GOVERNMENTPOLYTECHNIC,DHENKANAL

Programme:DiplomainMechanicalEngineering

Course:TheoryofMachines(Theory)

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UNIT1:SimpleMechanism

Introduction

Mechanics: Itisthatbranchofscientificanalysiswhichdealswithmotion,time and force.

Kinematics:isthestudyofmotion,withoutconsideringtheforceswhichproduce that motion. Kinematics of machines deals with the study of the relative motion of machine parts. It involves the study of position, displacement, velocity and acceleration of machine parts.

Dynamics:ofmachinesinvolvesthestudyofforcesactingonthemachinepartsand the motions resulting from these forces.

Kinematiclink(or)element

A machine part or a component of a mechanism is called a kinematic link or simply a link. A link is assumed to be completely rigid, or under the action of forces it does not suffer any deformation, signifying that the distance between anytwopointsonitremainsconstant.Althoughallrealmachinepartsareflexible to somedegree,itiscommonpracticetoassumethatdeflectionsarenegligibleand parts are rigid when analyzing a machine’s kinematic performance.

Typesoflink

(a)Basedonnumberofelementsoflink:

Binary link: Link which is connected to other links at two points.
Ternarylink: Linkwhichisconnectedtootherlinksatthreepoints
Quaternarylink: Linkwhichisconnectedtootherlinksatfourpoints

Inordertotransmitmotion,thedriverandthefollowermaybeconnectedbythe following three types of links:

1. ***Rigidlink*.**A rigidlinkisonewhichdoesnotundergoanydeformationwhile transmitting motion. Strictlyspeaking,rigid links do notexist. However,as the deformationofaconnectingrod,cranketc.ofareciprocatingsteamengineisnot appreciable, they can be considered as rigid links.

2. ***Flexiblelink*.**A flexible link is one which is partly deformed ina manner not to affectthetransmissionofmotion.Forexample,belts,ropes,chains andwiresare flexible links and transmit tensile forces only.

3. ***Fluid link*.**A fluid link is one which is formedby having afluidinareceptacle andthemotionistransmittedthroughthefluidbypressureorcompressiononly,asin the case of hydraulic presses, jacks and brakes.

Machine: Amachineisamechanismorcollectionofmechanisms,whichtransmitforce fromthesourceof powerto theresistance to be overcome. Though all machines are mechanisms, all mechanisms are not machines. Many instruments are mechanisms but are not machines, because they do no useful work nor do they transform energy.

Kinematicpair

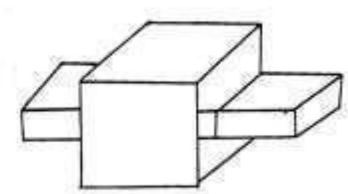
Thetwolinksorelementsofamachine,whenincontactwitheachother,aresaidto form a pair. If the relative motion between them is completely or successfullyconstrained(i.e.inadefinitedirection),thepairisknownas **kinematicpair**.

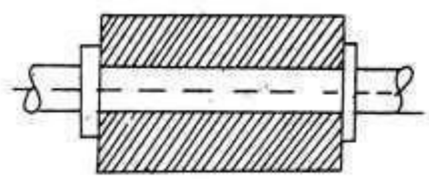
Classificationofkinematicpair

Thekinematicpairsmaybeclassifiedaccordingtothefollowingconsiderations:

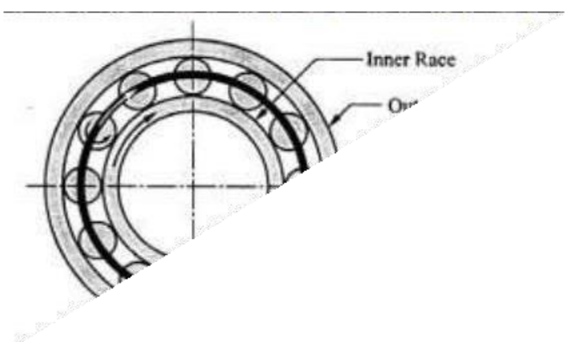
(i) Basedonnatureofcontactbetweenelements:

(a) Lowerpair. Ifthejointbywhichtwo membersareconnected hassurface contact,the pairisknownaslowerpair.Eg.pinjoints,shaftrotatinginbush,slider in slider crank mechanism.





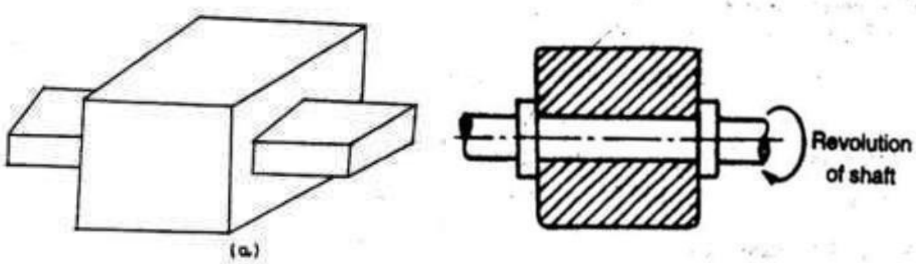
(b) Higherpair. Ifthecontactbetweenthepairingelementstakes placeatapoint oralongaline,suchasinaballbearingorbetweentwogearteethincontact,itisknown as a higher pair.



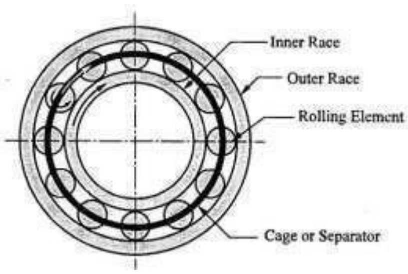
(ii) Basedonrelativemotionbetweenpairingelements:

(a) Sidingpair. Slidingpairisconstitutedbytwoelementssoconnectedthatone is constrained to have a sliding motion relative to the other

(b) Turningpair(revolutepair). Whenconnectionsofthetwoelementsaresuch thatonlyaconstrainedmotionofrotationofoneelementwithrespecttotheother is possible, the pair constitutes a turning pair

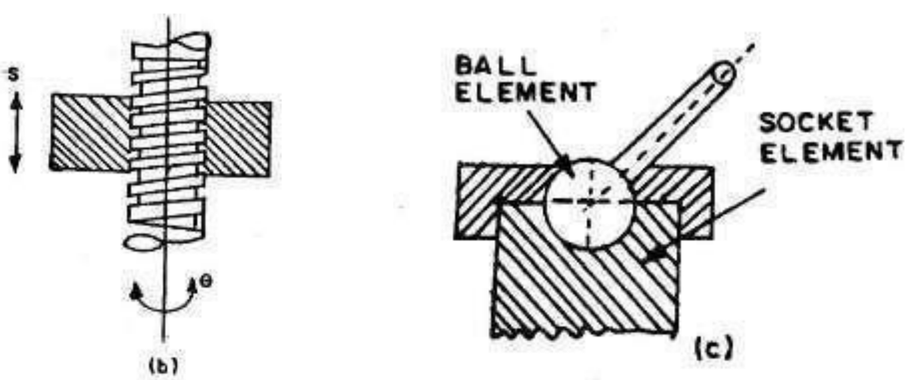


(c) Rollingpair. Whenthepairingelementshaverollingcontact,thepairformed is called rolling pair. Eg. Bearings, Belt and pulley



(d) Spherical pair.A spherical pair will havesurfacecontactand three degreesof freedom. Eg. Ball and socket joint.

(e) Helicalpairorscrewpair.Whenthenatureofcontactbetweentheelements of a pairis suchthatone elementcan turn aboutthe other byscrewthreads, it is known as screw pair. Eg. Nut and bolt



(a) Slidingpair(prismaticpair)eg.pistonandcylinder,crossheadandslides, tail stockonlathebed.(b) Turningpair(Revolutepair):eg:cyclewheelonaxle, lathe spindle in head stock.

(c) Cylindricalpair:eg.shaftturninginjournalbearing.
(d) Screwpair(Helicalpair):eg.boltandnut,leadscrewoflathewithnut, screw jack.
(e) Sphericalpair:eg.penholderonstand,castorballs.

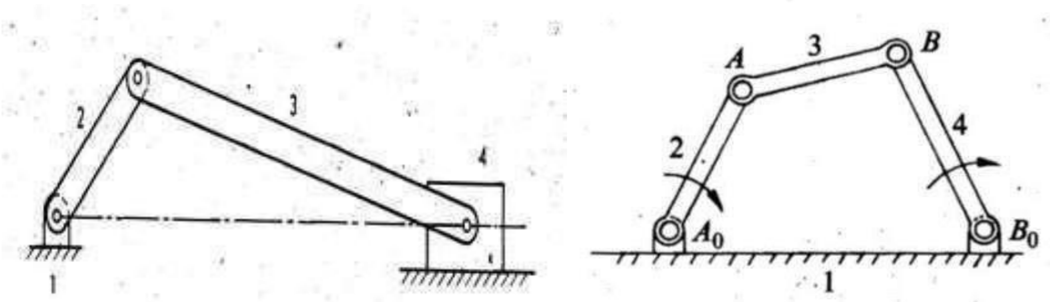
Mechanism

Whenoneofthelinksofakinematicchainisfixed,thechainisknownas ***mechanism***.

Amechanismwithfourlinksisknownas***simplemechanism***,and themechanismwithmorethanfourlinksisknownas***compoundmechanism***.

Whenamechanismisrequiredtotransmitpowerortodosomeparticulartypeof work, it then becomes a ***machine***.

Amechanismisaconstrainedkinematic chain.This meansthatthemotionof anyonelinkin the kinematic chainwillgivea definiteand predictablemotion relativetoeachoftheothers.Usuallyoneofthelinksofthekinematicchainisfixedin a mechanism.

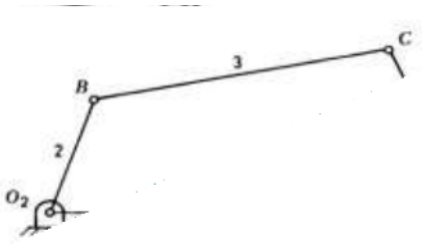


Slidercrankandfourbarmechanisms

InversionofMechanism

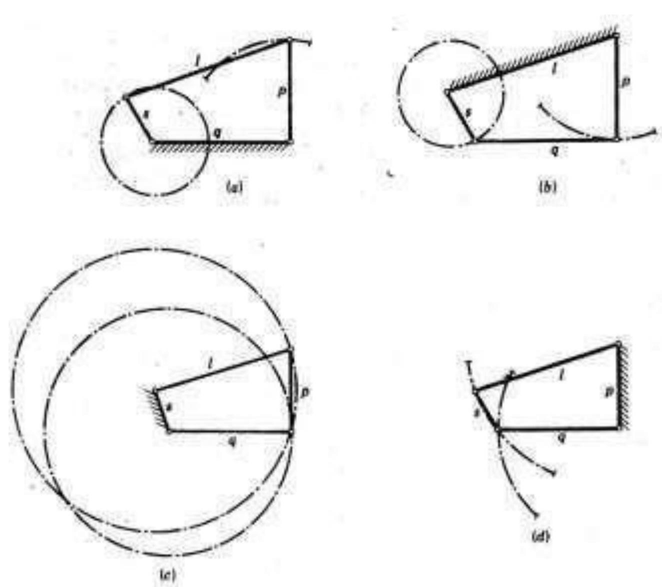
A mechanism is one in whichone of the links of a kinematic chainis fixed. Differentmechanismscanbeobtainedbyfixingdifferentlinksofthesame kinematic chain. These are called as inversions of the mechanism.

InversionsofFourBarChain



Oneofthemostusefulandmostcommonmechanismsisthefour-barlinkage.In this mechanism,thelinkwhichcanmakecompleterotationisknownascrank(link2). The link which oscillates is known as rocker or lever (link 4). And the link connecting these two is known as coupler (link 3). Link 1 is the frame.

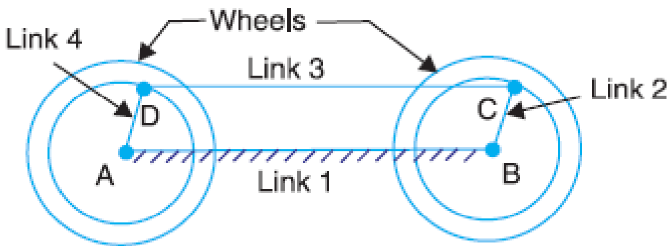
Inversions:



Inversionsoffourbarchain

Crank-rockermechanism: Inthismechanism,eitherlink1orlink3isfixed.Link2(crank) rotates completely and link 4 (rocker)oscillates. Itis similar to (a)or (b)

Doublecrankmechanism(Couplingrodoflocomotive). Thisisonetypeofdrag linkmechanism,where,links 1&3areequalandparallelandlinks2&4areequal and parallel.



