**SET A**

# UNIVERSITI KUALA LUMPUR
## Malaysia France Institute

# FINAL EXAMINATION
## SEPTEMBER 2014 SESSION

**SUBJECT CODE : FMB20202**

**SUBJECT TITLE : MECHANICS OF MACHINE**

**LEVEL : BACHELOR**

**TIME / DURATION : 9.00 AM – 11.30 AM**
**(2.5 HOURS)**

**DATE : 4 JANUARY 2015**

## INSTRUCTIONS TO CANDIDATES

1. Please read the instructions given in the question paper CAREFULLY.
2. This question paper is printed on both sides of the paper.
3. Please write your answers on the answer booklet provided.
4. Answer should be written in blue or black ink except for sketching, graphic and illustration.
5. This question paper consists of 5 questions. Choose and answer 4 questions only.
7. Formulae are appended.

**THERE ARE 5 PAGES OF QUESTIONS AND 3 PAGES OF FORMULAE, EXCLUDING THIS PAGE.**

**INSTRUCTION: Answer FOUR (4) questions only.**
**Answer on the answer booklet provided.**

## Question 1

An Internal Combustion Engine (ICE) mechanism is shown in *Figure 1* below. This engine is widely used to power up automotive drives. At a certain time, on combustion stroke, the crank angle, $\theta_2$ is at $195^o$. Using all the information given, obtain the parameters listed below:

a) Tabulate the Kinematic Representation Table

(8 marks)

b) Draw the Kinematic Diagram

(7 marks)

c) Determine the Degree-of-Freedom (DOF) of the mechanism

(3 marks)

d) Determine stroke, S

(7 marks)

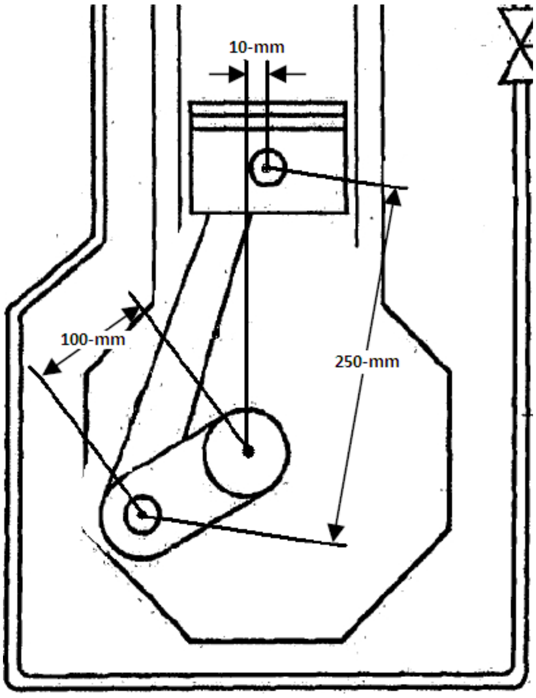


*Figure 1*

## Question 2

Referring to *Question 1*, the ICE is at combustion stroke. During the combustion stroke, the in-cylinder gas pressure acts on a *10-cm* diameter piston area, which brings a load P to the piston, to perform stroke motion. The total mass of the reciprocating parts M, is *5-kg*. It is also recorded that the angular velocity ω, of the mechanism is *4000π-rad/min*. The length of the crank rod $r$, the connecting rod $l$ and the crank angle $\theta_2$ are as in *Question 1*. The in-cylinder pressure can be obtained from *Figure 2*. Using all the information given, obtain the parameters listed below:

a) The total force, $F_P$ acting on the piston.

(20 marks)

b) The turning moment diagram, T of the mechanism.

