



50 essential mechanical engineering formulas

Every formula with a sketch, its symbols and SI units, and the assumption it rests on. Worked examples for each one are in our free guides.

How to use this sheet

- Work in consistent units: base SI (N, m, Pa, J, W, K), or N, mm and MPa for stresses (1 MPa = 1 N/mm²).
- Use absolute temperature (K) and absolute pressure in gas formulas.
- Check the assumption under each formula before you use it.
- Worked examples for all 50: inspireworkss.com/resources

Contents

- 1-10** Strength of materials
- 11-20** Thermodynamics
- 21-30** Fluid mechanics
- 31-40** Manufacturing
- 41-50** Machine design and heat transfer

Prefixes

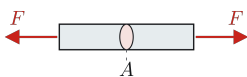
G (giga) 10 ⁹	200 GPa, steel's <i>E</i>
M (mega) 10 ⁶	250 MPa, yield
k (kilo) 10 ³	30 kN, load
m (milli) 10 ⁻³	25 mm, length
μ (micro) 10 ⁻⁶	0.8 μm, finish

Units and conversions

1 N	1 kg m/s ²	1 bar	100 kPa (≈ 14.5 psi)
1 Pa	1 N/m ²	1 psi	6.895 kPa
1 MPa	1 N/mm ²	1 inch	25.4 mm
1 J	1 N m	1 lbf	4.448 N
1 W	1 J/s	1 kgf	9.807 N
1 kWh	3.6 MJ	1 hp	745.7 W
T (K)	T (°C) + 273.15	1 rev/min	0.1047 rad/s

Steel $E \approx 200$ GPa, $G \approx 80$ GPa, $\rho = 7850$ kg/m³. Air $R = 287$ J/kg K, $\gamma = 1.4$.
Water $\rho = 1000$ kg/m³, $c = 4180$ J/kg K. $g = 9.81$ m/s².

1 Normal stress



$$\sigma = \frac{F}{A}$$

σ	normal stress	Pa
F	axial force	N
A	cross-sectional area	m ²

Load along the axis through the centroid; away from holes and shoulders.

How to read a panel

1. The red number matches our 50-formulas guide.
2. The sketch shows each symbol on a real part.
3. The equation sits on the pale steel plate.
4. Symbols are listed with their SI units.
5. The last line is the assumption: check it holds.

Need a part designed, checked or drawn for manufacture?

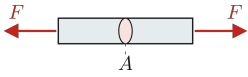
We design products and machines, make 3D CAD models and 2D drawings for manufacturing, prepare models for 3D printing and teach CAD.

Get a quote: inspireworkss.com/contact

Strength of materials

Worked examples for every formula: inspireworkss.com/resources/formulas-and-units/strength-of-materials-formulas/

1 Normal stress

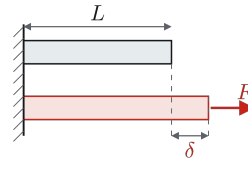


$$\sigma = \frac{F}{A}$$

σ	normal stress	Pa
F	axial force	N
A	cross-sectional area	m ²

Load along the axis through the centroid; away from holes and shoulders.

2 Strain and Hooke's law



$$\varepsilon = \frac{\delta}{L}, \quad \sigma = E \varepsilon$$

ε	strain	–
δ	change in length	m
L	original length	m
E	Young's modulus	Pa

Linear elastic: stress below the proportional limit.

3 Axial deformation

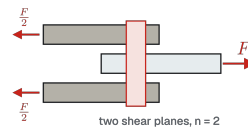


$$\delta = \frac{F L}{A E}$$

δ	extension	m
F	axial force	N
L	length	m
A	area	m ²
E	Young's modulus	Pa

Uniform bar and constant force along its length.

4 Direct shear stress

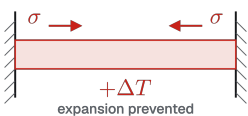


$$\tau = \frac{F}{n A}$$

τ	average shear stress	Pa
F	shear force	N
n	shear planes (2 = double shear)	–
A	area of one plane	m ²

Stress spread evenly over the shear plane; pin bending ignored.