Doublerockermechanism. Inthismechanism,link4isfixed.Link2makes complete rotation, whereas links 3 & 4 oscillate

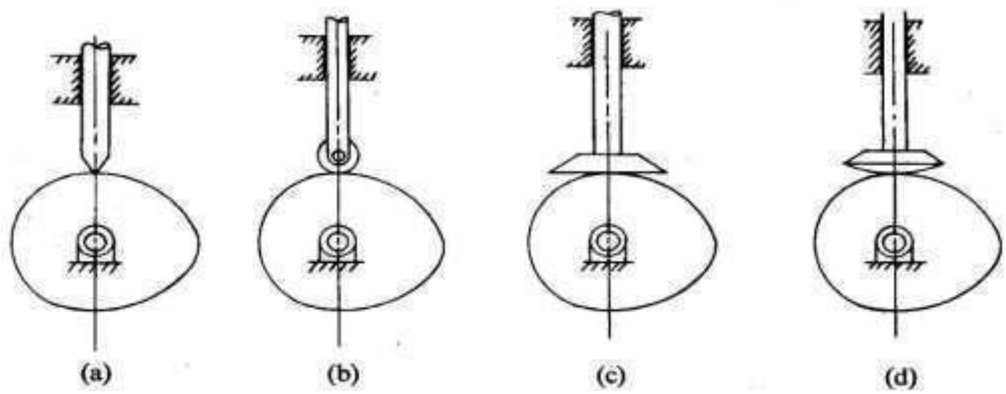
Cam - A mechanical device used to transmit motion to a follower by direct contact.WhereCam–drivermemberFollower-drivenmember.Thecamandthe follower have line contact and constitute a higher pair. In a cam - follower pair, the camnormally rotates at uniformspeed bya shaft, while the follower may is predetermined, will translate or oscillate according to the shape of the cam. A familiarexampleisthecamshaftofanautomobileengine,wherethecamsdrive thepushrods(thefollowers)toopenandclosethevalvesinsynchronizationwiththe motion of the pistons.

Applications: Thecamsarewidelyusedforoperatingtheinletandexhaustvalves of Internalcombustionengines,automaticattachmentofmachineries,papercutting machines, spinning and weaving textile machineries, feed mechanism of automatic lathes.

ClassificationofFollowers

(i) Basedonsurfaceincontact.

(a)Knifeedgefollower(b)Rollerfollower(c)Flatfacedfollower(d)Spherical follower



(ii) Basedontypeofmotion:

(a) Oscillatingfollower

(b) Translatingfollower

(iii) Basedonlineofmotion:

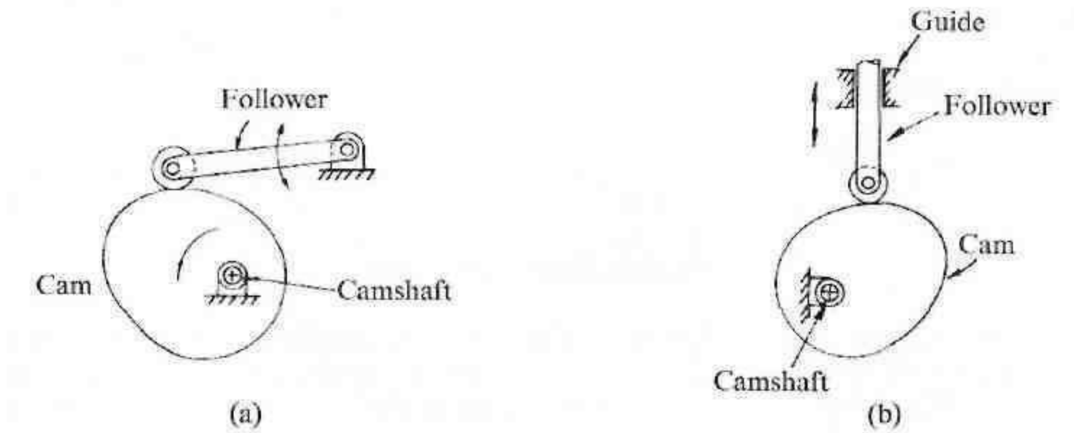
(a) Radialfollower:Thelinesofmovementofin-linecamfollowerspassthrough the centers of the camshafts

(b) Off-setfollower:Forthistype,thelinesof movementareoffsetfromthe centers of the camshafts

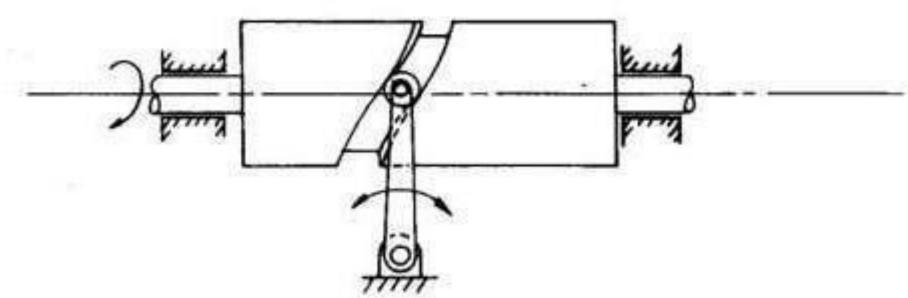
ClassificationofCams

Camscanbeclassifiedbasedontheirphysicalshape.

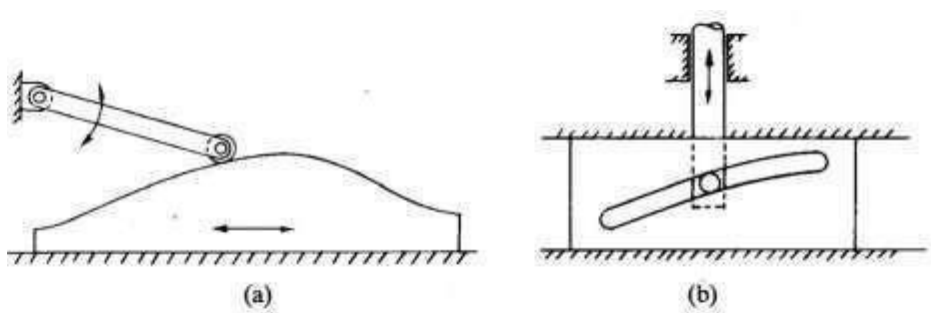
a) Diskorplatecam: The disk(orplate)camhasanirregularcontourto imparta specificmotiontothefollower.Thefollowermovesinaplaneperpendicular totheaxisof rotationof thecamshaftandisheldincontactwiththecamby springs or gravity.



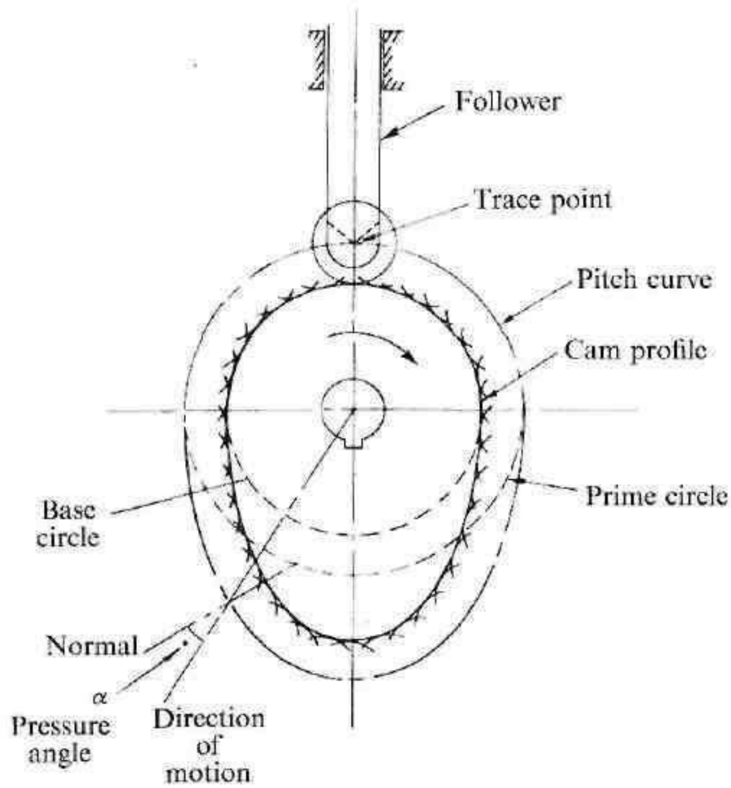
b) Cylindrical cam: The cylindrical cam has a groove cut along its cylindrical surface.Therollerfollowsthegroove,andthefollowermovesinaplaneparalleltothe axis of rotation of the cylinder



c) Translatingcam. Thetranslatingcamisacontouredorgroovedplateslidingon aguidingsurface(s).Thefollowermayoscillateorreciprocate.Thecontourorthe shape of the groove is determined by the specified motion of the follower.



TermsUsedinRadialCams



(a)Pressure angle: It is the angle between the directionof the follower motion andanormaltothepitchcurve.Thisangleisveryimportantindesigningacamprofile. Iftheangleis toolarge,areciprocatingfollower willjaminits bearings.

b) **Basecircle:**Itisthesmallestcirclethatcanbedrawntothecamprofile.
c) **Tracepoint:**Itisthereferencepointonthefollowerandisusedtogenerate thepitchcurve.Inthecaseofknifeedgefollower,theknifeedgerepresents the tracepointandthepitch curvecorrespondstothecamprofile.Intheroller follower, the centre of the roller represents the trace point.
d) **Pitchpoint:**Itisapointonthepitchcurve havingthemaximumpressure angle.
e) **Pitchcircle:**Itisacircledrawnfromthecentreofthecamthroughthepitchpoints.
f) **Pitchcurve:**Itisthecurvegeneratedbythetracepointasthefollowermoves relativetothecam.Foraknifeedgefollower,thepitchcurveandthecam profile are same whereas for a roller follower; they are separated by the radius of the follower.

g) **Primecircle:**Itisthesmallestcirclethatcanbedrawnfromthecentreofthe cam andtangenttothepoint.Foraknifeedgeandaflatfacefollower,theprime circle and the base circle and the base circle are identical. For a roller follower, the prime circle is larger than the base circle by the radius of the roller.

h) **Lift(or)stroke:**Itisthemaximumtravelofthefollowerfromitslowest position to the topmost position.

UNIT3:Powertransmission

Introduction

The beltsor ropes areusedto transmit powerfromone shaft to another bymeansofpulleyswhichrotateatthesamespeedoratdifferentspeeds.Theamo unt of power transmitted depends upon the following factors:

1. Thevelocityofthebelt.

2. Thetensionunderwhichthebeltisplacedonthepulleys.

3. Theconditionsunderwhichthebeltisused.

SelectionofaBeltDrive

Followingarethevariousimportantfactorsuponwhichtheselectionofabelt drive depends:

1. Speedofthedrivinganddrivenshafts,

2. Speedreductionratio,

3. Powertobetransmitted,

4. Centredistancebetweentheshafts,

5. Positivedriverequirements,

6. Shaftslayout,

7. Spaceavailable,and

8. Serviceconditions.

TypesofBeltDrives

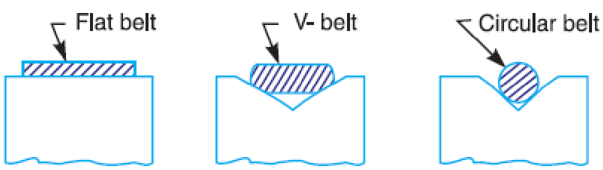
Thebeltdrivesareusuallyclassifiedintothefollowingthreegroups:

1. ***Lightdrives***.Theseareusedtotransmitsmallpowersatbeltspeedsupto about 10 m/s, as inagricultural machines and small machine tools.

2. ***Mediumdrives***.Theseareusedtotransmitmediumpoweratbeltspeedsover 10 m/s but up to 22 m/s, as in machine tools.

3. ***Heavydrives***.Theseareusedtotransmitlargepowersatbeltspeedsabove22m/s, as in compressors and generators.

TypesofBelts



(*a*) Flat belt. (*b*) V-belt. (*c*) Circular belt.

