

MODULE II • ALL 9 OUTLINE TOPICS

Mechanics of Machines

Formula Cheat Sheet

Every formula has its symbols and SI units, and the situation it is for. Work in **SI units** (N, m, kg, s, rad). A formula only earns marks when you choose the right one, so read the last column first.

UNITS YOU WILL NEED

$\text{km/h} \div 3.6 \rightarrow \text{m/s}$	$\text{mm} \div 1000 \rightarrow \text{m}; 1 \text{ tonne} = 1000 \text{ kg}$
$\text{rev/min} \times 2\pi/60 \rightarrow \text{rad/s}$	$g = 9.81 \text{ m/s}^2$
$\text{degrees} \times \pi/180 \rightarrow \text{rad}$	$\text{N s} = \text{kg m/s}; \text{N m} \times \text{rad/s} = \text{W}$

0 FOUNDATIONS

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$\Sigma F = ma, \quad \Sigma M = I\alpha$	F force (N); m mass (kg); a acceleration (m/s^2); M moment (N m); I (kg m^2); α (rad/s^2)	any accelerating body: draw the free-body diagram first
$P = Fv = T\omega = \frac{2\pi NT}{60}$	P power (W); v speed (m/s); T torque (N m); N (rev/min)	power in a line or a shaft
$\eta = \frac{P_{\text{out}}}{P_{\text{in}}}, \quad \text{MA} = \eta \times \text{VR}$	$\text{MA} = T_{\text{out}}/T_{\text{in}}$ or load/effort; $\text{VR} = N_{\text{in}}/N_{\text{out}}$	gearboxes, winches, efficiency

1 KINEMATICS

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$v = u + at, \quad s = ut + \frac{1}{2}at^2$	u, v initial and final velocity (m/s); s displacement (m); t time (s)	constant acceleration only
$v^2 = u^2 + 2as, \quad s = \frac{1}{2}(u + v)t$	pick the equation without the quantity you neither know nor need	constant a ; time or distance unknown
$\omega = \omega_0 + \alpha t, \quad \omega^2 = \omega_0^2 + 2\alpha\theta$	angular versions; θ angle turned (rad)	constant angular acceleration
$v = \frac{ds}{dt}, \quad a = \frac{dv}{dt}, \quad s = \int v dt$	add a constant; find it from a known value	acceleration varies with time
$v = \omega r, \quad a_t = \alpha r$	r radius (m); a_t tangential acceleration	a point on a rotating body
$a_c = \frac{v^2}{r}, \quad F_c = m\omega^2 r$	towards the centre	motion in a circle (belts, clutches, cornering, balancing)

On a v - t graph: slope = acceleration; area = displacement.

2 IMPULSE AND MOMENTUM

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$Ft = mv - mu$	Ft impulse (Ns); mv momentum (kg m/s)	a force acting for a known time
$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$	velocities are signed: opposite directions have opposite signs	collisions; "lock together" gives one common v
$v = \sqrt{2gh}$, $Mv = (M + m)V$	hammer M falls h ; pile m	pile driver: fall, then impact
$(R - (M + m)g)s = \frac{1}{2}(M + m)V^2$	R ground resistance (N); s penetration (m)	pile driver: penetration
$Tt = I\omega - I\omega_0$	T torque (Nm); $I\omega$ angular momentum (kg m ² /s)	a torque acting for a known time
$I_1\omega_1 + I_2\omega_2 = (I_1 + I_2)\omega$	ω common speed after joining	two shafts suddenly coupled

Momentum is conserved **through** an impact; kinetic energy is not. Use energy only before and after the impact.

