UNIT II
BALANCING

Balancing is the process of eliminating or at least reducing the ground forces and moments. It is achieved by changing the location of the mass centers of links. Balancing of rotating parts is a well known problem. A rotating body with fixed rotation axis can be fully balanced i.e. all the inertia forces and moments. For mechanism containing links rotating about axis which are not fixed, force balancing is possible, moment balancing by itself may be possible, but both not possible. We generally try to do force balancing. A fully force balance is possible, but any action in force balancing severe the moment balancing.

Balancing of rotating masses:
The process of providing the second mass in order to counteract the effect of the centrifugal force of the first mass is called balancing of rotating masses.

Static balancing:
The net dynamic force acting on the shaft is equal to zero. This requires that the line of action of three centrifugal forces must be the same. In other words, the centre of the masses of the system must lie on the axis of the rotation. This is the condition for static balancing.

Dynamic balancing:
The net couple due to dynamic forces acting on the shaft is equal to zero. The algebraic sum of the moments about any point in the plane must be zero.

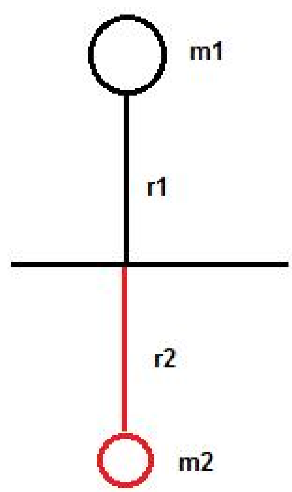
Various cases of balancing of rotating masses:

- ✓ Balancing of a single rotating mass by single mass rotating in the same plane.
- ✓ Balancing of a single rotating mass by two masses rotating in the different plane.
- ✓ Balancing of a several masses rotating in single plane.
- ✓ Balancing of a several masses rotating in different planes.

Balancing of a Single Rotating Mass By a Single Mass Rotating in the Same Plane

Consider r_1 be the radius of rotation of the mass m_1 attached to a shaft rotating at ω rad/s .
The centrifugal force exerted by the mass m_1 on the shaft,

$$F_{Cl} = m_1 \omega^2 r_1$$



This centrifugal force acts radially outwards and thus produces bending moment on the shaft. In order to counteract the effect of this force, a balancing mass (m_2) may be attached in the same plane of rotation as that of disturbing mass (m_1) such that the centrifugal forces due to the two masses are equal and opposite.

r_2 = Radius of rotation of the balancing mass m_2

Centrifugal force due to mass m_2, $F_{C2} = m_2\omega^2 r_2$

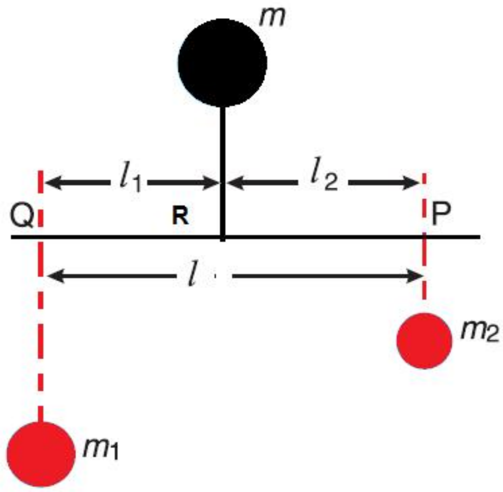
$$m_1 \omega^2 r_1 = m_2\omega^2 r_2$$

$$m_1 r_1 = m_2 r_2$$

Balancing of a Single Rotating Mass By Two Masses Rotating in Different Planes

A disturbing mass m lying in a plane A to be balanced by two rotating masses m_1 and m_2 lying in two different planes Q and P . Let r, r_1 and r_2 be the radii of rotation of the masses in planes R, Q and P respectively.

l_1 = Distance between the planes R and Q,
l_2 = Distance between the planes R and P, and
l = Distance between the planes Q and P



The centrifugal force exerted by the mass m on the shaft,
$F_C = m\,\omega^2 r$
Similarly for mass m_1 and mass m_1

$Fc_1 = m_1\,\omega^2 r_1$ and $Fc_2 = m_2\omega^2 r_2$

$Fc = Fc1 = Fc2$

$m\,\omega^2 r = m_1\,\omega^2 r_1 + m_2\omega^2 r_2$

To dynamic balancing, take moments about Q and P,

$F_{C1} \text{ x } l = F_C \text{ x } l_2$

$m_1 r_1 l = mr\, l_2$

Similarly,

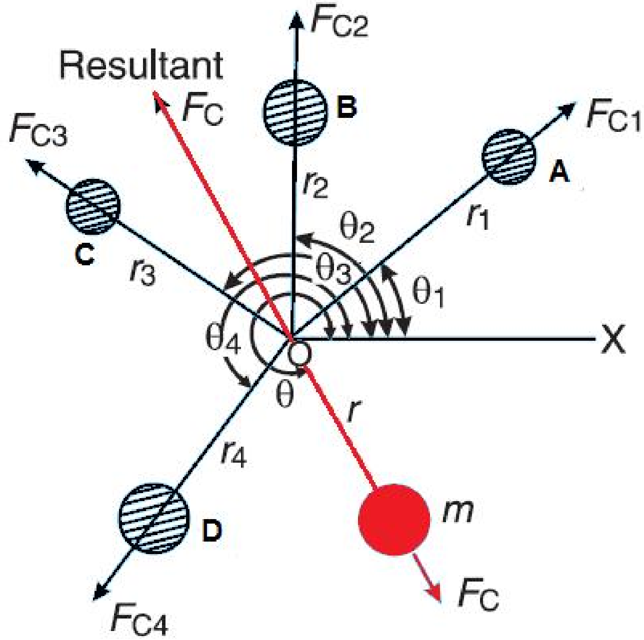
$F_{C2} \text{ x } l = F_C \text{ x } l_1$

$m_2 r_2 l = mr\, l_1$

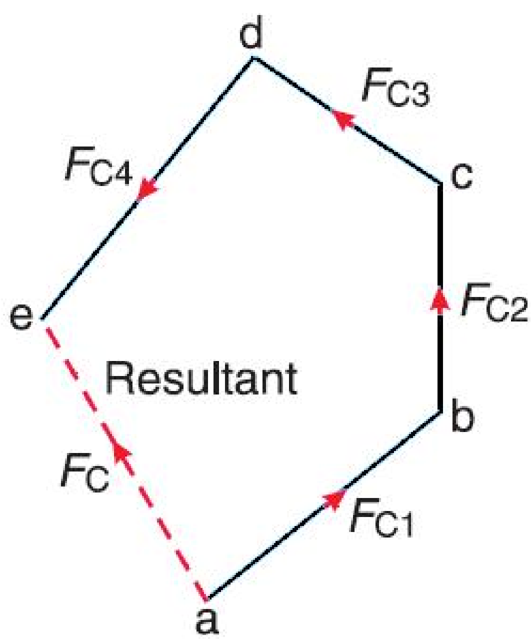
<u>Balancing of Several Masses Rotating in the Same Plane</u>

Consider any number of masses of magnitude *A, B, C and D* at distances of r_1, r_2, r_3 and r_4 from the axis of the rotating shaft. Let θ_1 , θ_2 , θ_3 and θ_4 be the angles of these masses with the horizontal line. The magnitude and position of the balancing mass may be found out graphically:

Angular Position diagram



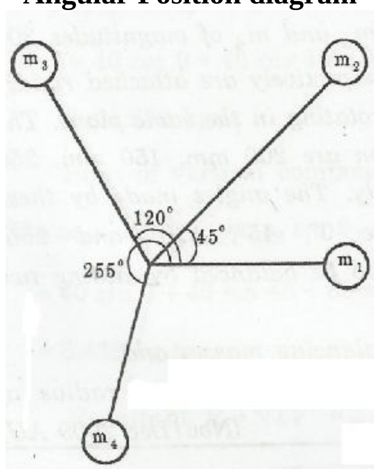
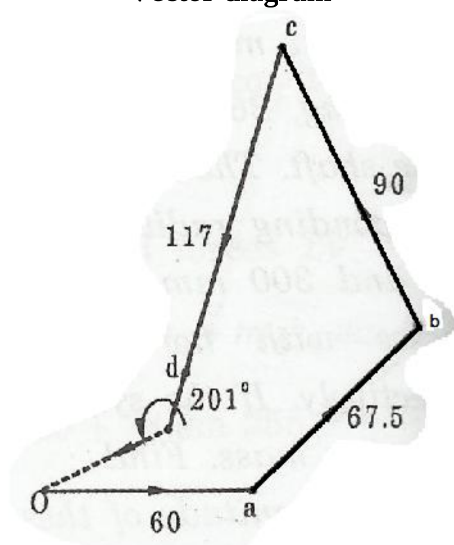
Vector diagram



Problem 1:

A shaft is rotating at a uniform speed with four masses m_1,m_2,m_3 and m_4 of magnitudes 300 kg, 450kg, 360kg and 390 kg respectively. The masses are rotating in the same plane. The corresponding radii of rotation are 200mm, 150mm, 250mm and 300mm. The angles made by these masses with respect to horizontal are 0°, 45°, 120° and 255° respectively. Find the magnitude and position of balance mass if it radius of rotation is 200mm.

