

MARKS'
STANDARD
HANDBOOK
FOR
MECHANICAL
ENGINEERS

BAUMEISTER
AVALLONE &
BAUMEISTER

EIGHTH
EDITION

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for Mechanical Engineers

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Marks'

Standard Handbook for Mechanical Engineers

Revised by a staff of specialists

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Preface to the Eighth Edition

In the preparation of the eighth edition of "Marks," the editors had several major objectives. First, to modernize and update the contents as required; second, to introduce the SI system of units where applicable; and third, to recast the Handbook into a two-column format to enhance the visual presentation of textual matter and thereby increase its readability and usefulness.

It is recognized that, at this time, the U. S. Customary System (USCS) of units cannot be completely replaced by the International System (SI). A transition from USCS to SI will proceed at a rational pace to accommodate the needs of the profession, of industry, of the polity, and of the citizenry. The transition period most likely will be long and complex, and duality of units probably will be demanded for several decades. Incorporation of dual units to the maximum extent possible will make the eighth edition useful for many years to professional engineers and to students.

Established practices and new concepts are the warp and woof which not only constitute the fabric of the profession, but also serve to keep it alive and progressive. For example, increased recognition of the social implications of engineering has resulted in a new section on environmental control.

The editors were cognizant of the competing requirements to offer the user the broad spectrum of information that has made the Handbook so useful for over sixty years, and yet to keep the size of the one volume within reason. This was achieved through the enthusiastic and timely cooperation of contributors, reviewers, and publisher.

Last, the Handbook is ultimately the responsibility of the editors. Meticulous care has been exercised to avoid errors, but, if any are inadvertently included, the editors will appreciate being informed so that they may be eliminated from subsequent printings of this edition.

*Willtown Bluff, SC
Chauncey, NY
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THEODORE BAUMEISTER
EUGENE A. AVALLONE
THEODORE BAUMEISTER III

Preface to the First Edition*

This Handbook is intended to supply both the practicing engineer and the student with a reference work which is authoritative in character and which covers the field of mechanical engineering in a comprehensive manner. It is no longer possible for a single individual or a small group of individuals to have so intimate an acquaintance with any major division of engineering as is necessary if critical judgment is to be exercised in the statement of current practice and the selection of engineering data. Only by the co-operation of a considerable number of specialists is it possible to obtain the desirable degree of reliability. This Handbook represents the work of fifty specialists.

Each contributor is to be regarded as responsible for the accuracy of his section. The number of contributors required to ensure sufficiently specialized knowledge for all the topics treated is necessarily large. It was found desirable to enlist the services of thirteen specialists for an adequate handling of the "Properties of Engineering Materials." Such topics as "Automobiles," "Aeronautics," "Illumination," "Patent Law," "Cost Accounting," "Industrial Buildings," "Corrosion," "Air Conditioning," "Fire Protection," "Prevention of Accidents," etc., though occupying relatively small spaces in the book, demanded each a separate writer.

A number of the contributions which deal with engineering practice, after examination by the Editor-in-Chief, were submitted by him to one or more specialists for criticism and suggestions. Their co-operation has proved of great value in securing greater accuracy and in ensuring that the subject matter does not embody solely the practice of one individual but is truly representative.

An accuracy of four significant figures has been assumed as the desirable limit; figures in excess of this number have been deleted, except in special cases. In the mathematical tables only four significant figures have been kept.

The Editor-in-Chief desires to express here his appreciation of the spirit of co-operation shown by the Contributors and of their patience in submitting to modifications of their sections. He wishes also to thank the Publishers for giving him complete freedom and hearty assistance in all matters relating to the book from the choice of contributors to the details of typography.

Cambridge, Mass.
April 23, 1916

LIONEL S. MARKS

*Excerpt.

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Symbols and Abbreviations

For symbols of chemical elements, see Sec. 6; for abbreviations applying to metric weights and measures and SI units, Sec. 1; SI unit prefixes are listed on p. 1-34.

Pairs of parentheses, brackets, etc., are frequently used in this work to indicate corresponding values. For example, the statement that "the cost per kw of a 30,000-kw plant is \$86; of a 15,000-kw plant, \$98; and of an 8,000-kw plant, \$112," is condensed as follows: The cost per kw of a 30,000 (15,000) [8,000]-kw plant is \$86 (98) [112].

In the citation of references readers should always attempt to consult the latest edition of referenced publications.

A or Å	Angstrom unit = 10^{-10} m; 3.937×10^{-11} in	AMCA	Air Moving & Conditioning Assoc., Inc.
A	mass number = $N + Z$; ampere	amu	atomic mass unit
AA	arithmetical average	AN	ammonium nitrate (explosive); Army-Navy Specification
AAA	Am. Automobile Assoc.	AN-FO	ammonium nitrate-fuel oil (explosive)
AAR	Assoc. of Am. Railroads	ANC	Army-Navy Civil Aeronautics Committee
AAS	Am. Astronautical Soc.	ANS	Am. Nuclear Soc.
ABAI	Am. Boiler & Affiliated Industries	ANSI	American National Standards Institute
abs	absolute	antilog	antilogarithm of
a.c.	aerodynamic center	API	Am. Petroleum Inst.
a-c, ac	alternating current	approx	approximately
ACI	Am. Concrete Inst.	APWA	Am. Public Works Assoc.
ACM	Assoc. for Computing Machinery	AREA	Am. Railroad Eng. Assoc.
ACRMA	Air Conditioning and Refrigerating Manufacturers Assoc.	ARI	Air Conditioning and Refrigeration Inst.
ACS	Am. Chemical Soc.	ARS	Am. Rocket Soc.
ACSR	aluminum cable steel-reinforced	ASCE	Am. Soc. of Civil Engineers
ACV	air cushion vehicle	ASHRAE	Am. Soc. of Heating, Refrigerating, and Air Conditioning Engineers
A.D.	anno Domini (in the year of our Lord)	ASLE	Am. Soc. of Lubricating Engineers
AEC	Atomic Energy Commission (U.S.)	ASM	Am. Soc. for Metals
a-f, af	audio frequency	ASME	Am. Soc. of Mechanical Engineers
AFBMA	Anti-friction Bearings Manufacturers' Assoc.	ASST	Am. Soc. for Steel Treating
AFS	Am. Foundrymen's Soc.	ASTM	Am. Soc. for Testing and Materials
AGA	Am. Gas Assoc.	ASTME	Am. Soc. of Tool & Manufacturing Engineers
AGMA	Am. Gear Manufacturers' Assoc.	atm	atmosphere
ahp	air horsepower	<i>Auto. Ind.</i>	Automotive Industries (New York)
AICHe	Am. Inst. of Chemical Engineers	avdp	avoidupois
AIEE	Am. Inst. of Electrical Engineers (see IEEE)	avg, ave	average
AIME	Am. Inst. of Mining Engineers	AWG	Am. Wire Gage
AIP	Am. Inst. of Physics	AWPA	Am. Wood Preservation Assoc.
AISC	American Institute of Steel Construction, Inc.	AWS	American Welding Soc.
AISE	Am. Iron & Steel Engineers	AWWA	American Water Works Assoc.
AISI	Am. Iron and Steel Inst.	b	barns
a.m.	ante meridiem (before noon)	bar	barometer
a-m, am	amplitude modulation	B&S	Brown & Sharp (gage); Beams and Stringers
<i>Am. Mach.</i>	Am. Machinist (New York)	bbl	barrels
AMA	Automobile Manufacturers' Assoc.; Acoustical Materials Assoc.	B.C.	before Christ

