MACHINERY'S HANDBOOK

23rd Edition

A Reference Book for the Mechanical Engineer, Designer, Manufacturing Engineer, Draftsman, Toolmaker, and Machinist

MACHINERY'S HANDBOOK

23rd Edition

By ERIK OBERG, FRANKLIN D. JONES and HOLBROOK L. HORTON

HENRY H. RYFFEL, *Editor*
ROBERT E. GREEN, *Associate Editor*
JAMES H. GERONIMO, *Associate Editor*

INDUSTRIAL PRESS INC.
New York

Library of Congress Cataloging-in-Publication Data

Oberg, Erik, 1881–
Machinery's handbook.

Includes index.
1. Mechanical engineering — Handbooks, manuals, etc. I. Jones, Franklin Day, 1879–
II. Horton, Holbrook Lynedon, 1907–
III. Ryffel, Henry H. IV. Title.
TJ151.0245 1988 621.8'0212 87-31093
ISBN 0-8311-1200-X
ISBN 0-8311-0900-9 (Thumb Indexed)

INDUSTRIAL PRESS INC.
200 Madison Avenue
New York, New York 10016-4078

MACHINERY'S HANDBOOK
Twenty-Third Edition, Third Printing, 1990

Recent composition by Dix Type Inc., Syracuse, New York.
Original composition by Machine Composition Company of Boston.
23RD EDITION printed and bound by
National Publishing Company, Philadelphia, Pennsylvania.

PREFACE

MACHINERY'S HANDBOOK, since the publication of its first edition 75 years ago, has continually increased in popularity throughout the world. The HANDBOOK is now used extensively as a standard work of reference in all countries where machines or other mechanical products are designed and manufactured.

The aim of the publisher is to make each new edition of greater practical value than the preceding one. In the 23rd edition, this objective has been accomplished by rearranging much of the material to make it more accessible to readers looking for information on specific subjects; and by revisions to the HANDBOOK which are carried out as frequently as is practical for a voluminous work that must necessarily be printed in large quantities to meet the constant demand for it both here and abroad.

The new material covers a large variety of subjects that are important to designers, manufacturing engineers, machinists, and builders of everything mechanical. Recent or revised engineering standards are included, together with a large amount of general information and mechanical data representing the latest designing and manufacturing practice.

In selecting material from the almost limitless supply of data pertaining to the mechanical field, the plan is to consider the requirements of the design and production departments of both large and small manufacturing plants as well as the needs of jobbing shops, trade schools, and technical schools.

It should be noted that throughout the HANDBOOK step-by-step worked-out examples are provided where needed to illustrate the use of formulas or to clarify a method of calculation. The formulas themselves are arranged in the best sequence for use with a calculator or computer; wherever useful, tables or charts based on these formulas have been provided.

As in previous editions, increased coverage has been provided for metric standards and data. This expanded coverage recognizes the international nature of manufacturing and the need for common dimensions to serve as the basis for interchangeability of manufactured products. Metric data are provided for the most commonly used elements in mechanical products including: metric module involute splines; M- and MJ-profile screw threads; nineteen types of metric screws, bolts, and nuts; prevailing torque hex nuts; and plain washers. Other areas that have been reviewed and revised include: cams and cam design; continued and conjugate fractions for finding factors for gear ratios; series approximations of functions; derivatives of functions; combined stresses in machine elements; cumulative fatigue damage; strength of perforated metal; geometric dimensioning and tolerancing; conversion coatings of metals; properties and treatment of ferrous and nonferrous materials; polygon shafts; die casting; silent chain; and calculating dimensions for gear replacements.

The ever-increasing use of numerical control in manufacturing requires that information about numerical control be available. For this reason, 48 pages of selected topics, arranged for quick reference, have been added in this edition.

Data and information from many American National Standards Institute (ANSI) Standards will be found in the HANDBOOK and have been extracted with permission of the publisher, the American Society of Mechanical Engineers, United Engineering Center, 345 East 47 Street, New York, New York 10017. These Standards are revised periodically; ASME should be contacted for information concerning the current edition of any particular document. In addition to American and British Standards, data and information from many other sources have been used with permission and the individual organizations acknowledged where this information is cited in the HANDBOOK.

Material from ANSI Standards B7.1-1978, B74.2-1982, B74.3-1974, B74.13-1982, B212.1-1984, B212.4-1986, and B212.5-1986 is reproduced with permission. These Standards are copyrighted by the American National Standards Institute. Copies of these Standards may be purchased from the American National Standards Institute at 1430 Broadway, New York, NY 10018.