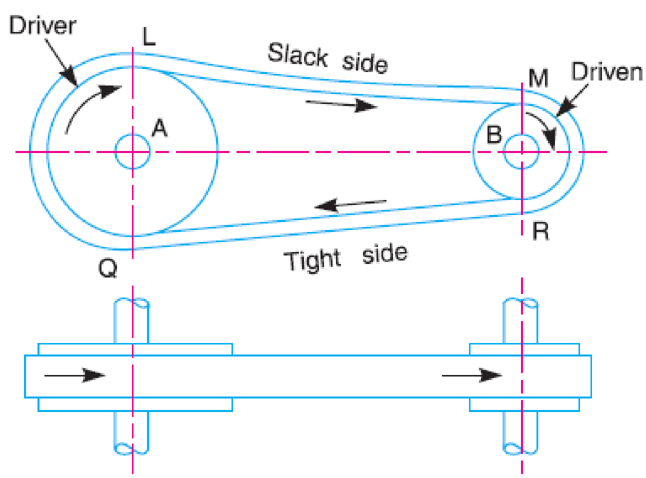
1. ***Flatbelt.***The flatbelt,asshowninFig.(*a*),ismostlyusedinthe factories and workshops,where amoderate amountof power is to be transmitted,from one pulley to another whenthe two pulleys are not more than 8 metres apart.

2. ***V-belt*.**TheV-belt,asshowninFig.(*b*),ismostlyusedinthefactoriesand workshops,whereamoderateamountofpoweristobetransmitted,fromone pulley to another, when the two pulleys are very near to each other.

3. ***Circularbeltorrope***.Thecircularbelt orrope,asshowninFig.(*c*),ismostly used in the factories and workshops, where a great amount of power is to be transmitted,fromonepulleytoanother,whenthetwopulleysaremorethan8 metersapart.Ifahugeamountofpoweristobetransmitted,thenasinglebelt may not be sufficient. Insucha case, wide pulleys (forV-belts or circular belts) with a number of grooves are used. Then a belt in each groove is provided to transmit the required amount of power from one pulley to another

TypesofFlatBeltDrives

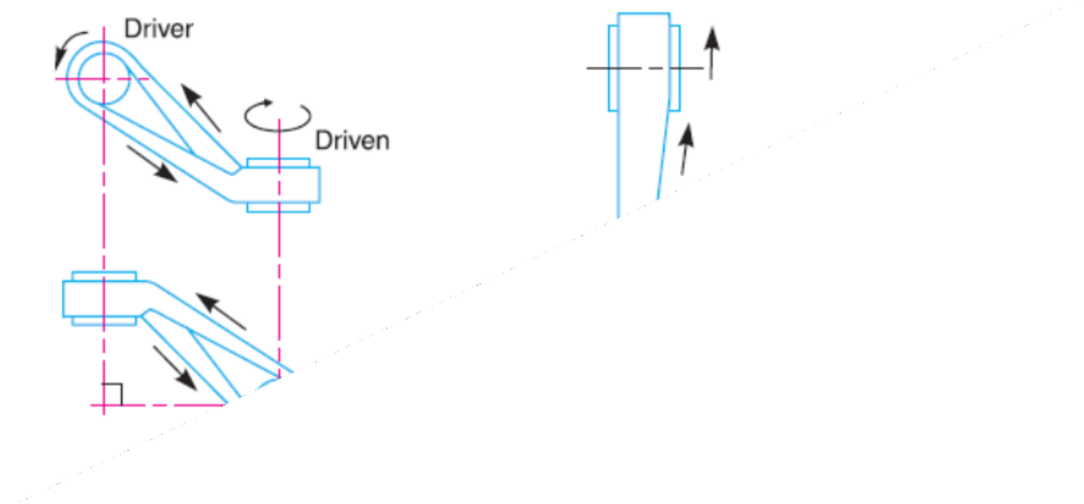
Thepowerfromonepulleytoanothermaybetransmittedbyanyofthefollowingtypes of belt drives: **1.** ***Open belt drive***. The open belt drive is used with shafts arrangedparallelandrotatinginthesamedirection.Inthiscase,thedriver *A* pulls the beltfromoneside(*i.e.* lowerside *RQ*) and delivers it to theother side (*i.e*. upper side *LM*). Thus the tension in the lower side belt will be more than that in the upper side belt. The lower side belt (because of more tension) is known as ***tight side***whereastheuppersidebelt(becauseoflesstension)isknownas ***slackside***,



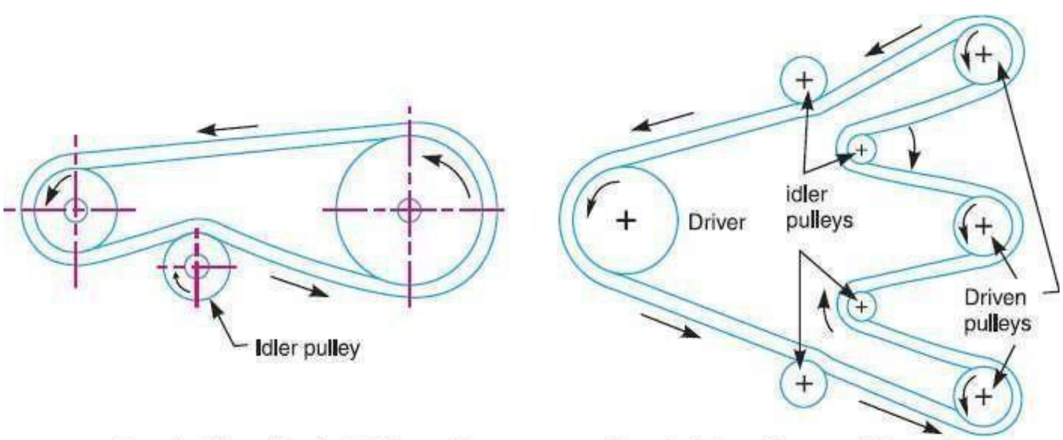
2. ***Crossed or twistbeltdrive***. Thecrossedor twist belt driveis used withshafts arranged parallelandrotatingin the opposite directions. Inthis case, the driver pulls the belt from one side (*i.e*. *RQ*) and delivers it to the other side (*i.e*. *LM*). Thusthe tensioninthe belt*RQ* willbemorethanthatinthe belt *LM*.The belt*RQ* (becauseofmoretension)isknownas ***tightside,***whereasthebelt*LM*(because of less tension) is known as ***slack side***,

3. ***Quarterturnbeltdrive*.**Thequarterturnbeltdrivealsoknownasrightanglebelt drive, as shown in Fig. (*a*), is used with shafts arranged at right angles and rotatinginone definite direction. Inorder to prevent the beltfrom leavingthe pulley, the width of the face of the pulley should be greater or equal to 1.4 *b*, where*b*isthewidthofbelt.Incasethepulleyscannotbearranged,asshownin

Fig.(*a*),orwhenthereversibleisdesired,thena***quarterturnbeltdrivewithguide pulley***, as shown in Fig. (*b*), may be used.



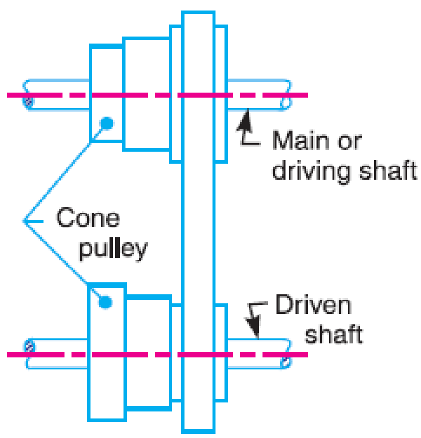
4. *Belt drive with idler pulleys*. A belt drive with an idler pulley, as shown in Fig. (*a*), is used with shafts arranged parallel and when an open belt drive cannot be used due to small angle of contact on the smaller pulley. This type of drive is provided to obtain high velocity ratio and when the required belt tension cannot be obtained by other means. When it is desired to transmit motion from oneshafttoseveralshafts,allarrangedinparallel,abeltdrivewithmanyidlerpulleys,as shown in Fig. (*b*), may be employed.



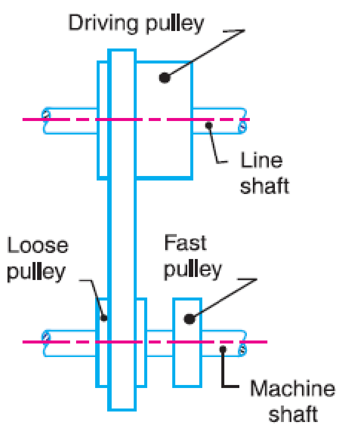
(*a*) Belt drive with single idler pulley. (*b*) Belt drive with many idler pulleys.

5. *Compoundbeltdrive*.Acompoundbeltdrive,asshowninFig.,is usedwhen poweristransmittedfromoneshafttoanother throughanumberofpulleys

6. ***Steppedorconepulleydrive***.Asteppedorconepulleydrive,as showninFig,is used forchangingthespeedofthe drivenshaftwhile themainordrivingshaftrunsat constant speed. This is accomplished by shifting the belt from one part of the steps to the other.



7. ***Fast and loose pulley drive***. A fast and loose pulley drive, as shown in Fig., is used when the driven or machine shaft is to be started or stopped whenever desired without interfering with the driving shaft. A pulley whichis keyed to the machineshaftiscalled***fastpulley***andrunsatthesamespeedasthatofmachineshaft. A loose pulley runs freely over the machine shaft and is incapable of transmittinganypower.Whenthedrivenshaftisrequiredtobestopped,thebelt is pushed on to the loose pulley by means of sliding bar having beltforks.



VelocityRatioofBeltDrive

Itistheratiobetweenthevelocitiesofthedriverandthefollowerordriven.Itmaybe expressed,mathematically,asdiscussedbelow:

Letd_1=Diameterofthedriver, d_2 =

Diameter of the follower,

N_1=Speedofthedriverinr.p.m.,andN_2=

Speed of the follower in r.p.m.

Lengthofthebeltthatpassesoverthedriver,inoneminute=$\pi d_1 N_1$

Similarly,lengthofthebeltthatpassesoverthefollower,inoneminute=$\pi d_2 N_2$

Sincethelengthofbeltthatpassesoverthedriverinoneminuteisequaltothelengthof beltthatpassesoverthefollowerinoneminute,therefore $\pi d_1 N_1 = \pi d_2 N_2$

Velocity ratio, $\frac{N_2}{N_1} = \frac{d_1}{d_2}$

Whenthethicknessofthebelt(*t*)isconsidered,thenvelocityratio

$$\frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t}$$

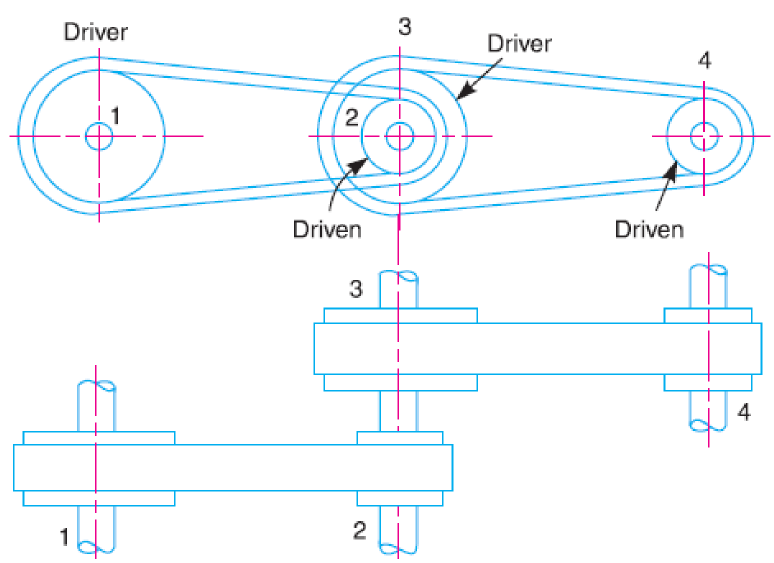
The velocity ratio of a belt drive may also be obtained as discusse
We know that peripheral velocity of the belt on the drivin

$$v_1 = \frac{\pi d_1 . N_1}{60} \text{ m/s}$$

and peripheral velocity of the belt on the driv

When there is

VelocityRatioofaCompoundBeltDriveSometimesthepoweristransmitted fromoneshafttoanother,throughanumberofpulleys,asshowninfig.Consider a pulley 1 driving the pulley 2. Since the pulleys 2 and 3 are keyed to the same shaft, therefore the pulley 1 also drives the pulley 3 which, in turn, drives the pulley 4.