(5 marks)

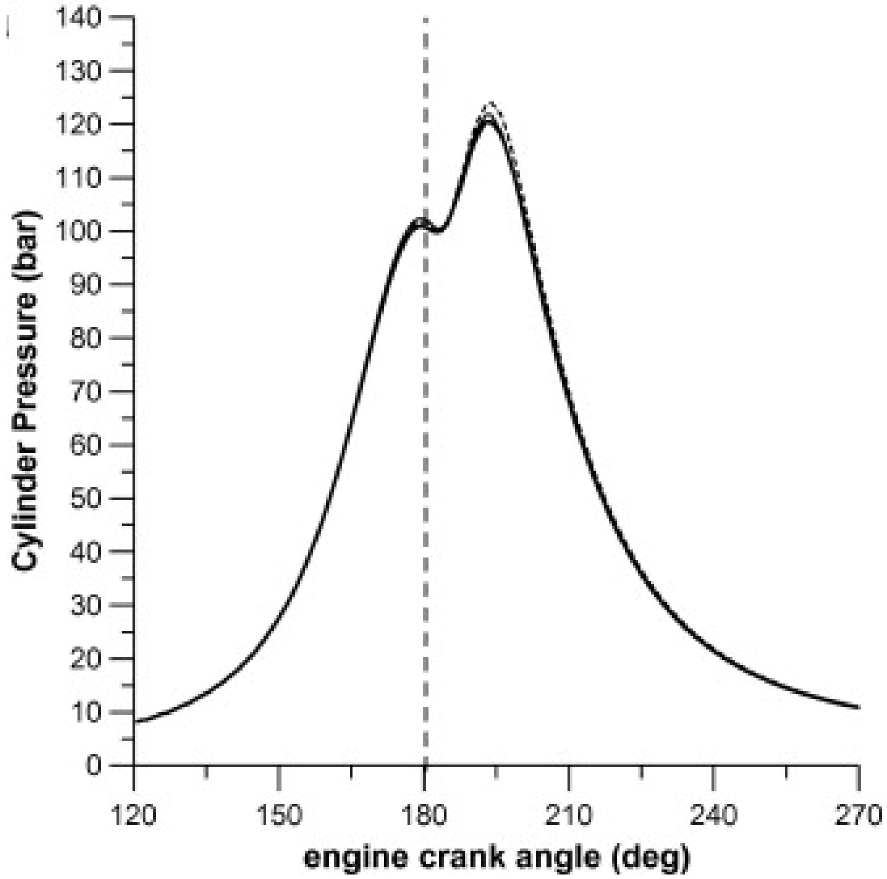


*Figure 2*

## Question 3

A flywheel is now connected with the ICE, as in *Question 1* through a crank shaft. The energy diagram of the flywheel is shown in *Figure 3*. The flywheel has a mass of *2-kg*, angular velocity ω, *is the same with ICE in Question 2*, radius of *15-cm*, and also with mass moment of inertia I, of $10x10^{-3}$*-kg.m*$^2$. The initial energy E, on the flywheel is *850-J*, *500-J* at $a_1$, *450-J* at $a_2$, *550-J* at $a_3$, *350-J* at $a_4$, *450-J* at $a_5$ and *400-J* at $a_6$. Using all the information given, obtain the parameters listed below:

a) Energy at A, B, C, D, E, F and G

(16 marks)

b) Maximum fluctuation of energy, ΔE

(3 marks)

c) Radius of gyration, k of the flywheel

(3 marks)

d) Mean kinetic energy, E in the flywheel

(3 marks)

