	用短语表达，短语
18. finned	有散热片的，带翅片的

15 Mechatronics Design

Mechatronics is a methodology used for the optimal design of electromechanical products.

A **methodology** is a collection of practices, procedures, and rules used by those who work in a particular branch of knowledge, or **discipline**. The familiar technological disciplines include thermodynamics, electrical engineering, computer science, and mechanical engineering, to name several. The mechatronic system is **multi-disciplinary**, embodying four fundamental disciplines: **electrical, mechanical, computer science, and information technology**.

The F-22 fighter, under development at Lockheed-Martin and Boeing, is an example of mechatronic technology in action. The design metric emphasizes reliability, maintainability, performance, and cost. Multi-disciplinary functionality, including the integrated flightpropulsion controls and two-dimensional, thrust-vectoring engine nozzles, is being designed into the aircraft starting at the preliminary design stage.

Multi-disciplinary systems are not new; they have been successfully designed and used for many years. One of the most common is the **electromechanical** system, which often uses a computer algorithm to modify the behavior of a mechanical system. Electronics are used to transduce information betweem the computer science and mechanical disciplines.

The difference between a mechatronic system and a multi-disciplinary system is not the constituents, but rather **the order in which they are designed**. Historically, multi-disciplinary system design has employed a sequential **design-by-discipline** approach. For example, the design of an electromechanical system is often accomplished in three steps beginning with the mechanical design. When the mechanical design is complete, the power and microelectronics are designed followed by the control algorithm design and its implementation. The major drawback of the design-by-discipline approach is that fixing the design at various points in the sequence cause new constraints, resulting from the design to that point; to be created and passed on the the next discipline. Many control system engineers are familiar with the following quip:

"Design and build the mechanical system. Then bring in the painters to paint it and the control system engineers to install the controls."

Control designs often fail because of these additional constraints. For example, cost reduction is a major factor in most systems. Tradeoffs made during the mechanical and electrical design stages often involve sensors and actuators. Lowering the sensor-actuator count and using less accurate sensors or less powerful actuators are some of the standard methods for achieving cost savings. Their effects on the control system are additional, and sometimes conflicting, constraints.

▸ **The mechatronic design methodology is based on a concurrent, instead of sequential, approach to discipline design, resulting in products with more sysnergy.**

The branch of engineering called **systems engineering** uses a concurrent approach for **preliminary design**. In a way, mechatronicas is an extension of the system engineering approach, but it is **supplemented** with information systems to **guide** the design and is applied at **all** stages of design, not just the preliminary design step, making it more **comprehensive**. There is a synergy in the integration of mechanical, electrical and computer systems with information systems for the design and manufacture of products and processes. The synergy is generated by the right combination of parameters; that is, the final product can be better than just the sum of its parts. Mechatronic products exhibit performance characteristics that were previously difficult to achieve withour the synergistic combination. The key elements of the mechatronics approach are presented in Fig.6.15.1.

Even though the literature often adopts this concise representation, a clearer but more complex representation is shown in Fig.6.15.2.

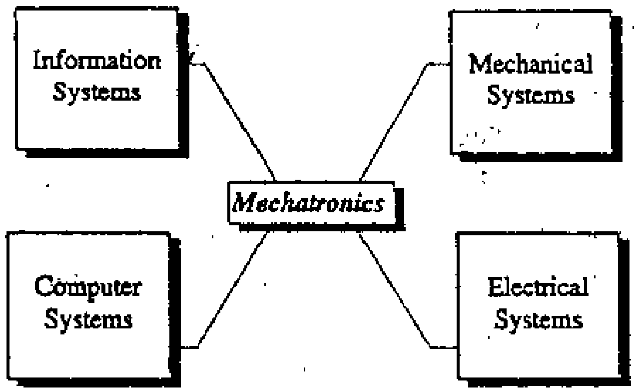

Fig.6.15.1 Mechatronics Constituents

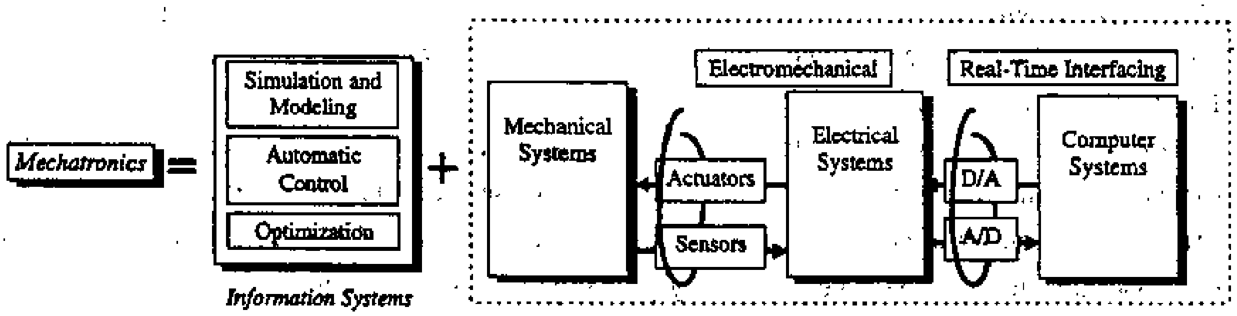

Fig.6.15.2 Mechatronics Key Elements

Mechatronics is the result of applying information systems to physical systems. The physical system, the rightmost dotted block, consists of mechanical, electrical, and computer systems as well as actuators, sensors, and real-time interfacing. In some of the literature, this block is called an electromechanical system.

▸ **A mechatronic system is not an electromechanical system and is more than a control system.**

Sensors and actuators are used to transduce energy from high power, usually the mechanical side, to low power, the electrical and computer side. The block labeled mechanical systems frequently consists of more than just mechanical components and may include fluid, pneumatic, thermal, acoustic, chemical, and other disciplines as well. New developments in sensing technologies have emerged in respones to the ever-increasing demand for solutions of specific monitoring applications. They have produced faster, more sensitive; and more precise measuring devices. Sensors are being miniaturized and implemented in solid state form so that several sensors can be integrated and their functions combined.

Control is a general term and can occur in living beings as well as machines. The term **automatic control** describes the situation in which a machine is controlled by another machine.

Irrespective of the application, such as industrial control, manufacturing, testing, or military, new developments in sensing technology are constantly emerging.

Integrated Design Issues in Mechatronics

The inberent concurrency, or simultaneous engineering, of the mechatronics approach relies heavily on the use of system modeling and simulation throughout the design and prototyping stages. Because the model will be used and altered by engineers from multiple disciplines, it is especially important that it be programmed in a visually intuitive environment. Such environments include block diagrams, flow charts, state transition diagrams, and Bond graphs. In contrast to the more conventional programming languages such as FORTRAN, BASIC, C, and Pascal, the visual modeling environment requires little training due to its inherent intuitiveness. Today the most widely used visual programming environment is the **block diagram**. This environment is extremely versatile, is low in cost, and often includes a **code generator** option that translates the block diagram into a C, or similar, high-level language suitable for target system implementation. Block diagram-based modeling and simulation packages are offered by many vendors, including Matrixx, Easy5, SimuLink, VisSim, and Lab View.

Mechtronics is a design philosophy, an integrating approach to engineering design. The primary factor in mechatronics is the involvement of these areas throughout the design process. Through a mechanism of simulating interdisciplinary ideas and techniques, mechatronics provides ideal conditions to raise the synergy, thereby providing a catalytic effect for the new solutions to technically complex situations. An important characteristic of mechatronic devices and systems is their built-in intelligence, which results through a combination of precision mechanical and electrical engineering and real-time programming integrated with the design process. Mechatronics makes possible the combination of actuators, sensors, control systems, and computers in the design process.

Starting with the basic design, and progressing through the manufacturing phase, mechatronic design optimizes the parameters at each pbase to produce a quality product in a short cycle time. Mechatronics uses the control systems in providing a coherent framework of component interactions for system analysis. The integration within a mechatronic system is performed through the conbination of hardware (components) and software (information processing). Hardware integration results from designing the mechatronic system as an overall system and bringing together the sensors, actuators, and microcomputers into the mechanical system. Software integration is primarily based on advanced control function. Fig.6.15.3 illustrates how the hardware and software integration take place. It also shows how process knowledge and information processing are involved in adthition to the feedback process.

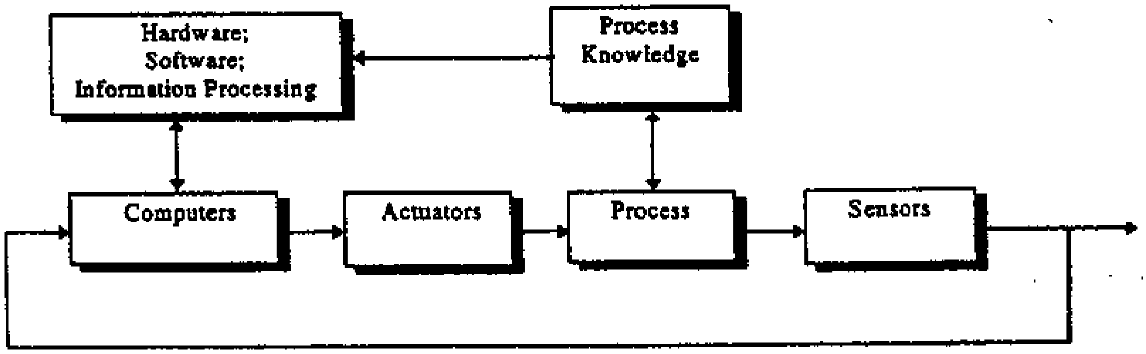

Fig.6.15.3 General Scheme of Hardware and Software Integration

The first step in the focused development of mechatronic systems is to analyze the customer needs and the technical environment in which the system is integrated. Complex technical systems designed to solve problems tend to be a combination of mechanical, electric, fluid power, and thermodynamic parts with hardware in digital and analog form coordinated by complex software. Typical mechatronic systems gather data and information from their technical environment using sensors. The next step is to use elaborate ways of modeling and description methods to cover all subtasks of this system in an integrated manner. This includes an effective description of the necessary interfaces between subsystems at an early stage. The data are processed and interpreted, leading to actions carried out by actuators. Mechatronic systems result in shorter developmental cycles, lower costs, and higher quality. They also provide additional influence through the acquisition of information from the process.

Mechatronic design supports the concepts of concurrent engineering. In the designing of a mechatronic product, it is necessary that the knowledge and required information be coordinated among different expert groups. Concurrent engineering is a design approach in which the design of product and manufacture of a product are merged in special way. Traditional barriers between design and manufacturing are removed. It has been influenced partly by the recognition that many of the high costs in manufacturing are decided at the product design stage itself. Even during the design stage, it is involved with customer perception, market analysis, optimized performance, life cycle performance, quality, reliability, and sales. Product design and process planning take place concurrently. The total philosophy of concurrent engineering in the organization is well suited for team-oriented project management, with emphasis on collective decision making. Successful implementation of concurrent engineering is possible by coordinating adequate exchange of information and dealing with organizational barriers to cross-functional cooperation. Due to the influence of concurrent engineering, traditional barriers between design and manufacturing have decreased; however, the lack of a common interface language has made the information exchange in concurrent engineering difficult.

A mechatronic product can achieve impressive results if it is effectively integrated with the concurrent engineering management strategy. The benefits that accrue are greater productivity, higher quality, and production reliability by the incorporation of intelligent, self-correcting sensory and feedback systems. The integration of sensors and control systems in a complex system reduces capital expenses, maintains a high degree of flexibility, and results in a higher percentage of machine utilization. In order to implement a mechatronic concurrent engineering system that can achieve these objectives, the organization must start with a long-range plan that can take into account tomorrow's changing needs in processes, data functions, control, and integration tools.

Word and Phrases

1. methodology	方法系统
2. discipline	学科，纪律
3. embody	具体表达，使具体化，包含，收录
4. fighter	战斗机，歼击机
5. propulsion	推进，推进力
6. constituent	组成，要素
7. constrain	强迫，抑制，拘束
8. quip	妙语，双关语
9. tradeoff	折衷，权衡
10. count	数，计算，计算在内，认为，有价值
11. synergy	协作，合作，最佳协同
12. prototype	原型，样机
13. inherent	固有的，内在的，与生俱来的
14. concurrent	同时发生的，并行的
15. simultaneous	同时发生的
16. modeling	建模，造型
17. simulation	模拟，仿真
18. intuitive	直觉的
19. implementation	执行
20. catalytic	催化
21. coherent	一致的，连贯的
22. coordinate	同等，并列，坐标（用复数）
23. elaborate	精心制作，详细阐述
24. acquisition	获得
25. merge	合并，结合，融合
26. perception	理解，感知，感觉
27. accrue	增加，产生

16 Artificial Intelligence in Mechatronics

Recent work using artificial intelligence has attempted to integrate various process control modules to increase productivity and quality in manufacturing operations. Further, the developments in expert systems, fuzzy logic, and neural networks are expected to be used at the higher level in the control hierarchy for machining processes.

Artificial Neural Networks in Mechatronics

A recent trend in the area of automation manufacturing is the incorporation of artificial intelligence to enhance the on-line process control and inspection. Intelligent on-line process control and inspection in modern manufacturing systems have significant potential for improving production performance and product quality. Various studies suggest that incorporation of artificial neural networks results in a very promising synergy in generating intelligent manufacturing systems and processes. One reason for this is the dependence on knowledge-based systems, which are widely used and acknowledged for their relevancy, consistency, organization, and completeness. The problem of acquiring expert knowledge in a form usable by an expert system is known as knowledge acquisition. This has been identified as a major bottleneck to the implementation of knowledge-based system technology. However, the acquisition process ends with the implementation of a knowledge-based system that cannot adapt to change and is unable to handle situations slightly different from known prototype conditions. This has paved the way for the development of brain-like computation-namely artificial neural networks that can efficiently conduct production process control and inspection with a wide range of tolerance and uncertainties.