B.C.C.	body centered cubic	coth	hyperbolic cotangent of
Bé	Baumé (degrees)	coth ⁻¹	inverse hyperbolic cotangent of
B.G.	Birmingham gage (hoop and sheet)	covers	coversed sine of
bgd	billions of gallons per day	c.p.	circular pitch; center of pressure
BHFN	Brinnell Hardness Number	cp	candle power
bhp	brake horsepower	cp	coef of performance
BLC	boundary layer control	CP	chemically pure
B.M.	board measure; bench mark	CPH	close packed hexagonal
bmep	brake mean effective pressure	cpm, cycles/ min	cycles per minute
B of M,		cps, cycles/s	cycles per second
BuMines	Bureau of Mines	CSA	Canadian Standards Assoc.
BOD	biochemical oxygen demand	csc	cosecant of
bp	boiling point	csc ⁻¹	arc whose cosecant is (see cos ⁻¹)
Bq	becquerel	csch	hyperbolic cosecant of
bsfc	brake specific fuel consumption	csch ⁻¹	inverse hyperbolic cosecant of
BSI	British Standards Inst.	cu	cubic
Btu	British thermal units	cyl	cylinder
Btuh, Btu/h	Btu per hr	db, dB	decibel
bu	bushels	d-c, dc	direct current
Bull.	Bulletin	def	definition
Buweapons	Bureau of Weapons, U.S. Navy	deg	degrees
BWG	Birmingham wire gage	diam. (dia)	diameter
c	velocity of light	DO	dissolved oxygen
°C	degrees Celsius (centigrade)	D ₂ O	deuterium (heavy water)
C	coulomb	d.p.	double pole
CAB	Civil Aeronautics Board	DP	Diametral pitch
CAGI	Compressed Air & Gas Inst.	DPH	diamond pyramid hardness
cal	calories	DST	daylight saving time
C-B-R	chemical, biological & radiological (filters)	d ⁴ tons	breaking strength, <i>d</i> = chain wire diam, in.
CBS	Columbia Broadcasting System	DX	direct expansion
cc, cm ³	cubic centimeters	<i>e</i>	base of Napierian logarithmic system (= 2.7182+)
CCR	critical compression ratio	EAP	equivalent air pressure
c to c	center to center	EDR	equivalent direct radiation
cd	candela	EEL	Edison Electric Inst.
c.f.	centrifugal force	eff	efficiency
cf.	confer (compare)	e.g.	exempli gratia (for example)
cfh, ft ³ /h	cubic feet per hour	ehp	effective horsepower
cfm, ft ³ /min	cubic feet per minute	EHV	extra high voltage
C.F.R.	Cooperative Fuel Research	El. Wld.	Electrical World (New York)
cfs, ft ³ /s	cubic feet per second	elec	electric
cg	center of gravity	elong	elongation
cgs	centimeter-gram-second	emf	electromotive force
Chm. Eng.	Chemical Eng'g (New York)	Engg.	Engineering (London)
chu	centigrade heat unit	Engr.	The Engineer (London)
C.I.	cast iron	ENT	emergency negative thrust
cir	circular	EP	extreme pressure (lubricant)
cir mil	circular mils	ERDA	Energy Research & Development Administration (successor to AEC; see also NRC)
cm	centimeters	Eq.	equation
CME	Chartered Mech. Engr (IMEchE)	est	estimated
C.N.	cetane number	etc.	et cetera (and so forth)
coef	coefficient	et seq.	et sequens (and the following)
COESA	U.S. Committee on Extension to the Standard Atmosphere	eV	electron volts
col	column	evap	evaporation
colog	cologarithm of	exp	exponential function of
const	constant	exsec	exterior secant of
cos	cosine of	ext	external
cos ⁻¹	arc whose cosine is, inverse cosine of	°F	degrees Fahrenheit
cosh	hyperbolic cosine of	F	farad
cosh ⁻¹	inverse hyperbolic cosine of	FAA	Federal Aviation Agency
cot	cotangent of		
cot ⁻¹	arc whose cotangent is (see cos ⁻¹)		

F.C.	fixed carbon, %	ICE	Inst. of Civil Engineers
FCC	Federal Communications Commission; Federal Construction Council	ICI	International Commission on Illumination
F.C.C.	face-centered-cubic (alloys)	I.C.T.	International Critical Tables
ff.	following (pages)	I.D., ID	inside diameter
fhp	friction horsepower	i.e.	id est (that is)
Fig.	figure	IEC	International Electrotechnical Commission
F.I.T.	Federal income tax	IEEE	Inst. of Electrical & Electronics Engineers (successor to AIEE, <i>q.v.</i>)
f-m, fm	frequency modulation	IES	Illuminating Engineering Soc.
F.O.B.	free on board (cars)	i-f, if	intermediate frequency
FP	fore perpendicular	IGT	Inst. of Gas Technology
FPC	Federal Power Commission	ihp	indicated horsepower
fpm, ft/min	feet per minute	IMechE	Inst. of Mechanical Engineers
fps	foot-pound-second system	imep	indicated mean effective pressure
ft/s	feet per second	Imp	Imperial
F.S.	Federal Specifications	in., in	inches
FSB	Federal Specifications Board	in.·lb, in·lb	inch-pounds
fsp	fiber saturation point	INA	Inst. of Naval Architects
ft	feet	<i>Ind. & Eng. Chem.</i>	Industrial & Eng'g Chemistry (Easton, Pa)
fc	foot candles	int	internal
fL	foot lamberts	i-p, ip	intermediate pressure
ft-lb	foot-pounds	ipm, in/min	inches per minute
<i>g</i>	acceleration due to gravity	ipr	inches per revolution
g	grams	IPS	iron pipe size
gal	gallons	IRE	Inst. of Radio Engineers
gc	gigacycles per sec	IRS	Internal Revenue Service
GCA	ground-controlled approach	ISO	International Organization for Standardization
g-cal	gram-calories	isoth	isothermal
gd	Gudermannian of	ISTM	International Soc. for Testing Materials
G.E.	General Electric Co.	IUPAC	International Union of Pure & Applied Chemistry
GEM	ground effect machine	J	joule
GFI	gullet feed index	J&P	joists & planks
G.M.	General Motors Co.	<i>Jour.</i>	Journal
GMT	Greenwich Mean Time	JP	jet propulsion fuel
GNP	gross national product	<i>k</i>	isentropic exponent; conductivity
gpcd	gallons per capita day	K	degrees Kelvin (Celsius abs)
gpd	gallons per day; grams per denier	K	Knudsen number
gpm, gal/min	gallons per minute	kB	kilo Btu (1000 Btu)
gps, gal/s	gallons per second	kc	kilocycles
gpt	grams per tex	kcps	kilocycles per sec
H	henry	kg	kilograms
h	Planck's constant = 6.624×10^{-27} erg-sec	kg·cal	kilogram-calories
h	Planck's constant, $h = h/2\pi$	kg·m	kilogram-meters
HEPA	high efficiency particulate matter	kip	1000 lb or 1 kilo-pound
h-f, hf	high frequency	kips	thousands of pounds
hhv	high heat value	km	kilometers
horiz	horizontal	kmc	kilomegacycles per sec
hp	horsepower	kmcps	kilomegacycles per sec
h-p	high-pressure	kpsi	thousands of pounds per sq in
HPAC	Heating, Piping, & Air Conditioning (Chicago)	ksi	one kip per sq in, 1000 psi (lb/in ²)
hp·hr	horsepower-hour	kts	knots
hr, h	hours	kVA	kilovolt-amperes
HSS	high speed steel	kW	kilowatts
H.T.	heat-treated	kWh	kilowatt-hours
HTHW	high temperature hot water	l < L	litres < lamberts
Hz	hertz = 1 cycle/s (cps)	£	Laplace operational symbol
IACS	International Annealed Copper Standard	lb	pounds
IAeS	Institute of Aerospace Sciences	L.B.P.	length between perpendiculars
ibid.	ibidem (in the same place)	lhv	low heat value
ICAO	International Civil Aviation Organization	lim	limit
ICC	Interstate Commerce Commission		