Mass (m) ***kg***	***Radius (r)*** ***m***	***Cent.force*** ö µ^2 ***(mr)*** ***kg-m***
300	0.2	60
450	0.15	67.5
360	0.25	90
390	0.3	117

Angular Position diagram	**Vector diagram**
	

mr = od = 38 kg-m

m =38/0.2 = **190 kg**

Balancing mass 190 kg at 201î w.r.t to horizontal.

Problem 2:

Four masses m_1, m_2, m_3 and m_4 are 200 kg, 300 kg, 240 kg and 260 kg respectively. The corresponding radii of rotation are 0.2 m, 0.15 m, 0.25 m and 0.3 m respectively and the angles between successive masses are 45°, 75° and 135°. Find the position and magnitude of the balance mass required, if its radius of rotation is 0.2 m.

Analytical method

Resolving $m_1.r_1$, $m_2.r_2$, $m_3.r_3$ and $m_4.r_4$ horizontally,

$\Sigma H = m_1.r_1 \cos\theta 1 + m_2.r_2 \cos\theta 2 + m_3.r_3 \cos\theta 3 + m_4.r_4 \cos\theta 4$

= 40 cos0° + 45cos45° + 60 cos120° + 78cos255°

= 40 + 31.8 - 30 -20.2 = 21.6 kg-m

Resolving vertically,

$\Sigma\ V = m_1.r_1 \sin\theta 1 + m_2.r_2 \sin\theta 2 + m_3.r_3 \sin\theta 3 + m_4.r_4 \sin\theta 4$

= 40 sin0° + 45sin45° + 60 sin120° + 78sin255°

= 0 + 31.8+ 52 - 75.3 = 8.5 kg-m

Resultant, $R = \sqrt{\text{p}H^2 + \text{p}V^2} = \sqrt{21.6^2 + 8.5^2} = 23.2$ *kg-m*

$mr = R = 23.2$ or $m = 23.2 / r = 23.2 / 0.2 =$ **116 kg**

$\tan\theta = \frac{\text{p}V}{\text{p}H} = \frac{8.5}{21.6} = 0.3985$

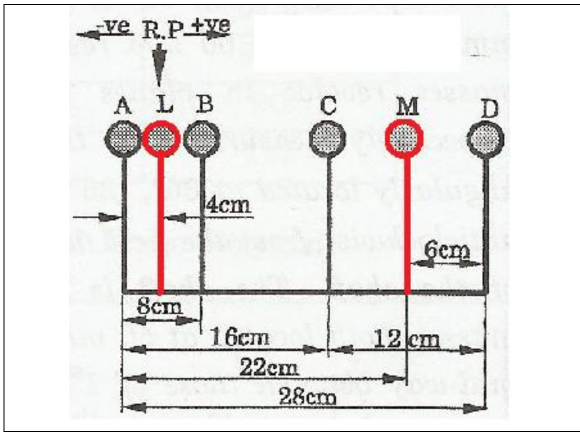
¯ **= 21.5î**

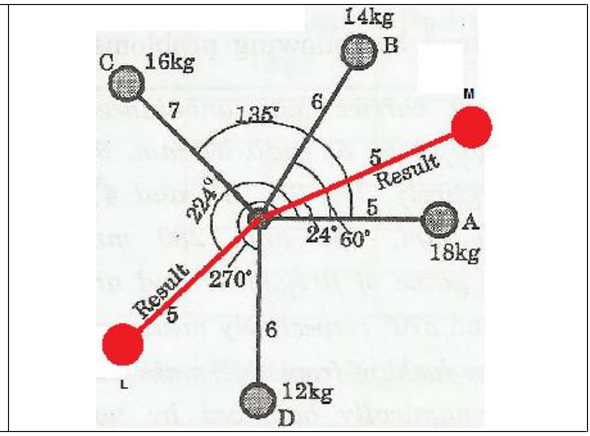
Angle of the balancing mass from the horizontal mass is θ = 180° + 21.5° = **201.5î**

Problem 3:

A rotating shaft carries four unbalanced mass 18kg, 14kg, 16kg and 12kg at radii 50mm, 60mm, 70mm and 60mm respectively. The second, third and fourth mass revolve in planes 80mm , 160mm , 280mm respectively from the first mass and angularly at 60°, 135° and 270° respectively in ACW from first mass. The shaft dynamically balanced by adding two masses at radii 50mm and first mass revolving in mid way between first and second and second mass revolving in mid way between third and fourth. Determine the angular position and magnitude of the balance mass required.

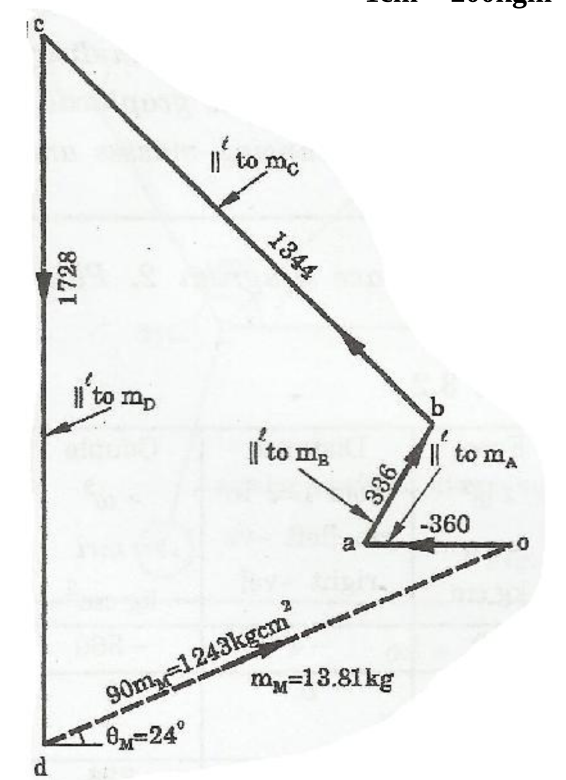
Plane	***Mass (m) kg***	***Radius (r) m***	***Cent.force*** ö µ^2 ***(mr) kg-m***	***Distance from ref. plane (l) m***	***Couple*** öµ^2 ***(m.r.l) kg-m^2***
A	18	5	90	-4	-360
L (R.P)	m_L	5	5 m_L	0	0
B	14	6	84	4	336
C	16	7	112	12	1344
M	m_M	5	5 m_M	18	90 m_M
D	12	6	72	24	1728
Plane Position diagram			**Angular Position diagram**		