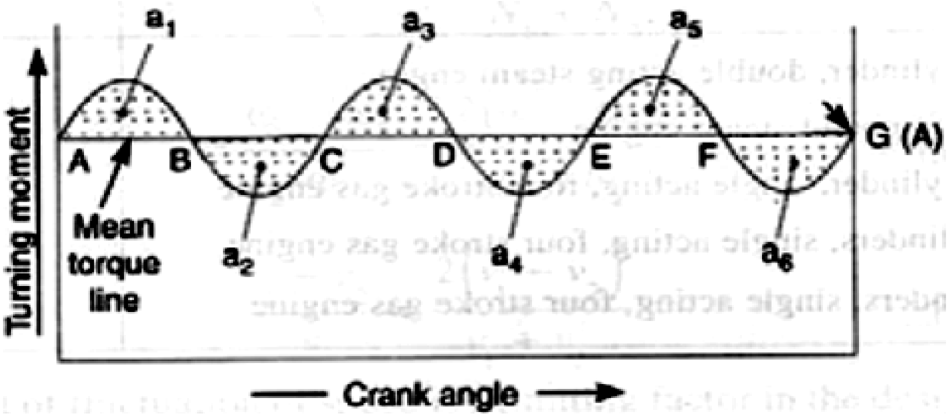


*Figure 3*

## Question 4

Engine-Pump mechanism, as shown in *Figure 4* below show gears meshing with different parameters. Every mesh between gears has a uniform efficiency of *97%*. It is known that Gear A is powered up by the engine. Gear A has *50-teeth*, torque of *500-N.m*, and angular velocity of *1000-RPM*. Gear B has *150-teeth*. Gear C has *40-teeth*. Gear D has *80-teeth*. Determine

a) Power at Gear D, $\mathbf{P_D}$.

(9 marks)

b) Angular velocity at Gear D, $\mathbf{n_D}$.

(8 marks)

c) Torque at Gear D, $\mathbf{T_D}$.

(5 marks)

d) Comment on the **changes** of torque and power at Gear D with regards to Gear A.

(3 marks)

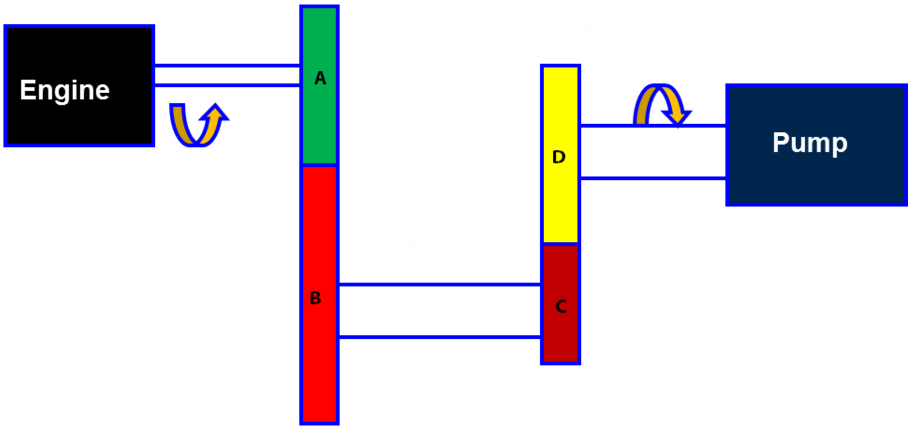


*Figure 4*

## Question 5

On the front side of the ICE, a belt drive is used to transmit power from crank shaft pulley to an air-conditioning compressor pulley through an open type flat belt drive. The crank shaft pulley (driver) has a diameter of *10-cm* and the compressor pulley (driven) is *double* from it. The center-to-center distance is *60-cm*. At the front end pulley, the tight tension is *500-N*, angular velocity ω, is the same with ICE in *Question 2*, coefficient of friction is *0.35* and the weight per unit length is *3-N/m*. Using all the information given, obtain the parameters listed below.

a) Is the center-to-center distance is ideal? State your reason.

(3 marks)

b) Angle of contact/wrap for both pulleys, $\theta_1$ & $\theta_2$

(6 marks)

c) Slack tension, $T_2$

(5 marks)

d) Torque on both pulleys, $T_1$ & $T_2$

(11 marks)