The field of artificial intelligence (AI), particularly the technologies of artificial neural networks, is very useful at higher levels in the control hierarchy of manufacturing processes. The two basic AI approaches for providing decision support have been the macro, or top-down, modeling of human intelligence and the micro, or bottom-up, modeling of human intelligence.

• In the macro approach, as in knowledge-based systems, the human brain is treated as a black-box, and the human reasoning process is modeled through cognitive analysis of the decision-making tasks as described by the expert.

• In the micro approach, as in neural networks, the human brain is treated as a white-box, and the human reasoning process is modeled through observation of neural connections in the brain.

On the most fundamental level, neural networks perform pattern recognition more effectively than any other technique known. Once the network has detected a pattern, the information can be used to classify, predict, and analyze the causes of the pattern. Below are some unusual features of neural networks.

• Recall of information is highly resistant to hardware failure (in contrast to traditional computers, in which retrieval can fail as result of a single memory element).

• Positive and negative aspects of information are automatically balanced as a network reorganizes to solve a problem.

- Abstraction of data occurs automatically as a by-product of learning information.
- Pattern recognition occurs via parallel consideration of multiple constraints.
- Hierarchical data structures can be conveniently represented as multiple-layer networks.
- Networks can exhibit properties reminiscent of adaptive biological learning and can select and generate their own pattern features from exposure to stimuli.
- ANN can capture patterns occurring both in time (for example, auditory information) and space (such as visual data) and can operate in discrete or continuous representation modes.

From an engineering perspective, this new paradigm is a very powerful method for searching through solution space; however, its wide-range applications also include other fields such as business, medical, etc. ANN is best at solving problems that involve pattern recognition, adaptation, generalization, and prediction. Its implementation also offers particular advantages when solving problems that are very noisy, in which the performance of the system cannot be measured with each example, or potentially small improvements in performance can result in a substantial advantage in resource allocation and profits. In the context of diagnostics, ANN is most valuable in applications that process continuous inputs, such as signal data. ANN solutions are hard at work detecting fraud (credit applications, insurance and warranty claims, and credit card fraud), in modeling and forecasting (bankruptcy prediction, credit scoring, securities trading, portfolio evaluation, mail list mangement, production marketing, and targeted marketing), and in process management (process modeling, process control, oil and gas exploration, reservoir management, production line management, machine diagnostics, flaw detection, product development, and industrial inspection). However, for ANN to reach its maximum potential, supporting hardware is needed that will make the network faster and thus more practical.

Knowledge-Based System

Knowledge-based systems are the part of the AI field that focuses mainly on replicating cognitive human behavior. They do so by capturing problem-solving expertise of experts within a narrow problem domain and making it available for other organizational systems. The expertise is typically stored in a knowledge base in static form of If-Then-Else rules or a hierarchy of frames and objects. The knowledge base is used by an inference engine, which reasons with the knowledge in a serial manner, and applied to the different problem presented by user. Conventional knowledge-based systems are generally static, which make them inflexible in dynamic environments that require constant learning based on action taken and feedback obtained from the action. Thus, an intelligent process control and inspection system cannot rely solely on a conventional knowledge-based system technology that uses a static knowledge base. Rather, it needs a dynamic learning mechanism thet can help the system to deal with an uncertain reasoning environment with high flexibility and adaptability to the change in its condition.

Knowledge acquisition is probably the most difficult step in the development of an expert or knowledge-based system. The complexity of the problem at hand and the human factors of interacting and understanding the decision-making process of individuals combine to make the task of knowledge acquisition one that requires special tools, time, and considerable skill to perform accurately and effectively. Yet even the experienced knowledge engineer encounters problems. Difficulties with the expert may arise if the information provided is incorrect or is problems. Difficulties with the expert may arise if the information provided is incorrect or is misinterpreted by the knowledge engineer. In addition, although experts may be highly skilled at solving the problem under sturdy, they may be limited in their ability to describe the decisionmaking process in the meticulous detail required to make the expert system function properly. The expert may also provide extraneous information that can be eliminated from the knowledge base without affecting the decision-making capability.

Knowledge Acquisition

The problems surrounding knowledge acquisition are not new to knowledge specialists in the field. Routinely, situations arise in which one missing piece of information disrupts the flow of the system and causes undesirable conclusions. This often becomes a stumbling block to the successful implementation of expert systems. In addition, many processes or manufacturing-oriented applications require sensory data input to the neural network, resulting in higher costs and a greater time investment to facilitate the information transfer from the shop floor or piece of machinery to the location where the expert or knowledge-based system is housed. The sensor, data acquisition port, associated wiring, and labor to install, maintain, and troubleshoot the sensory devices are expensive and therefore should be scrutinized before being adopted into an expert system. The cost/benefit tradeoff of including numerous sensory devices and determining their influence on the overall decision-making process is often an activity that is overlooked in the development of expert or knowledge-based systems.

Case Study: Real-Time Robotic Interface for Filter Inspection

This case study addresses the issue of robot intelligence via a prototype system called CRYSTAL-1. CRYSTAL-1 demonstrates the feasibility of an intelligent robot to help plant supervisors in autonomous parts inspection in changing environmental conditions. CRYSTAL-1 consists of an artificial neural network (ANN) system and a knowledge-based system (KBS) that are used to control and operate, in real time, the functions of a fixed industrial robot whose task isto recognize and replace industrial filters autonomously with the help of optical sensors. These components of CRYSTAL-1 are integrated with a visual programming platform that is designed to provide enough flexibility in assembling a wide variety of products that require precise inspection. The methodology used in CRYSTAL-1 achieves its flexibility and adaptability to changing environmental conditions (which in the present case is the filter quality through a signal from a sensor and then processes the signal with a neural net and KBS modules. The quality and the factor of acceptability of the filter are determined by the neural network.

As shown in Fig.6.16.1, in the CRYSTAL-1 architecture, the information signal on the filter quality is transmitted from the sensor on the robot through the robot interface module. The robot interface module transmits the sensor information through the ANN input interface to the ANN system and the information on the position of the robot arm to the knowledge base. The ANN system checks the status of the filter and, with the help of ANN output and KBS input interface modules, provides this information to the KBS system. The KBS system decides, depending on the surface reflection information and the robot arm position, whether or not the filter should be replaced. This decision is then transmitted back through the robot interface module to the robot, which executes the necessary action.

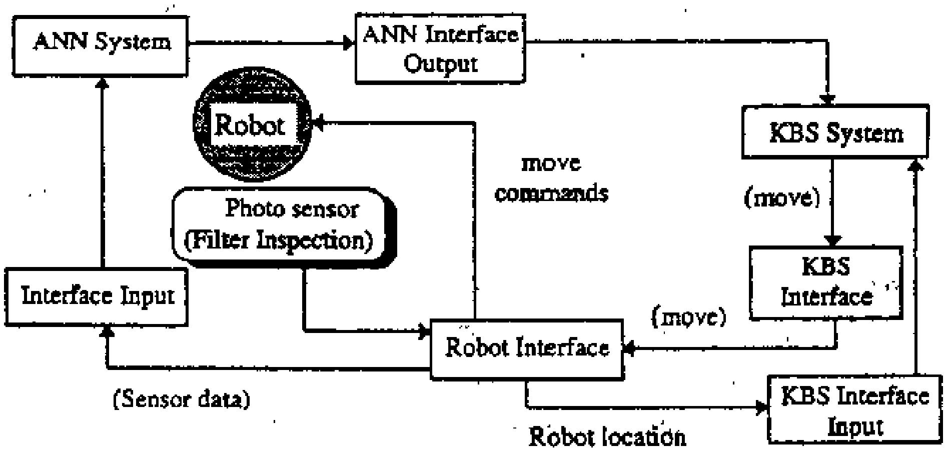

Fig.6.16.1 CRYSTAL-1 Architecture

The examples demonstrate how a quality control method can be developed and used for real-time monitoring and evaluation of product quality. The continuous monitoring of quality reduces the dependence on Taguchi and SPC methods, which are generally more costly. Robust design requires careful pre-planning of integrating quality in the design process, whereas SPC is expensive mainly because the quality control is post-production and involves waste in the form of discarding products that do not meet customer specifications. On the other hand, the real time method is less costly because it takes corrective action at the source of the problem in real time, and it is a highly flexible quality control method because it uses an ANN system. ANN systems are very flexible because they continuously learn and make quality control adjustments based on the data presented. In addition, ANN systems are not labor-intensive; once designed and trained, they can pretty much be operated in an autonomous environment. This makes them attractive in the current lean and globally competitive environment.

Artificial intelligence techniques are attractive means for performing this integration. Further developments in expert systems, fuzzy logic, and neural networks are found to be useful at the higher level in the control hierarchy for machining processes. The multi-variation environment of a manufacturing process generally does not produce a good analytical model of the process. However, as a by-product of the automation strategy in manufacturing, potentially useful raw data from the plant floor become available. By careful collection of the data and computer modeling, it is possible to use the knowledge base and visual simulation environment to integrate completely the design, control and inspection, and planning activities.

There have been efforts to implement neuro-computing-based sensory systems for real-time manufacturing. Analytical and neural network approaches are employed in parallel to model for real-time system monitoring and data acquisition. Some studies have demonstrated that neural network-based methodology not only is capable of predicting the errors in workplace but also is able to deliver a fast reference for on-line compensation of errors. Thus, further research and development work might continue on the implementation of artificial neural networks and knowledge-based systems dedicated to real-time manufacturing and inspection systems. In such a system, the geometry of the part from the design stage in a CAD format, data transferring, drafting, and the machining aspect in a machining center are included in the system under a common database. The new generation of integrated supervisory systems with multiple process control capability and with a common database from the CAD drawing are becoming available. Global competition will ensure that keeping costs low while manufacturing for quality remains a challenge. Mechatronic techniques currently being developed can be viewed as a key component of the next generation of quality control, and the move toward an integrated system is the trend in modern manufacturing.

Word and Phrases

1. fuzzy logic	模糊逻辑
2. neural networks	神经网络
3. bottleneck	瓶颈
4. hierarchy	等级结构的，分级的
5. retrieval	检索
6. meticulous	小心翼翼的
7. scrutinize	细察，详细审查
8. relevancy	关联，适当，中肯，贴切
9. consistency	相容性
10. knowledge acquisition	知识采集
11. cognitive	有认识能力的
12. pattern recognition	模式识别
13. inference	推理，推断，推论

17 Processing of Metals: Hot Working

Strand Casting

A second procedure of steel processing that bypasses ingot teeming, stripping, soaking, and rolling in roughing mills is called strand casting. It is also called continous casting, because the molten metal is continuously supplied to tundish or molten metal reservoir where it is fed through a water-cooled copper mold from which it emerges as a continuous strand of steel in a desired cross section as slabs or billets. Sprays of water under high pressure cool and harden the metal still further. The strand of metal is cut into suitable lengths by a traveling torch as the steel moves along on rolls toward the mill stand. In some strand casters, the descending column of metal is cut to the desired length while it is still in the vertical position, then the cut length falls forward onto the rolls and is carried away. At this time the metal is at a rolling or forging heat, just under the temperature of solidification. Both ingot and strand casting procedures are primarily designed for high-volume production. The continuous strand casting unit at Bethlehem's Burns Harbor, Indiana, plant can convert 300 tons of molten steel to solid slabs in about 45 minutes.

During the strand casting process the steel strand cools from the surface toward the center, forming large, columnar, dendritic grains (Fig.6.17.1). These large grains are characterized by low strength and high elongation, which in most cases is considered undesirable. In addition, internal voids can be created due to the shrinkage of the material. The shrinkage voids result in reduced cross sectional area and even more importantly they act as stress risers, which significantly reduce the strength of the structure. These undesirable grains and internal shrinkage voids can be removed or altered by the process of hot working: rolling, drawing, extruding, or forging. Whether the slabs or billets are made by casting ingots or by the continuous-strand casting process, the subsequent rolling processes in mill stands remain the same.

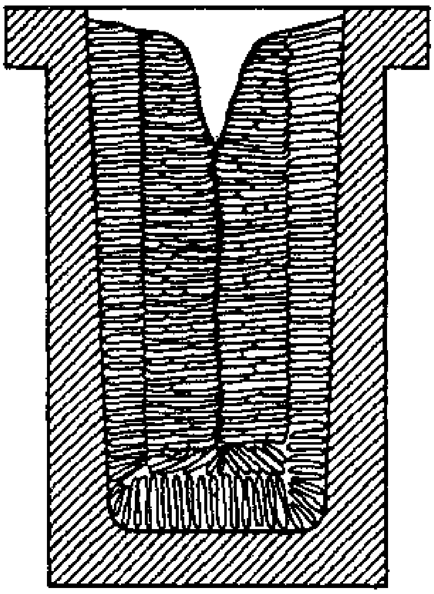

Fig.6.17.1 Large Dendritic Crystals from in Solidifying Steel, Which Must Be Reformed into Smaller Uniform Grains by the Rolling Process

Recrystallization

Steel ingot, with its typically coarse columnar grain structure, is quite unsatisfactory for applications where high strength is required. A part made directly from steel ingot can easily fail under impact load. The columnar grains in a cast ingot must be recrystallized to give steel the required strength. This is done by a hot working process, such as forging or rolling (Fig.6.17.2).