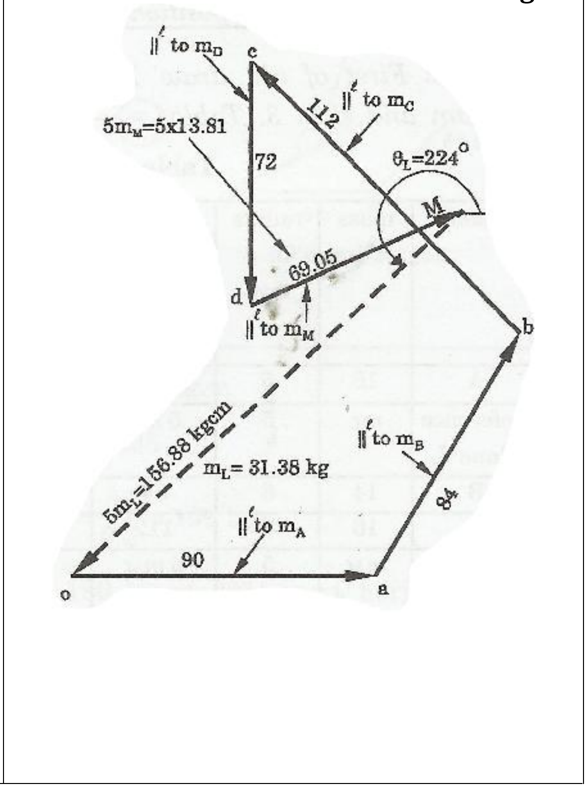
Couple polygon

1cm = 200kgm^2



Force Polygon

1mm = 1kg-m



First draw the couple polygon,
From that, vector od = 90 m_M
od = 1243 kg-m^2

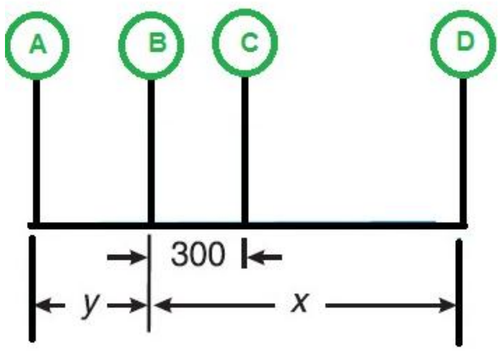
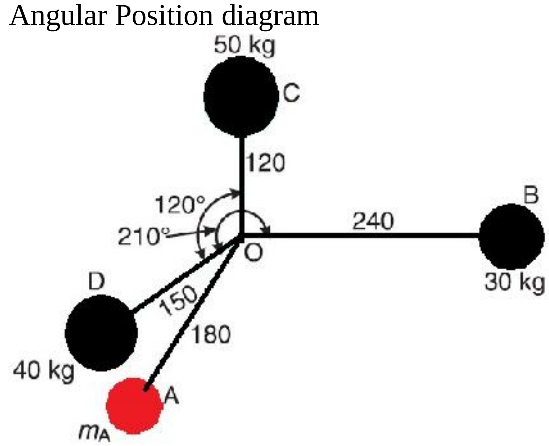
90 m_M = 1243 $\rightarrow$ m_M = **13.81 kg.**
Angle of m_M w.r. t A is 24î in ACW.

Substitute m_M in force and draw force polygon,

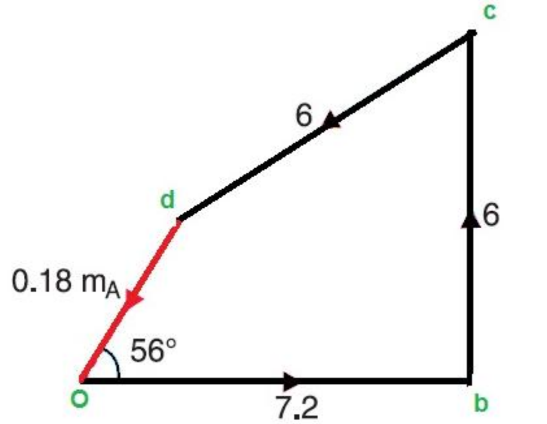
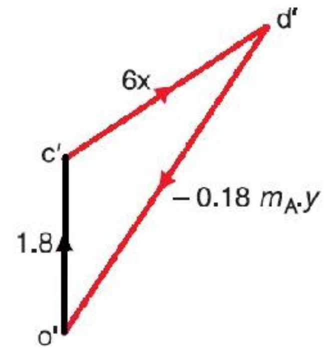
Vector oM =5 m_L
oM = 157 kg-m
5 m_L = 157 $\rightarrow$ m_L = **31.4 kg.**
Angle of m_L w.r. t A is 224î in ACW.

Problem 4:

Four masses A, B, C and D are to be completely balanced. Mass B, C and D are mass 30kg, 50kg and 40kg at radii 240mm, 120mm and 150mm respectively. The planes containing masses B and C are 300 mm apart. The angle between planes containing B and C is 90°. B and C make angles of 210° and 120° respectively with D in the same sense. Find : The magnitude and the angular position of mass A if its radius is 180mm ; and The position of planes A and D.

Plane Position diagram	Angular Position diagram
	

Plane	***Mass (m) kg***	***Radius (r) m***	***Cent.force* ö µ^2 *(mr) kg-m***	***Distance from ref. plane (l) m***	***Couple* ö µ^2 *(m.r.l) kg-m^2***
A	m_A	0.18	0.08 m_A	-y	-0.18 m_Ay
B	30	0.24	7.2	0	0
C	50	0.12	6	0.3	1.8
D	40	0.15	6	x	6x

Force Polygon **1cm = 1kg-m**	**Couple polygon** **5cm = 1kgm^2**
	

First draw force polygon, from that,

0.18 m_A = Vector *do* = 3.6 kg-m or $\boldsymbol{m_A}$ **= 20 kg**

Angular position of mass *A* from mass *B* in the anticlockwise direction is **236î**

To draw couple polygon, Draw vector *o' c'* parallel to *OC* and equal to 1.8 kg-m^2. From points *c'* and *o'* draw lines parallel to *OD* and *OA* respectively, such that they intersect at point *d'* ,

6 x = vector c' d' = 2.3 kg-m^2 or $\boldsymbol{x}$ **= 0.383 m**

The plane of mass *D* is 0.383 m or 383 mm towards left of plane *B*.

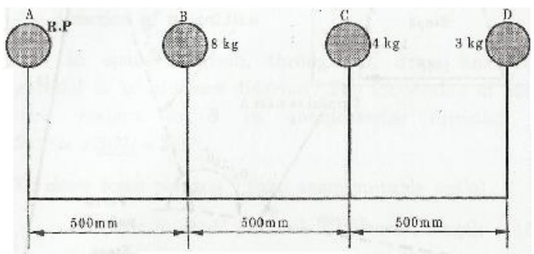
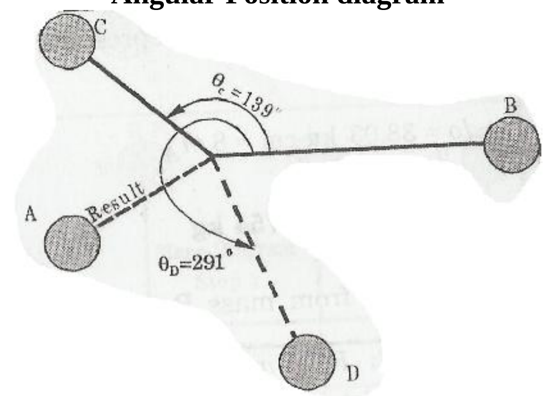
Similarly,
– 0.18 $m_A.y$ = vector *o'd'* = 3.6 kg-m^2

– 0.18 × 20 y = 3.6 or y = **– 1 m**

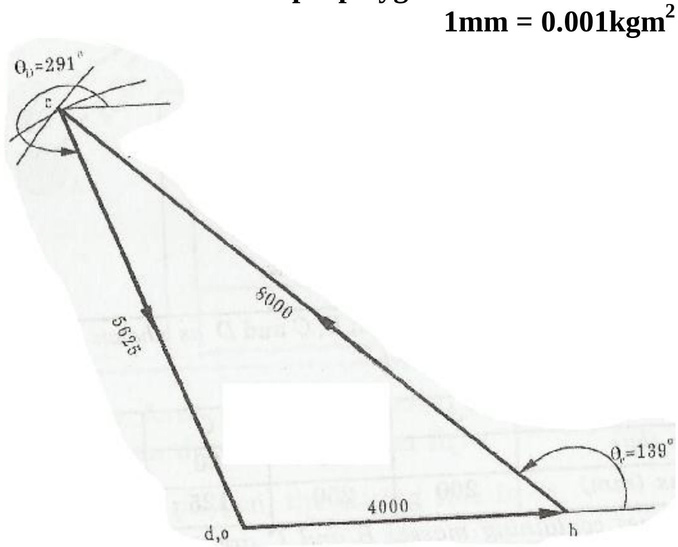
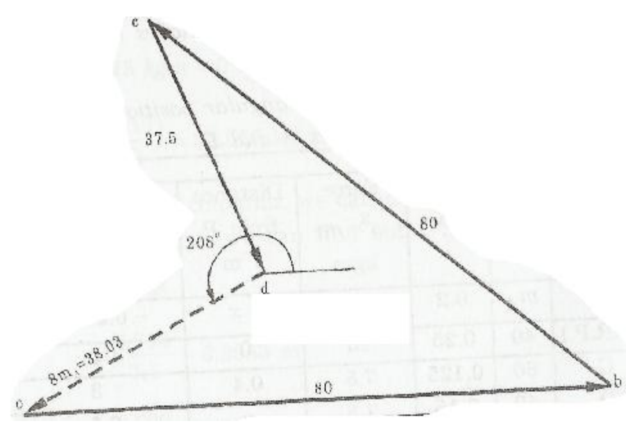
Plane A is 1000 mm towards right of plane *B*.