On August 24, 1969, the American Standards Association was reconstituted as the United States of America Standards Institute and standards approved as American Standards were designated as USA Standards. There was no change in their index identification or technical content. On October 6, 1969, the name was changed to American National Standards Institute. The present standards' designation is ANSI instead of ASA or USAS. Standards previously adopted by the American Standards Association and not revised are still referred to in the HANDBOOK by the designation ASA.

The editors appreciate the contributions in the 23rd Edition of Mr. Jerome Mogul to the materials and process sections; Professor Edward E. Messal for the three-dimensional stress presentation; Mr. James J. Childs and James Childs Jr. for the new, extensive coverage of numerical control; and Mr. Holbrook L. Horton, Editor Emeritus, for his continuing interest and counsel in the preparation of this new edition.

Directing the editor's attention to a possible defect or to the omission of some matter considered of general value often renders a service to the entire mechanical industry. For this reason and because we desire to perfect the HANDBOOK as far as possible, all criticisms and suggestions about either revisions or the inclusion of new matter are welcome.

Henry H. Ryffel, *Editor*

CONTENTS

Mathematics

Mechanics

Strength of Materials

Strength of Materials (*Continued*)

Properties, Treatment and Testing of Materials

Dimensioning, Gaging and Measuring

Tooling and Toolmaking

Machining Operations

Manufacturing Processes

Manufacturing Processes (*Continued*)

Fasteners

Threads and Threading

Threads and Threading (*Continued*)

Gears, Splines and Cams

Bearings and Other Machine Elements

Measuring Units

Index

Mathematical Signs and Commonly Used Abbreviations

$+$	Plus (sign of addition)	π	Pi (3.1416)
$+$	Positive	Σ	Sigma (sign of summation)
$-$	Minus (sign of subtraction)	ω	Omega (angles measured in radians)
$-$	Negative	g	Acceleration due to gravity (32.16 ft. per sec. per sec.)
$\pm$ ($\mp$)	Plus or minus (minus or plus)	i (or j)	Imaginary quantity ($\sqrt{-1}$)
$\times$	Multiplied by (multiplication sign)	sin	Sine
$\cdot$	Multiplied by (multiplication sign)	cos	Cosine
$\div$	Divided by (division sign)	tan	Tangent
$/$	Divided by (division sign)	cot	Cotangent
$:$	Is to (in proportion)	sec	Secant
$=$	Equals	csc	Cosecant
$\neq$	Is not equal to	vers	Versed sine
$\equiv$	Is identical to	covers	Coversed sine
$::$	Equals (in proportion)	$\sin^{-1}a$	Arc the sine of which is a
$\cong$	Approximately equals	arcsin a	
$\approx$		$(\sin a)^{-1}$	Reciprocal of sin a ($1 \div \sin a$)
$>$	Greater than	$\sin^n x$	nth power of sin x
$<$	Less than	$\sinh x$	Hyperbolic sine of x
$\geqq$	Greater than or equal to	$\cosh x$	Hyperbolic cosine of x
$\leqq$	Less than or equal to	Δ	Delta (increment of)
$\rightarrow$	Approaches as a limit	δ	Delta (variation of)
$\propto$	Varies directly as	d	Differential (in calculus)
$\therefore$	Therefore	∂	Partial differentiation (in calculus)
$\sqrt{\ }$	Square root	$\int$	Integral (in calculus)
$\sqrt[3]{\ }$	Cube root	$\int_b^a$	Integral between the limits a and b
$\sqrt[4]{\ }$	4th root	$!$	$5! = 1 \times 2 \times 3 \times 4 \times 5$
$\sqrt[n]{\ }$	nth root	$\angle$	Angle
a^2	a squared (2d power of a)	$\llcorner$	Right angle
a^3	a cubed (3d power of a)	$\perp$	Perpendicular to
a^4	4th power of a	$\triangle$	Triangle
a^n	nth power of a	$\bigcirc$	Circle
a^{-n}	$1 \div a^n$	$\square$	Parallelogram
$\frac{1}{n}$	Reciprocal value of n	$^\circ$	Degree (circular arc or temperature)
log	Logarithm	$'$	Minutes or feet
$\log_e$	Natural or Napierian logarithm	$''$	Seconds or inches
ln		a'	a prime
e	Base of natural logarithms (2.71828)	a''	a double prime
lim	Limit value (of an expression)	a_1	a sub one
∞	Infinity	a_2	a sub two
α	Alpha	a_n	a sub n
β	Beta	( )	Parentheses
γ	Gamma (commonly used to denote angles)	[ ]	Brackets
θ	Theta	{ }	Braces
ϕ	Phi		
μ	Mu (coefficient of friction)		

Prime Numbers and Factors of Numbers

The *factors* of a given number are those numbers which when multiplied together give a product equal to that number; thus, 2 and 3 are factors of 6; and 5 and 7 are factors of 35.