Let

d1=Diameterofthepulley1,

N1=Speedofthe pulley1inr.p.m.,

d2,d3,d4,andN2,N3,N4=Correspondingvaluesforpulleys2,3and4. We

know that velocity ratio of pulleys 1 and 2,

$$\frac{N_2}{N_1} = \frac{d_1}{d_2}$$

Similarly,velocityratioofpulleys3and4,

$$\frac{N_4}{N_3} = \frac{d_3}{d_4}$$

Multiplyingtheaboveequationsgives

$$\frac{N_2}{N_1} \times \frac{N_4}{N_3} = \frac{d_1}{d_2} \times \frac{d_3}{d_4}$$

$$\frac{N_4}{N_1} = \frac{d_1 \times d_3}{d_2 \times d_4} \quad \ldots(\because N_2 = N$$

SlipofBelt

In the previous articles, we have discussed the motion of belts and shafts assumingafirmfrictionalgripbetweenthebeltsandtheshafts.Butsometimes, thefrictionalgripbecomesinsufficient.Thismaycausesomeforwardmotionof the driver without carrying the belt with it. This may also cause some forward motionofthe beltwithoutcarryingthedrivenpulleywithit. Thisiscalled ***slipof thebelt***andisgenerallyexpressedasapercentage. Theresultofthebeltslipping is to reduce the velocity ratio of the system. As the slipping of the belt is a common phenomenon,thusthe beltshouldnever beusedwherea definitevelocityratio is of importance.

Let $s_1\,\%$ = Slip between the driver and the belt, and

$s_2\,\%$ = Slip between the belt and the follower.

∴ Velocity of the belt passing over the driver per second

$$v = \frac{\pi d_1 . N_1}{60} - \frac{\pi d_1 . N_1}{60} \times \frac{s_1}{100} = \frac{\pi d_1 . N_1}{60}\left(1 - \frac{s_1}{100}\right)$$

and velocity of the belt passing over the follower per second,

$$\frac{\pi d_2 . N_2}{60} = v - v \times \frac{s_2}{100} = v\left(1 - \frac{s_2}{100}\right)$$

Substituting the value of v from equation (*i*),

$$\frac{\pi d_2\, N_2}{60} = \frac{\pi d_1\, N_1}{60}\left(1 - \frac{s_1}{100}\right)\left(1 - \frac{s_2}{100}\right)$$

$$\frac{N_2}{N_1} = \frac{d_1}{d_2}\left(1 - \frac{s_1}{100} - \frac{s_2}{100}\right) \qquad \ldots\left(\text{Neglecting } \frac{s_1 \times s_2}{100 \times 100}\right)$$

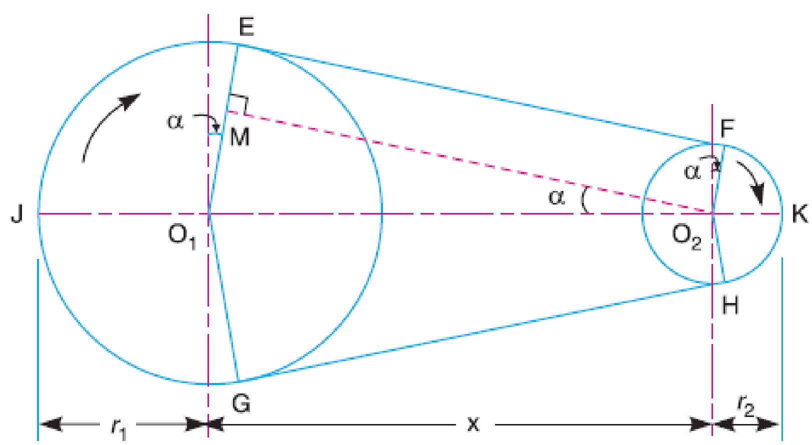
$$= \frac{d_1}{d_2}\left(1 - \frac{s_1 + s_2}{100}\right) = \frac{d_1}{d_2}\left(1 - \frac{s}{100}\right)$$

... (where $s = s_1 + s_2$, *i.e.* total percentage of slip)

If thickness of the belt (t) is considered, then

$$\frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t}\left(1 - \frac{s}{100}\right)$$

LengthofanopenBeltDrive



Let

r1andr2=Radiiofthelargerandsmallerpulleys,

x=Distancebetweenthecentresoftwopulleys(i.e.O1O2),andL=

Total length of the belt.

LetthebeltleavesthelargerpulleyatEandGandthesmallerpulleyatFandHasshownin Fig. Through

O2,drawO2MparalleltoFE.

Fromthegeometryofthefigure,wefindthatO2MwillbeperpendiculartoO1E.Letthe angle

MO2 O1 = α radians.

Weknowthatthelengthofthebelt,L= Arc

GJE + EF + Arc FKH + HG

=2(ArcJE+EF+ArcFK)

$$L = 2\left[r_1\left(\frac{\pi}{2} + \alpha\right) + x - \frac{(r_1 - r_2)^2}{2x} + r_2\left(\frac{\pi}{2} - \alpha\right)\right]$$

$$= 2\left[r_1 \times \frac{\pi}{2} + r_1.\alpha + x - \frac{(r_1 - r_2)^2}{2x} + r_2 \times \frac{\pi}{2} - r_2.\alpha\right]$$

$$= 2\left[\frac{\pi}{2}(r_1 + r_2) + \alpha(r_1 - r_2) + x - \frac{(r_1 - r_2)^2}{2x}\right]$$

$$= \pi(r_1 + r_2) + 2\alpha(r_1 - r_2) + 2x - \frac{(r_1 - r_2)^2}{x}$$

From the geometry of the figure, we find that

$$\sin\alpha = \frac{O_1 M}{O_1 O_2} = \frac{O_1 E - EM}{O_1 O_2} = \frac{r_1 - r_2}{x}$$

Since α is very small, therefore putting

$$\sin\alpha = \alpha \text{ (in radians)} = \frac{r_1 - r_2}{x}$$

Substituting the value of $\alpha = \frac{r_1 - r_2}{x}$

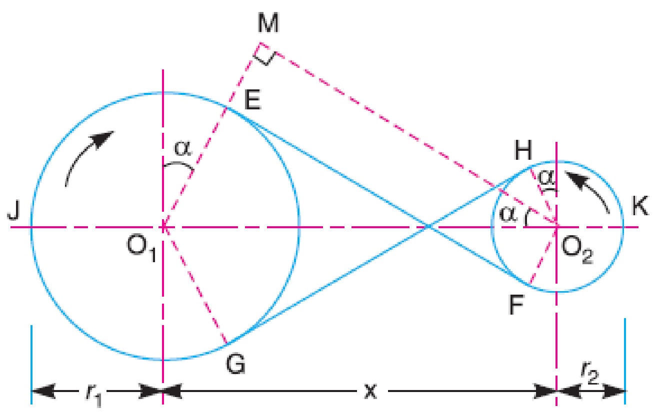
$$L = \pi(r_1 + r_2) + 2 \times \frac{(r_1 - r_2)}{x} \times (r_1 - r_2) + 2x - \frac{(r_1 - r_2)^2}{x}$$

$$= \pi(r_1 + r_2) + \frac{2(r_1 - r_2)^2}{x} + 2x - \frac{(r_1 - r_2)^2}{x}$$

$$= \pi(r_1 + r_2) + 2x + \frac{(r_1 - r_2)^2}{}$$

$$= \frac{\pi}{2}(d.$$

LengthofaCrossBeltDrive



Wehavealreadydiscussedthatinacrossbeltdrive,boththepulleysrotatein opposite directionsasshowninFig.

Letr1andr2=Radiiofthelargerandsmallerpulleys,

x=Distancebetweenthecentresoftwopulleys(i.e.O1O2),andL=

Total length of the belt.

LetthebeltleavesthelargerpulleyatEandGandthesmallerpulleyatFandH,as

showninFig.ThroughO2,drawO2Mparallelto FE.

Fromthegeometryofthefigure,wefindthatO2MwillbeperpendiculartoO1E.

Let the angle MO2 O1 = α radians

Weknowthatthelengthofthebelt,L= Arc

GJE + EF + Arc FKH + HG

=2(ArcJE+EF+ArcFK)

From the geometry of the figure, we find that

$$\sin\alpha = \frac{O_1 M}{O_1 O_2} = \frac{O_1 E + EM}{O_1 O_2} = \frac{r_1 + r_2}{x}$$

Since α is very small, therefore putting

$$\sin\alpha = \alpha \text{ (in radians)} = \frac{r_1 + r_2}{x}$$

$$\therefore \qquad \text{Arc } JE = r_1\left(\frac{\pi}{2} + \alpha\right)$$

Similarly $\quad$ $\text{Arc } FK = r_2\left(\frac{\pi}{2} + \alpha\right)$

$$EF = MO_2 = \sqrt{(O_1O_2)^2 - (O_1 M)^2} = \sqrt{x^2 - (r_1 + r_2)^2}$$

$$= x\sqrt{1 - \left(\frac{r_1 + r_2}{x}\right)^2}$$

Expanding this equation by binomial theorem,

$$EF = x\left[1 - \frac{1}{2}\left(\frac{r_1 + r_2}{x}\right)^2 + \ldots\right] = x - \frac{(r_1 + r_2)^2}{2x}$$

$$L = 2\left[r_1\left(\frac{\pi}{2} + \alpha\right) + x - \frac{(r_1 + r_2)^2}{2x} + r_2\left(\frac{\pi}{2} + \alpha\right)\right]$$

$$= 2\left[r_1 \times \frac{\pi}{2} + r_1.\alpha + x - \frac{(r_1 + r_2)^2}{2x} + r_2 \times \frac{\pi}{}\right.$$

$$= 2\left[\frac{\pi}{2}(r_1 + r_2) + \alpha(r_1 +\right.$$

$$= \pi($$

Substituting the value of $\alpha = \frac{r_1 + r_2}{x}$

$$L = \pi(r_1 + r_2) + \frac{2(r_1 + r_2)}{x} \times (r_1 + r_2) + 2x - \frac{(r_1 + r_2)^2}{x}$$

$$= \pi(r_1 + r_2) + \frac{2(r_1 + r_2)^2}{x} + 2x - \frac{(r_1 + r_2)^2}{x}$$

$$= \pi(r_1 + r_2) + 2x + \frac{(r_1 + r_2)^2}{x} \quad \text{...(In terms of pulley radii)}$$

$$= \frac{\pi}{2}(d_1 + d_2) + 2x + \frac{(d_1 + d_2)^2}{4x} \quad \text{...(In terms of pulley diameters)}$$

It may be noted that the above expression is a function of ($r1$ + $r2$). It is thus obviousthatifsumoftheradiiof thetwo pulleysbe constant,thenlengthofthe beltrequiredwillalsoremainconstant,providedthedistancebetweencentresof the pulleys remain unchanged.

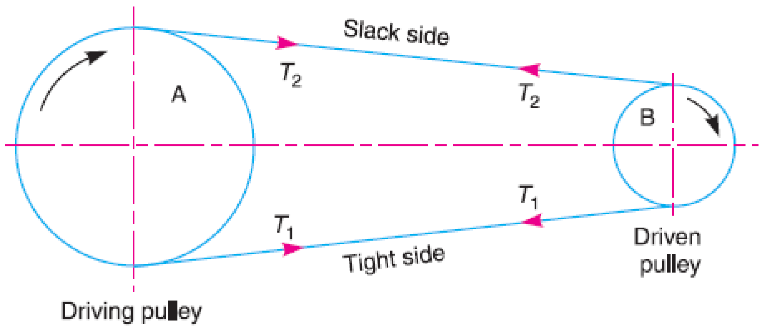
PowertransmittedbyaBelt

Fig.shows thedrivingpulley(ordriver) *A*andthedrivenpulley(orfollower) *B*. Wehavealreadydiscussedthatthedrivingpulleypullsthebeltfromonesideand delivers the same to the other side. It is thus obvious that the tension on the formerside(*i.e*.tightside) willbegreaterthanthelatterside(*i.e*.slackside)as shown in Fig.

Let T_1 and T_2 = Tensions in the tight and slack side of the belt respectively in newtons,

r_1 and r_2 = Radii of the driver and follower respectively, and

v = Velocity of the belt in m/s.



The effective turning (driving) force at the circumference of the follower is the difference between the two tensions (*i.e.* $T_1 - T_2$).