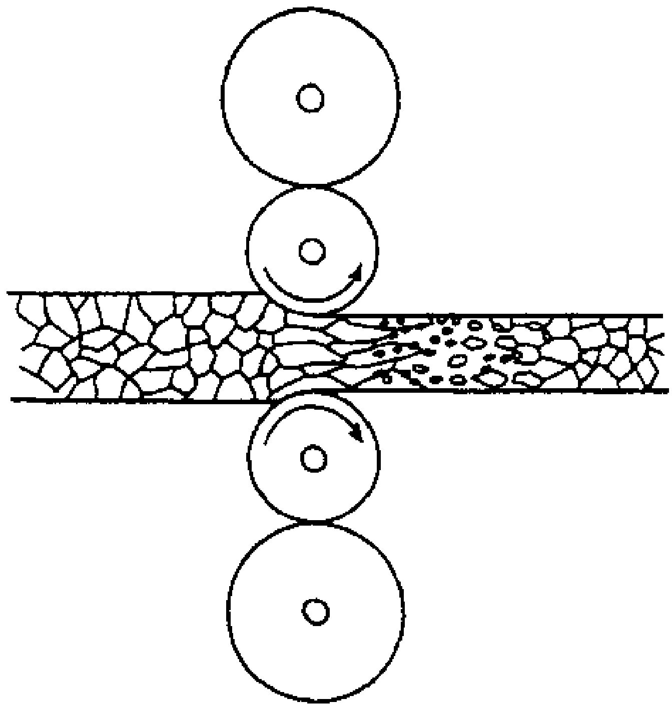

Fig.6.17.2 Recrystallization in Hot Rolling
(Neely, Metallurgy, 2d ed. © 1984 John Wiley & Sons, Inc.)

Factors that influence the grain size resulting from hot deformation are: (1) initial grain size, (2) amount of deformation, (3) finishing temperature, and (4) rate of cooling.

During hot or cold working process, grains are deformed and their internal energy is increased. Heating worked metal to an appropriate temperature will cause recrystallization of the grains. During recrystallization numerous nucleii are formed within the larger deformed grains. Keeping the structure at high temperature will cause the nucleii to grow, causing large grains to be transformed into smaller grains. In order to initiate this process it is required that at least minimum critical work be imparted on the material. The rate at which transformation occurs depends on the temperature to which the part is being heated. The amount of transformed grains and the size of new grains is a function of the time and temperature. If the structure is left for an extended period of time at high temperature, the recrystallization process will be followed by a grain growth stage at which smaller grains will continue to grow and eventually start merging into larger grains. The process of recrystallization and grain growth can occur simultaneously with hot working operation, and sometimes it is intentionally performed, as an intermediate annealing process. This allows the material to be worked to a great degree without fracturing.

The forming processes result in a condition called anisotropy, i.e., metal has nonuniform mechanical properties (e.g., strength, elongation) in different directions. This is due to the grain deformation and their longitudinal orientation. As a result, the material is more ductile, i.e., can be deformed without cracking or splitting, to greater extent along one direction than the other (Fig.6.17.3). For example, the metal can be bent to a smaller radius in the direction of rolling than it can at 90 degrees from direction of rolling. The anisotropy of cold or hot formed metals is very important in the welding and cold-forming processes.

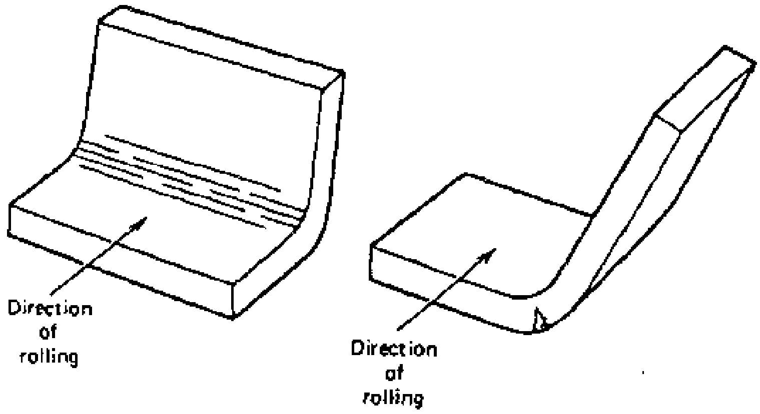

Fig.6.17.3 This Illustrates the Fibrous Quality of Rolled Steel, Called Anisotropy. Since the Fibers Are in the Direction of Rolling, the Metal is Stronger Along One Axis than in the Other
(Neely, Metallurgy, 2d ed., © 1984 John Wiley & Sons, Inc.)

Forging Processes

In ancient times, copper and other nonferrous metals, which are sufficiently soft and ductile, were shaped while cold by hammering. Iron and steel, which are very strong but not ductile enough to be hammered into a shape while cold unless the piece is very small or thin, were heated before forming. Heating metals to forging temperatures greatly increases their plasticity and workability. Therefore, hot forging was and still is a useful method of forming steel articles, both large and small.

In ancient Egypt, Greece, Persia, India, China, and Japan forging was used to produce armor, swords, and agricultural tools. In the thirteenth century, the tilt hammer came into use in which water power was used to raise or tilt a lever arm to which a weight was attached. When it fell , a heavy blow was delivered to the hot iron. In the mid-seventeenth century at the Saugus Iron Works in Massachusetts, a 500 pound weight on the end of a wooden beam was used as a forging hammer in which a cogged wheel driven by a waterwheel periodically raised and dropped the weight onto an anvil. Thus it was possible to make large forging such as heavy ship's anchors. In 1793, Henry Cort of England built a rolling mill that had grooved rolls, making shaped bars of uniform cross section possible.

Forging gives metal good static, fatigue, and impact strength. This is why most good tools are forged and critical parts such as automobile wheel spindles and axles are made as forgings. Forged parts are often machined to provide bearing surfaces, splines, key seats, and so forth, but the essential strength of the forging remains. When parts are made by machining from the solid material, the grain flow is always in the most advantageous direction and does not flow around shoulders and corners the way forgings do (Fig.6.17.4). Thus, machined parts are not as strong or resistant to failure as forgings.

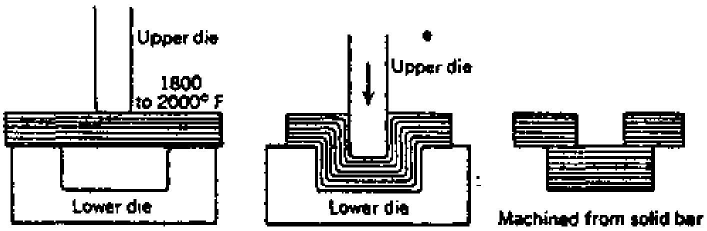

Fig.6.17.4 Grain Flow in a Solid Bar as It Is Being Forged, Compared to a Machined Solid Bar
(White, Neely, Kibbe, Meyer, Machine Tools and Machining Practices, Vol. 1, © 1997 John Wiley 7 Sons, Inc.)

Forging Machines

Today, large forgings are produced in massive hydraulic presses. Smaller articles are forged by a variety of methods and machines. **Open-die drop forging,** impression die drop forging, press forging, **swaging,** and **upset forging** are the most commonly used types of forging operations in manufacturing. When choosing a particular forging operation, several things must be considered: force and energy required, size of the forging, repeatability, speed and workability, and metallurgical structure. In addition, the amount of time hot metal is in contact with the die is important to die life and is also a consideration when choosing a forging machine for a particular forging operation.

Drop Hammer The drop hammer (Fig.6.17.5) is a development based on the old tilt

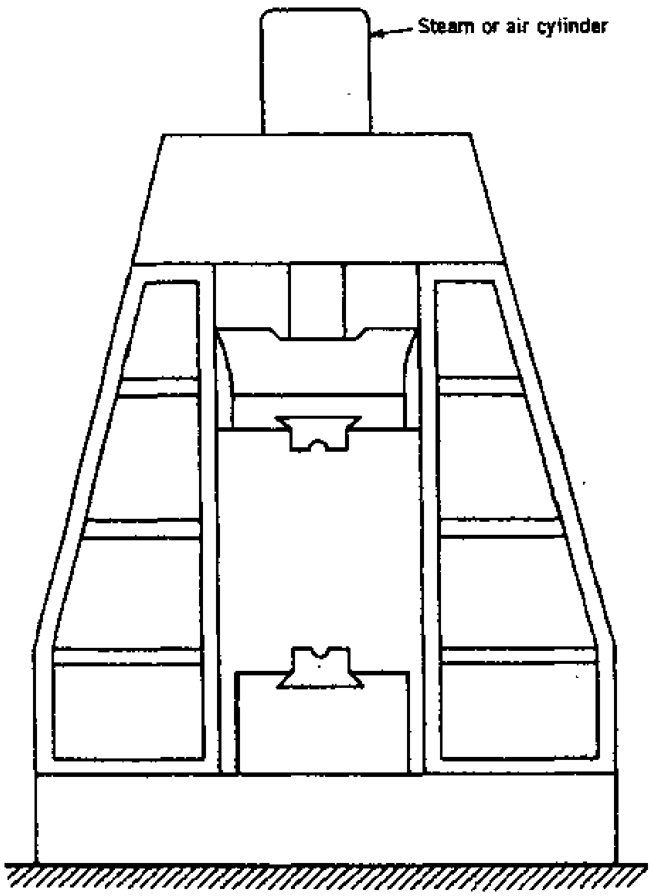

Fig.6.17.5 Drop Forging Hammer. Steam or Air Pressure Is Used to Raise the Hammer and Force It Down on the Heated Metal

hammer. Today, drop hammers are usually steam or air assisted to increase the force of the hammer blow and to raise the weight after each blow. Large articles such as machinery shafts that are to be finished by machining are usually open-die forged, using repeated blows while turning and moving the hot metal with tongs or a manipulator.

During this process the metal is squeezed or hammered to increase its length and decrease its cross section. or it is upset, i.e., pressed to increase its diameter and shorten the length. Drop hammers perform repetitive blows to bring the workpiece to size, whereas mechanical and hydraulic presses can often make a forging in one or two strokes. However, both types of forging machines are adaptable to automated forging processes.

In open-die forging, drop hammer operators require a skill in giving the hammer just the right amount of force. When upper and lower dies are used, it is called impression die forging. This method increases production rates and ensures repeatability. Often two or more progressive dies are used, each contributing to the final shape.

Mechanical Presses These machines make use of a heavy flywheel that stores energy for the forging stroke. Mechanical presses of this type have an eccentric shaft or crank that moves the ram down and back to the starting position when a clutch is actuated. The greatest pressure is exerted at the bottom of the stroke. Inherent problem with these mechanisms is the possibility of jamming the ram near the bottom dead center, but most mechanical presses have a stall release that frees the stuck ram and upper die when this happens. Compared to drop forging machines, these machines operate more quietly, allow more accurate control, and produce higher force and energy. For this reason, the mechanical press is often chosen when a part must be made to closer tolerances. During the past decades, there has been a gradual trend toward the mechanical press forging. Fewer blows are required per forging and less operator skill is needed with these machines. Mechanical presses squeeze rather than impact the hot metal with a shorter forging-to-die contact time, thus extending die life.

A modern version of an old principle is a high-energy type of mechanical forging press that utilizes a vertical screw instead of a crank or eccentric shaft to transfer the flywheel energy to the ram. This arrangement provides uniform force throughout the stroke, unlike crank presses in which the major tonnage is confined to the end of the stroke. Like the drop hammer, the screw press does not have a bottom dead center. A continuously rotating flywheel imparts motion to a screw when a clutch is engaged. It appears that the screw press combines two of the best features of the drop hammer and the crank press, high impact and a squeezing action. Even with hard blow forging, the press frame and mechanical copmonents are not subject to high stresses and the die is in contact with the hot metal a very short time. Often only one or two blows are needed to complete a single forging. High-energy forging presses provide high flexibility since they can be used for either open or closed die forging operations.

Hydraulic Presses Hydraulic presses are the slowest types, but their advantage is that they can exert very high forces required for large forgings. Instead of mechanical linkages and cranks., the press ram is powered with one or more large hydraulic cylinders. Oil is forced at high pressure into the cylinders and the ram moves at a constant rate. Smaller cylinders return the ram to its upper position. Large hydraulic presses can exert thousands of tons of pressure, making them ideal for some of the largest forgings.

Word and Phrases

1. bloom	大钢坯，钢锭
2. strand casting	连续铸造
3. ingot	浇铸，钢锭，坯料
4. teeming	铸，铸造
5. stripping	脱模
6. soaking	保温，长时间热处理，均热处理
7. tundish	浇口盘，中间包，漏斗
8. slabs	初轧的板坯，扁钢锭
9. billet	钢坯，段钢，方坯
10. dendritic	树枝状的
11. recrystallization	再结晶
12. anisotropy	各向异性，非均质
13. cog	齿
14. anchor	锚
15. anvil	砧
16. spline	花键，齿条，方拴
17. ram	撞锤

18 Powder Metallurgy

Powder metallurgy (P/M) is one of the four major methods of shaping metals (machining, hot and cold plastic deformation, casting, and P/M).The P/M process is essentially the compression of finely divided metal powder into a briquette of the desired shape that is then heated but not melted to form a metallurgical bond between the particles.

Although the P/M manufacturing method dates back to the nineteenth century, it was not until past decades that this field gained wide acceptance and use. Technological advances in P/M have been growing very rapidly also in the past decades. Products that are difficult if not impossible to produce by other means are being manufactured with P/M at high production rates at very competitive cost.

Parts manufactured by the P/M process have found a widespread use in a variety of applications. Over half of the P/M products manufactured are used in the transportation industry (automobiles and trucks). Parts used in farm and garden equipment and household appliances are also made by P/M. Many new applications will be found in the future for this unique method of forming metals.