**END OF QUESTION PAPER**

# Formulae

1. Grublers Criterion:
   **F = 3(n-1)-2l-h**

2. Scotch Yoke:

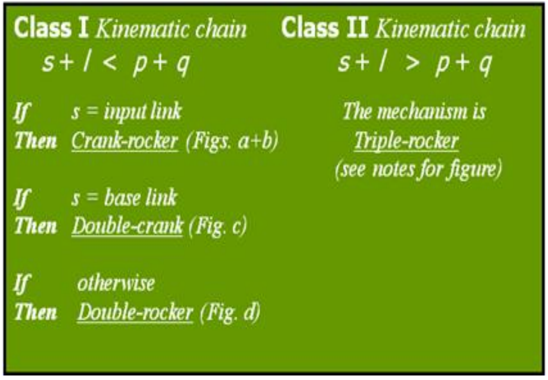
$$x = r - r\cos\theta \quad ; \quad \theta = \omega t$$

$$x = r(1 - r\cos\omega t)$$

$$v = \frac{dx}{dt} = r\omega\sin\omega t = r\omega\sin\theta$$

$$a = \frac{d^2x}{dt^2} = r\omega^2\cos\omega t = r\omega^2\cos\theta$$

3. Grashof's Criteria:
   $s + p + q \geq l$



**Class I** *Kinematic chain*
$s + l < p + q$

*If* *s = input link*
*Then* *Crank-rocker (Figs. a+b)*

*If* *s = base link*
*Then* *Double-crank (Fig. c)*

*If* *otherwise*
*Then* *Double-rocker (Fig. d)*

**Class II** *Kinematic chain*
$s + l > p + q$

*The mechanism is*
*Triple-rocker*
*(see notes for figure)*

4. Slider-crank Mechanisms:
   $r_2 < r_3$ and $r_1 \leq r_3 - r_2$

In-Line (No Offset)

$$S_1 = r_2 + r_3$$

$$S_2 = r_3 - r_2$$

$$Stroke = S_1 - S_2$$

$$\theta_3 = 180^o - \left(\theta_2 + \sin^{-1}\left[\frac{r_2}{r_3}\sin\theta_2\right]\right)$$

$$r_4 = \sqrt{r_2^2 + r_3^2 - \left(2.r_2.r_3.\cos\theta_3\right)}$$

Offset (Non In-Line)

$s_1 = [(r_2 + r_3)^2 - r_1^2]^{½}$

$s_2 = [(r_3 - r_2)^2 - r_1^2]^{½}$

Stroke $= s_1 - s_2$

$\alpha_1 = \sin^{-1}(r_1 / (r_2 + r_3))$

$\alpha_2 = \sin^{-1}(r_1 / (r_3 - r_2))$

$\Delta\theta_2 = 180^o + \alpha_2 - \alpha_1$

$$\theta_3 = 180^o - \left(\theta_2 + \sin^{-1}\left[\frac{r_1 + r_2\sin\theta_2}{r_3}\right]\right)$$

$\Delta t_1 = \Delta\theta_2 / \theta_3$

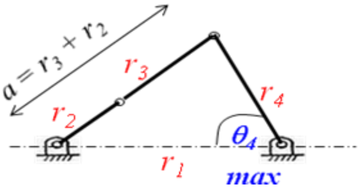
$\Delta t_2 = [2\pi - \Delta\theta_2] / \theta_3$

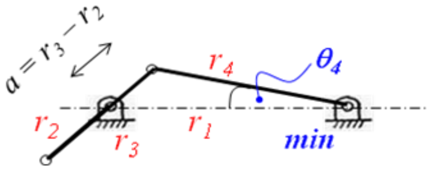
Time ratio $= \Delta t_1 / \Delta t_2$

$(v_{4,\ avg})$ left $=$ Stroke $/ \Delta t_1$

$(v_{4,\ avg})$ right $=$ Stroke $/ \Delta t_2$

5. 4-Bar Mechanism:





$$\theta_4 = \cos^{-1}\left(\frac{r_1^2 + r_4^2 - a^2}{2.r_1.r_4}\right)$$

$$\Delta\theta_4 = \theta_{4,Max} - \theta_{4,Min}$$

$$z = \sqrt{r_1^2 + r_2^2 - 2.r_1.r_2.\cos\theta_2}$$

$$\gamma = \cos^{-1}\left(\frac{r_3^2 + r_4^2 - z^2}{2.r_3.r_4}\right)$$

6. Simple Harmonic Motion:

General

$x(t) = A\cos(\omega t + \phi)$

$v(t) = -\omega A\sin(\omega t + \phi)$

$a(t) = -\omega^2 A\cos(\omega t + \phi)$

$$\omega = 2\pi f = \frac{2\pi}{T}$$

Mass on Spring

$$\omega = \sqrt{\frac{k}{m}}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Energy Conservation