5 Thermal stress

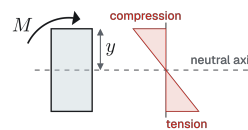


$$\sigma = E \alpha \Delta T$$

σ	stress if expansion is prevented	Pa
α	thermal expansion coefficient	K ⁻¹
ΔT	temperature change	K

Ends fully fixed; free bars just grow by $\alpha L \Delta T$.

6 Bending stress

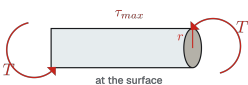


$$\sigma_b = \frac{M y}{I}$$

M	bending moment	N m
y	distance from neutral axis	m
I	second moment of area	m ⁴

Plane sections stay plane; rectangle $I = bh^3/12$.

7 Torsional shear stress

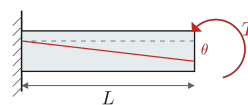


$$\tau = \frac{T r}{J}$$

T	torque	N m
r	radius	m
J	polar moment, $\pi d^4/32$ solid	m ⁴

Circular shaft, linear elastic material.

8 Angle of twist

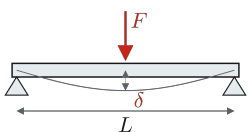


$$\theta = \frac{T L}{G J}$$

θ	angle of twist	rad
L	shaft length	m
G	shear modulus	Pa
J	polar moment of area	m ⁴

Constant torque and section along the length.

9 Beam deflection

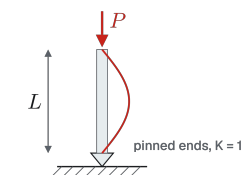


$$\delta_{max} = \frac{F L^3}{48 E I}$$

F	central point load	N
L	span	m
E	Young's modulus	Pa
I	second moment of area	m ⁴

Simply supported, central load, small deflections.

10 Euler buckling load



$$P_{cr} = \frac{\pi^2 E I}{(K L)^2}$$

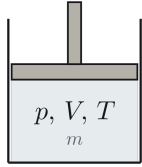
P_{cr}	critical load	N
K	effective length factor	–
L	column length	m
I	smallest second moment	m ⁴

Slender straight column; $K = 1$ pinned, 2 fixed-free, 0.5 fixed.

Thermodynamics

Worked examples for every formula: inspireworkss.com/resources/formulas-and-units/thermodynamics-formulas/

11 Ideal gas law

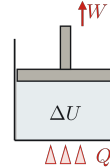


$$pV = mRT$$

p	absolute pressure	Pa
V	volume	m ³
m	mass	kg
R	gas constant (air 287)	J/kg K
T	absolute temperature	K

Ideal gas: air at ordinary pressures and temperatures.

12 First law, closed system

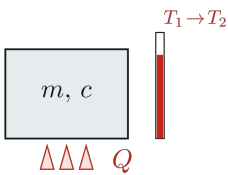


$$Q - W = \Delta U$$

Q	heat added	J
W	work done by the system	J
ΔU	change in internal energy	J

Fixed mass; kinetic and potential energy changes ignored.

13 Sensible heat

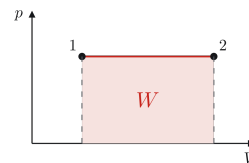


$$Q = mc\Delta T$$

Q	heat	J
m	mass	kg
c	specific heat (water 4180)	J/kg K
ΔT	temperature change	K

No change of phase; constant specific heat.

14 Work at constant pressure

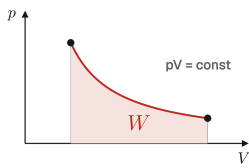


$$W = p(V_2 - V_1)$$

W	boundary work	J
p	constant pressure	Pa
V_1, V_2	initial and final volume	m ³

Slow (quasi-static) process.

15 Isothermal work

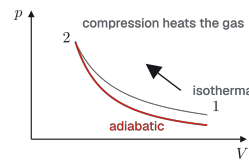


$$W = mRT \ln \frac{V_2}{V_1}$$

W	work done by the gas	J
T	constant temperature	K
V_1, V_2	volumes	m ³

Ideal gas, constant temperature: heat equals work.

16 Adiabatic process

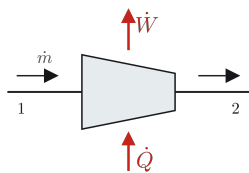


$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1} \right)^{\frac{\gamma-1}{\gamma}}$$

T	absolute temperature	K
p	absolute pressure	Pa
γ	c_p/c_v (air 1.4)	—

No heat transfer and no friction (isentropic).