A *prime number* is one which has no factors except itself and 1. Thus, 3, 5, 7, 11, etc., are prime numbers. A factor which is a prime number is called a *prime factor*.

The accompanying "Prime Number and Factor Tables" give the smallest prime factor of all odd numbers from 1 to 9600, and can be used for finding all the factors for numbers up to this limit. For example, find the factors of 931. In the column headed "900," and in the line indicated by "31" in the left-hand column, the smallest prime factor is found to be 7. As this leaves another factor 133 (since $931 \div 7 = 133$), find the smallest prime factor of this number. In the column headed "100" and in the line "33," this is found to be 7, leaving a factor 19. This latter is a prime number; hence, the factors of 931 are $7 \times 7 \times 19$. Where no factor is given for a number in the factor table, it indicates that the number is a prime number.

The last page of the tables lists all prime numbers from 9551 through 18691; and can be used to identify quickly all unfactorable numbers in that range.

For factoring, the following general rules will be found useful:

2 is a factor of any number the right-hand figure of which is an even number or 0. Thus, $28 = 2 \times 14$, and $210 = 2 \times 105$.

3 is a factor of any number the sum of the figures of which is evenly divisible by 3. Thus, 3 is a factor of 1869, because $1 + 8 + 6 + 9 = 24 \div 3 = 8$.

4 is a factor of any number the two right-hand figures of which, considered as one number, are evenly divisible by 4. Thus, 1844 has a factor 4, because $44 \div 4 = 11$.

5 is a factor of any number the right-hand figure of which is 0 or 5. Thus, $85 = 5 \times 17$; $70 = 5 \times 14$.

Tables of prime numbers and factors of numbers are particularly useful for calculations involving change-gear ratios for compound gearing, dividing heads, gear-generating machines, and mechanical designs having gear trains.

Example 1: A set of four gears is required in a mechanical design to provide an overall gear ratio of $4104 \div 1200$. Furthermore, no gear in the set is to have more than 120 teeth or less than 24 teeth. Determine the tooth numbers.

First, as explained previously, the factors of 4104 are determined to be: $2 \times 2 \times 2 \times 3 \times 3 \times 57 = 4104$. Next, the factors of 1200 are determined: $2 \times 2 \times 2 \times 2 \times 5 \times 5 \times 3 = 1200$. Therefore, $\frac{4104}{1200} = \frac{2 \times 2 \times 2 \times 3 \times 3 \times 57}{2 \times 2 \times 2 \times 2 \times 5 \times 5 \times 3} = \frac{72 \times 57}{24 \times 50}$. If the factors had been combined differently, say, to give $\frac{72 \times 57}{16 \times 75}$, then the 16-tooth gear in the denominator would not satisfy the requirement of no less than 24 teeth.

Example 2: Factor the number 25078 into two numbers neither of which is larger than 200.

The first factor of 25078 is obviously 2, leaving $25078 \div 2 = 12539$ to be factored further. However, from the last table it is seen that 12539 is a prime number; therefore, no solution exists.

