

36. UNITS AND CONVERSIONS

- Units are essential when describing real things.
- Good engineering practice demands that each number should always be accompanied with a unit.

36.1 HOW TO USE UNITS

• This table does not give an exhaustive list of conversion factors, but instead a minimal (but fairly complete) set is given. From the values below any conversion value can be derived. If you are not sure about this, ask the instructor to show you how.

- A simple example of unit conversion is given below,

**a simple unit conversion example:

Given,

$$d_x = 10m \quad d_y = 5ft$$

Find the distance 'd',

$$d = \sqrt{d_x^2 + d_y^2}$$

$$\therefore d = \sqrt{(10m)^2 + (5ft)^2}$$

$$\therefore d = \sqrt{100m^2 + 25ft^2}$$

$$\therefore d = \sqrt{100m^2 + 25ft^2 \left(\frac{0.3048m}{1ft} \right)^2}$$

$$\therefore d = \sqrt{100m^2 + 25ft^2 (0.092903) \frac{m^2}{ft^2}}$$

$$\therefore d = \sqrt{100m^2 + 25(0.092903)m^2}$$

$$\therefore d = \sqrt{102.32m^2} = 10.12m$$

keep the units in the equation

multiply by 1

From the tables

$$1ft = 0.3048m$$

$$\therefore 1 = \frac{0.3048m}{1ft}$$

cancel out units

36.2 HOW TO USE SI UNITS

1. Beware upper/lower case letter in many cases they can change meanings.

e.g. m = milli, mega

2. Try to move prefixes out of the denominator of the units.

e.g., N/cm or KN/m

3. Use a slash or exponents.

e.g., (kg•m/s²) or (kg•m•s⁻²)

4. Use a dot in compound units.

e.g., N•m

5. Use spaces to divide digits when there are more than 5 figures, commas are avoided because their use is equivalent to decimal points in some cultures.

• In some cases units are non-standard. There are two major variations US units are marked with 'US' and Imperial units are marked with 'IMP'.

36.3 THE TABLE

Major Division

Distance

1 ft. (feet) = 12 in. (inches) = 0.3048 m (meter)

1 mile = 1760 yards = 5280 ft = 1.609km

1 in.(inch) = 2.540 cm

1 yd (yard) = 3 ft.

1 nautical mile = 6080 ft. = 1852 m = 1.150782 mi

1 micron = 10⁻⁶ m

1 angstrom = 10⁻¹⁰ m

1 mil = 10⁻⁶ m

1 acre = 43,560 ft. = 0.4047 hectares

1 furlong = 660 ft
 1 lightyear = 9.460528e15 m
 1 parsec = 3.085678e16 m

Area

1 acre = 43,559.66 ft²
 1 Hectare (ha) = 10,000 m²
 1 Hectare (ha) = 10,000 m²
 1 Hectare (ha) = 10,000 m²
 1 Hectare (ha) = 10,000 m²

Velocity

1 mph = 0.8689762 knot

Angle

1 rev = 2PI radians = 360 degrees = 400 gradians
 1 degree = 60 minutes
 1 minute = 60 seconds

Volume

1 US gallon = 231 in³
 1 CC = 1 cm³
 1 IMP gallon = 277.274 in³
 1 barrel = 31 IMP gal. = 31.5 US gal.
 1 US gal. = 3.785 l = 4 quarts = 8 pints = 16 cups
 1 liter (l) = 0.001 m³ = 2.1 pints (pt) = 1.06 quarts (qt) = 0.26 gallons (gal)
 1 qt (quart) = 0.9464 l
 1 cup (c) = 0.2365882 l = 8 USoz
 1 US oz = 8 U.S. drams = 456.0129 drops = 480 US minim = 1.040842

IMP oz

= 2 tablespoons = 6 teaspoons
 1 IMP gal. = 1.201 U.S. gal.
 1 US pint = 16 US oz
 1 IMP pint = 20 IMP oz
 1tablespoon = 0.5 oz.
 1 bushel = 32 quarts
 1 peck = 8 quarts