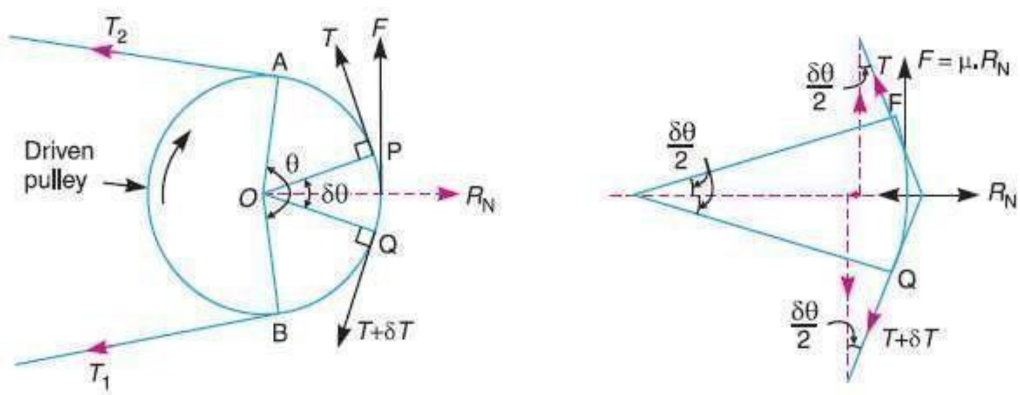
$\therefore$ Work done per second = $(T_1 - T_2)\, v$ N-m/s

and power transmitted, $P = (T_1 - T_2)\, v$ W ...($\because$ 1 N-m/s = 1 W)

A little consideration will show that the torque exerted on the driving pulley is $(T_1 - T_2)\, r_1$. Similarly, the torque exerted on the driven pulley *i.e.* follower is $(T_1 - T_2)\, r_2$.

RatioofDrivingTensionsforFlatBeltDrive

ConsideradrivenpulleyrotatingintheclockwisedirectionasshowninFig.



Let T_1 = Tension in the belt on the tight side,

T_2 = Tension in the belt on the slack side, and

θ = Angle of contact in radians (*i.e.* angle subten

which the belt touches the pulley at

Now consider a small portion of the belt *PQ*, sub

pulley as shown in Fig. 11.15. The belt *PQ* is in eq

1. Tension T in the belt at P,
2. Tension $(T + \delta T)$ in
3. Normal rea
4. Fr

Resolving all the forces horizontally and equating the same,

$$R_N = (T + \delta T) \sin \frac{\delta\theta}{2} + T \sin \frac{\delta\theta}{2} \qquad ...(i)$$

Since the angle $\delta\theta$ is very small, therefore putting $\sin \delta\theta / 2 = \delta\theta / 2$ in equation *(i)*,

$$R_N = (T + \delta T) \frac{\delta\theta}{2} + T \times \frac{\delta\theta}{2} = \frac{T.\delta\theta}{2} + \frac{\delta T.\delta\theta}{2} + \frac{T.\delta\theta}{2} = T.\delta\theta \qquad ...(ii)$$

$$...\left(\text{Neglecting } \frac{\delta T.\delta\theta}{2}\right)$$

Now resolving the forces vertically, we have

$$\mu \times R_N = (T + \delta T) \cos \frac{\delta\theta}{2} - T \cos \frac{\delta\theta}{2} \qquad ...(iii)$$

Since the angle $\delta\theta$ is very small, therefore putting $\cos \delta\theta / 2 = 1$ in equation *(iii)*,

$$\mu \times R_N = T + \delta T - T = \delta T \quad \text{or} \quad R_N = \frac{\delta T}{\mu} \qquad ...(iv)$$

Equating the values of R_N from equations *(ii)* and *(iv)*,

$$T.\delta\theta = \frac{\delta T}{\mu} \quad \text{or} \quad \frac{\delta T}{T} = \mu.\delta\theta$$

Integrating both sides between the limits T_2 and T_1 and from 0 to θ respectively,

i.e. $$\int_{T_2}^{T_1} \frac{\delta T}{T} = \mu \int_0^\theta \delta\theta \quad \text{or} \quad \log_e\left(\frac{T_1}{T_2}\right) = \mu.\theta \quad \text{or} \quad \frac{T_1}{T_2} = e^{\mu.\theta}$$

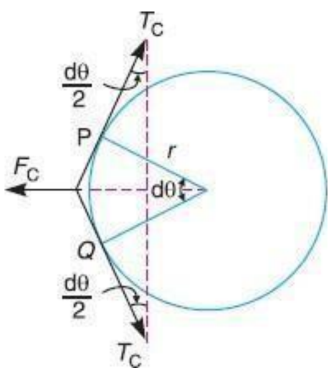
Equation (v) can be expressed in terms of corresponding logarithm to the base 10, *i.e.*

$$2.3 \log\left(\frac{T_1}{T_2}\right) = \mu.\theta$$

The above expression gives the relation between the tight side and slack side tensions, in terms of coefficient of friction and the angle of contact.

CentrifugalTension

Since the belt continuously runs over the pulleys, therefore, some centrifugal force is caused, whose effect is to increase the tension on both, tight as well as the slack sides. The tension caused by centrifugal force is called ***centrifugal tension***. At lower belt speeds (less than 10 m/s), the centrifugal tension is very small,butathigherbeltspeeds(morethan10m/s),itseffectisconsiderableand thus shouldbetakenintoaccount.Considerasmallportion *PQ*ofthebeltsubtending anangle *d*the centre of the pulley as shown inFig.



Let m = Mass of the belt per unit length in kg,

v = Linear velocity of the belt in m/s,

r = Radius of the pulley over which the belt runs in metres, and

T_C = Centrifugal tension acting tangentially at P and Q in newtons.

We know that length of the belt PQ

$$= r.\,d\theta$$

and mass of the belt PQ $= m.\,r.\,d\theta$

∴ Centrifugal force acting on the belt PQ,

$$F_C = (m.r.d\theta)\frac{v^2}{r} = m.d\theta.v^2$$

The centrifugal tension T_C acting tangentially at P and Q keeps the belt in equilibrium.

Now resolving the forces (*i.e.* centrifugal force and centrifugal tension) horizontally and equating the same, we have

$$T_C \sin\left(\frac{d\theta}{2}\right) + T_C \sin\left(\frac{d\theta}{2}\right) = F_C = m.d\theta.v^2$$

Since the angle $d\theta$ is very small, therefore, putting $\sin\left(\frac{d\theta}{2}\right) = \frac{d\theta}{2}$, in the above expression,

$$2T_C\left(\frac{d\theta}{2}\right) = m.d\theta.v^2 \quad \text{or} \quad T_C = m\,.\,v^2$$

MaximumTensionintheBelt

A little consideration will show that the maximum tension in the belt (T) is equal to the tension in the tight side of the belt (T_{t1}).

Let σ = Maximum safe stress in N/mm^2,

b = Width of the belt in mm

t = Thickness of th

We know that maximum tension in the

T

When centrifugal te

and wh

ConditionfortheTransmissionofMaximumPower

We know that power transmitted by a belt,

$$P = (T_1 - T_2)\,v \quad \text{...}(i)$$

where T_1 = Tension in the tight side of the belt in newtons,

T_2 = Tension in the slack side of the belt in newtons, and

v = Velocity of the belt in m/s.

From Art. 11.14, we have also seen that the ratio of driving tensions is

$$\frac{T_1}{T_2} = e^{\mu.\theta} \quad \text{or} \quad T_2 = \frac{T_1}{e^{\mu.\theta}} \quad \text{...}(ii)$$

Substituting the value of T_2 in equation (*i*),

$$P = \left(T_1 - \frac{T_1}{e^{\mu.\theta}}\right)v = T_1\left(1 - \frac{1}{e^{\mu.\theta}}\right)v = T_1.v.C \quad \text{...}(iii)$$

We know that $T_1 = T - T_C$ and for maximum power, $T_C = \frac{T}{3}$.

$$T_1 = T - \frac{T}{3} = \frac{2T}{3}$$

From equation (*iv*), the velocity of the belt for the maximum power,

$$v = \sqrt{\frac{T}{3m}}$$

Gears

Gears are also used for power transmission. This is accomplished by the successiveengagementofteeth.Thetwogearstransmitmotionbythedirect contact like chain drive. Gears also provide positive drive.

The drive between the two gears can be represented by using plain cylinders or discs1and2havingdiametersequaltotheirpitchcirclesasshowninFigure 3.5. The point of contact of the two pitch surfaces shell have velocity along the common tangent.Becausethereisnoslip,definitemotionofgear1canbetransmittedto gear 2 or vice-versa.

Classifygears

***Accordingtothepositionofaxesoftheshafts*.**

Theaxesofthetwoshaftsbetweenwhichthemotionistobetransmitted,maybe

Parallel,**(*b*)**Intersecting,and**(*c*)**Non-intersectingandnon-parallel.

2.*Accordingtotheperipheralvelocityofthegears*.Thegears,accordingtotheperipheral

velocityofthegearsmaybeclassifiedas:

(a)Lowvelocity,**(*b*)**Mediumvelocity,and**(*c*)**Highvelocity

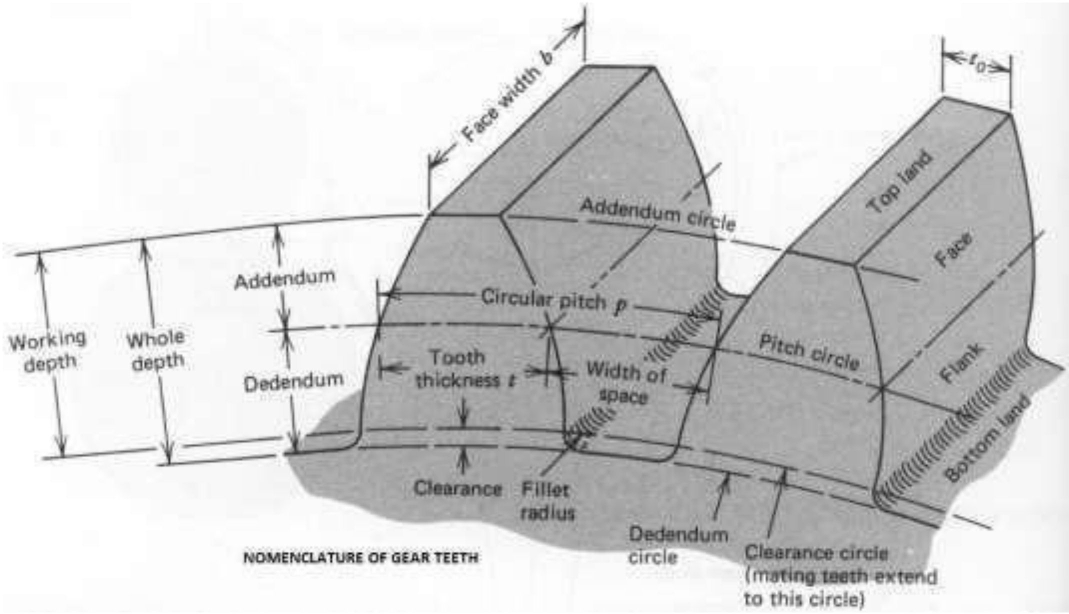
Accordingtothetypeofgearing.

Thegears,accordingtothetypeofgearingmaybeclassifiedas: External

gearing, **(*b*)** Internal gearing, and **(*c*)** Rack and pinion.

Accordingtopositionofteethonthegearsurface.Theteethonthegearsurfacemay be

(a)straight,**(*b*)**inclined,and**(*c*)**curved



NOMENCLATURE OF GEAR TEETH

Pitchcircle.Itisanimaginarycirclewhichbypurerollingaction,wouldgive the same motion as the actual gear.

2. ***Pitchcirclediameter***.Itisthediameterofthepitchcircle.Thesizeofthegearis usually specified by the pitch circle diameter. It is also known as ***pitch diameter***.

3. ***Pitchpoint***.Itisacommonpointofcontactbetweentwopitchcircles.

4. ***Pitchsurface***.Itisthesurfaceoftherollingdiscswhichthemeshinggears have replaced at the pitch circle.

5. ***Pressureangleorangleofobliquity***.Itistheangle betweenthe common normalto twogearteethatthepointofcontactandthecommontangent at the pitch point.

6. ***Addendum*****.**Itistheradialdistanceofatoothfromthepitchcircletothetopof the tooth.

7. ***Dedendum*****.**Itistheradialdistanceofatoothfromthepitchcircletothe bottom of the tooth.

8. ***Addendumcircle***.Itisthecircledrawnthroughthetopoftheteethand is concentric with the pitch circle.

9. ***Dedendumcircle***.Itisthecircledrawnthroughthebottomoftheteeth.Itis also called root circle.

10. ***Circularpitch***.Itisthedistancemeasuredonthecircumferenceofthe pitchcirclefromapointofonetoothtothecorrespondingpointonthenext tooth. It is usually denoted by *pc*.

Diametralpitch.Itistheratioofnumberofteethto thepitchcircle diameter in millimetres.

Itisdenotedbypd

. Mathematically,Diametralpitch,Pd=T/D

, D=diameter of pitch circle

T=numberofteethonthewheel

***Module*.**Itistheratioofthepitchcirclediameterinmillimeterstothe numberof teeth. It is usually denoted by *m*. Mathematically,

m=D/T

Working depth. It is the radial distance from the addendum circle to the clearancecircle.Itisequaltothesumoftheaddendumofthetwomeshinggears.