Problem 5:

Four masses A,B,C and D carried by a rorating shaft at radii 80mm, 100mm, 200mm and 125mm respectively. The planes of rotation are equi spaced by 500mm. The masses B,C and D are 8kg, 4kg and 3kg respectively. The magnitude of mass A and the angular position of entire system, if it completely balanced.

Plane Position diagram	Angular Position diagram
	

Plane	*Mass (m) kg*	*Radius (r) m*	*Cent.force ö µ^2 (mr) kg-m*	*Distance from ref. plane (l) m*	*Couple* öµ^2 *(m.r.l) kg-m^2*
A (R.P)	m_A	0.08	0.08 m_A	0	0
B	8	0.1	0.8	0.5	0.4
C	4	0.2	0.8	1	0.8
D	3	0.125	0.375	1.5	0.5625

Couple polygon **1mm = 0.001kgm^2**	Force Polygon **1mm = 0.01kg-m**
	

First draw the couple polygon with the mrl values. Assuming angle of mass B as horizontal, form a triangle to find the angular position for C and D.

Next draw couple polygon to find A,
Vector od = 0.08 m_A

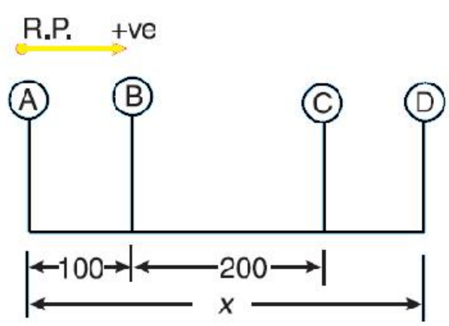
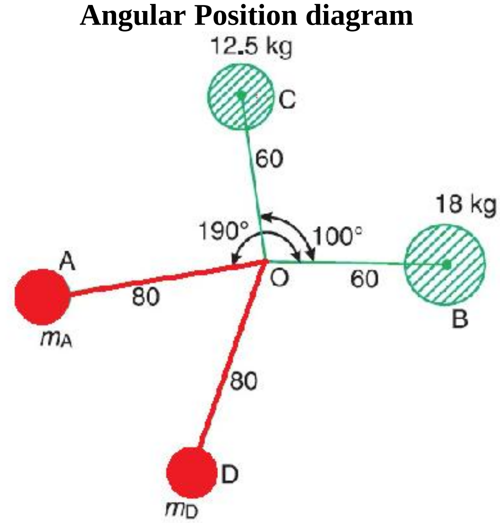
od = 0.381 kg-m

0.08 m_A = 0.381 kg-m $\rightarrow$ **m_A = 4.8kg**

Angular position of mass *A* from mass *B* in the clockwise direction is **208î**

Problem 6:

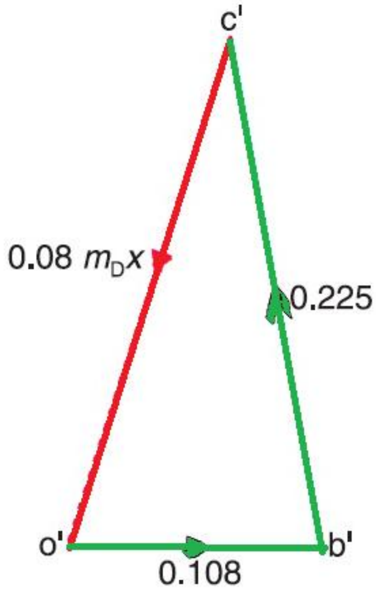
A shaft carries four masses in parallel planes A, B, C and D in this order along its length. The masses at B and C are 18 kg and 12.5 kg respectively, and each has an eccentricity of 60 mm. The masses at A and D have an eccentricity of 80 mm. The angle between the masses at B and C is 100° and that between the masses at B and A is 190°, both being measured in the same direction. The axial distance between the planes A and B is 100 mm and that between B and C is 200 mm. If the shaft is in complete dynamic balance, determine : **1.** The magnitude of the masses at A and D ; **2.** the distance between planes A and D ; and **3.** the angular position of the mass at D.

Plane Position diagram	**Angular Position diagram**
	

Plane	*Mass (m) kg*	*Radius (r) m*	*Cent.force ö μ^2 (mr) kg-m*	*Distance from ref. plane (l) m*	*Couple öμ^2 (m.r.l) kg-m^2*
A	m_A	0.08	0.08 m_A	0	0
B	18	0.06	1.08	0.1	0.108
C	12.5	0.06	0.75	0.3	0.225
D	m_D	0.08	0.08 m_D	x	0.08 m_Dx

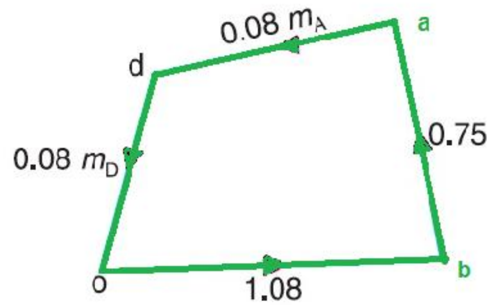
Couple polygon

1mm = 0.001kgm^2



Force Polygon

1mm = 0.01kg-m



First draw the couple polygon, assuming angle of mass B as horizontal.

$0.08\ m_D.x$ = vector *c'o'* = 0.235 kg-m^2

Then, draw the force polygon, Draw vector *ob* parallel to *OB* and equal to 1.08 kg-m. From point *b*, draw vector *bc* parallel to *OC* and equal to 0.75 kg-m. From point *c*, draw vector *cd* parallel to *OA* and from point *o* draw vector *od* parallel to *OD*. The vectors *cd* and *od* intersect at *d*.

$0.08\ m_A$ = vector *cd* = 0.77 kg-m or $\boldsymbol{m_A}$ **= 9.625 kg**

$0.08\ m_D$ = vector *do* = 0.65 kg-m or $\boldsymbol{m_D}$ **= 8.125 kg**

$0.08\ m_D.x = 0.235$ kg-m^2
$0.08 \times 8.125 \times x = 0.235$ kg-m^2
$0.65\ x = 0.235$

x=0.3615m

Angular position of mass at *D* from mass *B* in the anticlockwise direction **is 251î**

Exercises Problems:

1. Four masses *A*, *B*, *C* and *D* are attached to a shaft and revolve in the same plane. The masses are 12 kg, 10 kg, 18 kg and 15 kg respectively and their radii of rotations are 40 mm, 50 mm, 60 mm and 30 mm. The angular position of the masses *B*, *C* and *D* are 60°, 135° and 270° from the mass *A*. Find the magnitude and position of the balancing mass at a radius of 100 mm.
   [Ans. 7.56 kg ; 87° clockwise from *A*]

2. A shaft carries five masses *A*, *B*, *C*, *D* and *E* which revolve at the same radius in planes which are equidistant from one another. The magnitude of the masses in planes *A*, *C* and *D* are 50 kg, 40 kg and 80 kg respectively. The angle between *A* and *C* is 90° and that between *C* and *D* is 135°. Determine the magnitude of the masses in planes *B* and *E* and their positions to put the shaft in complete rotating balance.
   [Ans. 12 kg, 15 kg ; 130° and 24° from mass *A* in anticlockwise direction]