3-4 MOMENTS OF INERTIA

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$I = mk^2$, $k = \sqrt{I/m}$	k radius of gyration (m)	rotating bodies; $T = I\alpha$, $KE = \frac{1}{2}I\omega^2$
disc $\frac{1}{2}mR^2$; ring mR^2	hollow cylinder $\frac{1}{2}m(R_1^2 + R_2^2)$	drums, flywheels, pulleys
rod: centre $\frac{1}{12}mL^2$; end $\frac{1}{3}mL^2$	sphere about a diameter: $\frac{2}{5}mR^2$	arms, pendulums
$I_O = I_G + mh^2$	h distance between parallel axes (m); one axis through G	axis not through the centre of mass
$I_x = \int y^2 dA$, $\frac{bd^3}{12}$, $\frac{\pi D^4}{64}$	second moment of area (mm ⁴); $J = I_x + I_y$	cross-sections (beams, shafts)
$I_x = \Sigma(I_G + Ah^2)$, $I_{xy} = \Sigma A d_x d_y$	$I_{xy} = 0$ if either axis is symmetry	composite sections; product of inertia
$I_{\max, \min} = \frac{I_x + I_y}{2} \pm \sqrt{\left(\frac{I_x - I_y}{2}\right)^2 + I_{xy}^2}$	$\tan 2\theta_p = -2I_{xy} / (I_x - I_y)$	principal axes; Mohr's circle

5 BELT DRIVES

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$v = \frac{\pi dN}{60}$, $P = (T_1 - T_2)v$	d pulley diameter (m); T_1, T_2 tight and slack tensions (N)	power a belt carries
$\frac{T_1}{T_2} = e^{\mu\theta}$	μ friction coefficient; θ angle of lap in radians	belt on the point of slipping; equal pulleys $\theta = \pi$
$\frac{T_1}{T_2} = e^{\mu\theta \csc \beta}$	β half the groove angle	V-belts

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
Open: $\theta = \pi - 2\alpha$, $\sin \alpha = \frac{r_2 - r_1}{x}$	$r_1 < r_2$ pulley radii; x centre distance (m)	angle of lap; use the smaller pulley
Crossed: $\theta = \pi + 2\alpha$, $\sin \alpha = \frac{r_1 + r_2}{x}$	same θ on both pulleys	crossed belts
$T_c = mv^2$, $T_1 = T_{\max} - T_c$	m belt mass per metre (kg/m); T_c centrifugal tension	belt mass given
$P_{\max}$ when $T_c = \frac{T_{\max}}{3}$, $v = \sqrt{\frac{T_{\max}}{3m}}$		speed for maximum power

6 FRICTION CLUTCHES

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$T = n\mu WR$	W axial spring force (N); n pairs of surfaces (2 for one plate, both sides); R mean radius (m)	plate and multi-plate clutches
$R = \frac{r_1 + r_2}{2}$	r_1, r_2 outer and inner radii (m)	uniform wear (the default)
$R = \frac{2(r_1^3 - r_2^3)}{3(r_1^2 - r_2^2)}$	gives a slightly larger torque	uniform pressure (a new clutch)
$T = \frac{\mu WR}{\sin \alpha}$	α cone semi-angle	cone clutch
$T = n\mu(m\omega^2 r - S)R_d$, $S = m\omega_s^2 r$	n shoes of mass m ; r shoe radius; R_d drum radius; ω_s engagement speed	centrifugal clutch
$t_s = \frac{I\omega_1}{T}$, heat = $\frac{1}{2}I\omega_1^2$	driver held at constant ω_1	time of slip when engaging

7 GEARED SYSTEMS

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$\frac{N_1}{N_2} = \frac{t_2}{t_1}$; $\frac{N_{\text{first}}}{N_{\text{last}}} = \frac{\Pi \text{ driven}}{\Pi \text{ drivers}}$	t number of teeth; external mesh reverses direction	simple and compound trains
$m_{AB}(t_A + t_B) = m_{CD}(t_C + t_D)$	m module = d/t (mm)	reverted gearbox (input and output in line)
$t_A = t_S + 2t_P$	annulus, sun, planet teeth (one module)	epicyclic train
table: arm fixed, sun +1; $\times x$; +y	internal (annulus) mesh does not reverse	epicyclic speeds
$T_{\text{in}} + T_{\text{out}} + T_{\text{fix}} = 0$	signed torques; state the direction of T_{fix}	holding torque on casing or fixed gear
$\text{VR} = \frac{2r_h G}{d}$, $\eta = \frac{\text{MA}}{\text{VR}}$	r_h handle radius; G gear ratio; d drum diameter	winches and crabs