Force/Mass

1 N (newton) = 1 kg•m/s² = 100,000 dyne
 1 dyne = 2.248*10⁻⁶ lb. (pound)
 1 kg = 9.81 N (on earth surface) = 2.2046 lb
 1lb = 16 oz. (ounce) = 4.448N

1 oz. = 28.35 g (gram) = 0.2780N
 1 lb = 0.03108 slug
 1 kip = 1000 lb.
 1 slug = 14.59 kg
 1 imperial ton = 2000 lb = 907.2 kg
 1 metric tonne = 1000 kg
 1 troy oz = 480 grain (gr)
 1 g = 5 carat
 1 pennyweight = 24 grain
 1 stone = 14 lb
 1 long ton = 2240 lb
 1 short ton = 2000 lb

Pressure

1 Pascal (Pa) = $1 \text{ N/m}^2 = 6.895 \text{ kPa}$
 1 atm (metric atmos.) = 760 mmHg at $0^\circ\text{C} = 14.223 \text{ lb/in}^2 = 1.0132 \cdot 10^5 \text{ N/m}^2$
 1 psi = 2.0355 in. Hg at 32F = 2.0416 in. Hg at 62F
 1 microbar = 0.1 N/m^2

Scale/Magnitude

atto (a) = 10^{-18}
 femto (f) = 10^{-15}
 pico (p) = 10^{-12}
 nano (n) = 10^{-9}
 micro (μ) = 10^{-6}
 milli (m) = 10^{-3}
 centi (c) 10^{-2}
 deci (d) = 10^{-1}
 deka (da) = 10
 hecto (H) = 10^2
 kilo (K) = 10^3
 mega (M) = 10^6
 giga (G) = 10^9
 tera (T) = 10^{12}
 peta (P) = 10^{15}
 exa (E) = 10^{18}

Power

1 h.p. (horsepower) = 745.7 W (watts) = 2.545 BTU/hr. = 550 ft.lb./sec.
 1 ft•lb/s = 1.356 W
 1 J (joule) = 1 N•m = 10^7 ergs = 0.2389 cal.
 1 W = 1 J/s

$$1 \text{ ev} = 1.60219 \times 10^{-19} \text{ J}$$

$$1 \text{ erg} = 10^{-7} \text{ J}$$

Temperature

$$^{\circ}\text{F} = [(^{\circ}\text{C} \times 9) / 5] + 32, \text{ } ^{\circ}\text{C} = \text{Celsius (Centigrade)}, \text{ F} = \text{Fahrenheit}$$

K = Kelvin

$$\text{Rankine (R)} = \text{F} - 459.666$$

$$0.252 \text{ calories} = 1 \text{ BTU (British Thermal Unit)}$$

$$-273.2 \text{ } ^{\circ}\text{C} = -459.7 \text{ } ^{\circ}\text{F} = 0 \text{ K} = 0 \text{ R} = \text{absolute zero}$$

$$0 \text{ } ^{\circ}\text{C} = 32 \text{ } ^{\circ}\text{F} = 273.3 \text{ K} = 491.7 \text{ R} = \text{Water Freezes}$$

$$100 \text{ } ^{\circ}\text{C} = 212 \text{ } ^{\circ}\text{F} = 373.3 \text{ K} = 671.7 \text{ R} = \text{Water Boils (1 atm. pressure)}$$

$$1 \text{ therm} = 100,000 \text{ BTU}$$

Mathematical

$$\pi \text{ radians} = 3.1416 \text{ radians} = 180 \text{ degrees} = 0.5 \text{ cycles}$$

$$1 \text{ Hz} = 1 \text{ cycle/sec.}$$

$$1 \text{ rpm (revolutions per minute)} = 60 \text{ RPS (Revolutions per second)} = 60 \text{ Hz}$$