3. *A*, *B*, *C* and *D* are four masses carried by a rotating shaft at radii 100 mm, 150 mm, 150 mm and 200 mm respectively. The planes in which the masses rotate are spaced at 500 mm apart and the magnitude of the masses *B*, *C* and *D* are 9 kg, 5 kg and 4 kg respectively. Find the required mass *A* and the relative angular settings of the four masses so that the shaft shall be in complete balance.
   [Ans. 10 kg ; Between *B* and *A* 165°, Between *B* and *C* 295°, Between *B* and *D* 145°]

4. Four masses A, B, C and D revolve at equal radii and are equally spaced along a shaft. The mass B is 7 kg and the radii of C and D make angles of 90° and 240° respectively with the radius of B. Find the magnitude of the masses A, C and D and the angular position of A so that the system may be completely balanced.
   [Ans. 5 kg ; 6 kg ; 4.67 kg ; 205° from mass B in anticlockwise direction]

5. A rotating shaft carries four masses A, B, C and D which are radially attached to it. The mass centres are 30 mm, 38 mm, 40 mm and 35 mm respectively from the axis of rotation. The masses A, C and D are 7.5 kg, 5 kg and 4 kg respectively. The axial distances between the planes of rotation of A and B is 400 mm and between B and C is 500 mm. The masses A and C are at right angles to each other. Find for a complete balance,
   1. the angles between the masses B and D from mass A,
   2. the axial distance between the planes of rotation of C and D,
   3. the magnitude of mass B. [Ans. 162.5°, 47.5° ; 511 mm : 9.24 kg]

Unit II

Balancing

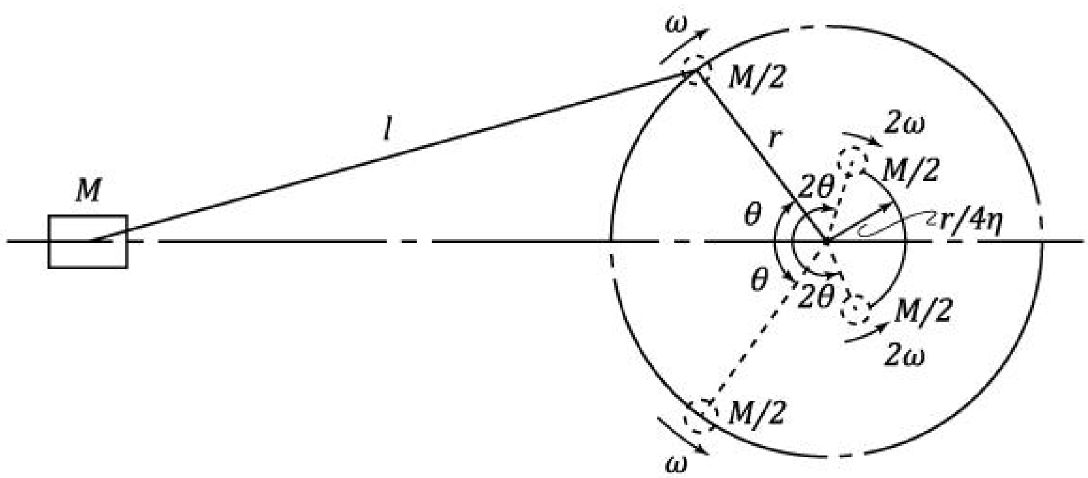
The Partial Balance of Two-cylinder Locomotives

It is normal for the cranks to be at right angles and as a result the secondary forces are small and in opposite directions. As a result they are usually neglected and only the primary forces and couples are considered.

It is usual to balance about two-thirds of the reciprocating parts with masses fixed to the wheels.The unbalanced vertical components of the reciprocating masses give rise to a variation of rail pressure known as Hammer Blow and a Rocking Couple about a fore and aft horizontal axis.The unbalanced reciprocating masses cause a variation in draw-bar pull and a swaying couple about a vertical axis

Radial Engines - Direct and Reverse Cranks

The primary force for a reciprocating mass M is equivalent to the resultant of the centrifugal forces of two masses $\frac{M}{2}$ rotating at a crank radius r and at a speed ω, one in the forward direction of motion and the other in the reverse direction. Note that the "direct" and "reverse" cranks are equally inclined to the dead centre position.

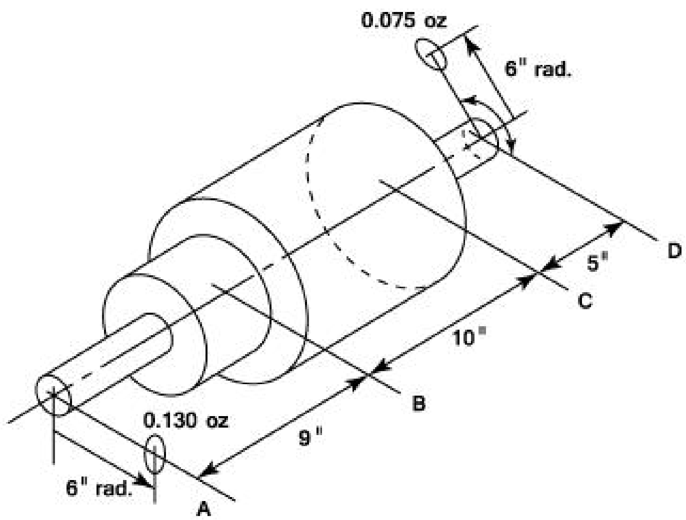


Similarly, the secondary force can be represented by direct and reverse cranks inclined at 2θ to the inner dead centre and each carrying a mass $\frac{M}{2}$ at a radius of $\frac{r}{4n}$ rotating at a speed of 2ω.

This method is particularly useful for examining the balance of radial engines with a number of connecting rods attached to the same crank. It is usually assumed that the crank and connecting rod lengths are the same for each cylinder, though from a practical consideration of design this is not generally true.

Example 1

A motor armature is in running balance when weights of 0.130 oz. and 0.075 oz. (There are 16 oz. in 1 lb.) are added temporarily in the positions shown in the planes A and D in the diagram.



If the actual balancing is to be carried out by the permanent addition of masses in the planes B and C each at 4 in radius, find their respective **magnitudes** and **angular positions** to the radius shown in plane A.

The problem is to determine the masses in the planes B and C which will provide the same resultant force and couple, when rotating, as the given masses in the planes A and D.
It is possible to eliminate one of the "unknowns" (say B) by taking B as the reference plane. The following table can now be constructed. The figures in bracket are added as and when they are calculated.
It is the couple which tends to make the leading wheels sway from side to side, produced due to separation of unbalanced primary forces along the line of stroke by some distance.

Planes	M oz.	r in.	x in.	Mr	Mrx	θ
A	0·13	6	-9	0·78	-7·02	0°
B	0·4	4	0	1·6	0	353°
C	0·291	4	10	1·166	11·66	148°
D	0·075	6	15	0·45	6·75	115°

The Mrx polygon can now be drawn. Note that A is negative.
The angular position and magnitude of Mrx for C can now be measured since C is the resultant of A and D

The Mr value of C is now Mrx for C divided by the appropriate value of x. With this information the Force polygon b can be constructed in which B and C give the same resultant as A and D.
The Mr value and angular position of B can now be added to the table.
The required magnitudes of B and C are calculated by dividing Mr by the corresponding value for r.

Tractive force

The term **tractive force** can either refer to the total traction a vehicle exerts on a surface, or the amount of the total traction that is parallel to the direction of motion.

Tractive effort

The term **tractive effort** is often qualified as **starting tractive effort**, **continuous tractive effort** and **maximum tractive effort**. These terms apply to different operating conditions, but are related by common mechanical factors:input torque to the driving wheels, the wheel diameter, coefficient of friction (**μ**) between the driving wheels and supporting surface, and the weight applied to the driving wheels (**m**). The product of **μ** and **m** is the factor of adhesion, which determines the maximum torque that can be applied before the onset of wheelspin or wheelslip.

Starting tractive effort: Starting tractive effort is the tractive force that can be generated at a standstill. This figure is important on railways because it determines the maximum train weight that a locomotive can set into motion.

Maximum tractive effort: Maximum tractive effort is defined as the highest tractive force that can be generated under any condition that is not injurious to the vehicle or machine. In most cases, maximum tractive effort is developed at low speed and may be the same as the starting tractive effort.