$$U = \tfrac{1}{2}kA^2\cos^2(\omega t)$$

$$K = \tfrac{1}{2}kA^2\sin^2(\omega t)$$

E = K + U

$$U_{\max} = \tfrac{1}{2}kA^2$$

$$K_{\max} = \tfrac{1}{2}mA^2\omega^2 = \tfrac{1}{2}mA^2(k/m) = \tfrac{1}{2}kA^2$$

Pendulum on Spring

$$T = 2\pi\sqrt{\frac{L}{g}}$$

$$T = 2\pi\sqrt{\frac{\ell}{g}}\left(\sqrt{\frac{I}{m\ell^2}}\right)$$

$$A = A_0 e^{-bt/2m}$$

1 bar = 100 kPa
1 atm = 101.3 kPa
1 HP = 745.7 Watt
1 rad/s = 0.1047 RPM
1m$^2$ = 10000 cm$^2$
= 1x10$^6$ mm$^2$

7. Gear Trains:

D = Pitch diameter of gear (m)
N = No. of gear teeth
n = speed of gear (RPM)
ω = angular velocity (rad/s)
v = pitch linear velocity (m/s)
T = torque (N.m)

**Subscript:**
P = Driver gear
G = Driven gear

Circular Pitch (Pc)

$$P_C = \frac{\pi.D_P}{N_P} = \frac{\pi.D_G}{N_G}$$

Diametral Pitch, (P$_D$)

$$P_D = \frac{N_P}{D_P} = \frac{N_G}{D_G}$$

Module (m)

$$m = \frac{D_P}{N_P} = \frac{D_G}{N_G}$$

Pitch Linear Velocity (v)

$$v = \omega_P.\frac{D_P}{2} = \omega_G.\frac{D_G}{2}$$

$$GearRatio = \frac{\omega_P}{\omega_G} = \frac{n_P}{n_G} = \frac{N_G}{N_P} = \frac{T_G}{T_P}$$

$$T = F.\frac{D}{2} = \frac{63025.HP}{n}$$

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

Efficiency

$$\eta = \frac{N_G T_G}{N_P T_P}.100\%$$

Total Torque = $T_1 + T_2 + T_3 + \ldots Tn = 0$

8. Turning Moment Diagram

Internal combustion engine (ICE)

The turning Moment T;

$$T = F_p \times r\left[\sin\theta + \frac{\sin 2\theta}{2\sqrt{n^2 - \sin^2\theta}}\right]$$

Where $n = \frac{l}{r}$

$F_P$ = Net load on the piston (P) + Inertia forces (Q)

$$F_P = P(N) + Q(N)$$

Load on the piston (P) can be calculated considering the in-cylinder gas pressure

$$Q = M\omega^2 \times r\left[\cos\theta + \frac{\cos 2\theta}{n}\right]$$

Flywheel

Kinetic Energy E = $\frac{1}{2}I\omega^2$

Energy available at A is E
Energy at B = E + $a_1$
Energy at C = E + $a_1$ - $a_2$
Energy at D = E + $a_1$ - $a_2$+ $a_3$
Energy at E = E + $a_1$ - $a_2$+ $a_3$ – $a_4$
Energy at F = E + $a_1$ - $a_2$+ $a_3$ – $a_4$ + $a_5$
Energy at **G** = E + $a_1$ - $a_2$+ $a_3$ – $a_4$ + $a_5$ – $a_6$