How P/M Parts are Made

The basic traditional process of making P/M parts consists of two basic steps—compacting (molding) and sintering (Fig.6.18.1). In addition to these two basic manufacturing steps involvéd in the P/M process, secondary operations are commonly performed to impart final desired properties to the P/M product (e.g., coining, sizing, repressing). Fig.6.18.1 shows the sequence of operations for powder metallurgy. The depth of die cavity and the length of plunger stroke is determined according to the density required. (a) A measured amount of metal powder is placed in the die cavity. (b) Pressure is applied. (c) The briquette is ejected from the die cavity. (d) The parts are sintered at a specified temperature for a given length of time. The parts are now ready for use. (e) if more precision is needed, they can be sized in a coining die.

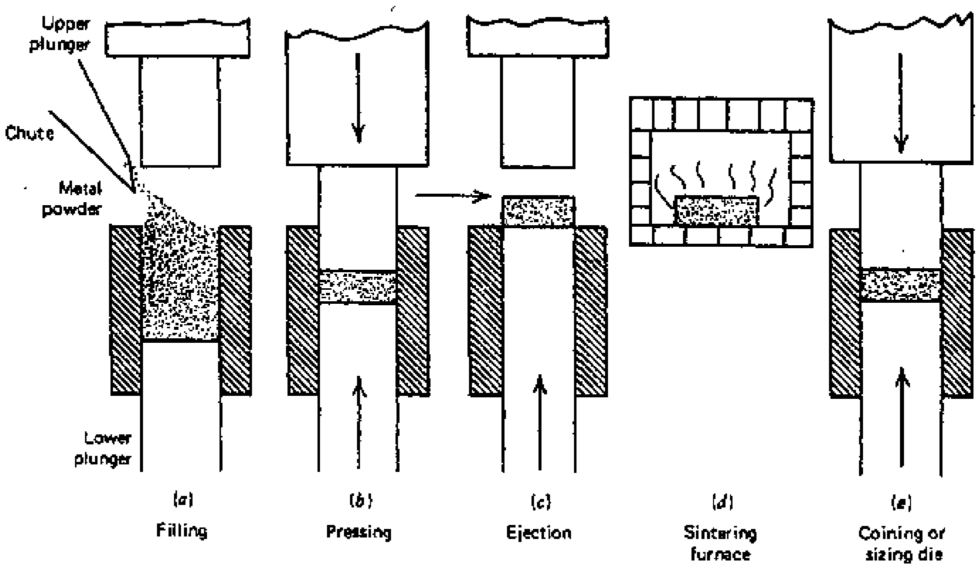

Fig.6.18.1 Sequence of Operations for Powder Metallurgy
(Neely, Metallurgy, 2d ed., © 1984 John Wiley & Sons, Inc.)

In the first step **(compacting)**, loose powder (or a blend of different powders) is placed in a die and it is then compacted between punches. This operation is commonly performed at room temperature. The compacted part (Fig.6.18.2), called a **briquette** or green compact, is now a solid shape. However, green compact can easily be broken or chipped by mishandling and requires careful handling. In the second step **(sintering)** the briquette is heated in an appropriate atmosphere to a temperature high enough to cause the powder particles to bond together by a solid state diffusion (Fig.6.18.3) and to homogenize any alloy constituents in the powder. Melting does not normally occur. The P/M part is now ready for use unless other finishing operations are needed.

Secondary operations may include sizing, machining, heat treating, tumble finishing, plating. or impregnating with oil, plastics, or liquids. Secondary operations can significantly increase the cost of the finished part. Therefore, designers should limit the use of secondary operations and, if possible, complete the product in the first two basic steps. However, the sintering process tends to deform and shrink the shaped briquette slightly. Thus, some parts (e.g., precision gears) must have a finishing operation in which they obtain desired tolerances.

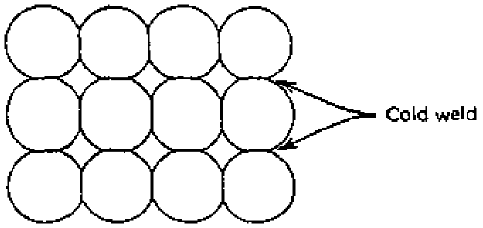

Fig.6.18.2 The Compressed Particles in the Briquette are Cold Welded Together at This Stage with Very Weak Bonding
(Neely, Metallurgy, 2d ed., © 1984 John Wiley & Sons, Inc.)

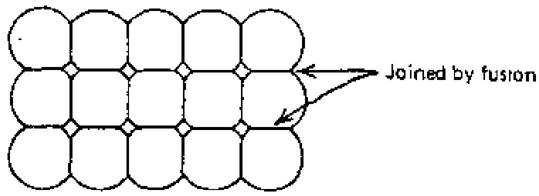

Fig.6.18.3 After Sintering, the Particles in the Briquette Become Fused Together
(Neely, Metallurgy, 2d ed., © 1984 John Wiley & Sons, Inc.)

Metal Powders

A number of different metals and their alloys are used in P/M (e.g., iron, alloy steel, stainless steel, copper, tin, lead). The three most important methods of producing metal powders are: (1) atomization, (2) chemical methods, and (3) electrolytic processes.

Atomization is a process in which a stream of molten metal is transformed into a spray of droplets that solidify into powder. Molten metal spray can be produced in several ways. The most common method is to use a stream of high velocity gas to atomize the molten metal. This method has several variations. In one method, the gas stream is expanded through a venturi tube, which siphons the molten metal from the crucible located below the tube. The gas breaks the stream of molten metal into small droplets that then solidify as they are carried by the gas stream. In another variation, the crucible with bottom gate is located above the gas tubes. The metal flows under the influence of gravity and passes through the gas stream, which breaks the molten metal stream. The solidified metal droplets are then collected in a collection chamber. In addition to gas, water and synthetic oils can also be used in the atomization process.

Several chemical methods can be used to make metal powders, such as reduction and precipitation. Chemical reduction is process in which metal powders are formed by chemical reaction between metal oxides and reducing agents (e.g., hydrogen or carbon monoxide). Hydrogen or carbon monoxide reacts with oxygen in metal oxide, resulting in pure metal.

The electrolytic process begins in the electrolytic cell where the source of desired metal is the anode. As the anode is dissolved, the desired metal is deposited on the cathode. After this step is complete, the metal deposit is removed from the cathode and is washed and dried.

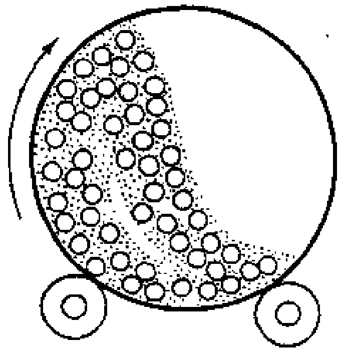

Fig.6.18.4 Action of the Ball Mill is Shown as a Continuous Grinding as the Drum Rotates
(Neely, Metallurgy, 2d ed., © 1984 John Wiley & Sons, Inc.)

In each process, the powders may be ground further to a desired fineness, usually in a ball mill (Fig.6.18.4). Metal powders are screened and larger particles are returned for further crushing or grinding. The powders are classified according to particle size and shape in addition to other considerations such as chemical composition, impurity, density, and metallurgical condition of the grains. Particle diameters range from about .002 in. to less than .0001 in. Test sieves are used to determine particle size. This method of testing has been standardized throughout the industry.

Various powders are often blended by tumbling or mixing. Lubricants (e.g., graphite) are added to improve flowability of material during feeding and pressing cycles. Deflocculants are also added to inhibit agglomeration of powders and improve flowability during feeding.

Powder Compaction

Compacting or pressing gives powder products their shape. Metal powder forming can be separated into two groups, conventional and alternative pressing and sintering techniques. The method most commonly used today is the conventional approach, which consists of the pressing operation first, followed by sintering. The alternative techniques can be classified into (1) alternative compaction methods, (2) combined compaction and sintering, and (3) alternative sintering methods.

In the conventional compacting process, the powder is pressed unidirectionally in a single- or a double-acting press. Unlike liquids, which flow in all directions under pressure, powders tend to flow mainly in the direction of the applied pressure. Die compaction can be done either hot or cold. Engineering properties such as tensile and compressive strength depend to a great extent on the density of compacted material. Hot pressing, in which the powder is pressed in the die at a high temperature, produces a density approaching that of rolled metal.

Mechanical presses are favored when the required load is not too high. Eccentric (crank) presses rarely exceed 30 tons (60 tons would be considered quite large). Toggle-type presses may reach a 500-ton force. The advantage of mechanical presses in that they are highproduction machines. Hydraulic presses can exert forces in excess of 5 000 tons. They have the advantage of a long stroke and easily adjustable stroke length. However, these machines provide low productivity compared to mechanical presses.

Compaction of powders with various presses has the advantage of speed, simplicity, economy, and reproducibility. Such compaction produces a strong, dimensionally accurate, and relatively inexpensive product. However, it does have limitations. The aspect ratio (length to diameter) must be relatively small. Parts with a large aspect ratio will have uneven densities, being denser nearest the punches. Hence, these parts many have nonuniform and uncertain properties, and should not be made by die compaction. Grooves or undercuts or parts with thin sections cannot be made by simple die compaction. Thus, not every part is a good candidate for powder metallurgy. However, some of these limitations are overcome by alternative forming techniques such as split die techniques to provide undercuts, isostatic pressing, and densification methods.

Advanced Processes

Since conventional presses can compact powder along only one axis, such presses cannot make some shapes, such as hollow hemispheres, long parts, and internal threads. However, one method allows pressure to be applied from all directions: isostatic pressing. In **cold isostatic**

pressing (CIP), the powder is loaded into molds made of rubber or other elastomeric material and subjected to high pressures at room temperature. Fig.6.18.5 shows the principle of Isostatic pressing: (a) Prepared powder is placed inside a flexible container or mold. A vacuum is drawn in the mold and it is then sealed. (b) The powder and mold are then placed in a pressure chamber into which water or oil is pumped under pressures of 15 000 psi or more. (c) The green compact is removed from the pressure chamber and the container is stripped off. Pressure is transmitted to the flexble container by water or oil. The compacted parts are removed and sintered, followed by secondary operations if needed. With **hot isostatic pressing (HIP)**, an inert gas such as argon or helium is used in a pressure chamber to provide the squeeze. This gas is reclaimed between each batch of pressings. Hot isostatic pressing provides more density and achieves a finer microstructure than the cold process. Powders are often preformed to an oversize shape prior to placing them in the isostatic chamber. Heat is applied to the perform by induction for a short time while the gas pressure compacts the perform. Temperatures may be as high as 1 600 to 2 000°F (871 to 1 093°C) with pressures in excess of 15 000 psi. Isostatic pressing is useful only for certain special applications. CIP is a comparatively show process, and HIP is ever slower. Parts made by either CIP or HIP are not limited by the shape constraints of rigid tooling.

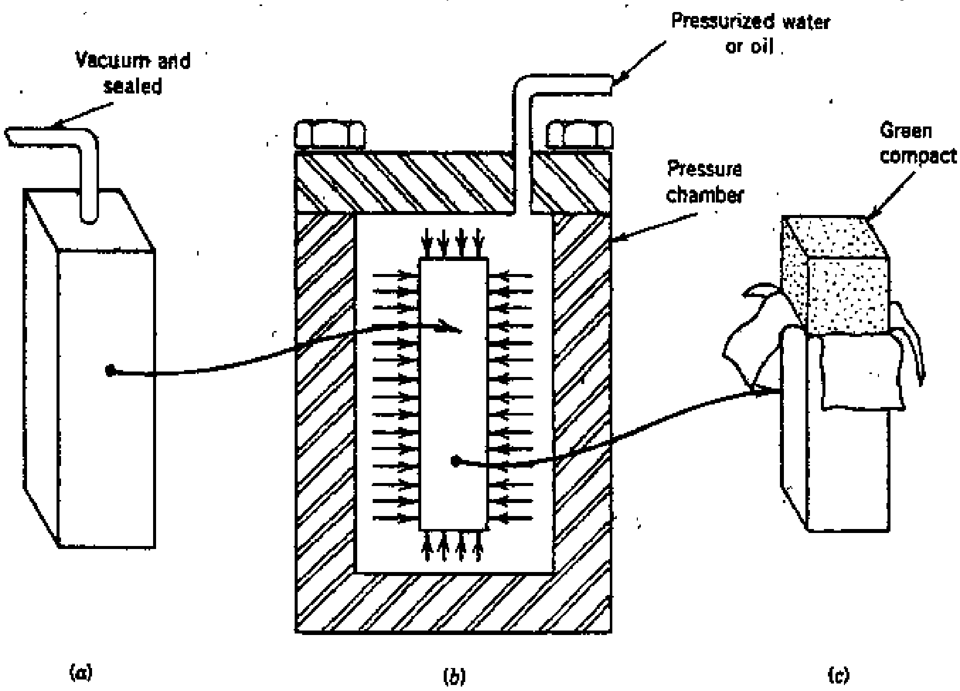

Fig.6.18.5 Isostatic Pressing

Powder Forging

Fully dense P/M parts equaling or surpassing mechanical properties of wrought products are being produced in commercial quantities by powder forging (P/F). The green compact or perform is made in a conventional press and then sintered. These operations are then followed by a restrike (forge) that brings the part to the final density. Mechanical properties may sometimes exceed those of wrought metals because a more uniform composition is achieved in P/M processes. Fatigue and impact strengths are particularly high in powder forgings compared to conventional P/M parts. P/M bearing races have been shown to outlast wrought steel races by a factor of 5 to 1.

Metal Powder Injection Molding

A P/M technology that borrows a plastic injection molding process shows great promise for production of small precision parts. In fact some variations of this process can use plastic molding machinery. In order to inject powders into molds, the particle size must be much finer than that used for conventional P/M processes. This "dust" is combined with a thermoplastic binder. The molding step is performed at injecting pressures of about 900 psi and about 325°F (163°C). The result is a green compact that is sintered in the conventional fashion after the thermoplastic binder has been removed in an oven at about 400°F (204°C). Thin walls, high densities, unsymmetrical shapes, and accurate dimensions are possible with this method. Compared to die pressing, injection molding is not a high-production method.