Continuous tractive effort: Continuous tractive effort is the tractive force that can be maintained indefinitely, as distinct from the higher tractive effort that can be maintained for a limited period of time before the power transmission system overheats. Due to the relationship between power (P), velocity (v) and force (F), described as:

$P = vF$ or $P/v = F$

tractive effort inversely varies with speed at any given level of available power. Continuous tractive effort is often shown in graph form at a range of speeds as part of a **tractive effort curve**.[2]

Vehicles having a hydrodynamic coupling, hydrodynamic torque multiplier or electric motor as part of the power transmission system may also have a **maximum continuous tractive effort** rating, which is the highest tractive force that can be produced for a short period of time without causing component harm. The period of time for which the maximum continuous tractive effort may be safely generated is usually limited by thermal considerations. such as temperature rise in a traction motor.

Hammer blow

Hammer blow, in rail terminology, refers to a vertical force which alternately adds to and subtracts from the locomotive's weight on a wheel.

It is transferred to the track by the driving wheels of many steam locomotives. It is an out-of-balance force on the wheel (known as overbalance. It is the result of a compromise when a locomotive's wheels are unbalanced to off-set horizontal reciprocating masses, such as connecting rods and pistons, to improve the ride. The hammer blow may cause damage to the locomotive and track if the wheel/rail force is high enough. 'Dynamic augment' is the US term for the same force.

Principles

The addition of extra weights on the wheels reduces the unbalanced reciprocating forces on the locomotive but causes it to be out of balance vertically creating hammer blow. Locomotives were balanced to their individual cases, especially if several of the same design were constructed (a class). Each class member was balanced for its normal operating speed. Between 40% and 50% of the reciprocating weights on each side were balanced by rotating weights in the wheels.

Causes

While the coupling rods of a locomotive can be completely balanced by weights on the driving wheels since their motion is completely rotational, the reciprocating motions of the pistons, piston rods, main rods and valve gear cannot be balanced in this way. A two-cylinder locomotive has its two cranks "quartered" — set at 90° apart — so that the four power strokes of the double-acting pistons are evenly distributed around the cycle and there are no points at which both pistons are at top or bottom dead centre simultaneously.

A four-cylinder locomotive can be completely balanced in the longitudinal and vertical axes, although there are some rocking and twisting motions which can be dealt with in the locomotive's suspension and centring; a three-cylinder locomotive can also be better balanced, but a two-cylinder locomotive only balanced for rotation will surge fore and aft. Additional balance weight — "overbalance" — can be added to counteract this, but at the cost of adding vertical forces, hammer blow. This can be extremely damaging to the track, and in extreme cases can actually cause the driving wheels to leave the track entirely.

The heavier the reciprocating machinery, the greater these forces are, and the greater a problem this becomes. Except for a short period early in the twentieth century when balanced compound locomotives were tried, American railroads were not interested in locomotives with inside cylinders, so the problem of balance could not be solved by adding more cylinders per coupled wheel set. As locomotives got larger and more powerful, their reciprocating machinery had to get stronger and thus heavier, and thus the problems posed by imbalance and hammer blow became more severe. Higher speeds also increased unbalanced forces which rise with the square of the wheel rotational speed.

Swaying couple is produced due to unbalanced parts of the primary disturbing forces acting at a distance between the line of stroke of the cylinders. Hammer blow is the maximum value of the unbalanced vertical force of the balance weights.

Examples

1. Asingle cylinder engine has stroke of 50 cm and runs at 300 rpm. The reciprocating masses are 60 kg and revolving masses are equivalent to 35 kg at a radius of 20 cm at a radius of 20 cm. Determine the balancing mass to be placed opposite to the crank at a radius of 40 cm which is equivalent to mass of revolving masses and two third of reciprocating masses. Find the magnitude of the remaining unbalanced force when the crank has turned through 30 degrees from inner dead centre.

Given Data:

r2= 0.5/2= 0.25 m

N = 300 rpm
ω = 2πN/60 = 2 X π X 300 / 60 = 31.42 rad / s

Balancing masses to be placed at a radius of b (0.4) = B
We know that,
Bb = $m_1 r_1$ +C $m_2 r_2$ When all the masses rotating in same plane.
Where,
m_1 = revolving masses = 35 kg
$$m_2 = reciprocating\ masses = 60\ kg$$

r_1 = 0.2 m
C = fraction of reciprocating masses to be balanced = 2/3
Bb = (35 X 0.2) + $\frac{2\ x\ 60\ x 0.25}{3}$
B X 0.4 = 17
B = 42.5 kg
Balancing mass (B) = 42.5 kg
To find the remaining unbalanced force,
We know that,
∑H = Horizontal component of unbalanced force (or) Unbalanced force along the line of stroke
= (1 –C)$m_2(\dot{\omega})^2$r cos ⊙
∑V= Vertical component of unbalanced force (or) Unbalanced force perpendicular to the line of stroke
=C$m_2(\dot{\omega})^2$r sin ⊙

R = Resultant of unbalanced force
= $\sqrt[2]{\sum H^2 + \sum V^2}$
$$= \sqrt[2]{((1 - C\ )m_2(\dot{\omega})^2 r\ \cos\odot)^2 + (Cm_2(\dot{\omega})^2 r\ \sin\odot)^2}$$
= $m_2(\dot{\omega})^2 r \sqrt[2]{m_2(\dot{\omega})^2 r}$
= 60 x 31.42^2 x 0.25 x$\sqrt[2]{0.0833 + 0.1111}$
= 6529.2 N

2. The following particulars relate to an outside cylinder of an uncoupled locomotive
Rotating mass / cylinder = 250 kg
Length of each crank = 0.35 m
Distance between wheels = 1.6 m
Distance between cylinder centers = 1.9 m
Dia of driving wheel = 1.85 m
Radius of balancing mass = 0.8 m

If all the rotating masses and $2/3^{rd}$ of the reciprocating masses are to be balanced, determine the magnitude and position of the balancing mass in the plane of the wheel. The angle between the cranks of the cylinder is 90 degrees.

Solution

Balancing masses are fitted in the wheel A and B. Since the cylinders are outside of the wheel, these are called outside cylinder locomotive.

M_1 = mass to be balanced on cylinder 1

$$m_1 = 200 + \frac{2}{3} X\, 250 = 366.7 kg$$

M_2 = mass to be balanced on cylinder 2

$$m_2 = 200 + \frac{2}{3} X\, 250 = 366.7 kg$$

Take A as reference plane

By using given data we can draw a table,

Plane	Mass in kg	r in m	Force/ω^2 = mr kg m	Distance from wheel A l m	Couple /ω^2 = mrlkg m^2
Cylinder 1	$200 + \frac{2}{3} X\, 250 = 366.7 kg$	0.35	128.345	-0.15	-19.253
R.P wheel A	m_A	0.8	0.8 m_A	0	0
Wheel B	m_B	0.8	0.8 m_B (141.14)	1.6	1.28 m_B
Cylinder 2	$200 + \frac{2}{3} X\, 250 = 366.7 kg$	0.35	128.345	1.75	225

Draw a couple polygon first, since it contains only one unknown and measure 1.28 m_B

1.28 m_B = 222.72 kg

$$m_b = \frac{222.72}{1.28} = 174 kg$$

Substitute m_B value in force column and draw force polygon

Measure

0.8 m_A = 139.2

m_A = 139.2/0.8

= 174 kg

Measure

= 175 degrees from cylinder 1

3. The Centre distance between the cylinders of inner cylinder locomotive is 0.8m. It has a stroke of 0.5m. The rotating mass per cylinder is equivalent to 200kg at the crank pin and the reciprocating mass per cylinder is 240kg. The wheel Centre lines are 1.7m apart. The cranks are at right angle.

The whole of the rotating mass and 2/3rd of the reciprocating masses are balanced by masses at a radius of 0.6m. Find the magnitude and direction of the balancing masses.