xx SYMBOLS AND ABBREVIATIONS

lin	linear	NASA	National Aeronautics and Space Administration
ln	Napierian logarithm of	nat.	natural
loc. cit.	loco citato (place already cited)	NBC	National Broadcasting Company
log	common logarithm of	NBFU	National Board of Fire Underwriters
LOX	liquid oxygen explosive	NBS	National Bureau of Standards
l-p, lp	low pressure	NCN	nitrocarbonitrate (explosive)
LPG	liquified petroleum gas	NDHA	National District Heating Assoc.
lpw, lm/W	lumens per watt	NEC	National Electrical Code
lx	lux	NEMA	National Electrical Manufacturers Assoc.
L.W.L.	load water line	NFPA	National Fire Protection Assoc.
lm	lumen	NLGI	National Lubricating Grease Institute
m	metres	nm	nautical miles
M	thousand; Mach number; moisture, %	No. (Nos.)	number(s)
mA	milliamperes	NPSH	net positive suction head
<i>Machy.</i>	Machinery (New York)	NRC	Nuclear Regulator Commission (successor to AEC; see also ERDA)
max	maximum	NTp	normal temperature and pressure
MBh	thousands of Btu per hr	O.D., OD	outside diameter (pipes)
mc	megacycles per sec	O.H	open-hearth (steel)
m.c.	moisture content	O.N.	octane number
Mcf	thousand cubic feet	op. cit.	opere citato (work already cited)
mcps	megacycles per sec	OSHA	Occupational Safety & Health Administration
<i>Mech. Eng.</i>	Mechanical Eng'g (ASME)	OSW	Office of Saline Water
mcp	mean effective pressure	OTS	Office of Technical Services, U.S. Dept. of Commerce
METO	maximum, except during take-off	oz	ounces
meV	million electron volts	p. (pp.)	page (pages)
MF	maintenance factor	Pa	pascal
mhc	mean horizontal candles	P.C.	propulsive coefficient
mi	mile	PE	polyethylene
MIL-STD	U.S. Military Standard	PEG	polyethylene glycol
min	minutes; minimum	P.E.L.	proportional elastic limit
mip	mean indicated pressure	PETN	an explosive
MKS	meter-kilogram-second system	pf	power factor
MKSA	meter-kilogram-second-ampere system	PFI	Pipe Fabrication Inst.
mL	millilamberts	PIV	peak inverse voltage
ml	millilitre = 1.000027 cm ³	p.m.	post meridiem (after noon)
mlhc	mean lower hemispherical candles	PM	preventive maintenance
mm	millimetres	P.N.	performance number
mm-free	mineral matter free	ppb	parts per billion
mmf	magnetomotive force	PPI	plan position indicator
mol	mole	ppm	parts per million
mp	melting point	press	pressure
MPC	maximum permissible concentration	<i>Proc.</i>	Proceedings
mph, mi/h	miles per hour	PSD	power spectral density, g ² /cps
MRT	mean radiant temperature	psi, lb/in ²	lb per sq in
ms	manuscript; milliseconds	psia	lb per sq in. abs
msc	mean spherical candles	psig	lb per sq in. gage
MSS	Manufacturers Standardization Soc. of the Valve & Fittings Industry	pt	point; pint
Mu	micron, micro	PVC	polyvinyl chloride
MW	megawatts	Q	10 ¹⁸ Btu
MW day	megawatt day	qt	quarts
MWT	mean water temperature	q.v.	quod vide (which see)
n	polytropic exponent	r	roentgens
N	number (in mathematical tables)	<i>R</i>	gas constant
N	number of neutrons; newton	R	deg Rankine (Fahrenheit abs); Reynolds number
N _s	specific speed	rad	radius; radiation absorbed dose; radian
NA	not available	RBE	see rem
NAA	National Assoc. of Accountants	R-C	resistor-capacitor
NACA	National Advisory Committee on Aeronautics (see NASA)		
NACM	National Assoc. of Chain Manufacturers		

RCA	Radio Corporation of America	$\tanh^{-1}$	inverse hyperbolic tangent of
R&D	research & development	TDH	total dynamic head
RDX	cyclonite, a military explosive	TEL	tetraethyl lead
rem	Roentgen equivalent man (formerly RBE)	temp	temperature
rev	revolutions	THI	temperature-humidity (discomfort) index
r-f, rf	radio frequency	thp	thrust horsepower
RMA	Rubber Manufacturers Assoc.	TNT	trinitrotoluol (explosive)
rms	square root of mean square	torr	= 1 mm Hg = 1.332 millibars (1/760) atm = (1.013250/760) dynes per cm ²
rpm, r/min	revolutions per minute	TP	total pressure
rps, r/s	revolutions per second	tph	tons per hour
RSHF	room sensible heat factor	tpi	turns per in
ry.	railway	TR	transmitter-receiver
s	entropy	Trans.	Transactions
s	seconds	T.S.	tensile strength; tensile stress
S	sulphur, %; siemens	tsi	tons per sq in
SAE	Soc. of Automotive Engineers	<i>ttd</i>	terminal temperature difference
sat	saturated	UHF	ultra high frequency
SBI	Steel Boiler Inst.	UKAEA	United Kingdom Atomic Energy Authority
sefm	standard cu ft per min	UL	Underwriters' Laboratory
SCR	silicon controlled rectifier	ult	ultimate
sec	secant of	UMS	universal maintenance standards
sec ⁻¹	arc whose secant is (see cos ⁻¹)	USAF	U.S. Air Force
Sec.	Section	USCG	U.S. Coast Guard
sech	hyperbolic secant of	USCS	U.S. Commercial Standard; U.S. Customary System
sech ⁻¹	inverse hyperbolic secant of	USDA	U.S. Dept. of Agriculture
segm	segment	USEPL	U.S. Forest Products Laboratory
SE No.	steam emulsion number	USGS	U.S. Geologic Survey
sfc	specific fuel consumption, lb per hphr	USHEW	U.S. Dept. of Health, Education & Welfare
sfm	surface feet per minute	USN	U.S. Navy
sfp	surface ft per minute	USP	U.S. Pharmacopoeia
shp	shaft horsepower	USPHS	U.S. Public Health Service
SI	International System of Units (Le Système International d'Unités)	USS	United States Standard
sin	sine of	USSG	U.S. Standard Gage
sin ⁻¹	arc whose sine is (see cos ⁻¹)	UTC	Coordinated Universal Time
sinh	hyperbolic sine of	V	volt
sinh ⁻¹	inverse hyperbolic sine of	VCF	visual confort factor
SME	Society of Manufacturing Engineers (successor to ASTM)	VCI	visual comfort index
SNA&ME	Soc. of Naval Architects and Marine Engineers	VDI	Verein Deutscher Ingenieure
SP	static pressure	vel	velocity
sp	specific	vers	versed sine of
specif	specification	vert	vertical
sp gr	specific gravity	VHF	very high frequency
sp ht	specific heat	VI	viscosity index
spp	species unspecified (botanical)	viz.	videlicet (namely)
SPS	standard pipe size	V.M.	volatile matter, %
sq	square	vol	volume
sr	steradian	VP	velocity pressure
SSF	sec Saybolt Furol	vs	versus
SSU	seconds Saybolt Universal (same as SUS)	W	watt
std	standard	Wb	weber
SUS	Saybolt Universal seconds (same as SSU)	W&M	Washburn & Moen wire gage
SWG	Standard (British) wire gage	w.g.	water gage
T	tesla	WHO	World Health Organization
TAC	Technical Advisory Committee on Weather Design Conditions (ASHRAE)	W.I.	wrought iron
tan	tangent of	W.P.A.	Western Pine Assoc.
tan ⁻¹	arc whose tangent is (see cos ⁻¹)	wt	weight
tanh	hyperbolic tangent of	yd	yards
		Y.P.	yield point
		yr	year(s)

xxii SYMBOLS AND ABBREVIATIONS

Y.S.	yield strength; yield stress
z	atomic number; figure of merit
Zeit.	Zeitschrift
Δ	mass defect
μc	microcurie