17 Steady flow energy equation

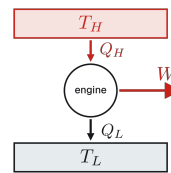


$$\dot{Q} - \dot{W} = \dot{m} \left[\Delta h + \frac{\Delta V^2}{2} + g \Delta z \right]$$

$\dot{Q}, \dot{W}$	heat in, shaft power out	W
$\dot{m}$	mass flow rate	kg/s
h	specific enthalpy	J/kg
V, z	velocity, height	m/s, m

Steady flow, one inlet and one outlet.

18 Carnot efficiency

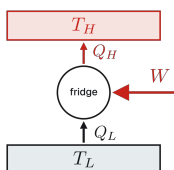


$$\eta = 1 - \frac{T_L}{T_H}$$

η	maximum thermal efficiency	—
T_H	hot source temperature	K
T_L	cold sink temperature	K

Fully reversible engine: the upper limit.

19 Coefficient of performance

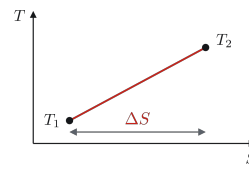


$$COP_R = \frac{Q_L}{W}$$

Q_L	heat removed from the cold space	J or W
W	work input	J or W
Q_H	$= Q_L + W$, heat rejected	J or W

Steady operation; heat pump $COP = COP_R + 1$.

20 Entropy change



$$\Delta S = mc \ln \frac{T_2}{T_1}$$

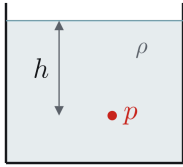
ΔS	entropy change	J/K
c	specific heat	J/kg K
T_1, T_2	absolute temperatures	K

Solids and liquids with constant specific heat.

Fluid mechanics

Worked examples for every formula: inspireworkss.com/resources/formulas-and-units/fluid-mechanics-formulas/

21 Hydrostatic pressure

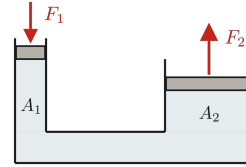


$$p = \rho g h$$

p	gauge pressure	Pa
ρ	density (water 1000)	kg/m ³
g	9.81	m/s ²
h	depth	m

Fluid at rest and incompressible.

22 Hydraulic press

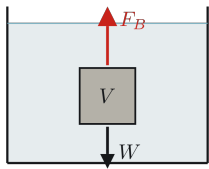


$$F_2 = F_1 \frac{A_2}{A_1}$$

F_1, F_2	input and output force	N
A_1, A_2	piston areas	m ²

Confined fluid at rest; no friction or leakage.

23 Buoyancy

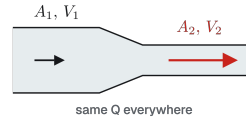


$$F_B = \rho_f g V$$

F_B	upward buoyant force	N
ρ_f	fluid density	kg/m ³
V	submerged volume	m ³

Fluid at rest with uniform density.

24 Continuity

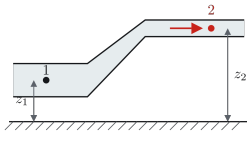


$$Q = A_1 V_1 = A_2 V_2$$

Q	volume flow rate	m ³ /s
A	flow area	m ²
V	average velocity	m/s

Steady, incompressible flow, no leaks.

25 Bernoulli's equation

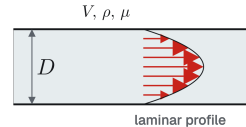


$$p + \frac{1}{2} \rho V^2 + \rho g z = \text{const}$$

p	static pressure	Pa
V	velocity	m/s
z	height above datum	m

Steady, incompressible, frictionless, along a streamline.

26 Reynolds number

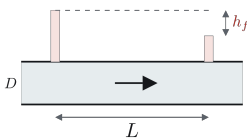


$$Re = \frac{\rho V D}{\mu}$$

V	average velocity	m/s
D	inside diameter	m
μ	dynamic viscosity	Pa s

Round bore: laminar below 2300, turbulent above 4000.