Find the hammer blow, variation in tractive effort and the magnitude of the swaying couple at a speed of 300 rpm

Solution

Since whole of the rotating masses (m1) and 2/3rd of the reciprocating masses (m2) are balanced,

The total balancing mass / cylinder = m1 + Cm2

= 200 + 2/3 X 240

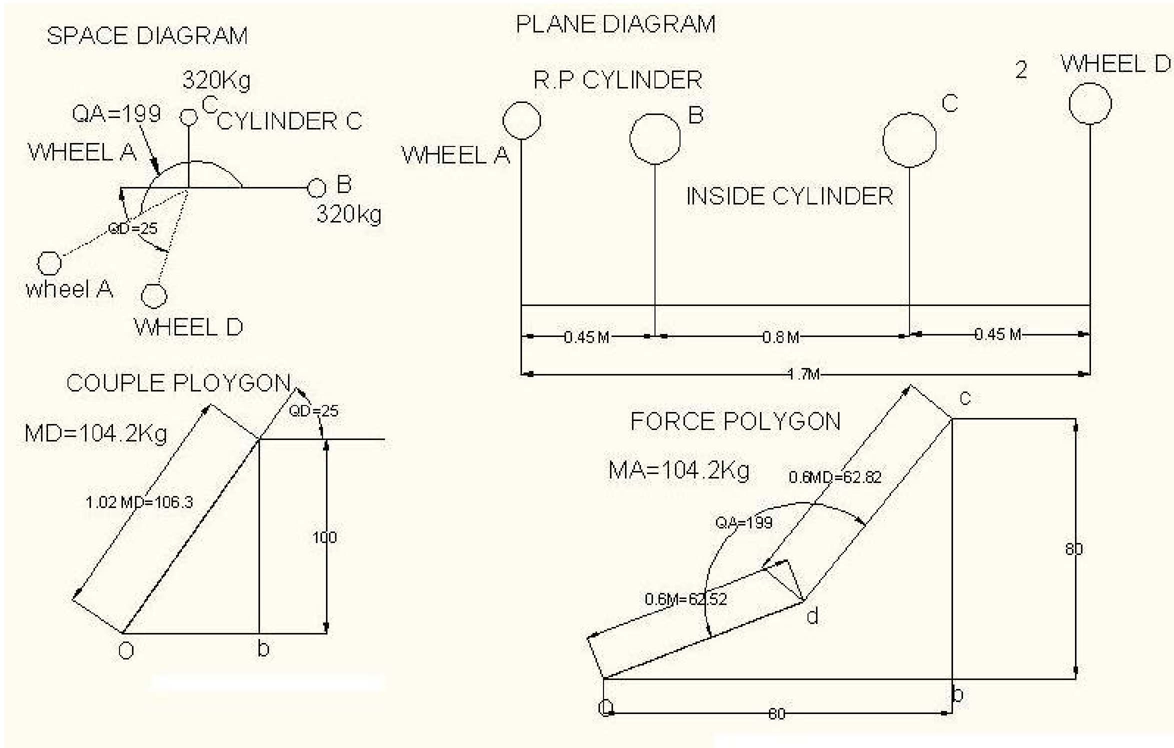
= 320 kg

To balance the above masses in cylinder B and C, we place balancing masses mA and m_D at a radius of 0.6m at an angle of Θ_A and Θ_D from the first crank B.

Procedure

1. Draw space diagram. Assume crank B as horizontal position and crank C is at 90 degrees to B.
2. Draw plane diagram. Take wheel A as reference plane (R.P)
3. Since couple column (mrl) contains only one unknown value (1.02mD m_D) we can draw couple polygon first to find m_D.

Plane	Mass m kg	Radius r m	Centrifugal force/	Distance from plane A l m	Couple/
A (R.P)	m_A	0.6	$0.6m_A$	0	0
B	320	0.25	80	1.45	36
C	320	0.25	80	1.25	100
D	m_D	0.6	$0.6\ m_D$	1.7	$1.02\ m_D$



In couple polygon,

The closing side CO represents

$1.02m_D = 106.3$ kg m ,

$m_D = 104.2$ kg

$\theta_D = 71 + 180 = 251\,^{\circ}$from B .

By knowing $m_D$value substitute in mr column and draw force polygon.

In force polygon the closing side do represents 0.6 m_A = 62.52 kg m

$$\text{mA} = \frac{62.52}{0.6} = 104.2kg$$

θ_A = 199 degrees from B

To find hammer blow,

Each balancing mass is 104.2 kg.

Total 320 kg is balanced by 104.2 kg . In this 104.2 kg we have to find out the contribution of reciprocating mass alone.

2/3 x 240 = 160 kg of reciprocating mass is balanced in 320 kg.

So 320 kg mass contains 160 kg of reciprocating mass alone.

104.2 kg mass contains 160/320 X 104.2 = 52.1 kg of reciprocating mass alone.

Hence B = 52.1 kg ; b = 0.6 m

$\omega = 2\pi N/60 = 2\text{x}\pi\text{x}300/60 = 31.42$ rad/s

Hammer blow per cylinder = $B\omega^2 b$

$= 52.1 \times 31.42^2 \times 0.6$

$= 30852.4$ N

Variation in tractive effort

M_2 = reciprocating mass = 240 kg

Max variation of tractive effort

$$\pm\sqrt{2}(1-C)m_2\mu^2 r$$

$$\pm\sqrt{2}(1-\frac{2}{3})240x31.42^2 x0.25$$

= 27923 N

Swaying couple

Max swaying couple

$$\pm\sqrt{2}(1-C)m_2\mu^2 r\frac{a}{2}$$

$$=\pm\sqrt{2}(1-\frac{2}{3})240x31.42^2 x0.25x\frac{0.8}{2}$$

= 11169 Nm

4. A two cylinders uncoupled locomotive has inside cylinders 0.6m apart. The radius of each crank is 300mm and is at right angles. The revolving masses per cylinder are 250kg and the reciprocating mass per cylinder is 300kg. The whole of the revolving and 2/3rd of the reciprocating masses to be balanced and the balancing masses are to be placed in the plane of rotation of the driving wheels at a radius of 0.8m. The driving wheels are 2m in diameter and 1.5m apart. If the speed of the engine is 80kmph, find the hammer blow, max variation in tractive effort and max swaying couple.