σ , s	Boltzmann constant
μ	micro ($=10^{-6}$), as in μs
μm	micrometer (micron) $= 10^{-6}$ m (10^{-3} mm)
Ω	ohm

MATHEMATICAL SIGNS AND SYMBOLS

+	plus (sign of addition)
+	positive
-	minus (sign of subtraction)
-	negative
$\pm$ ($\mp$)	plus or minus (minus or plus)
$\times$	times, by (multiplication sign)
$\cdot$	multiplied by
$\div$	sign of division
/	divided by
:	ratio sign, divided by, is to
::	equals, as (proportion)
<	less than
>	greater than
<<	much less than
>>	much greater than
=	equals
$\equiv$	identical with
$\sim$	similar to
$\approx$	approximately equals
$\cong$	approximately equals, congruent
$\leq$	equal to or less than
$\geq$	equal to or greater than
$\neq$	not equal to
$\rightarrow$	approaches
$\propto$	varies as
∞	infinity
$\sqrt{\quad}$	square root of
$\sqrt[3]{\quad}$	cube root of
$\therefore$	therefore
$\parallel$	parallel to
() [] {}	parentheses, brackets and braces; quantities enclosed by them to be taken together in multiplying, dividing, etc.

$\overline{AB}$	length of line from A to B
π	pi, $= 3.14159 +$
$^{\circ}$	degrees
'	minutes
"	seconds
$\angle$	angle
dx	differential of x
Δ (delta)	difference
Δx	increment of x
$\partial u / \partial x$	partial derivative of u with respect to x
$\int$	integral of
$\int_a^b$	integral of, between limits a and b
$\oint$	line integral around a closed path
Σ (sigma)	summation of
$f(x)$, $F(x)$	functions of x
$\exp x = e^x$	[e $= 2.71828^x$ (base of natural, or Napierian, logarithms)]
∇	del or nabla, vector differential operator
∇^2	Laplacian operator
$\mathcal{L}$	Laplace operational symbol
4!	factorial 4 $= 1 \times 2 \times 3 \times 4$
x	absolute value of x
$\dot{x}$	first derivative of x with respect to time
$\ddot{x}$	second derivative of x with respect to time
$\mathbf{A} \times \mathbf{B}$	vector product; magnitude of A times magnitude of B times sine of the angle from A to B; $AB \sin \overline{AB}$
$\mathbf{A} \cdot \mathbf{B}$	scalar product; magnitude of A times magnitude of B times cosine of the angle from A to B; $AB \cos \overline{AB}$

fiber. There are two major chemical-pulping processes, which differ both in chemical treatment and in the nature of the pulp produced. In **sulfate pulping**, also referred to as the **kraft** or **alkaline** process, the pulping chemicals must be recovered and reused for economic reasons. Sulfate pulps result in papers of high physical strength, bulk, and opacity; low unbleached brightness; slow beating rates; and relatively poor sheet-formation properties. Both bleached and unbleached sulfate pulps are used in packaging papers, container board, and a variety of printing and bond papers. In **sulfite pulping**, the delignifying agents are sulfurous acid and an alkali, with several variations of the exact chemical conditions in commercial use. In general, sulfite pulps have lower physical strength properties and lower bulk and opacity than kraft pulps, with higher unbleached brightness and better sheet-formation properties. The pulps are blended with groundwood for newsprint and are used in printing and bond papers, tissues, and glassine.

"Chemimechanical" processes combine both chemical and mechanical methods of defibration, the most important commercial process being the NSSC (Neutral Sulfite Semi Chemical). A wide range of yields and properties can be obtained.

Bleaching

Chemical pulps may be bleached to varying degrees of brightness, depending on the end use. During some bleaching operations, the remaining lignin is removed and residual coloring matter destroyed. Alternatively, a nondelignifying bleach lightens the color of high-lignin pulps.

Refining

The final character of the pulp is developed in the **refining** (beating) operation. Pulp fibers are fibrillated, hydrated, and cut. The fibers are roughened and frayed, and a gelatinous substance is produced. This results in greater fiber coherence in the finished paper.

Sizing, Loading, and Coating

Sizing is used, principally in book papers, to make the paper water-repellent and to enhance interfiber bonding and surface characteristics. Sizing materials may be premixed with the pulp or applied after sheet formation.

Loading materials, or **fillers**, are used by the papermaker to smooth the surface, to provide ink affinity, to brighten color, and to increase opacity. The most widely used filler is clay.

Coatings consisting of pigment and binder are often applied to the base stock to create better printing surfaces. A variety of particulate, inorganic materials are combined with binders such as starch or casein in paper coatings. Coating is generally followed by calendering.

Converting and Packaging

A host of products is made from paper; the converting industry represents a substantial portion of the total paper industry. Principal products are in the fine-paper and book-paper fields. Slush pulps are used to make molded pulp products such as egg cartons and paper plates.

Combinations of paper laminated with other materials such as plastic film and metal foil have found wide use in the packaging market.

Plastic-Fiber Paper

A tough, durable product, such as Tyvek, can be made from

100 percent high-density polyethylene fibers by spinning very fine fibers and then bonding them together with heat and pressure. Binders, sizes, or fillers are not required. Such sheets combine some of the best properties of the fabrics, films, and papers with excellent puncture resistance. They can readily be printed by conventional processes, dyed to pastel colors, embossed for decorative effects, coated with a range of materials, and can be folded, sheeted, die-cut, sewn, hot-melt-sealed, glued, and pasted. Nylon paper, such as Nomex type 410, is produced from short fibers (floc) and smaller binder particles (fibrils) of a high-temperature-resistant polyamide polymer, formed into a sheet product without additional binders, fillers, or sizes, and calendered with heat and pressure to form a nonporous structure. It possesses excellent electrical, thermal, and mechanical properties, and finds use in the electrical industry. Fiber impregnation of ordinary paper, using glass or plastic fibers, produces a highly tear-resistant product.

PLASTICS

by Harris J. Bixler
Amicon Corporation

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Plastics are materials which are wholly or in part composed of long, chainlike molecules called **high polymers**. While carbon is the element common to all commercial high polymers, hydrogen, oxygen, nitrogen, sulfur, halogens, and silicon can be present in varying proportions. High polymers may be divided into two classes: **thermoplastic** and **thermosetting**. The former reversibly melt to become highly viscous liquids and, upon cooling, solidify to give, depending on their structure, elastic, ductile, tough, or brittle solids. Melting temperatures range from 100 to 300°C. The thermosetting polymers are infusible without thermal or mechanical degradation. Many thermosetting polymers are prepared by curing thermoplastic **prepolymers** or "**B-stage**" resins. **Curing** (a chain-linking chemical reaction) is usually initiated with heat. The more highly cured the polymer, the higher its heat-distortion temperature and the harder and more brittle it becomes.