27 Friction loss (Darcy-Weisbach)

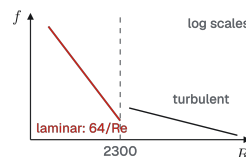


$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

h_f	head loss	m
f	Darcy friction factor	-
L, D	length, diameter	m

Fully developed flow in a straight, round bore.

28 Laminar friction factor

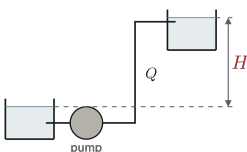


$$f = \frac{64}{Re}$$

f	Darcy friction factor	-
Re	Reynolds number	-

Laminar flow only; independent of roughness.

29 Pump power

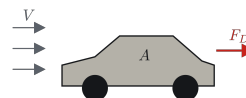


$$P = \frac{\rho g Q H}{\eta}$$

P	shaft power	W
Q	flow rate	m ³ /s
H	total head	m
η	pump efficiency	-

Steady flow of an incompressible liquid.

30 Drag force



$$F_D = \frac{1}{2} \rho V^2 C_D A$$

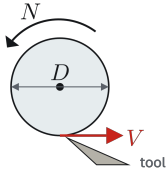
F_D	drag force	N
V	speed relative to the fluid	m/s
C_D	drag coefficient	-
A	frontal area	m ²

C_D roughly constant over the speed range.

Manufacturing

Worked examples for every formula: inspireworkss.com/resources/formulas-and-units/manufacturing-calculations/

31 Spindle speed

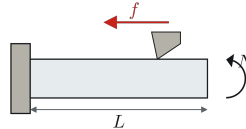


$$N = \frac{1000 V}{\pi D}$$

N	spindle speed	rev/min
V	cutting speed	m/min
D	work or cutter diameter	mm

V from the tool maker's data.

32 Turning time

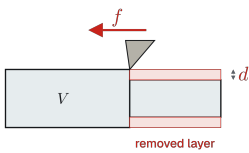


$$t = \frac{L}{f N}$$

t	time per pass	min
L	length of cut	mm
f	feed	mm/rev
N	spindle speed	rev/min

Constant feed and speed through the pass.

33 Removal rate, turning

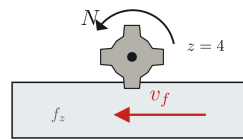


$$MRR = 1000 V f d$$

MRR	material removal rate	mm ³ /min
V	cutting speed	m/min
f	feed	mm/rev
d	depth of cut	mm

Depth of cut small compared with the diameter.

34 Milling feed rate

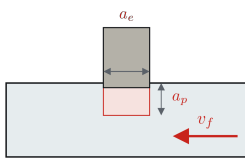


$$v_f = f_z z N$$

v_f	table feed	mm/min
f_z	feed per tooth	mm
z	number of teeth	–
N	spindle speed	rev/min

Chip load from the cutter maker's data.

35 Removal rate, milling

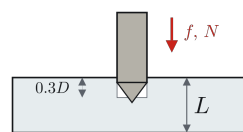


$$MRR = a_e a_p v_f$$

a_e	width of cut	mm
a_p	depth of cut	mm
v_f	table feed	mm/min

Steady cutting with constant engagement.

36 Drilling time

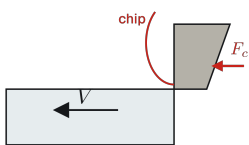


$$t = \frac{L + 0.3D + c}{f N}$$

L	hole depth	mm
$0.3D$	drill point length (118°)	mm
c	clearance, 1–2	mm
f, N	feed, speed	mm/rev, rev/min

Through hole with a standard twist drill.

37 Cutting force and power

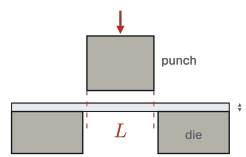


$$F_c = k_c f d, \quad P = \frac{F_c V}{60}$$

k_c	specific cutting force (steel ≈ 2000)	N/mm ²
F_c	cutting force	N
P	power at the tool	W

Divide by machine efficiency for motor power.

38 Blanking force

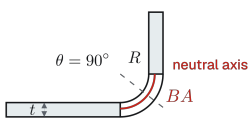


$$F = L t \tau_s$$

L	cut perimeter	mm
t	sheet thickness	mm
τ_s	shear strength	N/mm ²

Flat punch and die with normal clearance.