Prime Number and Factor Table

From to	0 100	100 200	200 300	300 400	400 500	500 600	600 700	700 800	800 900	900 1000	1000 1100	1100 1200
1	P	P	3	7	P	3	P	P	3	17	7	3
3	P	P	7	3	13	P	3	19	11	3	17	P
5	P	3	5	5	3	5	5	3	5	5	3	5
7	P	P	3	P	11	3	P	7	3	P	19	3
9	3	P	11	3	P	P	3	P	P	3	P	P
11	P	3	P	P	3	7	13	3	P	P	3	11
13	P	P	3	P	7	3	P	23	3	11	P	3
15	3	5	5	3	5	5	3	5	5	3	5	5
17	P	3	7	P	3	11	P	3	19	7	3	P
19	P	7	3	11	P	3	P	P	3	P	P	3
21	3	11	13	3	P	P	3	7	P	3	P	19
23	P	3	P	17	3	P	7	3	P	13	3	P
25	5	5	3	5	5	3	5	5	3	5	5	3
27	3	P	P	3	7	17	3	P	P	3	13	7
29	P	3	P	7	3	23	17	3	P	P	3	P
31	P	P	3	P	P	3	P	17	3	7	P	3
33	3	7	P	3	P	13	3	P	7	3	P	11
35	5	3	5	5	3	5	5	3	5	5	3	5
37	P	P	3	P	19	3	7	11	3	P	17	3
39	3	P	P	3	P	7	3	P	P	3	P	17
41	P	3	P	11	3	P	P	3	29	P	3	7
43	P	11	3	7	P	3	P	P	3	23	7	3
45	3	5	5	3	5	5	3	5	5	3	5	5
47	P	3	13	P	3	P	P	3	7	P	3	31
49	7	P	3	P	P	3	11	7	3	13	P	3
51	3	P	P	3	11	19	3	P	23	3	P	P
53	P	3	11	P	3	7	P	3	P	P	3	P
55	5	5	3	5	5	3	5	5	3	5	5	3
57	3	P	P	3	P	P	3	P	P	3	7	13
59	P	3	7	P	3	13	P	3	P	7	3	19
61	P	7	3	19	P	3	P	P	3	31	P	3
63	3	P	P	3	P	P	3	7	P	3	P	P
65	5	3	5	5	3	5	5	3	5	5	3	5
67	P	P	3	P	P	3	23	13	3	P	11	3
69	3	13	P	3	7	P	3	P	11	3	P	7
71	P	3	P	7	3	P	11	3	13	P	3	P
73	P	P	3	P	11	3	P	P	3	7	29	3
75	3	5	5	3	5	5	3	5	5	3	5	5
77	7	3	P	13	3	P	P	3	P	P	3	11
79	P	P	3	P	P	3	7	19	3	11	13	3
81	3	P	P	3	13	7	3	11	P	3	23	P
83	P	3	P	P	3	11	P	3	P	P	3	7
85	5	5	3	5	5	3	5	5	3	5	5	3
87	3	11	7	3	P	P	3	P	P	3	P	P
89	P	3	17	P	3	19	13	3	7	23	3	29
91	7	P	3	17	P	3	P	7	3	P	P	3
93	3	P	P	3	17	P	3	13	19	3	P	P
95	5	3	5	5	3	5	5	3	5	5	3	5
97	P	P	3	P	7	3	17	P	3	P	P	3
99	3	P	13	3	P	P	3	17	29	3	7	11

Prime Number and Factor Table

From to	1200 1300	1300 1400	1400 1500	1500 1600	1600 1700	1700 1800	1800 1900	1900 2000	2000 2100	2100 2200	2200 2300	2300 2400
1	P	P	3	19	P	3	P	P	3	11	31	3
3	3	P	23	3	7	13	3	11	P	3	P	7
5	5	3	5	5	3	5	5	3	5	5	3	5
7	17	P	3	11	P	3	13	P	3	7	P	3
9	3	7	P	3	P	P	3	23	7	3	47	P
11	7	3	17	P	3	29	P	3	P	P	3	P
13	P	13	3	17	P	3	7	P	3	P	P	3
15	3	5	5	3	5	5	3	5	5	3	5	5
17	P	3	13	37	3	17	23	3	P	29	3	7
19	23	P	3	7	P	3	17	19	3	13	7	3
21	3	P	7	3	P	P	3	17	43	3	P	11
23	P	3	P	P	3	P	P	3	7	11	3	23
25	5	5	3	5	5	3	5	5	3	5	5	3
27	3	P	P	3	P	11	3	41	P	3	17	13
29	P	3	P	11	3	7	31	3	P	P	3	17
31	P	11	3	P	7	3	P	P	3	P	23	3
33	3	31	P	3	23	P	3	P	19	3	7	P
35	5	3	5	5	3	5	5	3	5	5	3	5
37	P	7	3	29	P	3	11	13	3	P	P	3
39	3	13	P	3	11	37	3	7	P	3	P	P
41	17	3	11	23	3	P	7	3	13	P	3	P
43	11	17	3	P	31	3	19	29	3	P	P	3
45	3	5	5	3	5	5	3	5	5	3	5	5
47	29	3	P	7	3	P	P	3	23	19	3	P
49	P	19	3	P	17	3	43	P	3	7	13	3
51	3	7	P	3	13	17	3	P	7	3	P	P
53	7	3	P	P	3	P	17	3	P	P	3	13
55	5	5	3	5	5	3	5	5	3	5	5	3
57	3	23	31	3	P	7	3	19	11	3	37	P
59	P	3	P	P	3	P	11	3	29	17	3	7
61	13	P	3	7	11	3	P	37	3	P	7	3
63	3	29	7	3	P	41	3	13	P	3	31	17
65	5	3	5	5	3	5	5	3	5	5	3	5
67	7	P	3	P	P	3	P	7	3	11	P	3
69	3	37	13	3	P	29	3	11	P	3	P	23
71	31	3	P	P	3	7	P	3	19	13	3	P
73	19	P	3	11	7	3	P	P	3	41	P	3
75	3	5	5	3	5	5	3	5	5	3	5	5
77	P	3	7	19	3	P	P	3	31	7	3	P
79	P	7	3	P	23	3	P	P	3	P	43	3
81	3	P	P	3	41	13	3	7	P	3	P	P
83	P	3	P	P	3	P	7	3	P	37	3	P
85	5	5	3	5	5	3	5	5	3	5	5	3
87	3	19	P	3	7	P	3	P	P	3	P	7
89	P	3	P	7	3	P	P	3	P	11	3	P
91	P	13	3	37	19	3	31	11	3	7	29	3
93	3	7	P	3	P	11	3	P	7	3	P	P
95	5	3	5	5	3	5	5	3	5	5	3	5
97	P	11	3	P	P	3	7	P	3	13	P	3
99	3	P	P	3	P	7	3	P	P	3	11	P