Thermoplastics

Thermoplastic polymers are often used with only minor additions (colorants, stabilizers, lubricants). Important characteristics are low density, low cost, toughness, optical clarity, ease of forming complex shapes, low thermal conductivity, chemical resistance, flexibility, and useful electrical properties. Fabrication into plastic objects is achieved by compression, injection, blow, and slush molding; vacuum forming; melt extrusion; solvent casting; stamping; calendering; and powder-metallurgy processes (see also Sec. 13). The starting material in these processes is bulk polymer in the form of small parti-

Table 1. Thermoplastics—Properties and Uses

Item	High-density polyethylene	Low-density polyethylene	Polypropylene	
Key properties	Chemical resistance, strength, low cost	Electrical properties, flexibility, low cost	Toughness, gloss, light weight, heat resistance	
Major uses	Film, bleach, bottles, pipe	Film, containers, wire coating	Housewares, appliance parts, tank liners	
Density, g per cc	0.94-0.96	0.91-0.93	0.90-0.92	
Tensile strength, psi	3,100-5,500	1,000-2,300	3,500-6,000	
Tensile modulus, psi $\times 10^{-8}$	0.4-1.5	0.17-0.35	1-2	
Maximum continuous-use temp, deg F	250	180-212	200-320	
Molding temp, deg F	300-800	275-700	350-600	
Dielectric strength, volts per mil	440-600	420-700	450-650	
Dielectric constant, 1,000 cps	2.30-2.35	2.25-2.35	2.3	
Dissipation factor, 1,000 cps	Less than 0.0002	Less than 0.0005	0.0002-0.0008	
Water absorption, 24 hr, percent	Less than 0.01	Less than 0.015	Less than 0.02	
Item	Cellulose acetate	Rigid vinyl	Plasticized vinyl	
Key properties	Low cost, toughness, clarity, colorability	Compounding flexibility, low cost, chemical resistance	Compounding flexibility, low cost, pliability	
Major uses	Door knobs, blister packs, appliance housings	Conduit, pipe, building panels	Tubing, gaskets, upholstery, footwear	
Density, g per cc	1.26-1.34	1.35-1.45	1.16-1.35	
Tensile strength, psi	1,900-8,300	5,000-9,000	1,500-3,500	
Tensile modulus, psi $\times 10^{-6}$	1.0-4.0	4-6		
Maximum continuous-use temp, deg F	140-220	120-160	150-175	
Molding temp, deg F	260-490	285-400	285-385	
Dielectric strength, volts per mil	200-300	375-750	275-900	
Dielectric constant, 1,000 cps	3.5-7.0	3.0-3.3	4.0-8.0	
Dissipation factor, 1,000 cps	0.01-0.06	0.01-0.02	0.07-0.16	
Water absorption, 24 hr, percent	1.9-6.5	0.07-0.4	0.15-0.75	
Item	Cellulose acetate butyrate	Nylon 6, 6	Polymethyl methacrylate (Lucite or Plexiglas)	Polytetrafluoroethylene (Teflon)
Key properties	Impact resistance, clarity, weatherability	Toughness, low coefficient of friction, machinability	Crystal clarity, strength, weatherability, colorability	Thermal stability, low coefficient of friction, chemical resistance
Major uses	Outdoor signs, lenses	Gears, bearings, hinges, fibers	Automotive lenses, shaped glazing, signs	Gaskets, non-stick surfaces, insulation, electrical applications
Density, g per cc	1.15-1.22	1.09-1.14	1.17-1.20	2.13-2.22
Tensile strength, psi	2,600-6,900	7,000-12,000	7,000-11,000	2,000-4,500
Tensile modulus, psi $\times 10^{-5}$	0.5-2.0	2.6-4.0	4.5	0.58
Maximum continuous-use temp, deg F	140-220	270-300	140-190	550
Molding temp, deg F	265-480	470-720	300-500	
Dielectric strength, volts per mil	250-350	340-410	350-400	430

Table 1. Thermoplastics—Properties and Uses (Continued)

Item	Cellulose acetate butyrate	Nylon 6, 6	Polymethyl methacrylate (Lucite or Plexiglas)	Polytetrafluoroethylene (Teflon)
Dielectric constant, 1,000 cps	3.3–6.3	4.0–4.5	3.0–3.5	2.0
Dissipation factor, 1,000 cps	0.01–0.04	0.02–0.04	0.03–0.05	Less than 0.0002
Water absorption, 24 hr, percent	0.9–2.2	0.4–1.5	0.3–0.4	0.00
Item	Polystyrene (general-purpose)	High-impact polystyrene	ABS acrylonitrile butadiene-styrene	
Key properties	Low cost, crystal clarity	Low cost, impact strength, craze resistance	Toughness, strength, processability	
Major uses	Food containers, lighting panels, film	Appliance housing, luggage, pipe and fittings	Automotive accessories, refrigerator liners, telephone sets	
Density, g per cc	1.05–1.07	0.98–1.10	1.01–1.15	
Tensile strength, psi	5,000–9,000	2,000–6,800	2,400–9,000	
Tensile modulus, psi $\times 10^{-5}$	4–5	2–4.5	1–4	
Maximum continuous-use temp, deg F	150–170	140–175	140–250	
Molding temp, deg F	265–600	250–600	300–600	
Dielectric strength, volts per mil	400–600	300–600	310–400	
Dielectric constant, 1,000 cps	2.4–2.65	2.4–4.5	2.4–4.75	
Dissipation factor, 1,000 cps	Less than 0.0003	0.0004–0.002	0.002–0.012	
Water absorption, 24 hr, percent	0.03–0.05	0.1–0.3	0.1–0.3	

Conversion factors: 1 psi (lb/in²) = 689.48 N/m², $t_C = N/2$, $t_C = 5/9(t_F - 32)$, Cps = 1/Hz.

cles called **molding powders**, extruded sheet, or **plastisol**. Plastisols are liquid or semisolid dispersions of finely powdered polymer in a nonvolatile, nonmigrating liquid, which result in a homogeneous, tough mass upon heating. Expanded, or **foamed**, thermoplastics are finding widespread use as thermal insulation and cushioning material. Hollow beads (or, in some cases, a plastisol) containing a heat-triggerable blowing agent are charged into a heated mold where the polymer softens, is expanded by the blowing agent, and upon cooling, solidifies to a **low-density** (as low as 2 lb/ft³) **open- or closed-cell** plastic foam with low thermal conductivity.

Filled thermoplastics (primarily vinyls) containing up to 50 percent by weight of fillers such as asbestos, wood flour, clay, titania, or carbon black are used in flooring tile, electrical-wire insulation, and pipe or conduit.

Table 1 summarizes the **physical properties** and **major end uses** of a number of thermoplastics of industrial importance.

Thermosetting Plastics

Most **thermosetting plastics** are composite structures, being either multicomponent laminates or blends of polymer and particulate or fibrous fillers. The selection and blending or laminating together (called **compounding**) of suitable polymers and fillers are the heart of thermosetting-plastics technology. These plastics are noted for thermal and dimensional stability, chemical resistance, strength, durability, and good electrical

properties. The costs of thermosetting plastics vary considerably—from very cheap phenolics for container caps, through dinnerware-quality melamine-formaldehydes, to highly engineered epoxy and phenolic composites for space vehicles.

Compounding is done in Banbury and dough mixers, ribbon blenders, rubber mills, extruders, or for fibrous fillers like cellulose and asbestos, a papermaker's beater (beater addition products).

Fillers include wood flour, silica, mica, clay, glass fiber, cellulose, asbestos, and natural and synthetic textile fibers. To promote adhesion between the filler and the polymeric binder, the former is frequently precoated with sizing agents.