$$1 \text{ fps (foot per second)} = 1 \text{ ft/sec}$$

$$1 \text{ mph (miles per hour)} = 1 \text{ mi./hr.}$$

$$1 \text{ cfm (cubic foot per minute)} = 1 \text{ ft}^3/\text{min.}$$

$$e = 2.718$$

Time

$$1 \text{ Hz (hertz)} = 1 \text{ s}^{-1}$$

$$1 \text{ year} = 365 \text{ days} = 52 \text{ weeks} = 12 \text{ months}$$

$$1 \text{ leap year} = 366 \text{ days}$$

$$1 \text{ day} = 24 \text{ hours}$$

$$1 \text{ fortnight} = 14 \text{ days}$$

$$1 \text{ hour} = 60 \text{ min.}$$

$$1 \text{ min} = 60 \text{ seconds}$$

$$1 \text{ millenium} = 1000 \text{ years}$$

$$1 \text{ century} = 100 \text{ years}$$

$$1 \text{ decade} = 10 \text{ years}$$

Physical Constants

$$R = 1.987 \text{ cal/mole K} = \text{ideal gas law constant}$$

$$k = \text{Boltzmann's constant} = 1.3 \times 10^{-16} \text{ erg/K} = 1.3 \times 10^{-23} \text{ J/K}$$

$$h = \text{Planck's constant} = 6.62 \times 10^{-27} \text{ erg-sec} = 6.62 \times 10^{-34} \text{ J.sec}$$

$$\text{Avagadro's number} = 6.02 \times 10^{23} \text{ atoms/atomic weight}$$

$$\text{density of water} = 1 \text{ g/cm}^3$$

$$\text{electron charge} = 1.60 \times 10^{-19} \text{ coul.}$$

$$\text{electron rest mass} = 9.11 \times 10^{-31} \text{ kg}$$

$$\text{proton rest mass} = 1.67 \times 10^{-27} \text{ kg}$$

speed of light (c) = 3.00×10^{10} cm/sec
speed of sound in dry air 25 C = 331 m/s
gravitational constant = 6.67×10^{-11} Nm²/kg²
permittivity of free space = 8.85×10^{-12} farad/m
permeability of free space = 1.26×10^{-6} henry/m
mean radius of earth = 6370 Km
mass of earth = 5.98×10^{24} kg

Electromagnetic

magnetic flux = weber (We) = 10^8 maxwell
inductance = henry
magnetic flux density = tesla (T) = 10^4 gauss
magnetic intensity = ampere/m = $0.004 \times \text{PI}$ oersted
electric flux density = coulomb/m²
capacitance = farad
permeability = henry/m
electric field strength = V/m
luminous flux = lumen
luminance = candela/m²
1 flame = 4 foot candles = 43.05564 lux = 43.05564 meter-candles
illumination = lux
resistance = ohm

36.4 ASCII, HEX, BINARY CONVERSION

- The table below will allow conversions between decimal, binary, hexadecimal, and ASCII values. The values shown only go up to 127. ASCII values above this are not commonly used in robust applications.

decimal	hexadecimal	binary	ASCII	decimal	hexadecimal	binary	ASCII
0	0	00000000	NUL	32	20	00100000	space
1	1	00000001	SOH	33	21	00100001	!
2	2	00000010	STX	34	22	00100010	“
3	3	00000011	ETX	35	23	00100011	#
4	4	00000100	EOT	36	24	00100100	\$
5	5	00000101	ENQ	37	25	00100101	%
6	6	00000110	ACK	38	26	00100110	&
7	7	00000111	BEL	39	27	00100111	‘
8	8	00001000	BS	40	28	00101000	(
9	9	00001001	HT	41	29	00101001)
10	A	00001010	LF	42	2A	00101010	*
11	B	00001011	VT	43	2B	00101011	+
12	C	00001100	FF	44	2C	00101100	,
13	D	00001101	CR	45	2D	00101101	-
14	E	00001110	S0	46	2E	00101110	.
15	F	00001111	S1	47	2F	00101111	/
16	10	00010000	DLE	48	30	00110000	0
17	11	00010001	DC1	49	31	00110001	1
18	12	00010010	DC2	50	32	00110010	2
19	13	00010011	DC3	51	33	00110011	3
20	14	00010100	DC4	52	34	00110100	4
21	15	00010101	NAK	53	35	00110101	5
22	16	00010110	SYN	54	36	00110110	6
23	17	00010111	ETB	55	37	00110111	7
24	18	00011000	CAN	56	38	00111000	8
25	19	00011001	EM	57	39	00111001	9
26	1A	00011010	SUB	58	3A	00111010	:
27	1B	00011011	ESC	59	3B	00111011	;
28	1C	00011100	FS	60	3C	00111100	<
29	1D	00011101	GS	61	3D	00111101	=
30	1E	00011110	RS	62	3E	00111110	>
31	1F	00011111	US	63	3F	00111111	?