39 Bend allowance



$$BA = \theta \frac{\pi}{180} (R + Kt)$$

θ	bend angle	deg
R	inside radius	mm
K	K-factor, 0.33–0.5	–
t	thickness	mm

K-factor from test bends or the CAD sheet-metal table.

40 Taylor tool life



$$V T^n = C$$

V	cutting speed	m/min
T	tool life	min
n	exponent (carbide 0.2–0.3)	–
C	constant	m/min

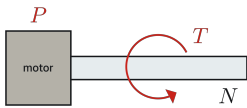
Constants for one tool–material pair, fixed feed and depth.

Machine design and heat transfer

Worked examples for every formula:

inspireworkss.com/resources/formulas-and-units/essential-mechanical-engineering-formulas/

41 Power from torque

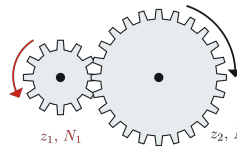


$$P = \frac{2\pi NT}{60}$$

P	power	W
N	speed	rev/min
T	torque	N m

Steady speed; $P = T\omega$ with ω in rad/s.

42 Gear ratio

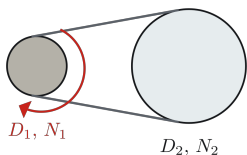


$$i = \frac{N_1}{N_2} = \frac{z_2}{z_1}$$

i	gear ratio	-
N	speeds	rev/min
z	numbers of teeth	-

Torque rises by i , less about 1-2 % per mesh.

43 Belt drive speed ratio

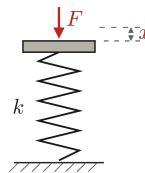


$$N_1 D_1 = N_2 D_2$$

N	pulley speeds	rev/min
D	pitch diameters	mm

No slip (friction belts slip about 1-2 %).

44 Spring force

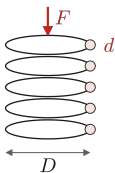


$$F = kx, \quad k = \frac{G d^4}{8 D^3 n}$$

k	spring rate	N/m
x	deflection	m
d, D	wire and mean coil diameter	m
n	active coils	-

Within the spring's linear working range.

45 Helical spring stress

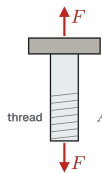


$$\tau = K_w \frac{8FD}{\pi d^3}$$

τ	shear stress in the wire	Pa
K_w	Wahl factor, from $C = D/d$	-
F	spring force	N

Spring index C between about 4 and 12.

46 Bolt tensile stress

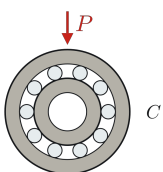


$$\sigma = \frac{F}{A_t}$$

F	bolt tension	N
A_t	tensile stress area (M10: 58.0)	mm ²

Grade 8.8 yield 640 MPa; preload about 70 % of yield.

47 Bearing rating life

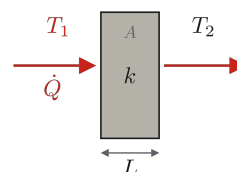


$$L_{10} = \left(\frac{C}{P} \right)^3$$

L_{10}	life reached by 90 % of bearings	10 ⁶ rev
C	dynamic load rating	N
P	equivalent load	N

Ball bearings; use the exponent 10/3 for roller bearings.

48 Conduction

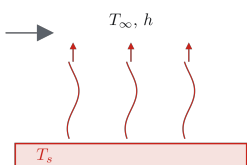


$$\dot{Q} = \frac{k A \Delta T}{L}$$

k	thermal conductivity	W/m K
A	area	m ²
ΔT	temperature difference	K
L	thickness	m

Steady, one-dimensional flow through a flat wall.

49 Convection

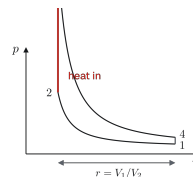


$$\dot{Q} = h A (T_s - T_\infty)$$

h	convection coefficient	W/m ² K
T_s	surface temperature	K
T_∞	fluid temperature	K

h from tables or correlations; forced air 25-250.

50 Otto cycle efficiency



$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

r	compression ratio V_1/V_2	-
γ	1.4 for air	-

Ideal air-standard cycle; real engines reach far less.