Metal Powder-to-Strip Technology

Direct rolling of metal strip from a powder slurry (powder-to-strip process) is a process in which thin strip is directly produced without numberous hot or cold rolling operations. In this process, an appropriate powder mix is blended with water and a cellulose binder to form a fine slurry. The slurry is deposited on a moving band as a continuous film (Fig.6.18.6). After drying, the moving strip is compacted between rolls and then sintered, first to remove the binder and then to bind the particles. It is rolled a second time and resintered to remove porosity. As in all of these advanced P/M processes, metals or alloys not possible to form in any other way can be produced with powdered metals. Bimetal alloys can be produced in a strip, and high-strength titanium strip is being produced for the aircraft industry.

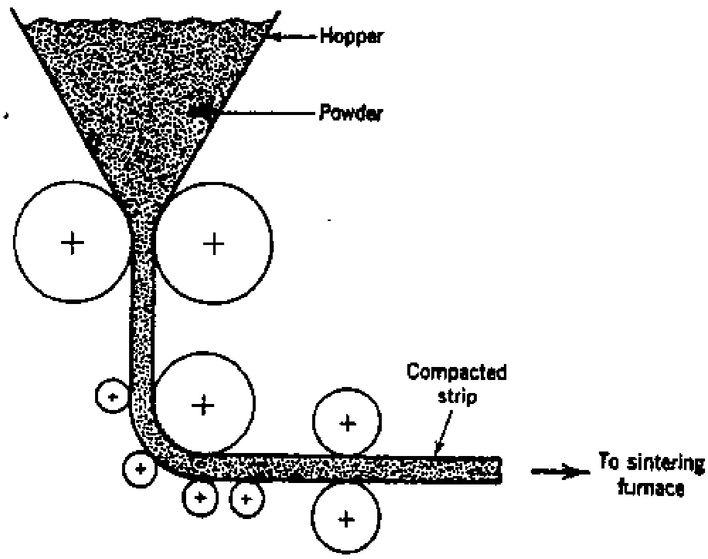

Fig.6.18.6 Powder Rolling Can Produce a Compacted Strip of Difficult-to-Work, Refractory, or Reactive Metals

Powder Extrusion

Metal powders can be hot extruded with or without presintering. Metal powders are placed inside a can that is then evacuated sealed. The unit is then heated and extruded. Metal billets and tubing from powder are made by this process.

Word and Phrases

1. powder metallurgy	粉末冶金
2. briquette	坯饼
3. sintering	烧结
4. homogenize	均质化，使均匀
5. tumble	磨光，抛光，在滚筒里转动
6. impregnating	注入
7. atomization	雾化
8. venturi tube	文丘利管
9. crucible	坩锅，严酷的考验
10. reduction	还原
11. precipitation	沉淀
12. reducing agent	还原剂
13. electrolytic	电解
14. anode	阳极，正极
15. cathode	阴极
16. ball mill	球磨机
17. screen	筛，滤网
18. sieve	筛，滤网，过滤
19. deflocculants	反絮凝剂，散凝剂，胶体稳定剂
20. inhabit	居住于，存在于，占据，栖息
21. agglomeration	结块，凝聚，块
22. sintering	烧结
23. reproducibility	再现（重复性），再生性
24. densification	压实，使密实
25. eccentric	偏心的
26. thread	线，细丝，线索，思路，螺纹
27. slurry	泥浆，浆
28. binder	粘结剂
29. cellulose	纤维索
30. billet	坯料

19 Machinability of Work Materials

The term **machinability** is a widely used term in both research and industry. **In Metals**

Handbook, American Society for Metals, (1985), it is defined as "the relative ease for a material to be machined." To the people engaged in a particular set of operations, it has a clear meaning, such as the number of components produced per hour or per tool, or the relative ease in achieving surface or dimensional specifications. However, the criteria used for various tests can be different. A material with good machinability by one criterion may have poor machinability by another criterion. Unlike most material properties, there is no generally accepted criterion used for its measurement. The term tends to reflect the interests of the user. The most commonly used criteria in practice are as follows:

1. **Tool life**: The amount of material removed by a tool under standard conditions before the tool performance becomes unacceptable or the tool is worn by a standard amount. The main criterion for the ISO standard is basically tool life.

2. **Limiting material-removal rate**: This is often the criterion for ultrahard work materials.

3. **Surface finish achieved**: It is usually one of the dominant factors in machining of ductile materials.

4. **Chip control**: In machining of some ductile materials, this can be the most significant factor in certain operations.

5. **Force and power consumption**: The force can be the limiting factor when the setup lacks rigidity. When cutting "easy-to-machine" types of materials at a very high speed and high volume, the available power is often the limiting factor.

Machinability Tests

The maachinability index in the **Metals Handbook** (American Society for Metals, 1985) and many other industry reports are the results of machinability tests. The long-term absolute machinability standard became available in 1977 (ISO 3685-1977). Until then, the test conditions and criteria were determined by individual researchers. This resulted in a vast amount of machinability data that were impossible to correlate for a cohesive body of data. The ISO standard test indicates the relative merit (as of tool life) of two or more work-tool combinations for a range of cutting conditions. The test material should be mounted between centers or between the chuck and center. It should have a length-to-diameter ratio of less than 10 to 1. The tool material should be HSS, P30, P10, K20, or K10. Four sets of machining conditions are recommended. These conditions are intended to cover anything from light to heavy roughing operations. At least four speeds should be used that ideally result in tool life of 5, 10, 20, or 40 min. The tool failure criteria for HSS are

1. catastrophic tool failure, i.e., breakage

2. 0.3 mm average flank-wear land width if flank wear is even

3. 0.6 mm maximum flank wear if flank wear is irregular, scratched, chipped, or badly grooved.

For carbide grades, the first criterion is crater depth of $(0.06+0.3f)$ mm, where f is the feed in mm/rev. The criteria for ceramic tools are the same as with HSS. Of the failure modes, flank wear is by far the most commonly used, except in high-speed machining of cast iron, where the most significant failure mode is cratering.

In addition to long machinability tests, there are many types of short-term tests often conducted for a particular tool material combination. Czaplicki (1962) proposed a relationship between cutting speed, which results in a 60 min tool life, and chemical content as

$$V_{60} = 161.5 - 141.4\%\mathrm{C} - 42.4\%\mathrm{Si} - 39.2\%\mathrm{Mn} - 179.4\%\mathrm{P} + 121.4\%\mathrm{S} \quad (\mathrm{m/min}) \tag{6.19—2}$$

Boulger, Moorhead, and Govery (1951) determined a relationship of the relative machinability index (MI; base 100) as

$$\mathrm{MI} = 146 - 400\%\mathrm{C} - 1500\%\mathrm{Si} + 200\%\mathrm{S} \tag{6.19—3}$$

Henkin and Datsko (1963) developed a relation using dimensional-analysis techniques based on the material's physical properties:

$$V_{60} \propto \frac{B}{LH_B}\sqrt{1-\frac{A_r}{100}} \tag{6.19—4}$$

where B is the thermal conductivity, L is a characteristic length, H_B is Brinell hardness, and A_r is the percentage reduction in tensile test. Similar work by Janitzky (1944) yielded the expression

$$V_{60} \propto \frac{D}{H_B A_r} \tag{6.19—5}$$

where D is a constant dependent on the size of cut. However, the application of these relationships is restricted to materials of the same type and thermal history. A more common form of machinability empirical relation was developed by Gilbert and cited by Olson (1985):

$$V = \frac{ABCDEFGPQ^{0.25}}{H^{1.72}T^{n}R^{0.16}f^{58}d^{2}} \tag{6.19—6}$$

The parameter definitions and typical values are summarized in Table 6.19.1 Eq. (6.19—6) is a very powerful relation, especially when adapted to a given system with known products.

In addition to these nonmachining tests, actual machining tests are also conducted in practice. There are constant-pressure tests in which a constant feed force is maintained. Accelerated tests in which a higher-than-normal speed is used to shorten test time and so on.

Most machinability assessments are for single-point turning operations. Constant pressure and other types of tests have also been carried out for various processes, including drilling operations. Tool failure results from either catastrophic failure or some measure of drill-tip wear. There is a high poosibility, particularly in small-diameter drills, of drill breakage. Drill length has a strong impact on drill breakage. Because there are a variety of milling operations. The chip equivalent concept (Colding, 1961) is often used to relate machinability to milling operations. However, as already indicated, machinability is highly dependent on process and an cutting conditions. It is difficult to relate results from one process to another uuless the processes involved are practically the same.

The machinability of several basic types of work materials for all criteria will be discussed in

Table 6.19.1 Parameters and Typical Values for Equation

Para.	Factor	Typical	Values
V	Cutting speed	Selected speed in ft/min	
A	Tool material	HSS: 180 000 Ceramics: 1 500 000	Carbides: 300 000
B	Coolant	Dry: 1.0 Soluble oils: 1.25	Cutting oils: 1.15
C	Material	Carbon steel: 0.8 Alloy steels: 1.1 Free-machining brass: 2.0 Magnesium alloys: 0.9	Free-machining steel 1.05 Cast irons: 0.75 Aluminum alloys: 0.85
D	Micro structure	Austenitic: 0.7 Coarse spher: 1.4	Most steel: 1.0
E	Surface	Sand cast: 0.7 Heat treatment: 0.8—0.95	Sand cast, blast: 0.75 Clean surface: 1.0
F	Tool type	Single-point turning: 1.0 Drill, form Tools: 0.7	Boring, milling: 1.0 Reamers: 0.7
G	Tool profile	Sharp, 0° entering; 1.0 High entering: 1.5	High radius: 1.5
P	Tool material	HSS: 1.0 Ceramics: 8.0	Carbides: 5.0
Q	Flank wear	About 0.3 mm	Depends on tool material
H	Hardness BHN		
R	Number of points	Single point: 1.0	Equal number for multiples
T	Tool life	A few minutes to a few hundred minutes	
n	Taylor expansion	HSS: 0.125 Ceramics: 0.68	Carbides: 0.25
f	Feed rate	inch/rev	
d	Depth of cut	inch	

following sections. The influence of some physical and mechanical properties of materials are as follows:

1. Material with high yield strength and work-hardening ability requires more power input, exerts higher compression stress, and, in general, generates higher temperature on the tool surface.

2. In addition to high-energy input, machining ductile material also results in poor surface finish.

3. Material with high-fracture toughness tends to generate long chips that are hard to break.

4. Material with high work-hardening capability requires more energy on the share plane. The

tool may constantly cut against the work-hardened surface left by a previous cut.

5. Good thermal conductivity can reduce tool-surface temperature.

6. Material that tends to react chemically with the tool material at high temperatures can deteriorate tools.

Steels

Steels with very low carbon (commercially pure iron and steels with carbon content up to 0.15%C) have poor machinability by all criteria, because of their high ductility. A very low shear angle and large contact area on the rake face have been observed. The chips tend to adhere to the tool surface and may become hard to break, which often causes trouble. The high strain generates more heat, which requires more energy input and results in a higher temperature on the tool surface. Surface finish is also difficult to control because of rubbing.

The added alloys to low-carbon steel improve machinability in certain instances, depending on the additive elements and quantity. The increased carbon content decreases the ductility of steel, so that the energy consumption and required force are reduced. A more significant improvement can be achieved in surface finish. Although the heat generated becomes lower, the compression stress on the rake does not change much, because the contact area is also reduced. The highest tool-temperature point on the rake face moves closer to the tool edge. The added carbon content also improves the work material strength and hardness. For steels with a carbon contert of greater than 0.30%, the power input and tool-surface temperature increases for steel of lesser carbon content for the same machining conditions. The surface finish improves as the carbon content goes up to 0.35%, but if the carbon content goes above 0.35%, the quality of the surface finish begins to go down again.

Other added alloys to low-alloy steels (manganese, chromium, and so on) increase the strength and hardness of steel. In general, the tool wear rate increases with alloy content, but other machining characteristics remain unchanged. Machinability is also strongly affected by heat treatment. As a general rule, the material should be treated to the minimum hardness requirement.

One important problem in cutting steel is tool-life variations. When cutting steel with steel-grade carbides at high speeds, major variation in tool life is attributed to the nonmetallic inclusions that attach to the rake face and form an unstable glassy barrier. Although the phenomenon is not as pronounced in WC-Co or HSS tools, these tool materials do not cut steel effectively. This gives rise to free-machining steels.

Free-Machining Steels

Free-machining steels are typically alloys of steel and sulfur, lead, or other suitable alloying agent. The addition of 0.1 to 0.3% S or 0.1 to 0.35% Pb or a small amount of Bi (bismuth), Se(selenium), Te (tellurium), and P (phosphorus) can greatly reduce force, power input, tool-surface temperature, and tool wear rate. Surface finish and chip control can also be improved. Most importantly, the tool performance is more consistent, because of less sensitivity to detailed heat history. The difference in tool life may be very large for the material with standard specifications but quite different for nonfreemachining steels. However, the mechanical properties of free-machining steels are not as good as regular steel, and they cost more. A compromise can be made among material cost, operation cost, and product performance. The manganese content of these steels must be high enough to ensure that all the sulfur present is in the form of MnS.

Stainless Steels

There are three major types of stainless steels with respect to microtructure: austenitic, ferritic, and martensitic. These materials have higher tensile strength and greater spread between yield and fracture strength than low-alloy steels. The energy input and the temperature on the tool surface are also higher than ordinary steels. Due to their high alloy content, they contain abrasive carbide phases. Both of these characteristics produce faster tool wear.