Fabrication (shaping and/or curing) is done by injection, compression, and transfer molding; press laminating; casting; tunnel-oven curing (sheet stock and extrudates); lay-up; and bag molding. For lay-up, bag molding, and laminating, prepolymer impregnation of woven and nonwoven felts may be the sole compounding step. Although heat is usually employed to accelerate curing, many room-temperature-curing plastics are now in use. (See also Sec. 13.)

Polyurethane foams are a unique class of thermosetting plastics. By mixing two relatively low-viscosity liquids (prepolymer and blowing, plus curing agents), an expanded foam can be formed and cured in minutes at room temperature. These have found widespread use as poured-in-place insulation.

Tables 2 to 4 summarize the **physical properties** and **major end uses** of a number of industrially important thermosets.

Table 8. Ball-Bearing Grease Relubrication Intervals
(Hours of operation)

Bearing bore, mm	Bearing speed, r/min				
	5,000	3,600	1,750	1,000	200
10	8,700	12,000	25,000	44,000	220,000
20	5,500	8,000	17,000	30,000	150,000
30	4,000	6,000	13,000	24,000	127,000
40	2,800	4,500	11,000	20,000	111,000
50		3,500	9,300	18,000	97,000
60		2,600	8,000	16,000	88,000
70			6,700	14,000	81,000
80			5,700	12,000	75,000
90			4,800	11,000	70,000
100			4,000	10,000	66,000

PACKINGS AND SEALS

by Edward W. Fisher

REFERENCES: Staniar, "Plant Engineering Handbook," McGraw-Hill. Thorn, Rubber and Plastic Packings, *Rubber Age*, Jan. 1956. Roberts, Gaskets and Bolted Joints, *Jour. Applied Mechanics*, June 1950. Non-metallic Gaskets, *Machine Design*, Nov. 1954. Elonka, "Basic Data on Seals," a *Power* reprint, McGraw-Hill.

Packings include those means used to prevent or minimize leakage of a fluid through mechanical clearances in either the static or dynamic state.

Gaskets are installed in static clearances which normally exist between parallel flanges or concentric cylinders. Sealing of flat flange gaskets is effected by compressive loading achieved through bolting or other mechanical means. The full face gasket (Fig. 1) is not recommended because the material outside the bolt holes is ineffective. The simple ring gasket (Fig. 2) is more efficient and economical. With irregularly contoured flanges, bolt holes may serve to locate the gasket, in which case they should be placed in lobes with full sealing flange width maintained between the inner edge of the holes and the inside of the gasket. **Metal-to-metal** fits require a recess whose volume is greater than that of the gasket to be used. The gasket, such as an O ring (Fig. 13), either rectangular or round cross-sectioned, extends above the groove sufficiently to provide a minimum cross-sectional compression of 15 percent for initial seating. In service, the fluid load automatically provides the sealing force. **Warped or wavy** flanges, often resulting from welding or as found in glass-lined equipment, require gaskets that are softer or thicker than normal in order to adjust to high and low areas. Excessive thickness, even though installed in a groove, must be avoided or "mushrooming" and inadequate loading will result. Tongue-and-groove joints (Fig. 4) confine the gasket and thus are well adapted to accommodating such extra thickness.

In addition to the types (Figs. 5, 6, and 7) shown, as defined in the table (Fig. 37), there are the machined metal-profile

gasket (Fig. 8) and solid metal designs in flat, round, and either octagonal or oval API ring joint gaskets for extreme pressures and temperatures against steam, oil, and gases. Compressibilities are very low and depend on cross section. The envelope gasket (Fig. 3), usually polytetrafluoroethylene with a variety of cores, is particularly useful for extremely corrosive or noncontaminating service under average pressure conditions.

Cylindrical or concentric gasketing involves the use of a gland to provide retention and mechanical loading, as in the standard mechanical joint for cast-iron pipe (Fig. 10) or the condenser tube-sheet ferrule (Fig. 11). There are also gaskets shaped like cups and designed to be self-tightening under pressure (Fig. 12). The O ring (Fig. 13) located in an annular groove and precompressed as in the grooved flange, is a self-energized gasket. A cylindrical ring with internal single or double lips, also automatic in action, is quite common in pipe joints.

Beyond these types are many specialty gaskets designed for specific or proprietary use, for example, a seal for a removable drumhead.

The compressibility of various gasketing materials is shown in Fig. 37, and their common usage is listed in the accompanying table. Beyond rubber are many elastomeric materials generally similar in mechanical behavior but varying in temperature limits and fluid compatibility (see Sec. 6).

The **proper design** of a gasketed joint requires flange rigidity to avoid bowing, surface finish commensurate with gasket type and fluid pressure, and adequate bolt loading. The load must seat the gasket, i.e., cause the material to flow into and fill flange irregularities. It must also carry the fluid load with sufficient excess so that the residual pressure on the gasket exceeds the fluid pressure. These values, known respectively as the seating load y in lb/in² and the gasket factor m , vary with gasket material and thickness. The ASME Code for Unfired Pressure Vessels, Section VIII, gives sufficient detail

for typical joint design and tabulates values for y and m for various gasketing materials.

While high bolt loading is desirable for tight and enduring joints, it must not crush the gasket material. Crushing-strength values, which will vary with thickness and temperature, can be obtained from the gasket manufacturers. Consistent with condition of the flanges, the thinner the gasket the more efficient the joint.

Data on the design of **O-ring joints** are available from suppliers. The nominal pressure limit for O rings, based on typical mechanical clearances, is 1,500 lb/in² (10 MN/m²) without backup rings and 3,000 lb/in² (20 MN/m²) with backup rings. If clearances can be eliminated, as in a flanged joint with close metal-to-metal contact, no limit can be set. Other self-energizing joints, such as the boiler hand-hole plate (Fig. 9), need only sufficient load to effect an initial seal.

Valve disks are specialized gaskets designed for joints that are frequently broken and restored. Disks for globe valves (Fig. 14) are usually encased in a disk holder with a swivel mounting so that they do not rotate while closing. They are made of firm rubber for bib washers to hard rubber and phenolics for more severe service. Plastics such as nylon and polytetrafluoroethylene are also used. Pump valves (Fig. 15) are described in Sec. 14. Valve seats of rubber are used with metal valve disks on some pumps, e.g., the rotary drilling pump (Fig. 16). Plastics are also used for seats, notably in ball valves.

Dynamic packings include all packings that operate on moving surfaces. In functioning, to retain fluid under pressure, they carry the hydraulic load. When no pressure exists, as in many oil-seal applications, the packing is mechanically loaded as by a spring (Fig. 28) or by its own resiliency. Dynamic packings therefore operate as bearings, thereby indicating the need for lubrication to serve as both a separating film and a coolant. The presence of a film is vital for satisfactory service life, but it also means that leakage will occur. Low-viscosity fluids and high pressures add to leakage problems, as both require thin films to minimize leakage. This causes higher friction and results in heat, which is the one most detrimental factor in packing life. Deep packings reduce leakage but seriously increase frictional heat, particularly at high speeds. Normally the fluid being sealed serves as the lubricant. Thus, where oils are involved, maximum efficiency is obtained. Next in order are clean water, solvents, and fluids containing solids which progressively yield more unsatisfactory results unless supplemental lubrication is provided. Lubrication may be provided by using a lantern ring in the center of the set through which the more satisfactory lubricant is fed to the packings (Fig. 27). The preferred method of introducing the medium is to supply it at a slightly higher pressure, 5 to 10 lb/in² (3.5 to 7 kN/m²), than the material being sealed. The choice of fluid is governed by the media involved, since the two should be compatible. In cases of extreme contamination, the lantern is moved to the bottom of the box and is used as a means to introduce a flushing fluid. The lantern is also effective in excluding air from a device operating at negative heads. In centrifugal pumps equipped in this manner, it is called a **water seal**.