Solution

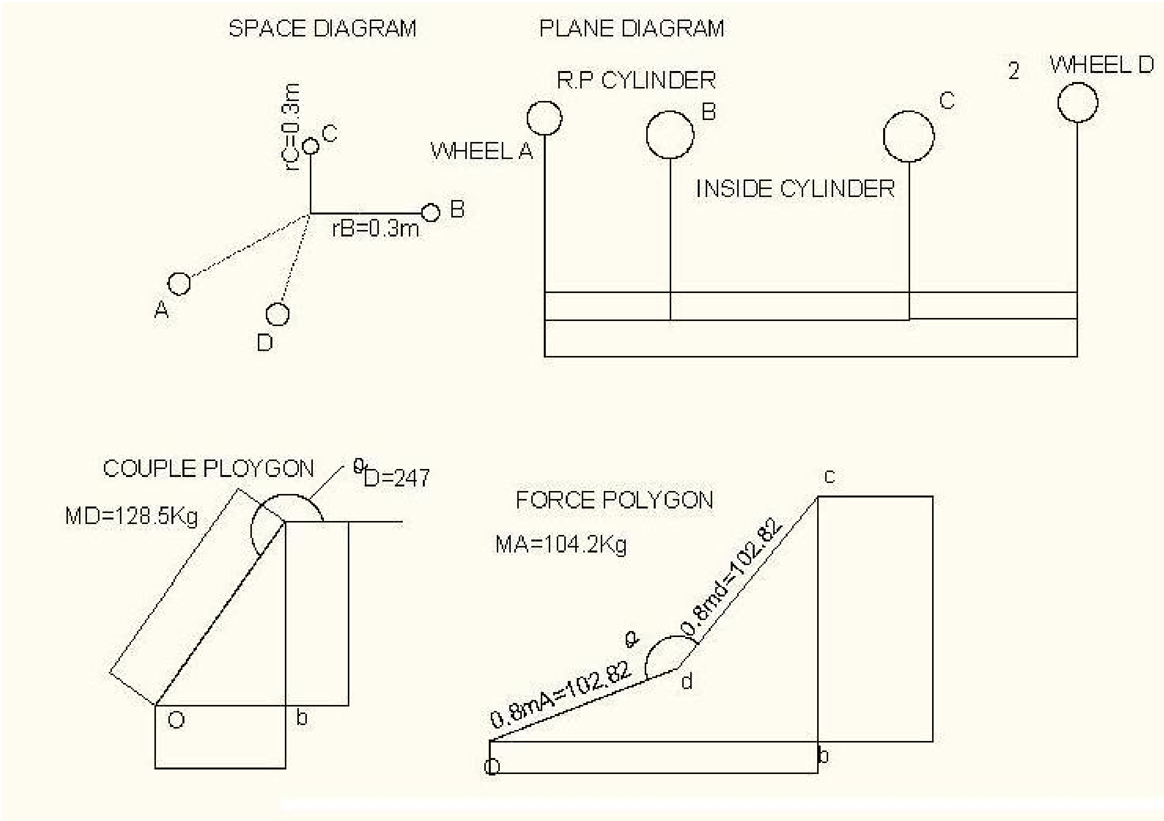
Balancing masses are m_A and m_B

$m_A = m_B$ =Whole revolving mass + 2/3rd of reciprocating mass

= 250 + 2/3 x300 = 450 kg

Take A as reference plane

Plane	Mass in kg	r in m	Force/ω^2 = mr kg m	Distance from wheel A l m	Couple /ω^2 = mrl kg m^2
A	m_A	0.8	$0.8m_A$	0	0
B	450	0.3	135	0.45	60.75
C	450	0.3	135	1.05	141.75
D	m_D	0.3	$0.8m_D$	1.5	$1.2m_D$



Draw couple polygon first to find m_D and $\Theta_{D.}$ Then draw force polygon to find m_A and Θ_A.

From couple polygon,

$1.2m_D = 154.22$

$m_D = 128.52$ kg

$\Theta_D = 247$®

Substitute $m_D = 128.52$ kg in force column and draw force polygon.

From force polygon,

$0.8m_A = 102.83$ kgm

mA = 128.52 kg

$\Theta_A = 203$®

To find hammer blow

450kg of mass contains 2/3 x 300 = 200kg of reciprocating mass alone.

128.52 kg mass contain = 200/450 x 128.52

= 57.12 kg

This balancing mass 57.12 kg is the cause for the hammer blow.

ω, B = 57.12 kg and b = 0.8 m

Speed of engine, V = 80 km/hr

= 22.22 m/s

Angular velocity (ω) = V /radius of wheel

= 22.22/1.5

= 14.815 rad/s

Hammer blow = B ω^2b

= 57.12 x 14.85^2x 0.8

= 10.029 N

To find max variation in tractive effort

$\pm\sqrt{2}(1-C)\ m_2\mu^2 r$

$\pm\sqrt{2}(1-\frac{2}{3})300x14.815^2x0.8$

= 9312 N

To find max swaying couple,

$\pm\frac{q}{\sqrt{2}}(1-C)\ m_2\mu^2 r$

= 3951 Nm

5. The 3 cranks of a 3 cylinder locomotive are all on the same shaft and are set at 120 degrees. The distance between cylinders is 1m and the radius of the crank of the cylinder is 0.4m. The reciprocating masses are 300 kg for inside cylinder and 250 kg for outside cylinder and the plane of rotation of the balancing masses are 0.75m from the inside crank.

If 50 % of the reciprocating masses are balanced, determine the magnitude and the positioning of the balancing masses required at a radius of 0.6m. The hammer blow per wheel when the shaft makes 360 rpm. The speed in kmph at which the wheel will lift off the rails, when the load on each driving wheel is 100 KN and the diameter of the tread of wheel is 1m.

Solution

C = 0.5

Here we have to balance only reciprocating masses. Since 50 % of the reciprocating masses are to be balanced.

The reciprocating masses to be balanced for each outside cylinder

= m_A = m_C = 0.5 X 250 = 125 kg

The reciprocating masses are to be balanced for inside cylinder

= m_B

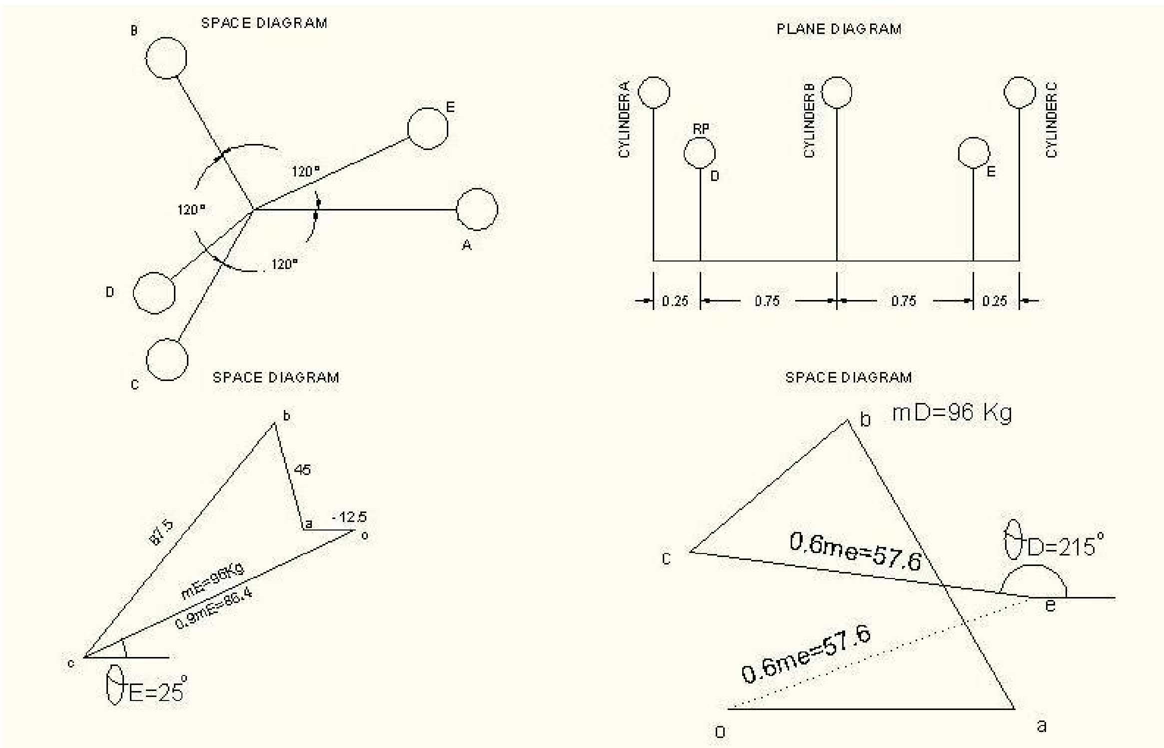
= 0.5 X 300

= 150 kg

Take D as reference plane (R.P)

Plane	Mass in kg	r in m	Force/ω^2 = mr kg m	Distance from wheel A l m	Couple /ω^2 = mrl kg m^2

Outside cylinder A	125	0.4	50	-0.25	-12.5
D (R. P)	m_D	0.6	$0.6m_D$	0	0
Inside cylinder B	150	0.4	60	0.75	45
E	m_E	0.6	$0.6m_E$ (57.6)	1.5	0.9mE
Outside cylinder C	125	0.4	50	1.75	87.5



Draw couple polygon first and the force polygon to find m_E and m_D .

By measurement m_E = 96 kg :m_D = 96 kg

Hammer blow (or) Fluctuation in rail pressure

In this problem rotating masses are not given. We have considered only the masses. So the balancing masses D and E are used to balance only reciprocating masses

Here

$m_D = m_E$ balancing masses for reciprocating mass alone

= B = 96 kg also b = 0.6m

$$= \mu = \frac{2\text{®}N}{60} = \frac{2\text{®}x360}{60} = 37.7 rad / s$$

Hammer blow per wheel = $B\,\omega^2 b$

$= 96 \times 37.7^2 \times 0.6$

= 81866.3 N

peed in km/hr at which the wheel will lift off the rails when the load on each driving wheel is 100 KN and the diameter of the tread of driving wheel is 1m.

$$\mu_{\lim iting} = \sqrt{\frac{W}{Bb} = \sqrt{\frac{100x10^3}{96x0.6}} = 41.67 rad / s}$$

$$V_{\lim iting} = \mu R = 41.67 X 1 = 41.67 m / s$$

$$= 150 \text{ km/hr}$$

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