8 RIGID BODY IN TRANSLATION: VEHICLES

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$\Sigma F_x = ma_G, \Sigma F_y = 0, \Sigma M_G = 0$	G centre of mass	vehicles; axle loads and load transfer
$F = R + mg \sin \theta + ma$	F tractive effort; R resistance (N); slope 1 in n : $\sin \theta = 1/n$	driving force on level or slope
$P_{\text{engine}} = \frac{Fv}{\eta}, G = \frac{N_{\text{engine}}}{N_{\text{wheel}}}$	η transmission efficiency	engine power; gear ratio
$F = \frac{G\eta T_e}{r}$	T_e engine torque (N m); r wheel radius (m)	driving force from engine torque
$m_{\text{eq}} = m + m_w \frac{k_w^2}{r^2} + m_e \frac{k_e^2}{r^2} G^2 \eta$	m_w, k_w all wheels; m_e, k_e engine rotating parts	accelerating with rotating parts: $F - R = m_{\text{eq}} a$
$a_{\text{max}} = \mu g, \text{ transfer} = \frac{ma h}{L}$	h height of G ; L wheelbase	braking, all wheels skidding
$v_{\text{skid}}^2 = \mu g r, v_{\text{over}}^2 = \frac{g r b}{2h}, \tan \theta = \frac{v^2}{g r}$	b track width; r curve radius; θ banking	cornering: the lower speed happens first

9 ROTATION, HOISTS AND BALANCING

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$\Sigma M_O = I_O \alpha, a = \alpha r$	O fixed axis; r drum radius	rotation about a fixed axis
$T_r = m(g + a), T = T_r r + I \alpha + T_f$	T_r rope tension; T_f friction torque	hoist raising and accelerating a load
$\Sigma mr = 0$	each mr is a vector at its mass's angle (kg m)	static balance (one plane)
$\Sigma mr = 0$ and $\Sigma mrl = 0$	l distance from the reference plane (m)	dynamic balance (several planes): couples first
$F = (\Sigma mr) \omega^2, R_Q = \frac{\omega^2 \Sigma mrl}{L}$	R_Q bearing load; L bearing span; l from bearing P	unbalanced force; bearing loads

10 PLANE MOTION: ROLLING AND SLIPPING

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$\Sigma F = ma_G, \Sigma M_G = I_G \alpha$	a_G acceleration of the centre; α angular acceleration	bodies that move and spin together
$a_G = \alpha r, F \leq \mu N$	F friction; N normal force at contact	assume rolling, then check friction
If $F > \mu N$ the body slips: set $F = \mu N$ and solve a_G and α separately.		

Five mark-losers to avoid

1. **rev/min inside $T\omega$ or $\omega^2 r$.** Convert to rad/s with $\omega = 2\pi N/60$.
2. **Degrees in $e^{\mu\theta}$.** The angle of lap must be in radians.
3. **Energy through an impact.** Use momentum across a collision; energy only before and after it.
4. **Tooth ratios on an epicyclic train.** Planets ride on a moving arm: use the table. Internal meshes do not reverse.
5. **Answers without direction.** A fixing torque, a balancing mass or a bearing load needs its sense or angle as well as its size.

A formula sheet tells you *what*. It cannot show you *when* or *why*.

Most Mechanics of Machines marks go to choosing the right principle, setting it up correctly and showing the working. Papers also ask for derivations, such as $T_1/T_2 = e^{\mu\theta}$, $T = \mu WR$ and $a_c = v^2/r$. A sheet like this cannot teach that. Here is how to build it, one step at a time:

YOUR NEXT STEPS

Step 1 – free: the **MOM Exam Question Decoder**. A six-step method for any question, a “which principle?” finder, three fully decoded exam-style questions and a practice test with worked answers. Get it at [LINK – to be confirmed].

Step 2 – the complete guide: the **SomaReady Mechanics of Machines Revision Guide** (38 pages). It covers all the topics on this sheet, step by step:

- the derivations the past papers ask for, written out in full;
- 42 original examples, from direct to exam style, each explaining *why* each step is taken;
- worked answers to every practice question, plus common mistakes for every topic.

Price: **KSh 249** (launch price). **Get it at:** [LINK – to be confirmed].

Get the complete Mechanics of Machines guide: KSh 249

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