16. ***Ooththickness***.Itisthewidthofthetoothmeasuredalongthepitchcircle.

17. ***Toothspace***.Itisthewidthofspacebetweenthetwoadjacentteeth measured along the pitch circle.

18. ***Backlash***. It is the difference between the tooth space and the tooth thickness, as measured along the pitch circle. Theoretically, the backlash should be zero, but in actual practice some backlash must be allowed to preventjammingoftheteethdue totootherrorsandthermalexpansion.

19. ***Faceoftooth***.Itisthesurfaceofthegeartoothabovethepitchsurface.

20. ***Flankoftooth***.Itisthesurfaceofthegeartoothbelowthepitch surface.

21. ***Topland***.Itisthesurfaceofthetopofthetooth.

22. ***Facewidth***.Itisthewidthofthegeartoothmeasuredparalleltoitsaxis.

23. ***Profile***.Itisthecurveformedbythefaceandflankofthetooth.

24. ***Filletradius***.Itistheradiusthatconnectstherootcircletotheprofileofthe tooth.

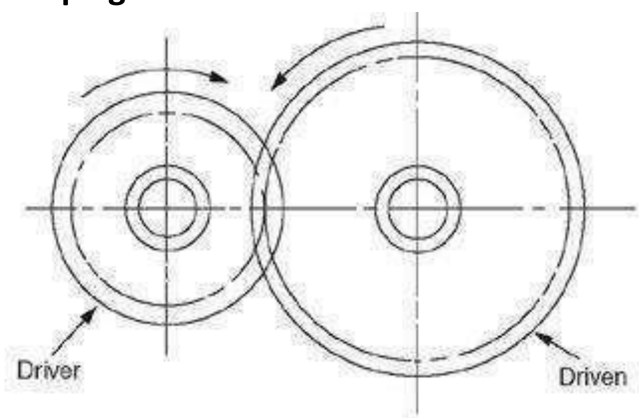
25. ***Pathofcontact***.Itisthepathtracedbythepointofcontactoftwo teethfrom the beginning to the end of engagement.

26. ****Lengthofthepathofcontact**.Itisthelengthofthecommonnormalcut-off by the addendum circles of the wheel and pinion.

27. *** **Arc of contact***. It is the path traced by a point on the pitch circle fromthebeginningtotheendofengagementofagivenpairofteeth.The arc of contact consists of two parts, *i.e*.

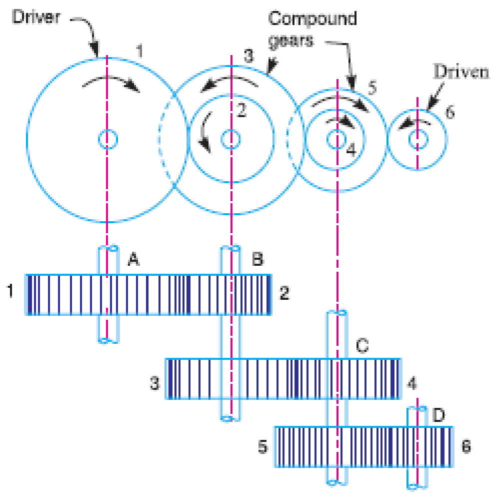
(*a*)*Arcofapproach*.Itistheportionofthepathofcontactfromthebeginningof the engagement to the pitch point

Simplegeartrain



Asimplegeartrainusestwogears,whichmaybeofdifferentsizes.Ifoneof these gearsisattachedtoamotororacrankthenitiscalledthe drivergear.The gear that is turned by
the driver gear iscalled the driven gear. Theinputand theoutputshaftare necessarily being parallel to eachother. In this gear train, there are series of gears whichare capable of receivingand transmitting motionfrom one geartoanother.Theymaymeshexternallyorinternally.Eachgearrotates aboutseparateaxisfixedto theframe.Twogearsmaybeexternalmeshing and internal meshing.
Velocity ratio:
N1/N2=T2/T1=d2/d1

Compoundgeartrain



Whenthereare more thanonegearonashaft,,itiscalleda ***compound train of gear***.

inasimple trainofgears donoteffectthe speedratioofthesystem.But thesegears areusefulin bridgingoverthespacebetweenthedriverand the driven

InacompoundtrainofgearsasshowninFig.thegear1isthedrivinggear mountedon shaft*A*,gears2and3arecompoundgearswhicharemountedonshaft*B*. Thegears4and5arealso compoundgearswhicharemountedonshaft*C*andthegear6isthedrivengear mounted on shaft *D*.

Let N_1 = Speed of driving gear 1,
T_1 = Number of teeth on driving gear 1,
$N_2, N_3 ..., N_6$ = Speed of respective gears in r.p.m., and
$T_2, T_3 ..., T_6$ = Number of teeth on respective gears.

Since gear 1 is in mesh with gear 2, therefore its speed ratio is

$$\frac{N_1}{N_2} = \frac{T_2}{T_1} \quad ...(i)$$

Similarly, for gears 3 and 4, speed ratio is

$$\frac{N_3}{N_4} = \frac{T_4}{T_3} \quad ...(ii)$$

and for gears 5 and 6, speed ratio is

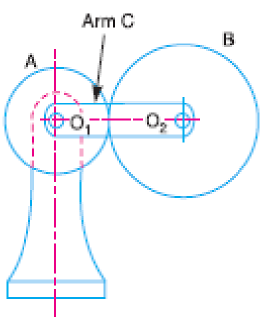
$$\frac{N_5}{N_6} = \frac{T_6}{T_5} \quad ...(iii)$$

The speed ratio of compound gear train is obtained by multiplying the equations (*i*), (*ii*) and (*iii*),

$$\therefore \quad \frac{N_1}{N_2} \times \frac{N_3}{N_4} \times \frac{N_5}{N_6} = \frac{T_2}{T_1} \times \frac{T_4}{T_3} \times \frac{T_6}{T_5} \quad \text{or} \quad \frac{N_1}{N_6} = \frac{T_2 \times T_4 \times T_6}{T_1 \times T_3 \times T_5}$$

Epicyclicgeartrain

in an epicyclic gear train, the axes of the shafts, over which the gears are mounted,may move relativetoafixedaxis.Asimpleepicyclic geartrainisshown inFig.,wherea gear*A*andthearm*C*have acommonaxisat *O*1aboutwhichthey can rotate. The gear *B* meshes with gear *A* and has its axis on the arm at *O*2, aboutwhichthe gear *B* can rotate. If the armis fixed,the gear train is simple and gear*A* can drive gear *B* or ***vice- versa***,butif gear *A* is fixed andthe arm is rotated about the axis of gear *A* (*i.e*. *O* 1), then the gear *B* is forced to rotate ***upon*** and ***around*** gear *A*. Such a motion is called **epicyclic** and the gear trains arranged in such a manner that one or more of their members move upon and around anothermemberareknownas ***epicyclicgeartrains***(***epi*.**meansuponand***cyclic*** means around). The epicyclic gear trains may be ***simple*** or ***compound*.** The epicyclic gear trains are usefulfor transmitting high velocity ratios with gears of moderatesizeinacomparativelylesserspace.Theepicyclicgeartrainsareused in the back gear of lathe, differential gears of the automobiles, hoists, pulley blocks, wrist watches etc.



UNIT4:GOVERNORS&FLYWHEELS

Introduction

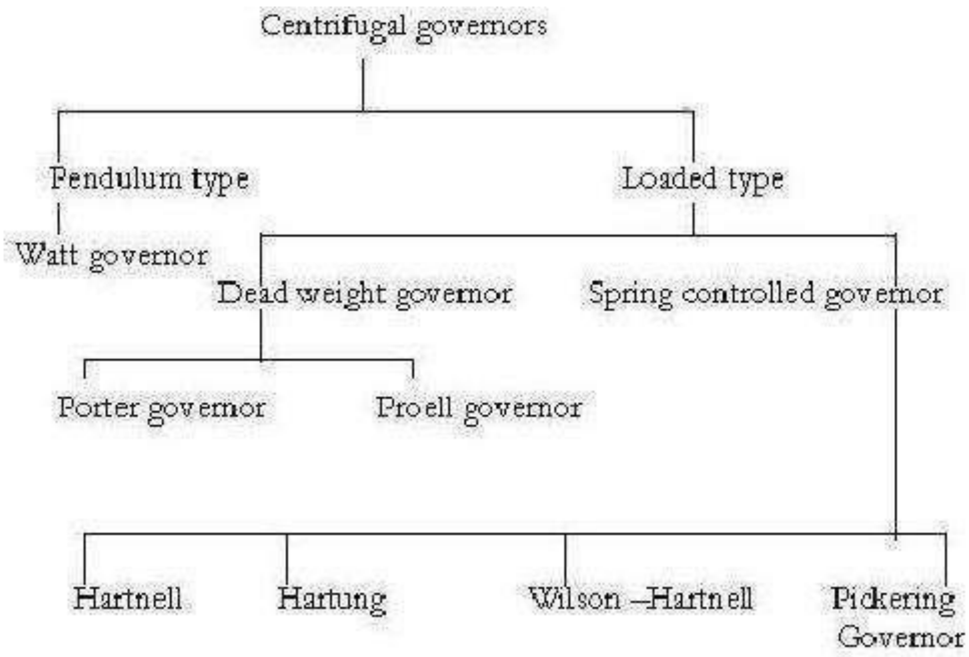
The governor is a device which is regulate the mean speed of an engine, when therearevariationsintheload,duringlongperiods.Ontheotherhand,whentheload on the engine decreases, its speed increases and thus less working fluid is required.the governor has no influence over cyclic speed fluctuation.

Typesofgovernor

Governorsareclassifiedbasedupontwodifferentprinciples.These are:Centrifugal governors are further classified as –

- •Centrifugalgovernor
- •Inertiagovernors

Centrifugalgovernorsarefurtherclassifiedas–



WattGovernor

Thesimplestformofacentrifugalgovernorisa Wattgovernor,Itconsistof pair of two ballsandwhichis attachedwiththespindle withhelpofarms.The upper arm pinnedatpointO. the lowerarmarefixedconnecttothesleeve.Thesleevefreely moveonthespindle whichisdrivenbyengine.Thespindlerotatetheballstakeof position depending upon speed of spindle

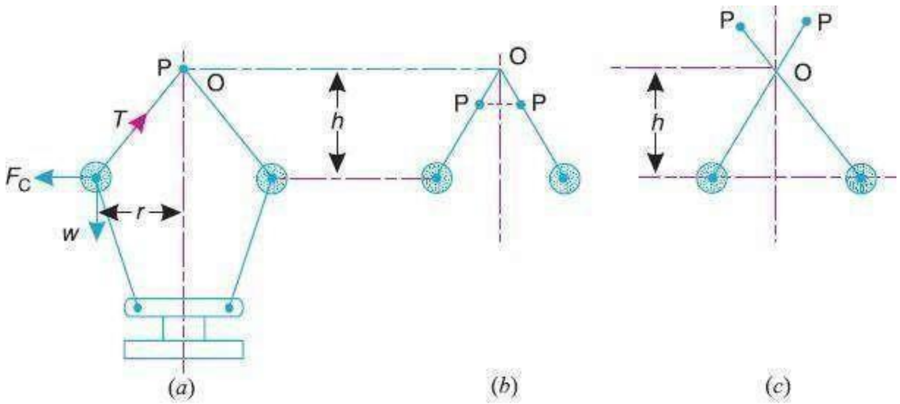
Thearmsofthegovernormaybeconnectedtothespindleinthefollowingthreeways:

1. Thepivot*P*,maybeonthespindleaxis.

2. Thepivot*P*,maybeoffsetfromthespindleaxisandthearmswhenproduced intersect at *O*.

3. Thepivot*P*,maybeoffset,butthearmscrosstheaxisat*O*.

Let



Watt governor.

m=Massoftheballinkg,

w=Weightoftheballinnewtons=*m*.*g*,*T*=Tensioninthearminnewtons,ω= Angular

velocity of the arm and ball about the spindle axis in rad/s,

r=Radiusofthepathofrotationoftheball*i*.*e*.horizontaldistancefromthecentreof the ball to the spindle axis in metres,

FC=Centrifugalforceactingontheballinnewtons=*m*v2/r*h*= *Height*

of the governor in metres.

Itisassumedthattheweightofthearms,linksandthesleevearenegligibleas comparedtotheweightoftheballs.Now,theballisinequilibriumunderthe action of

1. thecentrifugalforce(*F*C)actingontheball,

2. thetension(*T*)inthearm,

3. theweight(*w*)oftheball.