decimal	hexadecimal	binary	ASCII	decimal	hexadecimal	binary	ASCII
64	40	01000000	@	96	60	01100000	`
65	41	01000001	A	97	61	01100001	a
66	42	01000010	B	98	62	01100010	b
67	43	01000011	C	99	63	01100011	c
68	44	01000100	D	100	64	01100100	d
69	45	01000101	E	101	65	01100101	e
70	46	01000110	F	102	66	01100110	f
71	47	01000111	G	103	67	01100111	g
72	48	01001000	H	104	68	01101000	h
73	49	01001001	I	105	69	01101001	i
74	4A	01001010	J	106	6A	01101010	j
75	4B	01001011	K	107	6B	01101011	k
76	4C	01001100	L	108	6C	01101100	l
77	4D	01001101	M	109	6D	01101101	m
78	4E	01001110	N	110	6E	01101110	n
79	4F	01001111	O	111	6F	01101111	o
80	50	01010000	P	112	70	01110000	p
81	51	01010001	Q	113	71	01110001	q
82	52	01010010	R	114	72	01110010	r
83	53	01010011	S	115	73	01110011	s
84	54	01010100	T	116	74	01110100	t
85	55	01010101	U	117	75	01110101	u
86	56	01010110	V	118	76	01110110	v
87	57	01010111	W	119	77	01110111	w
88	58	01011000	X	120	78	01111000	x
89	59	01011001	Y	121	79	01111001	y
90	5A	01011010	Z	122	7A	01111010	z
91	5B	01011011	[123	7B	01111011	{
92	5C	01011100	yen	124	7C	01111100	
93	5D	01011101]	125	7D	01111101	}
94	5E	01011110	^	126	7E	01111110	r arr.
95	5F	01011111	_	127	7F	01111111	l arr.

36.5 G-CODES

• Note that G and M codes not universal standards, and may vary between machines. In any case of doubt, the manuals for the machine should be checked.

• A basic list of 'G' operation codes is given below. These direct motion of the tool.

- G00 - Rapid move (not cutting)
- G01 - Linear move
- G02 - Clockwise circular motion
- G03 - Counterclockwise circular motion
- G04 - Dwell
- G05 - Pause (for operator intervention)
- G08 - Acceleration
- G09 - Deceleration
- G17 - x-y plane for circular interpolation
- G18 - z-x plane for circular interpolation
- G19 - y-z plane for circular interpolation
- G20 - turning cycle or inch data specification
- G21 - thread cutting cycle or metric data specification
- G24 - face turning cycle
- G25 - wait for input #1 to go low (Prolight Mill)
- G26 - wait for input #1 to go high (Prolight Mill)
- G28 - return to reference point
- G29 - return from reference point
- G31 - Stop on input (INROB1 is high) (Prolight Mill)
- G33-35 - thread cutting functions (Emco Lathe)
- G35 - wait for input #2 to go low (Prolight Mill)
- G36 - wait for input #2 to go high (Prolight Mill)
- G40 - cutter compensation cancel
- G41 - cutter compensation to the left
- G42 - cutter compensation to the right
- G43 - tool length compensation, positive
- G44 - tool length compensation, negative
- G50 - Preset position
- G70 - set inch based units or finishing cycle
- G71 - set metric units or stock removal
- G72 - indicate finishing cycle (EMCO Lathe)
- G72 - 3D circular interpolation clockwise (Prolight Mill)
- G73 - turning cycle contour (EMCO Lathe)
- G73 - 3D circular interpolation counter clockwise (Prolight Mill)
- G74 - facing cycle contour (Emco Lathe)
- G74.1 - disable 360 deg arcs (Prolight Mill)
- G75 - pattern repeating (Emco Lathe)
- G75.1 - enable 360 degree arcs (Prolight Mill)
- G76 - deep hole drilling, cut cycle in z-axis
- G77 - cut-in cycle in x-axis
- G78 - multiple threading cycle
- G80 - fixed cycle cancel