Dynamic packings are classified in three ways:

1. On the basis of shape of the surfaces: cylindrical, conical, spherical, or flat. Cylindrical packings are in turn classified according to whether they pack on the outside perimeter, as in piston packings (Figs. 17 to 20) or inside perimeter, as on rods or shafts (Figs. 21 to 28). Other examples are: conical, the

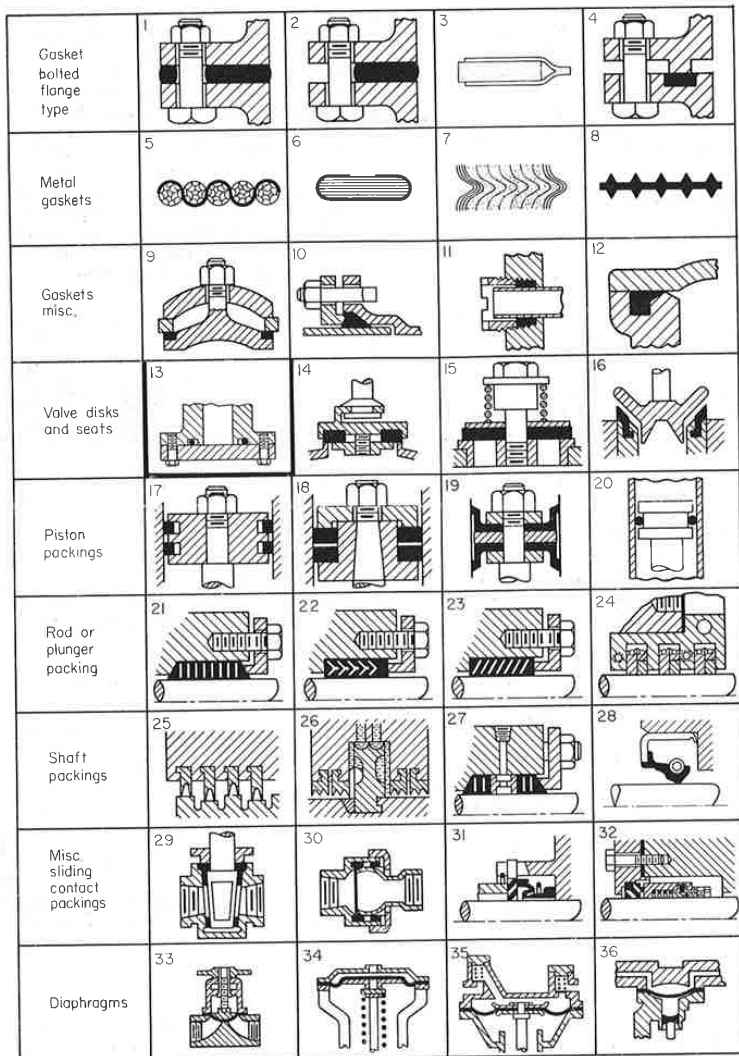
plug-cock lining (Fig. 29); spherical, the ball joint (Fig. 30); and flat, the mechanical seals (Figs. 31 and 32).

2. On the basis of the type of motion: rotary, oscillating, reciprocating, or helical (as in a rising-stem valve packing).

3. On the basis of nonautomatic: soft or jamb packings (tightened by external means, generally a gland); or automatic-preformed, molded shapes (self-tightening under pressure).

The selection of a packing is a matter of economics. In most cases several types are available, some of which, though expensive in the first place, yield exceptional service. A less costly choice might yield degraded service.

For reciprocating elements, the **O ring** (Fig. 20) is extremely simple; however, suppliers' data reveal it is a precision part requiring close tolerances. As an elastomeric material completely exposed to the operating fluid, it is subject to attack. Careful choice of elastomer is necessary to ensure compatibility or else either shrinkage or swelling may occur, causing early failure. It is best suited to medium pressure service from 1,500 to 3,000 lb/in² (10 to 20 MN/m²) with backup rings and intermittent movement, as in hydraulic cylinder or valve stem service. It is not a good choice for pump service. Backup rings are preferably of the heavy blocklike cross section in either leather or tetrafluoroethylene, avoiding the thin spiral type. The **split piston ring** (Fig. 17), generally of cast iron, is widely used in gas, oil, and steam engines. Large pistons frequently employ segmental rings similar to floating metal rod packings (Fig. 24) but facing outward. **Floating metal packing rings** are made of numerous radial or tangential segments, making it possible for them to contract on the shaft; they are assembled, generally, in sets of two to break the joints and are held together with garter springs. They are used for steam, gas, or air, in either engines or compressors under the most severe conditions of operation and pressure up to 35,000 lb/in². Normally oil lubrication is provided; however, for less severe service, filled polytetrafluoroethylene rings perform very well in dry gases without auxiliary lubrication. Step-, scarf-, or butt-cut rings of laminated cotton fabric, bonded with an elastomer or phenolic resin, are employed in water pumps, gasoline pumps, etc. They may float as cast-iron piston rings or be retained by a gland as in Fig. 18. **Cups** (Fig. 19) or their inverted form with the lip on the ID known as **flange packings**, are fully automatic and very tight. They are used principally for slow-speed applications such as air hoists. **Nested V and conical rings** (Figs. 22 and 23) are automatic, though often provided with a gland to effect initial fit. They are made of a wide range of materials from homogeneous elastomers through cotton or asbestos fabric reinforcement for severe duty. They range in hardness from soft and flexible to semirigid. Use of multiple rings allows them to be cut open for ease of installation and replacement. **Soft or jamb packings** are best suited for rod or plunger service, since an adjustable gland (Fig. 21) is required. They are normally formed in rectangular section with a butt joint staggered from ring to ring at installation. Many materials are employed, such as braided flax saturated with wax or viscous lubricants for water and aqueous solutions; braided asbestos similarly treated or often impregnated with polytetrafluoroethylene suspensoid for superior and more severe service; laminated rubberized cotton fabric for hot water, low-pressure steam and ammonia; rolled rubberized asbestos fabric for steam; and rolled or twisted metal foil for high-temperature and high-pressure conditions. Packings containing woven or braided asbestos fibers are also made



Figs. 1 to 36 Packings.

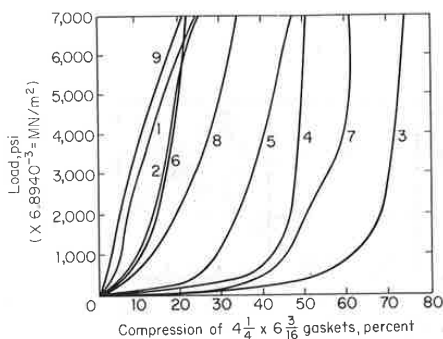


Fig. 37 Compressibility of gaskets.

from wire-inserted yarns to gain additional strength. For pipe expansion joints, see Sec. 8.