In addition to the preceding properties, austenitic stainless steels also possess strong work-hardening capability and low thermal conductivity. These severely reduce the machinability measures for all criteria. Not only will higher temperature be encountered, but the chips tend to bond to the tool surface and are hard to break. Specifically, problems arise when the tool edge is cutting into a work-hardened surface, left by a previously machined surface. Because of this, a sharp tool, a reasonable feed rate, and a reasonable depth of cut are recommended to avoid excessive wear caused by continuously cutting a work-hardened surface. In order to improve the generally low machinability of austenitic stainless steels, sulfur, selenium, and tellurium are added to reduce ductility. These are called free-machining stainless steels. They are more expensive and the additives reduce the corrosion resistance slightly.

Cast Irons

Flake graphite and spheroidal graphite (SG) cast irons have good machinability with respect to all criteria. The graphite flakes and spheres initiate fracture on the shear plane at very frequent intervals. The process experiences a low tool wear rate, high MRR, low force, and low power consumption. Good surface finish can be easily achieved. The chips fall in very short segments for flake graphite and easy-to-break longer segments for SG. Tool life decreases mainly with hardness. In recent years there have been more applications for using ceramic tools at a very high speed. Due to the high production rate and high surface finish achieved, additional grinding operation can be eliminated. Another ceramic tool application on cast irons is for chilled irons with hardness of 430 HV at speeds up to 50 m/min. CBN can also be used for cast-iron hardness range from 55-58 Rc (600-650 HV) at speeds up to 80 m/min. A higher clearance angle is recommended for SG cast iron to eliminate extremely ductile flow-zone material from clinging to the flank.

Nickel-Based Alloys

Nickel-based alloys are among the most difficult to machine materials, because of their very strong work-hardening capability and hard abrasive-carbide phases. At much lower speeds than cutting steels, the tool temperature can reach the point at which plastic deformation and diffusion can take place. Because of this work hardening, the feed rate is very important. When it is too low, the tool is continuously cutting through workhardened material generated by previous cut. Conversely, at high feed rates, even if the theoretical surface finish is acceptable, the stresses on the tool may be too high and can cause catastrophic tool failure. As a compromise between two extremes, a feed rate of 0.18 to 0.25 mm is recommended. In order to eliminate rubbing effects, a positive rake should be used. WC-Co grades of carbide can be used at speeds up to 60 m/min. Steelcutting grade tools fail more rapidly, and even coatings have shown little advantage. However, in recent years, ceramics, CBN, and Sialon tools have been found to be more effective in cutting nickel-based, high-temperature alloys. The surface speed can be as high as 250 m/min.

Aluminum Alloys

Pure aluminum is very ductile. The chip tends to adhere to the tool surface and it can be very hard to break the stringy chip. It is difficult to achieve a good surface finish, especially at low cutting speeds. However, aluminum alloys have good machinability in almost all criteria. Cast-aluminum alloys with silicon as the main alloying element are the most important casting group. These alloys contain abrasive silicon particles, which can reduce tool life, and therefore are more economically machined at lower cutting speeds and feeds than other types of aluminum alloys. The addition of copper can improve not only material strength, but tool life as well. Due to reduced ductility the chips are easier to control. The aluminum-magnesium and aluminum-zinc-magnesium alloys all have good machinability. The cutting speed can go up to 300 m/min for HSS tools and 2 000 m/min for WC-Co carbides. The machinability of wrought aluminum can be improved by addition of low-melting-point insoluble metals, tin, bismuth, and lead. The flank wear is most pronounced in cutting aluminum alloys and is usually the measure of tool failure.

Copper and Its Alloys

Pure copper is similar to other pure metals and has poor machinability. Unlike other pure metals, however, copper with a very low alloy content is widely used in electronic components and fittings. The cutting speed of these small-size components are usually limited by spindle speed (up to 140-220 m/min). A built-up edge does not occur in this type of application. The tool forces are very high due to the large contact area on rake face and the low shear angle. However, the surface finish and chip control can become a problem. For this reason, high-conductivity coppers are regarded as one of the most difficult materials to machine. In drilling deep holes, for example, the forces are often high enough to break the drill. The addition of lead, sulfur, and tellurium improves the machinability after cold working. For most operations, the important concern is chip control.

Word and Phrases

1. machinability　　切削性
2. cohesive　　粘着的

3. carbide	碳化物
4. turning	车削
5. boring	镗削
6. milling	铣削
7. reamer	铰孔
8. chuck	卡盘，用卡盘夹住
9. breakage	破坏，破损，破损量
10. rake face	（刀具的）前面
11. rubbing	摩擦
12. pronounced	显著的
13. austenitic	奥氏体
14. ferritic	铁素体
15. martensitic	马氏体
16. abrasive	研磨剂，研磨的
17. clinging	有粘性的，执着的

20 Introduction to Manufacturing

Basic Definitions for Manufacturing systems

Today, the terms manufacturing, manufacturing engineering, and manufacturing systems have been widely used in both industry and academia. However, the general definitions of related terminologies are still not standardized. In this section, several important terms in the area of manufacturing systems are defined.

1. **Manufacturing** is a set of correlated operations and activities, which includes product design, material selection, planning, production, inspection, management, and marketing of the products, for the manufacturing industries.

2. **Manufacturing production** is a series of processes adopted to fabricate a product, and such processes exclude the activities for designing, planning, and controlling the production.

3. **Manufacturing processes** are the lower-level manufacturing activities used to make products. There are traditional machining processes, for example, turning, milling, and grinding, and more advanced nonchipping processes, for example, electrochemical machining (ECM) and electrodescharge machining (EDM).

4. **Manufacturing engineering** involves the design, operation, and control of manufacturing processes (planning, scheduling, as wells control of the manufacturing production and batch quality). It is the heart of design, planning, and control of the manufacturing systems and requires knowledge from other disciplines, such as electrical engineering, mechanical engineering materials engineering, chemical engineering, and systems/information engineering.

5. **Manufacturing system** is an organization that comprises several interrelated manufac-

turing subsets. Its objective is to interface with outside production functions in order to optimize the total productivity performance of the system, such as production time, cost, and machine utilization. The activities of these subsets include design, planning, manufacturing, and control. These subsets are also connected with production functions outside the system, such as accounting, marketing, financing, and personnel.

Fig.6.20.1 illustrates the relationship between the subsets and functions outside of a manufacturing system. The activity in a manufacturing system initiates from the designing of a product, then proceeds with the planning of manufacturing processes, and develops control strategies for the system. After the planning and control operations are verified, the raw material can then be processed and output (product) is produced. The output of the manufacturing systems can be classified in two categories: (1) physical output, or product, and (2) manufacturing performance information that can be used as feedback to the system for adaptive adjustment of the machinery and control mechanisms.

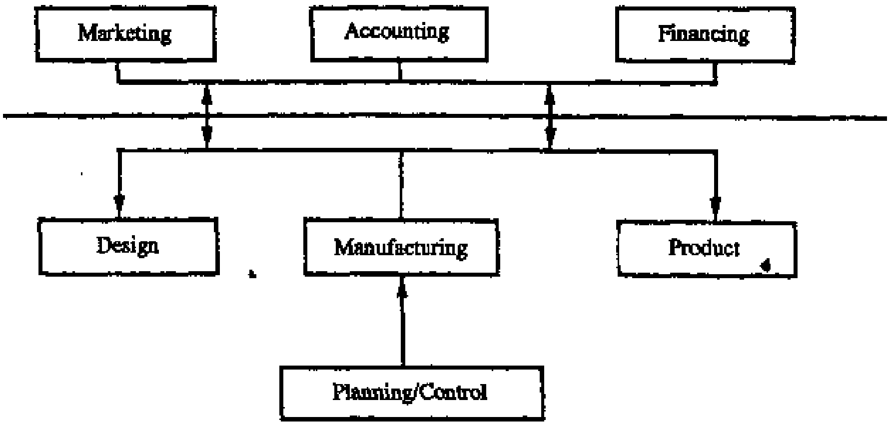

Fig.6.20.1 Manufacturing-System Diagram

Design Activities for Manufacturing Systems

Product design is the first step of the manufacturing activity that deals with the conceptualization and planning of the physical and functional characteristics of a product. An ideal design always stresses the ease of machining and assembly. In other words, the purpose of engineering design is to study how to design a product so that manufacturing cost and time can be reduced while preserving the functional requirements of a product. The major subsets (Fig.6.20.2) included in the design activities follow:

1. **Design conceptualization** and **function identification** are two vital elements of design. The designer begins by gathering all the appropriate technical information about the proposed product, for example, the materials, components, processes, and configurations that are required to satisly the need. In other words, the function requirements of a product should be identified and asserted. Suh and Rinderle (1982) suggest an axiomatic approach for manufacturing design that can be treated as a general gnideline for designers:

Axiom 1: Always maintain the independence of product functional requirements.

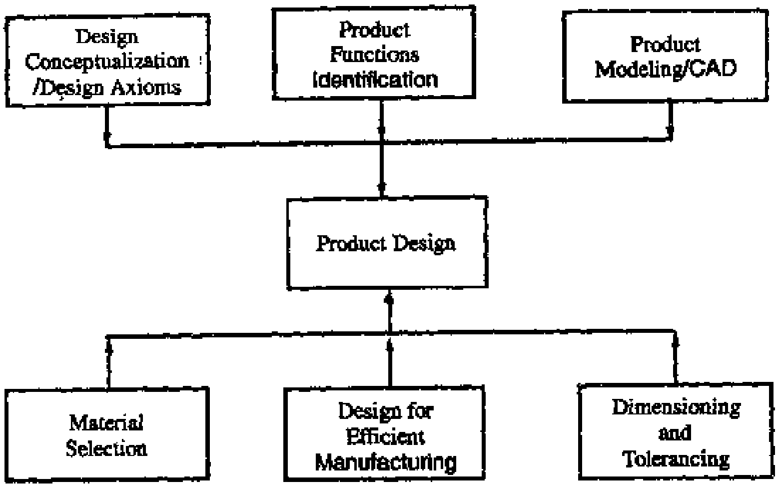

Fig.6.20.2 Design Activities of the Manufacturing System

Axiom 2: Minimize the information content of any functional requirements and constraints.

2. **Product modeling** establishes the analytical and graphical representation of a product, which can preserve and communicate the product configuration and functional requirements in an effective manner. Computer-aided design (CAD) is a popular modeling method and is detailed in Chapter 3.

3. **Material selection** is a key issue in engineering design. It involves more than selecting a proper material that has the properties (part performance) to meet the functional requirements. The material is also closely connected with the processing (part manufacturing) of the raw material into a final product. Several sources of information on material properties are available such as [Lynch (1974), American Society for Metals (1978), and Reinhart (1987)].

4. **Design for efficient manufacturing** is the most convoluted portion of design activities. As the assembly parts illustrate in Fig.6.20.3, an improvement is made by having a rounded corner or chamfer on the insert. This modification results in easing the positional requirements for the assembly process.

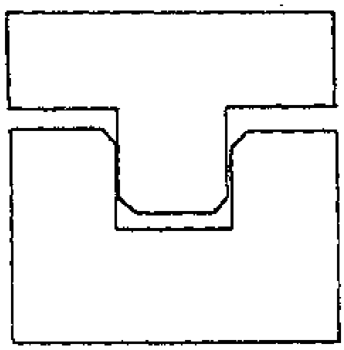

Fig.6.20.3 Assembly

5. **Dimensioning** and **tolerancing** of a product are intimately connected to the selection of machinery and a manufacturing process with proper capabilities. Tolerancing overspecification is one of the most common mistakes made by design engineers. It is a prevailing trend that engineering designers obtain a background in manufacturing processes before they dimension and specify a product. This will be discussed in detail in Chapter 2.

Planning and Control Activities for Manufacturing Systems

The performance of a manufacturing system can be guaranteed only by detailed preliminary planning and the legitimate control and feedback of the system. Without these control mechanisms, it is meaningless to have a plan. The planning and control activities for manufacturing systems can be categorized based on specific factors, specifically the physical resource, information/knowledge, and time. Material-requirements planning (MRP), capacity planning, facility planning, inventory control, and tool management are planning and control activities for physical resources. Production scheduling is the planning and control of manufacturing resources over time. As to manufacturing information/knowledge control, it comprises the information communication and manufacturing database management. All these planning and control activities are interrelated, and each component is discussed in the following (refer to Fig.6.20.4):

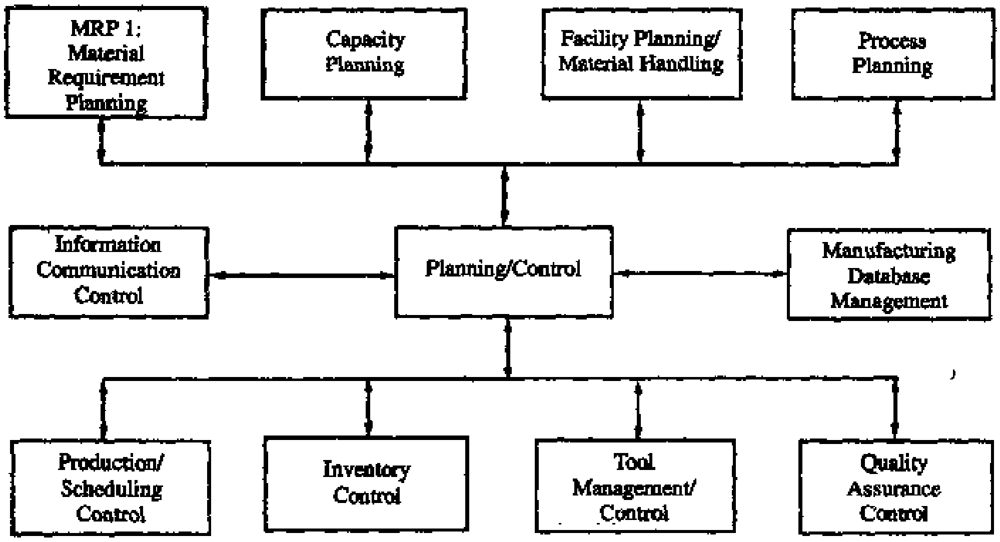

Fig.6.20.4 Planning/Control Activities of the Manufacturing System

1. **Material-requirements planning** works as an initiator for the manufacturing system. When management determines the master production-schedule requirements (the MRP process unit integrates this information with the existing plant-capacity status and generates purchase orders, work orders, and schedule notices), based on the raw material required (bill of material) and subassembly sequences determined by the engineering designer, and the inventory status reported from the storage warehouse manager, work orders and scheduling notices are sent to the shop floor control manager to prepare for production.