Maximum fluctuation of energy;
ΔE = Maximum energy - Minimum energy

Mean kinetic energy (K.E.) in the flywheel;

$$E = \frac{1}{2}\times I\omega^2 = \frac{1}{2}\times mk^2\omega^2$$

where
m – mass of the Flywheel in kg,
k – radius of gyration in meters,
I – mass moment of inertia about the axis of rotation,

$$k = radius\ of\ \ gyration = \sqrt{\frac{I}{m}}$$

Maximum fluctuation of energy (as speed changes from $\omega_1$ to $\omega_2$)

$$\Delta E = I\omega^2 C_s$$

$$C_s = \frac{\omega_1 - \omega_2}{\omega}$$ Coefficient of fluctuation of speed

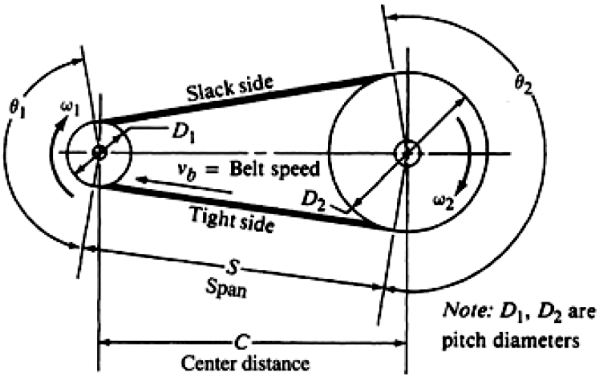
$$\omega = \frac{\omega_1 + \omega_2}{2}$$ Mean speed

The ratio of the maximum fluctuation of energy to the work done per cycle is called coefficient of fluctuation of energy:

$$C_E = \frac{Maximum\ \ fluctuation\ of\ \ energy}{Work\ \ done\ \ per\ \ cycle}$$

Work done per cycle = $T_{mean} \times \theta = \frac{P\times 60}{n}$
Where
$\theta$ – angle turned in one cycle
$T_{mean}$ - mean torque
$\omega = \frac{\omega_1+\omega_2}{2}$ $\quad T_{mean} = \frac{P\times 60}{2\pi N} = \frac{P}{\omega}$
n – Number of working strokes per minute
P - power transmitted in watts
N – speed in rev/min, ω – speed in rad/s

## 9. Belt Drives



*Note:* $D_1$, $D_2$ are pitch diameters

$$L = 2C + \frac{2}{\pi}(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C}$$

$$C = \frac{B + \sqrt{B^2 - 32(D_2 - D_1)^2}}{16}$$

$$where: \qquad B = 4L - 2\pi(D_2 - D_1)$$

$Ideal\ Center\ Dis\tan ce\ (m):$

$$D_2 < C < 3(D_1 + D_2)$$

$$S = \sqrt{C^2 - \left[\frac{(D_2 - D_1)}{2}\right]^2}$$

$$\theta_1 = 180^\circ - 2\sin^{-1}\left[\frac{D_2 - D_1}{2C}\right]$$

$$\theta_2 = 180^\circ + 2\sin^{-1}\left[\frac{D_2 - D_1}{2C}\right]$$

$$Driving\ force, F_d = T_1 - T_2$$

$$Centrifugal\ \ force, F_c = k * \upsilon_b^2$$

$$(k = weight/length[N/m])$$

$$T_1\ \&\ T_2\ relation, \frac{T_1}{T_2} = e^{\mu\theta_1}$$

$$(\mu = coeffient of\ \ friction)$$

$$Torque\ on\ driver, T_{DR} = F_d * \frac{D_1}{2}$$

$$Torque\ on\ driven, T_{DN} = F_d * \frac{D_2}{2}$$

$$Initial\ tension, T_i = \frac{T_1 - T_2}{2}$$

$$Belt\ velocity, v_b = r_1\omega_1 = r_2\omega_2 = \frac{D_1\omega_1}{2} = \frac{D_2\omega_2}{2}$$

$$Belt\ velocity\ for\ \max\ power, v_{b,Max} = \sqrt{\frac{T_i}{3k}}$$

$$Velocity\ ratio(VR) = \frac{\omega_1}{\omega_2} = \frac{r_2}{r_1} = \frac{D_2}{D_1}$$

$$P(W) = F_d * v_b$$

$$P(HP) = \frac{F_d * v_b}{33000}$$