Taking moments about point O, we have

$$F_C \times h = w \times r = m.g.r$$

or $$m.\omega^2.r.h = m.g.r \quad \text{or} \quad h = g/\omega^2 \qquad \ldots (i)$$

When g is expressed in m/s^2 and ω in rad/s, then h is in metres. If N is the speed in r.p.m., then

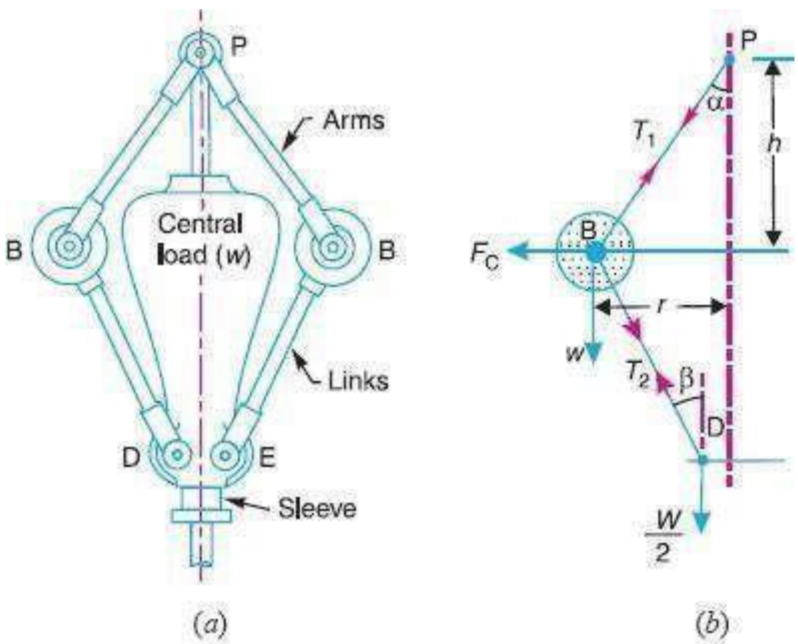
$$\omega = 2\pi N/60$$

$$\therefore \quad h = \frac{9.81}{(2\pi N/60)^2} = \frac{895}{N^2} \text{ metres} \qquad \ldots (\because g = 9.81 \text{ m/s}^2) \ldots (ii)$$

PorterGovernor

Itdiffersfromthewattgovernorisintheuseofaheavilyweightedsleeve.Theload moves up and down the central spindle. This additional downward force increases thespeed of revolution required to enable theballs to rise to any predetermined level.

Considertheforcesactingonone-halfofthegovernor



Porter governor.

Let$m$=Massofeachballin kg,

w=Weightofeachballinnewtons=$m.g$,M=Massofthecentralloadinkg,

W=Weightofthecentralloadinnewtons=$M.g$,r=Radiusofrotationinmetres,

h=Heightofgovernorinmetres, N =

Speedoftheballsinr.p.m.,

ω=Angularspeedoftheballsinrad/s=2N/60rad/s,

F_C=Centrifugalforceactingontheballinnewtons=mv^2/r,T_1=Forceinthearmin newtons, *T2=Forceinthelinkinnewtons,*

=Angleofinclinationofthearm(orupperlink)tothevertical,and= Angle

of inclination of the link (or lower link) to the vertical.

Theweightofarmsandweightofsuspensionlinksandeffectoffrictiontothemovementof sleeve are neglected.

Thoughthereareseveralwaysofdeterminingtherelationbetweentheheightof the governor (*h*) and the angular speed of the balls (ω).

I. *Method of resolution of forces*

Considering the equilibrium of the forces acting at *D*, we have

$$T_2 \cos\beta = \frac{W}{2} = \frac{M.g}{2}$$

or

$$T_2 = \frac{M.g}{2\cos\beta}$$

Again, considering the equilibrium of the forces acting on *B*. The point *B* is in equilibrium under the action of the following forces, as shown in Fig. 18.3 (*b*).

(*i*) The weight of ball ($w = m.g$),

(*ii*) The centrifugal force (F_C),

(*iii*) The tension in the arm (T_1), and

(*iv*) The tension in the link (T_2).

Resolving the forces vertically,

$$T_1 \cos\alpha = T_2 \cos\beta + w = \frac{M.g}{2} + m.g \quad \ldots (ii)$$

$$\ldots \left(\because T_2 \cos\beta = \frac{M.g}{2}\right)$$

Resolving the forces horizontally,

$$T_1 \sin\alpha + T_2 \sin\beta = F_C$$

$$T_1 \sin\alpha + \frac{M.g}{2\cos\beta} \times \sin\beta = F_C \quad \ldots \left(\because T_2 = \frac{M.g}{2\cos\beta}\right)$$

$$T_1 \sin\alpha + \frac{M.g}{2} \times \tan\beta = F_C$$

$$\therefore \quad T_1 \sin\alpha = F_C - \frac{M.g}{2} \times \tan\beta \quad \ldots (iii)$$

ProellGovernor

TheproellgovernorhasballfixedatBandCatextensionoflinkDFandEG.TheaemFP and GQ are pivoted at P and Q respectvily

Consider the equilibrium forces one-half of governor as shown in fig b.the instantneouscentrIliesonontheintersectionoflinePFproducedandfromDdrawn perpendicular to spindle axis. The perpendicular BM is drawn on ID

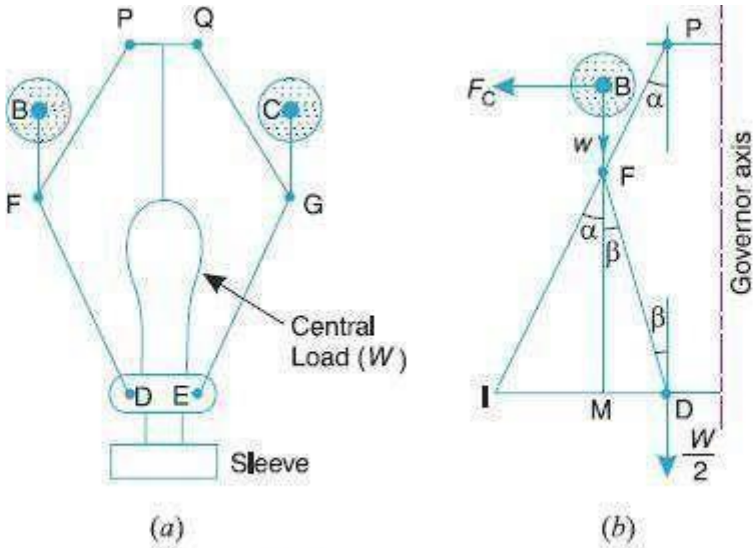


Fig. Proell governor.

Takingmomentsabout*I*,usingthesamenotations

$$F_C \times BM = w \times IM + \frac{W}{2} \times ID = m.g \times IM + \frac{M.g}{2} \times ID \quad \ldots (i)$$

$$\therefore \quad F_C = m.g \times \frac{IM}{BM} + \frac{M.g}{2}\left(\frac{IM + MD}{BM}\right) \quad \ldots (\because \; ID = IM + MD)$$

Multiplying and dividing by FM, we have

$$F_C = \frac{FM}{BM}\left[m.g \times \frac{IM}{FM} + \frac{M.g}{2}\left(\frac{IM}{FM} + \frac{MD}{FM}\right)\right]$$

$$= \frac{FM}{BM}\left[m.g \times \tan\alpha + \frac{M.g}{2}(\tan\alpha + \tan\beta)\right]$$

$$= \frac{FM}{BM} \times \tan\alpha\left[m.g + \frac{M.g}{2}\left(1 + \frac{\tan\beta}{\tan\alpha}\right)\right]$$

We know that $F_C = m.\omega^2 r$; $\tan\alpha = \frac{r}{h}$ and $q = \frac{\tan\beta}{\tan\alpha}$

$$\therefore \quad m.\omega^2.r = \frac{FM}{BM} \times \frac{r}{h}\left[m.g + \frac{M.g}{2}(1+q)\right]$$

and

$$\omega^2 = \frac{FM}{BM}\left[\frac{m + \frac{M}{2}(1+q)}{m}\right]\frac{g}{h} \quad \ldots (ii)$$

Substituting $\omega = 2\pi N/60$, and $g = 9.81 \text{ m/s}^2$, we get

$$N^2 = \frac{FM}{BM}\left[\frac{m + \frac{M}{2}(1+q)}{m}\right]\frac{895}{h} \quad \ldots (iii)$$

HartnellGovernor

AHartnellgovernor isaspringloadedgovernor.Itconsistsoftwo bellcranklevers pivoted at the points *O*,*O* to the frame. The frame is attached to the governor spindle and therefore rotates with it. Each lever carries a ball at the end of the verticalarm*OB*anda rollerattheendof thehorizontalarm *OR*.Ahelicalspringin compressionprovidesequaldownwardforcesonthe tworollers throughacollar onthesleeve.Thespringforce maybeadjustedbyscrewinga nutupordownon the sleeve.

Let$m$=Massofeachballin kg,

M=*Massofsleeveinkg,*

r_1=Minimumradius ofrotationinmetres,

r_2=Maximumradiusofrotationinmetres

ω_1=Angularspeedofthegovernoratminimumradiusinrad/s,

ω_2=Angularspeedofthegovernoratmaximumradiusinrad/s,

S_1=SpringforceexertedonthesleeveS_2=Springforceexertedonthesleeveat F_{C1}=Centrifugalforce=$m(\omega_1)^2 r_1$

F_{C2}=*Centrifugalforceat*=$m(\omega_2)^2 r_2$,

s=*Stiffnessofthespringortheforcerequiredtocompressthespringbyonemm*,x=

Length of the vertical or ball arm of the lever in metres,

y=*Lengthofthehorizontalorsleevearmoftheleverinmetres,and*

r=Distanceoffulcrum*O*fromthegovernoraxisortheradiusofrotationwhenthe governor is in mid-position.

SensitivenessofGovernors

AgovernorissaidtobesensItive,ifitschangeofspeedsfromnoLoadtofullloadmay

beassmallafractionofthemeanequilibriumspeedaspossibleandthe corresponding sleeve lift may be as large as possible.

Supposeω_1=max.Equilibriumspeedω_2=min.equilibriumspeed

ω=meanequilibriumspeed=$(\omega_1+\omega_2)/2$Thereforesensitiveness=$(\omega_1-\omega_2)/2$

StabilityofGovernors

Agovernorissaidtobe***stable***whenforeveryspeedwithintheworkingrangethereis definite configuration *i.e*. there is only one radius of rotation of the governorballsatwhichthe governorequilibrium.Forastable governor,if the equilibriumspeed increases, the radius of governor balls must also increase.

IsochronousGovernors

This isanextremecaseofsensitiveness.Whentheequilibriumspeedisconstant forallradiiofrotationofthe balls withintheworkingrange,the governorissaid to bein isochronism. Thismeansthatthedifferencebetweenthemaximumand minimum equilibriumspeeds is zero and the sensitiveness shall be infinite.

FLYWHEEL:-

Aflywheelisawheelofheavymassmountedonthecrankshaftanditstoresenergy during the period when the supply of energy is more

duringtheperiodwhentheflywheelabsorbsenergyitsspeedincreasesandduringthe period when it releases energy its speed decreases.

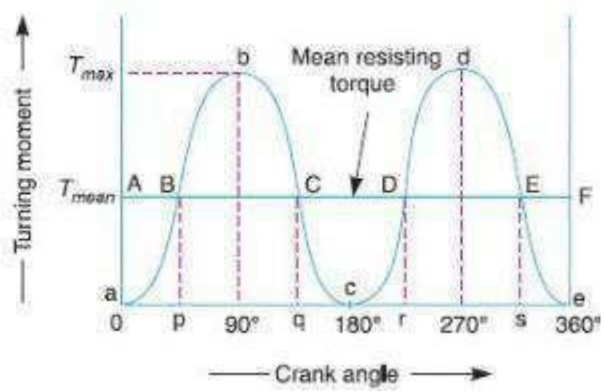
In engine, the flywheel absorbs the stroke and gives out the energy during idle strokes and thus keeps the maximum speed and minimum speed of crankshaft near the mean shaft in a thermodynamic cycle. In power press, the flywheel absorbsthemechanicalenergyproducedbyelectricmotorduringidleperiodand gives the energy when actual operation is performed. In this way with the use of flywheel, motor of smaller capacity is able to serve the purpose.

FluctuationofEnergy

Thefluctuationofenergymaybedeterminedbytheturningmomentdiagramfor one completecycleofoperation. Considertheturningmomentdiagramforasingle cylinder double acting steam

engineasshowninFig.