2. **Capacity planning** comprises the information that is required to accomplish the production goal, such as identifying the number of machines, persons, material-handing resources, tooling, and so on. The availability of shifts per work day, the work days per week, overtime, subcontracting, and machine/tool/material-handling device requirements are fed back to the MRP control unit, which adjusts the work orders, purchase orders, and schedule notices.

3. **Facility and material-handling device planning** are planning activities for selecting and arranging the physical layout of the manufacturing facilities, the material handing devices, and the storage space. For several decades, group technology (GT) has gained increasing acceptance in this area. For small-to-medium production. GT cellular layout can reduce the part routing time and reduce part fixturing during transfer from machine to machine.

4. **Inventory control** deals with the control of (economic) inventory levels and the reorder point for any raw material, semifinished, and finished parts. Also, the control of work in process (WIP) is another key element of this area. The philosophy of just-in-time (JIT) is a prevailing trend for reducing the WIP as well as the inventory. An ideal inventory-control mechanism guarantees no delays of the material supply.

5. **Tool management** is a vital activity that is frequently neglected by the manufacturing engineer. It deals with tracking of tool location, cutting elapsed time, times for reconditioning, and so on. Minimizing tool breakage is a critical task of this control module.

6. **Scheduling** deals with the dispatching of job orders. Several rules such as FIFO (first in, first out), SPT (shortest-processing-time), and LIFO (last in, first out) are commonly used to schedule activities at workstations. The mean flow time, make span, machine utilization, and due-date constraints are measures of performance for the manufacturing system.

7. **Quality control** is the process that ensures the final acceptability of a product. Quality control deals with activities ranging from inspection and related procedures to sampling procedures used in manufacturing.

8. **Manufacturing information management** deals with the flow and allocation of information concerning manufacturing resources and functions. Included here are resources such as workers, machines, materials, tooling, and so on. This information is necessary for virtually all other manufacturing functions. Computer databases for managing manufacturing information can save storage space and standardize the information format, which is the major step for computer-integrated manufacturing.

9. **Information** and **communication** are especially important for large and computer-integrated manufacturing systems. Several different types of electronic communication protocol are available for different considerations. Manufacturing Applications Protocol (MAP) is an electronic hierarchical manufacturing-control protocol gaining rapid acceptance. Hierarchical control is suitable for many manufacturing systems, both manual and computer-controlled.

Word and Phrases

1. axiom	公理
2. convoluted	旋绕的，费解的
3. chamfer	斜面
4. prevailing	占优势的，主要的，流行的
5. legitimate	合法的，合理的，正统的
6. inventory	详细目录，存货，财产清册，总量
7. fixturing	固定设备，夹具
8. reconditioning	修理，使复原，使正常
9. communications protocol	通信协议

附录A　专业英语常用词缀

附表1　常　用　前　缀

内涵	词缀	意义	词例
否定	dis-, in-, non-, un-,	不、无、非、未等	disorder 无序，inelastic 非弹性的，unloaded 未加载的，uncertainty 不定性
	mal-, mis-,	不善，坏	malfunction 故障，miscalculate 算错
	de-, dis-, un-	去，解，消，除	decentralize 分散，disconnect 分离，unloading 卸载
	anti-, contra-, counter-	反、逆、对、抗	antirusting 防锈的，contraflexure 反向挠曲，counterbalance 抗衡
空间位置和方向	extra-	外，向外	extroneous 外加的，extrapolate 外推
	in-	向，向内	incurve 内弯，inclination 倾斜
	infra-	在下，在下部	Infrastructure 基础，基础设施
	inter-,	在……间，相互	Interrelate 相互有关，interdepend 互相依赖
	intra-	在内，内部	intramural 城市内的，intranet 局域网
	mid-	中，间	midposition 中间位置，midsection 中间截面
	out-	外，向外，出	outline 轮廓，outward 向外的
	over-	在上面，在外	overground 地上的，overlook 俯视
	pre-, pro-	向前，在前	preface 序言，proceed 前进
	sub-, under-	下，在下面	subway 地下铁道，underground 地下的
	super-, sur-	在……上	superstructure 上部结构，surface 表面
时间次序	fore-	预先，先前	foreshock 前震，forecast 预报
	post-	后、次	posttensioned 后张的，postgraduate 研究生
	pre-	事先	prestress 预应力，precaution 预防
	re-	再，重新	renew 更新，readjustment 再调整
比较程度	extra-	格外，超越	extraordinary 非常的，extra-light 特轻的
	hyper-	超过，极度	hypersonic 超声的，hyperplane 超平面
	over-	超过，过度	overload 超载，overmix 拌和过度
共同相等	co-	共同，和	coexist 共存，cooperation 合作
	equi-	同等	equilibrium 平衡，equivalent 等价的
	sym-, syn-	同，共	symmetry 对称，synchronous 同步的
通过遍及	dia-	通过，横过	diameter 直径，diagonal 对角线
	trans-	横过，贯通	transport 运输，transparent 透明的
数量	deca-, deci-	十，十分之一	decameter10 米，decigram 分克
	hecto-, centi-	百，百分之一	hectoliter100 公升，centimeter 厘米
	kilo-, milli-	千，千分之一	kilogram 千克，millimeter 毫米
	mega-, micro-	兆，微（百万分之一）	megacycle 兆周，microampere 微安培
	multi-	许多，多数	multimeter 万用表，multilateral 多边的
	hemi-, semi-	半，一半	hemicycle 半圆，semiconductor 半导体
其他	macro-, magni-	长，大，宏大，巨大	macroseism 强震，magnification 放大
	micro-	微小，小型	microphone 显微镜，microwave 微波
	ortho-	直，正，垂直	orthogon 矩形，orthograph 正视图

附表2 常　用　后　缀

词性	词缀	意义	词例
名词	-er	……者（人或物）	observer 观察者，computer 计算机
	-ician	……家，……能手	technician 技师，mechanician 机械师
	-ist	从事……者	scientist 科学家，chemist 化学家
	-or	……者（人或物）	operator 操作者，censor 传感器
	-acy	性质、状态等	accuracy 精密，determinacy 确定性
	-age	状态、行为等	storage 储存，voltage 电压
	-al	动作、过程等	approval 赞许，removal 移去
	-ance, -ence	性质、状态、行为、过程等	resistance 抵抗，difference 差别
	-ancy, -ency	性质、状态、行为、过程等	constancy 恒定，efficiency 效率
	-bility	动作、性质、状态等	reliability 可靠性，possibility 可能性
	-ety	性质、状态等	variety 变化，dubiety 怀疑
	-faction, -facture	做成，……化，作用等	liquefaction 液化，manufacture 手工制造
	-fication	做成，……化	amplification 放大，simplification 简化
	-ine	表示抽象概念	discipline 学科，machine 机器
	-ing	动作的过程、结果、对象等	reading 读数，building 建筑
	-ion, -sion, -tion, -ation, -ition	行为的过程、结果、状况等	action 作用，conclusion 结论，production 生产，specification 规范，composition 组成
	-ity	性质、状态、程度等	density 密度，reality 现实
	-ment	性质、状态、过程、手段等	movement 运动，treatment 处理
	-ness	性质、状态、程度等	hardness 硬度，slenderness 柔性
	-ship	情况、状态、性质、技巧等	scholarship 学识，relationship 关系
	-th	动作、过程、性质、状态	width 宽度，growth 增长
	-tude	性质、状态、程度	magnitude 量值，latitude 纬度
	-ure	行为、结果	fracture 断裂，pressure 压力
	-graphy	……学、写法等	petrography 岩石学，bibliography 书目
	-ics	……学，……法	dynamics 动力学，bionics 仿生学
	-logy	……学，……论	geology 地质学，hydrology 水文学
	-ant, -ent	产生的物品或物质	resultant 合力，solvent 溶剂
形容词	-able, -ible	可能的，可以的	applicable 能应用的，permissible 容许的
	-al	……的	lateral 横向的，additional 附加的
	-ant, -ent	……的	important 重要的，dependent 依赖的
	-ar	……形状的，……特性的	regular 有规则的，linear 线性的
	-ary	属于……的，与……有关的	contrary 相反的，elementary 基本的
	-ive	与……特性的，与……有关的	substantive 本质的，decisive 决定性的
	-ory	属于……的，……性质的	preparatory 预备的，compulsory 强制的
	-ful	充满的，引起……的	plentiful 充足的，useful 有用的
	-ous	充满……的	continuous 连续的，porous 多孔的

续附表 2

词性	词缀	意义	词例
形容词	-en	由……制的，……质的	wooden 木制的，earthen 泥土的
	-ble, -ple	……倍的	double 两倍的，quadruple 四倍的
	-fold	倍数	twofold 两倍的，manifold 多倍的
	-most	最……的	utmost 极度的，topmost 最上的
	-less	没有……的，无……的	wireless 无线的，stainless 不锈的
	-ic, atic, -ical	属于……的，与……有关的	metallic 金属的，systematic 系统的
动词	-en	使成为，引起	harden 硬化，strengthen 加强
	-fy	致使，使成为	verify 证实，classify 分类
	-ize (ise)	变成，……化	realize 实现，standardize 使……标准化
副词	-ly	状态，程度	relatively 相对地，comparatively 比较地
	-ward (s)	方向	onwards 向前，upwards 向上
	-ways	方向，方式	endways 竖立，sideways 向一边
	-wise	方向，方式	endwise 侧着，lengthwise 顺着

附录 B　常用数学符号的文字表达

1/2	a half, one half
1/3	a third, one third
2/3	two thirds
1/4	a quarter, one quarter, a fourth, one fourth
1/100	a (one) hundredth
1/1000	a (one) thousandth
113/324	one hundred and thirteen over three hundred and twenty four
$4\frac{2}{3}$	four and two thirds
0.25	zero (O,naught) point two five
+	plus, positive
−	minus, negative
±	plus or minus
×	multiplied by, times
÷	divided by
=	be equal to, equals
≈	be approximately equal to, approximately equals
( )	round brackets；parentheses
[ ]	square (angular) brackets
{ }	braces
⩽	less than or equal to
⩾	more than or equal to
∞	infinity
∵	because
∴	therefore
→	maps into
$x+y$	x plus y
$(a+b)$	bracket a plus b bracket closed
$a=b$	a equals b；a is equal to b；a is b
$a\neq b$	a is not equal to b；a is not b
$a\pm b$	a plus or minus b
$a\approx b$	a is approximately equal to b

$a > b$	*a* is greater than *b*
$a >> b$	*a* is much [far] greater than *b*
$a \geqslant b$	*a* is greater than or equal to *b*
$a < b$	*a* is less than *b*
$a << b$	*a* is much less than *b*
$a \leqslant b$	*a* is less than or equal to *b*
$a \perp b$	*a* is perpendicular to *b*
$x \to \infty$	*x* approaches infinity
$a \equiv b$	*a* is identically equal to *b*; *a* is of identity to *b*
$\angle a$	angle *a*
$a \parallel b$	*a* is parallel to *b*
$a \sim b$	*a* is similar to *b*
$a \propto b$	*a* varies directly as *b*
x^2	*x* square; *x* squared; the square of *x*; the second power of *x*; *x* to second power
x^3	*x* cube; *x* cubed; the cube of *x*; the third power of *x*; *x* to the third power
$\sqrt{x}$	the square root of *x*
$\sqrt[3]{x}$	the cube root of *x*
%	per cent
2%	two per cent
‰	per mill
5‰	five per mill
$\log_n x$	log *x* to the base *n*
$\log_{10} x$	log *x* to the base 10, common logarithm
$\log_e x$, $\ln x$	log *x* to the base *e*, natural logarithm, Napierian logarithm
e^x, $\exp(x)$	exponential function of *x*, *e* to the power *x*
x^n	the *n*th power of *x*, *x* to the power *n*
$x^{\frac{1}{n}}$ 或 $\sqrt[n]{x}$	the *n*th root of *x*, *x* to the power one over *n*
sin	sine
cos	cosine
tg, tan	tangent
ctg, cot	cotangent
sc, sec	secant
csc, cosec	cosecant
$\sin^{-1}$, arcsin	arc sine
$\cos^{-1}$, arccos	arc cosine
sinh	the hyperbolic sine
cosh	the hyperbolic cosine
$\sum$	the summation of