Rotary shafts are generally packed with adjustable soft packings, with the notable exception of the mechanical seals (Figs. 31 and 32), and where pressures are low, nested V or conical styles may be used. At zero or negligible pressures, the oil seal, a spring-loaded flange packing (Fig. 28), is very widely used. Where some leakage can be tolerated, the labyrinth (Fig. 25) and controlled gap seals are used, particularly on high-speed equipment such as steam and gas turbines. The **soft packings** are of the same general type as those used for reciprocating service, with the asbestos braid lubricated with grease and graphite or with polytetrafluoroethylene suspensoid. The latter is the most popular for typical applications on centrifugal pumps and valve stems. **Plastic packings** consisting of mixtures of unoriented asbestos fibers, graphite, soft metal particles, and a binder furnished either in bulk or in formed rings. To prevent loss of plastic from the stuffing box, end rings of metal foil, braid, or laminated fabric and rubber are generally used. For continuous rotary service, **automatic packings** are best restricted to low pressure because their tightness under high pressure tends to cause overheating. However, for intermittent service, as on valve stems, they are excellent.

Oil seals (Fig. 28) are unique flange packings having an elastomer lip generally bonded to a metal cup which is press-fitted into a smooth cylindrical bore. Basically, an oil seal is a flange packing with a flexible lip and a narrow contact area about $\frac{1}{16}$ in (1.6 mm) wide which, under pressure, causes extreme local heating and wear. They can therefore be recommended only for nonpressure service and are best against good lubricating media. To accommodate shaft runout up to 0.020 in (0.5 mm) depending on r/min, the lip is spring-loaded. Since the lip is completely exposed to the media, particular care should be taken to ensure compatibility between the elastomer and the fluid. Temperature is another element important in this area.

Mechanical, rotary, or end-face seals (Figs. 31 and 32) consist of radial planar surfaces, normal to the shaft axis, cooperating as a thrust bearing. One face, the seat, is generally resiliently gasketed to the housing (Fig. 38). The mating face is driven by the shaft and sealed thereon by a secondary seal such as a bellows (Fig. 31) or automatic-type packing (Fig. 32) permitting axial movement to compensate for end play and wear.

Initial bearing contact is through spring loading augmented in service by fluid pressure (Fig. 38). For extreme speeds, often the seat is mounted on the shaft and the seal in the stationary housing eliminates critical dynamic balancing of the seal assembly, transferring it to the simple seat. Accurate centering of the seal is necessary but is more economical and positive than dynamic balance of the seal. Abrasive materials, such as silt, must be kept from the seal faces. One means is a throat bushing installed in the bottom of the seal cavity. A clean fluid is directed at the faces at a pressure slightly higher than the pumpage, creating a counterflow through the bushing (Fig. 38), which also provides cooling. Retention of hazardous fluids or gases is accomplished by mounting two seals back to back and filling the space between with a lubricious barrier liquid compatible with the system at a pressure slightly over the sealed fluid (Fig. 39). Continuous circulation offers cooling and cleaning opportunities for optimum performance. In essence, the environment is controlled.

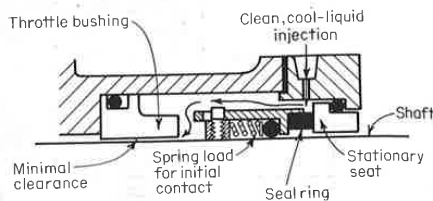


Fig. 38 Throttle bushing with restrictive clearance and counterflow.

There are other possibilities depending on the application. Mating bearing-seal faces may require chemical resistance. Wide choice of face materials, one of which is usually carbon, offers an extreme range of pressures, service, and chemical conditions at very high efficiency. Typical mating faces are cast iron and bronze for mild conditions, with ceramics, cermets, carbides, stainless steels, and related alloys for severe

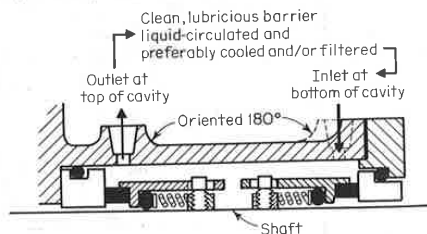


Fig. 39 Back-to-back seal installation with barrier liquid for hazardous fluids.

applications. Probably one of the simplest designs is the bellows-supported phenolic-cotton washer bearing against a machined face of the cast-iron pump body of an automotive water pump (Fig. 31). A more refined, flexible design is shown in Fig. 32, and detailed in part in Fig. 40, which illustrates unbalanced and balanced constructions and how they are respectively suitable for pressures up to 250 and 3,000 lb/in² (1.7 and 20 MN/m²). The purpose of balancing is to reduce the

unit face load to approximately 60 to 70 percent of the unit fluid load. A complete balance is not practical.

For extremely high speeds, where it is desirable to eliminate all rubbing contact, the **labyrinth seal** (Fig. 25) is chosen. This seal is not fluid-tight but restricts a serious flow by means of a tortuous path and induced turbulence. It is widely used on steam turbines (Sec. 9). Where no leakage is permissible, a liquid seal based on the U-tube principle (Fig. 26) may be used. The natural weight of the liquid is amplified by centrifugal force so that under high r/min a fair pressure differential can be sealed. Another noncontacting seal is the **controlled gap seal** which is being used on gas turbines where pressure differentials are not excessive and a small amount of leakage can be tolerated. The seal consists of a ring with a shaft clearance in the range of 0.0005 to 0.0015 in (0.013 to 0.038 mm) and is made of such materials that this clearance is maintained at all operating temperatures. Usually one end of the ring is faced to form an axial seal against the inside of its housing.

Diaphragms are a form of dynamic packing but include the requirements of a gasket where they are gripped or held in position. In service they are leakless, although generally limited in travel. By literally rolling one cylinder inside another, considerable increase in travel is possible. This type is often called a bellows, and a simple application is the mechanical seal suspension shown in Fig. 31. In the diaphragm valve (Fig. 33) the diaphragm replaces both the conventional stem packing and valve disk. **Diaphragms** of fabric such as cotton or nylon (except friable materials such as glass) covered with an elastomer suitable for the media and temperatures involved are used

in pumps (fuel pump, Fig. 35) and in motors (Fig. 34) to operate valves, switches, and other controls. Correctly designed diaphragms are made with slack to permit a natural rolling action. Flat sheet stock should be used only where limited travel is desired. An unusual application is found in the **Pulsa-feeder pump** (Fig. 36) in that the diaphragm is under

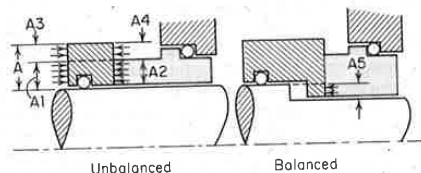


Fig. 40 Mechanical seal-face loading. A = gross area under fluid load; A_1 = effective fluid-load area for closing the seal; A_2 = pressure-gradient area where average unit load equals that of the fluid on A_1 (shaft clearance ignored); A_3 , A_4 = fluid-load areas which balance each other; A_5 = balancing area, normally such that $A_2 + A_5$ will reduce the average unit load on this face to 60 to 70 percent of the unit fluid load on A_1 .

balanced fluid pressure on both sides and is therefore unstressed. Thin sheet metal, usually with concentric corrugations, is used where movement is limited and long life is desired. However, where considerable movement is involved, the possibility of fatigue must be considered.

PIPE AND PIPE FITTINGS

by Reno C. King

REFERENCES: King, "Piping Handbook," McGraw-Hill. ANSI Code for Power Piping. ASTM Specifications. Tube Turns Division, Natural Cylinder Gas Co., catalogs. Crane Co., catalogs and bulletins. Grinnell Co., Inc., "Piping Design and Engineering." M. W. Kellogg Co., "Design of Piping Systems," Wiley. United States Steel Co., catalogs and bulletins.

PIPING STANDARDS

Standardization in the piping industry is the function of many groups, among whom are the American Society for Testing and Materials (ASTM), the American National Standards Institute (ANSI), the American Water Works Association