Prime Number and Factor Table

From to	2400 2500	2500 2600	2600 2700	2700 2800	2800 2900	2900 3000	3000 3100	3100 3200	3200 3300	3300 3400	3400 3500	3500 3600
1	7	41	3	37	P	3	P	7	3	P	19	3
3	3	P	19	3	P	P	3	29	P	3	41	31
5	5	3	5	5	3	5	5	3	5	5	3	5
7	29	23	3	P	7	3	31	13	3	P	P	3
9	3	13	P	3	53	P	3	P	P	3	7	11
11	P	3	7	P	3	41	P	3	13	7	3	P
13	19	7	3	P	29	3	23	11	3	P	P	3
15	3	5	5	3	5	5	3	5	5	3	5	5
17	P	3	P	11	3	P	7	3	P	31	3	P
19	41	11	3	P	P	3	P	P	3	P	13	3
21	3	P	P	3	7	23	3	P	P	3	11	7
23	P	3	43	7	3	37	P	3	11	P	3	13
25	5	5	3	5	5	3	5	5	3	5	5	3
27	3	7	37	3	11	P	3	53	7	3	23	P
29	7	3	11	P	3	29	13	3	P	P	3	P
31	11	P	3	P	19	3	7	31	3	P	47	3
33	3	17	P	3	P	7	3	13	53	3	P	P
35	5	3	5	5	3	5	5	3	5	5	3	5
37	P	43	3	7	P	3	P	P	3	47	7	3
39	3	P	7	3	17	P	3	43	41	3	19	P
41	P	3	19	P	3	17	P	3	7	13	3	P
43	7	P	3	13	P	3	17	7	3	P	11	3
45	3	5	5	3	5	5	3	5	5	3	5	5
47	P	3	P	41	3	7	11	3	17	P	3	P
49	31	P	3	P	7	3	P	47	3	17	P	3
51	3	P	11	3	P	13	3	23	P	3	7	53
53	11	3	7	P	3	P	43	3	P	7	3	11
55	5	5	3	5	5	3	5	5	3	5	5	3
57	3	P	P	3	P	P	3	7	P	3	P	P
59	P	3	P	31	3	11	7	3	P	P	3	P
61	23	13	3	11	P	3	P	29	3	P	P	3
63	3	11	P	3	7	P	3	P	13	3	P	7
65	5	3	5	5	3	5	5	3	5	5	3	5
67	P	17	3	P	47	3	P	P	3	7	P	3
69	3	7	17	3	19	P	3	P	7	3	P	43
71	7	3	P	17	3	P	37	3	P	P	3	P
73	P	31	3	47	13	3	7	19	3	P	23	3
75	3	5	5	3	5	5	3	5	5	3	5	5
77	P	3	P	P	3	13	17	3	29	11	3	7
79	37	P	3	7	P	3	P	11	3	31	7	3
81	3	29	7	3	43	11	3	P	17	3	59	P
83	13	3	P	11	3	19	P	3	7	17	3	P
85	5	5	3	5	5	3	5	5	3	5	5	3
87	3	13	P	3	P	29	3	P	19	3	11	17
89	19	3	P	P	3	7	P	3	11	P	3	37
91	47	P	3	P	7	3	11	P	3	P	P	3
93	3	P	P	3	11	41	3	31	37	3	7	P
95	5	3	5	5	3	5	5	3	5	5	3	5
97	11	7	3	P	P	3	19	23	3	43	13	3
99	3	23	P	3	13	P	3	7	P	3	P	59