$\sum_{i=1}^{n} x_i$	the summation of x sub i, where i goes from 1 to n
$\prod$	the product of
$\prod_{i=1}^{n} x_i$	the product of x sub i, where i goes from 1 to n
$\|x\|$	the absolute value of x
$\bar{x}$	the mean value of x; x bar
b'	b prime
b''	b double prime; b second prime
b'''	b triple prime
$f(x)$	function f of x
Δ	finite difference or increment
Δx, δx	the increment of x
dx	dee x; dee of x; differential x
$\frac{dy}{dx}$	the differential coefficient of y with respect to x; the first derivative of y with respect of x
$\frac{d^2y}{dx^2}$	the second derivative of y with respect of x
$\frac{d^ny}{dx^n}$	the nth derivative of y with respect of x
$\frac{\partial y}{\partial u}$	the partial derivative of y with respect of u, where y is a function of u and another variable (or variables)
$\int$	integral of
$\iint$	double integral of
$\int \cdots \int$	n-fold integral of
$\int_a^b$	integral between limits a and b (… from a to b)
$\vec{F}$	vector F
a_2	a sub two
$20°$	twenty degrees
$7'$	seven minutes; seven feet
$13''$	thirteen seconds; thirteen inches
0°C	zero degree Centigrade [Celsius]
100°C	one [a] hundred degrees Centigrade
32°F	thirty-two degrees Fahrenheit

附录 C　Internet 常用词汇

ADN	Advanced Digital Network. Normally refers to a 56K/bps leased-line.
Alias	A name that points to another name. Aliases are used to make the original name easier to remember or to protect the site's identity.
Anchor	An HTML term for the destination end of a link. (The site to which you are linking your page)
Archie	A program that catalogs files on over 1 000 Internet servers.
Applet	A small (mini) program that adds functionality to another program.
Anonymous FTP	Sites (Servers) that allow anyone access to download files (usually software).
AOL	America Online. A popular commercial online service with an easy-to-use graphical interface.
ARPANet	Advanced Research Projects Administration Network. The forerunner to the Internet.
Authentication	A method for identifying a user prior to granting permission to access, change, or delete information in a system. The most common type of authentication is a user password.
Backbone	A high-speed line or series of connections that forms a major pathway within a computer network.
Bandwidth	The width or amount of information you can send through a connection. Usually measured in bits-per-second.
BBS	Bulletin Board System (a.k.a. electronic bulletin board). A BBS usually consists of a PC, modem, and communication software attached to one or more phone lines. Callers dial up the BBS and are able to download software, and send and receive messages.
Binhex	Binary hexadecimal. A method for converting non-text files (non-ASCII) into ASCII.
BITNET	Because It's Time NETwork. A wide area educational network that is part of the Internet.
Bounce	E-mail that does not go through is said "bounced".
Bps	Bits-per-second. The speed that data is moved from one place to another. A "28.8 baud modem" can move 28 800 bits-per-second.
Browser	An Internet application that lets users travel (surf) the World Wide Web (WWW).
CERN	A high energy physics research laboratory located in Geneva, Switzerland that was the origin of the World Wide Web.
CGI	Common Gateway Interface. A language that works with HTML to improve the capabilities of a homepage.
Client/Server	A computing paradigm where processing is divided between an (graphical front-end) application running on a user's desktop machine and a (back-end) server that performs intensive processing tasks in response to client requests.
Compression	A process that reduces the size of a file. Compressed files take up less space on computers and can be transferred more quickly.

CompuServe	One of the largest and the oldest commercial online services.
Crawlers	Also called search engines. Programs designed to search and categorize the World Wide Web.
CU-SeeMe	A free video-conferencing program (under copyright of Cornell University.)
Cyberpunk	The term grew out of the work of William Gibson and Bruce Sterling and has evolved into a cultural label encompassing many different kinds of human, machine, and punk attitudes of those who inhabit Cyberspace.
Cyberspace	Term originated by author William Gibson in his novel "NEUROMANCER". The word Cyberspace is currently used to describe that space where people communicate through electronic computer networks.
Daemon	A program that runs continuously on UNIX machines. Daemon programs are key to running e-mail and web servers.
Database	A computer file that contains any type of data. Once information is collected in these files, they can be queried to provide organized informational reports.
DNS	Domain Name Service. An Internet service that allows us to use symbolic names (www.gm.com) instead of IP addresses (129.21 9.55.217) when contacting computers connected to the Internet.
Domain name	A unique name that identifies an Internet site. Domain names always have two or more parts, separated by dots, i.e., www.asu.edu.
Domain name Server	A server (computer) that tracks other machines and their numeric IP addresses. When a computer is referred to by name, a domain name server puts that name into the numeric IP address assigned to that computer.
Download	File transfer from a server computer to the client computer.
Downstream	Usenet users who get their news from you are "downstream" from the information flow.
E-mail	Software that lets users exchange messages across a network. It is the electronic version of a letter sent by the postal system.
FAQ	Frequently Asked Questions. A list of commonly asked questions with their answers.
Fire Wall	A combination of hardware and software that separates a computer network from some areas of the Internet.
Freenet	Computer networks and BBSs that provide free Internet access, many times through schools and libraries.
Freeware	Free software that is available on the Internet! Generally, you can use it and distribute it but not modify it because of author rights.
FTP	File Transfer Protocol. The Internet protocol that provides network file transfer between any two networks.
FYI	For Your Information.
Gateway	Hardware or software that translates between two dissimilar protocols. Most commercial online services have a gateway that translates between its internal, proprietary e-mail format and Internet e-mail format.
Gopher	A successful system of making menus of material available over the Internet developed by the University of Minnesota. Gopher uses a standard Client and Server style program.
Hacker	A person who is a computer guru who uses his expertise to "hack" into others' computers.
Homepage	Usually the first page of a World Wide Web site.
Host	A server computer on a network that is a repository for services available to client computers on the network.

HTML	HyperText Markup Language. The tagging or coding language used to create hypertext documents for use on the World Wide Web. Generally read or viewed by Web Browsers.
HTTP	HyperText Transport Protocol. The TCP/IP-based communications protocol developed for use on WWW. HTTP defines how clients and servers communicate over the Web.
Hyperlink	A "link" to other documents—pictures, buttons, "hot words" or phrases in a document that can be chosen by a reader to display more information.
Hypermedia	A computer-based information delivery method using text, graphics, animation, sound, video that can be linked and treated as a single unit.
Hypertext	Originally used for all hyperlinks and still used for text that contains "links" to other documents. A non-linear method of organizing contains "links" to other documents. A non-linear method of organizing text, graphics and other kinds of data, which allows individual elements point to one another.
Internet	The interconnected computer networks that all use TCP/IP protocols. Evolving from the ARPANET of the late 60's and early 70's, the Internet now (July 1995) connects roughly 60 000 independent networks into this vast global network.
IP	Internet Protocol is the main network protocol for TCP/IP. Sometimes called a "dotted quad", this number consists of four parts separated by dots. (i.e., 255.255.255.255)
ISH	Information Super Highway Another name for the Internet or global electronic communication network.
IRC	Internet Relay Chat. Multi-user live chat facility that permits users to "talk" to one another via real-time text. Private channels can (and are) created for multi-person "conference calls".
ISDN	Integrated Services Digital Network. A way to move more data over existing regular phone lines. ISDN is rapidly becoming available to much of the USA and in most markets.
ISP	Internet Service Provider. Organizations, such as America Online (AOL), CompuServe, Prodigy, etc., that provide Internet access to a customer. These organizations usually charge for their services.
Java	A programming language invented by Sun Microsystems that is specifically designed for writing programs that can be safely downloaded to your computer through the Internet. Using small Java programs (called "applets"), Web pages can include animations, calculators, and other fancy tricks.
LAN	Local-Area Network. A computer network limited to an immediate area, usually the same building.
Link	A link connects users to http files located on various computers around the world via the World Wide Web.
Listserv	An automated maillist that distributes mail to a list of subscribers. Listservs originated on BITNET, but they are now common on the Internet.
Login	An account name used to gain access to a computer system. It can also mean the act of accessing a computer system - going online.
Lurker	A person who views CUSeeMe and newsgroup discussions, but does not participate in them.
Maillist (or Mailing List)	A system that allows people to send e-mail to a computer, whereupon their message is forwarded to all of the subscribers of that maillist.
MIME	Multipurpose Internet Mail Extension. A standard way of attaching non-text files (sound, graphics, spreadsheets, and formatted word-processor

documents) to Internet e-mail messages.

Mirror Site A site that mirrors the contents of another site. Used to lessen the load on a popular site.

MODEM **MO**dulator, **DEM**odulator. A device that connects your computer to a phone line and allows the computer to talk to other computers.

Moderator A person who reads all the posts to a newsgroup before they are posted, to decide whether a particular message is appropriate to that newsgroup.

MOO Mud Object Oriented. A multi-user environments where people role play and interact in real-time using objects.

Mosaic Marc Andressen's first Web browser that was available for the Macintosh, Windows, and UNIX computers.

MUD Multi-User Dungeon or Dimension. A (text-based) multi-user simulation environment.

MUSH Multi-User Simulated Hallucination. Generally a MUD that uses a popular movie for its environment theme.

Netiquette Etiquette of the Internet.

Netizen From the term, "citizen", refers to a citizen of the internet.

Netscapc A WWW Browser and the name of a company. The Netscape (tm) browser was originally based on the Mosaic program developed by Marc Andressen at the National Center for Supercomputing Applications (NCSA).

Network Two or more computers connected to share resources.

Newsgroup A discussion group on Usenet.

Newsreader A software program used to read newsgroups.

NIC Networked Information Center. An office that handles information for a network. The most famous of these on the Internet is the InterNIC, which is where new domain names are registered.

Nickname A name given to an e-mail address.

Node Any single computer connected to a network.

Offline A computer not connected to a computer network.

Online A computer connected to a computer network. More often referred to as a computer that is connected to the Internet.

Page One file on a WWW site. It can contain any amount of information, depending upon the size of the file.

Password A personal code used to gain access to a locked system. Good passwords contain letters and non-letters, not simple combinations.

POP Two commonly used meanings: "Point Of Presence" and "Post Office Protocol".

Posting A message entered into a network communications system.

Prodigy A popular commercial online service.

Protocol A specific language that computers use to talk with each other; decided upon by the majority of users.

Provider A company or group that provides service.

Public domain Software that is free to be used, distributed, or modified. It has been given to the public free of copyright infringement.

PPP Point to Point Protocol. A popular protocol that allows a computer to use a regular telephone line and a modem to make TCP/IP connection to the Internet.

Querie A search or question asked by a user of a database. Generally used to search for information.

Quick Time An Apple software program used to display video files. Quick Time movie files can contain text, sound, animation, and video, and are often very large. Because of their size, it can take a long time to download, especially if you are using modem dialup access.

RealAudio A commercial software program that plays audio on as the file is being loaded, reducing the long waits for large Files to transfer.

Router A unique computer (or software package) that handles the connection between two or more networks "routing" file transmissions.

Search engines Also called Crawlers. Programs designed to ceaselessly search the Web, looking for specific content or simply following links to see where they go.

Self-extracting Archive A compressed file that can be uncompressed simply by clicking on it.

Server A computer that provides a specific kind of service to client computers. Generally, this is file-sharing, information routing, or message delivery.

Shareware Software generally available on the Internet that you are permitted to try out. If you feel you will use it, a modest fee is expected to be paid to the developer. Usually these are demo or abbreviated versions of more powerful commercial versions.

Signature A text file that is automatically appended to an email message. Generally these include several lines of text, and used as an easy way of signing e-mail messages.

Site a location on the Internet, i.e. WWW site, gopher site.

SLIP Serial Line Internet Protocol. A standard for using a regular telephone line (a "serial line") and a modem to connect a computer. SLIP connections are similar to and gradually being replaced hy PPP.

SMDS Switched Multimegabit Data Service. A new high-speed data transfer standard.

Snail mail Traditional methods of sending mail—US Post Office.

Sysop Systems operator. The person responsible for the operations of a computer system or network resource.

T-1 A leased-line connection capable of carrying data at 1 544 000 bits-per-second. A T-1 line could move a megabyte in less than 10 seconds. While this might seem fast, it cannot transfer full-screen full motion video.

T-3 A leased-line connection capable of carrying data at 44 736 000 bits-per-second. Much faster than a T-1 and capable of transferring full-screen full motion video.

TCP/IP Transmission Control Protocol/Internet Protocol is the standard used for transmitting data over the Internet.

Telnet A protocol that allows you to connect to a remote computer over the Internet.

Terminal The term used for a computer being used for work on a server computer.

Thread A theme or concept that relates to a group of messages on a newsgroup or BBS.

Timeout A program or connection closes after a certain amount of idle time. When this happens, it is said to have "timed out".

TIFN Ta Ta For Now. A shorthand appended to a message meaning good-bye. Taken from Winnie the Pooh.

Turbogopher A faster and graphic version of the Internet menu browsing system known as Gopher.

UNIX A common operating system used on RISC-based computers, and a popular operating for servers on the Internet.

Upload To transfer a file from the local or client computer to the server or host computer.

Upstream	Usenet users who send news are upstream, they send the information down to you.
URL	Universal Resource Locator. The address or location of the resource.
Usenet	A huge system of discussion groups, with over 10000 discussion areas called newsgroups.
Userid	The account name you use when you log on to a server computer.
Username	Synonymous with userid.
Veronica	A Gopher-based search engine.
VR	Virtual Reality. A computer-generated environment that simulates a real or fantasy world environment.
VRML	Virtual Reality Modeling Language. A programming language that creates a virtual environment accessible from Web browsers.
WAIS	Wide Area Information Servers. Search engine used to search for documents over the Internet.
WAN	Wide Area Network. Any computer network that covers an area larger than a single building or campus.
Windows	A popular Graphical User Interface (GUI) that allows users to easily access the resources of a personal computer.
WWW	World Wide Web is a global system of hypertext documents linked together by the Internet.
XMODEM	A file-transfer protocol, similar to Kermit, YMODEM, and ZMODEM.
YMODEM	A file-transfer protocol, similar to Kermit, XMODEM, and ZMODEM.
ZMODEM	The fastest file transfer-protocol, similar to Kermit, XMODEM, and YMODEM.

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