G81-89 - fixed cycles specified by machine tool manufacturers
G81 - drilling cycle (Prolight Mill)
G82 - straight drilling cycle with dwell (Prolight Mill)
G83 - drilling cycle (EMCO Lathe)
G83 - peck drilling cycle (Prolight Mill)
G84 - tapping cycle (EMCO Lathe)
G85 - reaming cycle (EMCO Lathe)
G85 - boring cycle (Prolight mill)
G86 - boring with spindle off and dwell cycle (Prolight Mill)
G89 - boring cycle with dwell (Prolight Mill)
G90 - absolute dimension program
G91 - incremental dimensions
G92 - Spindle speed limit
G93 - Coordinate system setting
G94 - Feed rate in ipm (EMCO Lathe)
G95 - Feed rate in ipr (EMCO Lathe)
G96 - Surface cutting speed (EMCO Lathe)
G97 - Rotational speed rpm (EMCO Lathe)
G98 - withdraw the tool to the starting point or feed per minute
G99 - withdraw the tool to a safe plane or feed per revolution
G101 - Spline interpolation (Prolight Mill)

• M-Codes control machine functions and these include,

M00 - program stop
M01 - optional stop using stop button
M02 - end of program
M03 - spindle on CW
M04 - spindle on CCW
M05 - spindle off
M06 - tool change
M07 - flood with coolant
M08 - mist with coolant
M08 - turn on accessory #1 (120VAC outlet) (Prolight Mill)
M09 - coolant off
M09 - turn off accessory #1 (120VAC outlet) (Prolight Mill)
M10 - turn on accessory #2 (120VAC outlet) (Prolight Mill)
M11 - turn off accessory #2 (120VAC outlet) (Prolight Mill) or tool change
M17 - subroutine end
M20 - tailstock back (EMCO Lathe)
M20 - Chain to next program (Prolight Mill)
M21 - tailstock forward (EMCO Lathe)
M22 - Write current position to data file (Prolight Mill)
M25 - open chuck (EMCO Lathe)
M25 - set output #1 off (Prolight Mill)

M26 - close chuck (EMCO Lathe)
M26 - set output #1 on (Prolight Mill)
M30 - end of tape (rewind)
M35 - set output #2 off (Prolight Mill)
M36 - set output #2 on (Prolight Mill)
M38 - put stepper motors on low power standby (Prolight Mill)
M47 - restart a program continuously, or a fixed number of times (Prolight Mill)
M71 - puff blowing on (EMCO Lathe)
M72 - puff blowing off (EMCO Lathe)
M96 - compensate for rounded external curves
M97 - compensate for sharp external curves
M98 - subprogram call
M99 - return from subprogram, jump instruction
M101 - move x-axis home (Prolight Mill)
M102 - move y-axis home (Prolight Mill)
M103 - move z-axis home (Prolight Mill)

• Other codes and keywords include,

Annn - an orientation, or second x-axis spline control point
Bnnn - an orientation, or second y-axis spline control point
Cnnn - an orientation, or second z-axis spline control point, or chamfer
Fnnn - a feed value (in ipm or m/s, not ipr), or thread pitch
Innn - x-axis center for circular interpolation, or first x-axis spline control point
Jnnn - y-axis center for circular interpolation, or first y-axis spline control point
Knnn - z-axis center for circular interpolation, or first z-axis spline control point
Lnnn - arc angle, loop counter and program cycle counter
Nnnn - a sequence/line number
Onnn - subprogram block number
Pnnn - subprogram reference number
Rnnn - a clearance plane for tool movement, or arc radius, or taper value
Qnnn - peck depth for pecking cycle
Snnn - cutting speed (rpm), spindle speed
Tnnn - a tool number
Unnn - relative motion in x
Vnnn - relative motion in y
Wnnn - relative motion in z
Xnnn - an x-axis value
Ynnn - a y-axis value
Znnn - a z-axis value
; - starts a comment (proLight Mill), or end of block (EMCO Lathe)