Weseethatthemeanresisting torque line *AF* cutstheturning moment diagram atpoints *B*,*C*,*D*and *E*. Whenthecrankmovesfrom*a*to *p*,the workdone bythe engine is equal to the area *aBp*, whereas the energy required is represented by theareaaABp.Inotherwords,the engine hasdoneless work(equaltothearea *a AB*) than the requirement. This amount of energy is taken from the flywheel and hencethespeedoftheflywheeldecreases.Nowthecrankmovesfrom*p*to*q*,thework done by the engine is equal to the area *pBbCq*, whereas the requirement of energy is represented by the area *pBCq*. Therefore, the engine has done more work than the requirement.



This excess work(equal to the area *BbC*) is stored in the flywheel andhence the speed of the flywheel increases while the crank moves from *p* to *q*. Similarly, when the crank moves from *q* to *r*, more work is taken from the engine than is developed. Thislossofworkisrepresentedbythearea *CcD*. Tosupplythisloss, theflywheelgivesupsomeofitsenergyandthusthespeeddecreaseswhilethecrank moves from *q* to *r*. As the crank moves from *r* to *s*, excess energy is again developed given by the area *D d E* and the speed again increases. As the piston moves from *s* to *e*, again there is a loss of work and the speed decreases. The variations of energy above and below the mean resisting torque line are called ***fluctuations of energy*.**

UNIT5:Balancingofmachine:Conceptofstaticanddynamic balancing

Explaintheconceptofbalancing:

Balancingistheprocessofeliminatingoratleastreducingthegroundforces and/ormoments.Itisachievedbychangingthelocationofthemasscentresof 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.Wegenerallytrytodoforcebalancing.Afullyforcebalanceispossible,butany action in force balancing severe the moment balancing

Balancingofrotatingmasses: Theprocessofprovidingthesecondmassinorder to counteracttheeffectof thecentrifugalforceofthefirstmassiscalledbalancing of rotating masses.

Staticbalancing: The netdynamicforceactingontheshaftisequal tozero.This requires thatthe lineofactionofthree centrifugalforcesmustbethesame.In otherwords,thecentreof the massesofthesystemmustlieontheaxisof the rotation. This is the condition for static balancing.

Dynamicbalancing:Thenetcoupleduetodynamicforcesactingontheshaftisequalto zero. The algebraic sum of the moments about any point in the plane must be zero.

Staticbalancingofrotatingmass

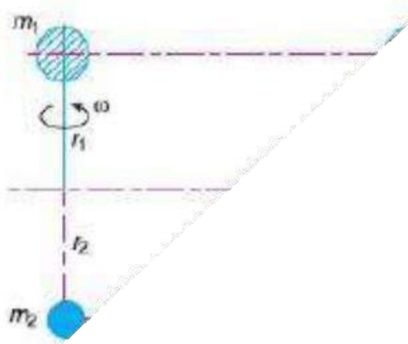
Balancingofasinglerotatingmassbysinglemassrotatinginthesameplane:

Consider a disturbing mass m_1 attached to a shaft rotating at ω rad/s as shown in Fig. Let r_1 be the radius of rotation of the mass m_1 (*i.e.* distance between the axis of rotation of the s' and the centre of gravity of the mass m_1).

We know that the centrifugal force exerted by the mass m_1 on the shaft,

$$F_{C1} = m_1 \cdot \omega^2 \cdot r_1$$

This centrifugal force acts radially outwards and thus produces ber shaft. In order to counteract the effect of this force, a balancing mass (m same plane of rotation as that of disturbing mass (m_1) such that the c two masses are equal and opposite.



Balancin

Let r

∴ Centri

CASE2:

BALANCINGOFASINGLEROTATINGMASSBYTWOMASSESROTATING IN

DIFFERENT PLANES.

Therearetwopossibilitieswhileattachingtwobalancingmasses:

1. Theplaneofthedisturbingmassmaybeinbetweentheplanesofthetwo balancing masses.

2. Theplaneofthedisturbingmassmaybeontheleftorrightsideoftwoplanes containing the balancing masses.

whichareparalleltotheplaneofrotationofthedisturbingmassi)thenetdynamicforce

acting on the shaft must be equal to zero, i.e. the centre of the masses of the system must lie on the axis of rotation and this is the condition for static balancingii)thenetcoupleduetothedynamicforcesactingontheshaftmustbe equaltozero,i.e.thealgebraicsumofthemomentsaboutanypointintheplanemustbe zero. The conditions i) and ii) together give dynamic balancing. **THE PLANE OF THE DISTURBING MASS LIES IN BETWEEN THE PLANES**

OFTHETWOBALANCINGMASSES.

Consider the disturbing mass m lying in a plane A which is to be balanced by two rotating masses m_1 and m_2 lying in two different planes M and N which are parallel to the plane A as shown.

Let r, r_1 and r_2 be the radii of rotation of the masses in planes A, M and N respectively.
Let L_1, L_2 and L be the distance between A and M, A and N, and M and N respectively.
Now,
The centrifugal force exerted by the mass m in plane A will be,

$$F_c = m\ \omega^2 r \text{ ------------------- } (1)$$

Similarly,
The centrifugal force exerted by the mass m_1 in plane M will be,

$$F_{c1} = m_1 \omega^2 r_1 \text{ ------------------- } (2)$$

And the centrifugal force exerted by the mass m_2 in plane N will be,

$$F_{c2} = m_2 \omega^2 r_2 \text{-------------}$$

For the condition of static balancing,

$$F_c = F_{c1} + F_{c2}$$

or

Now, to determine the magnitude of balancing force in the plane 'M' or the dynamic force at the bearing 'O' of a shaft, take moments about ' P ' which is the point of intersection of the plane N and the axis of rotation.

Therefore,

$$F_{c1} \times L = F_c \times L_2$$

$$\text{or} \quad m_1 \omega^2 r_1 \times L = m\omega^2 r \times L_2$$

Therefore,

$$m_1 r_1 L = mrL_2 \quad \text{or} \quad m_1 r_1 = mr\frac{L_2}{L} \text{---------}(5)$$

Similarly, in order to find the balancing force in plane 'N' or the dynamic force at the bearing 'P' of a shaft, take moments about ' O ' which is the point of intersection of the plane M and the axis of rotation.

Therefore,

$$F_{c2} \times L = F_c \times L_1$$

$$\text{or} \quad m_2 \omega^2 r_2 \times L = m\omega^2 r \times L_1$$

Therefore,

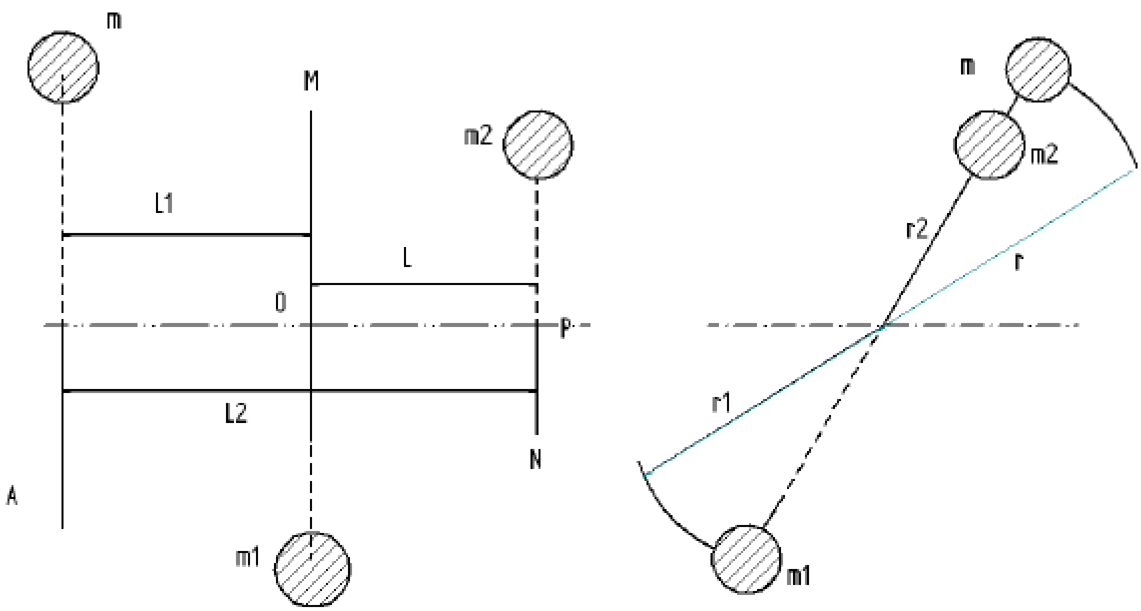
$$m_2 r_2 L = mrL_1 \quad \text{or} \quad m_2 r_2 = mr\frac{L_1}{L} \text{---------}(6)$$

For dynamic balancing equations (5) or (6) must be satisfied along with equation (4).

CASE 2(II):

WHEN THE PLANE OF THE DISTURBING MASS LIES ON ONE END OF THE TWO PLANES CONTAINING THE BALANCING MASSES.

When the plane of the disturbing mass lies on one end of the planes of the balancing masses



$F_{c1} x L = F_c x L_2$

or $m_1 \omega^2 r_1 \times L = m\omega^2 r \times L_2$

Therefore,

$m_1 r_1 L = mrL_2$ or $m_1 r_1 = mr\frac{L_2}{L}$ ----

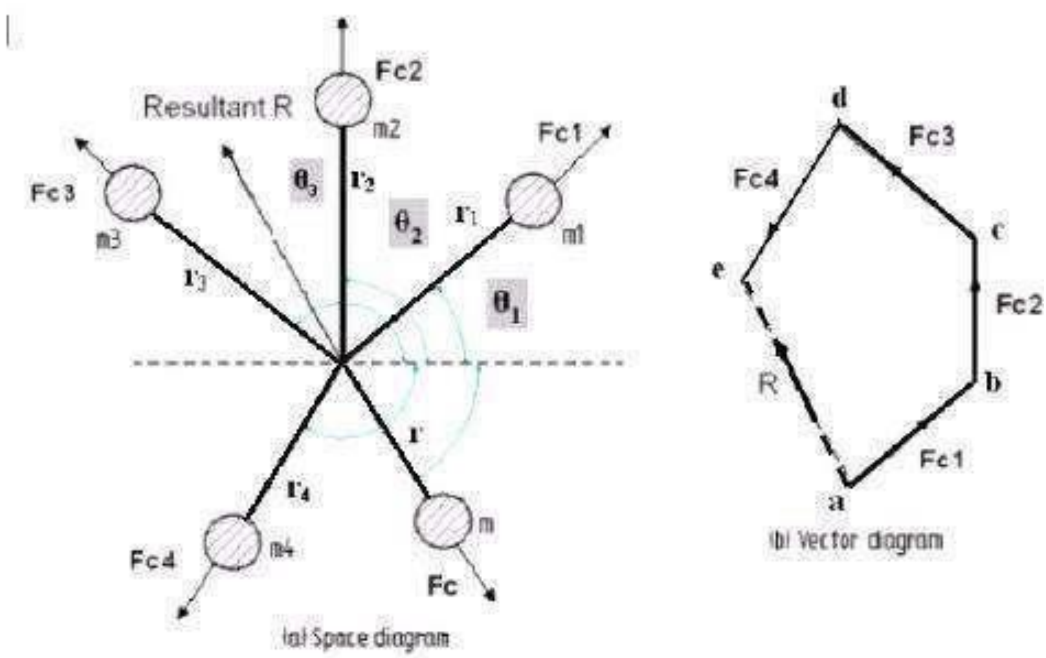
Similarly, to find the balancing force in th

$F_{c2} x L = F_c x L_1$

or $m_2 \omega^2$

The

CASE 3:
BALANCING OF SEVERAL MASSES ROTATING IN THE SAME PLANE



BALANCING OF SEVERAL MASSES ROTATING IN THE SAME PLANE

Considerarigidrotorrevolvingwithaconstantangularvelocity_rad/s.Anumber of masses say, four are depicted by point masses at different radii in the same transverse plane

If m_1, m_2, m_3 and m_4 are the masses revolving at radii r_1, r_2, r_3 and r_4 respectively in the same plane.
The centrifugal forces exerted by each of the masses are F_{c1}, F_{c2}, F_{c3} and F_{c4} resp
Let F be the vector sum of these forces. i.e.

$$F = F_{c1} + F_{c2} + F_{c3} + F_{c4}$$
$$= m_1 \omega^2 r_1 + m_2 \omega^2 r_2 + m_3 \omega^2 r_3 + m_4 \omega^2 r_4 -$$

The rotor is said to be statically balanced if the vect
is not zero, i.e. the rotor is unbalanced, then intr
of mass 'm' at radius 'r' to balance the rotor

$$m_1 \omega^2 r_1 + m_2 \omega^2 r_2 + m_3 \omega$$

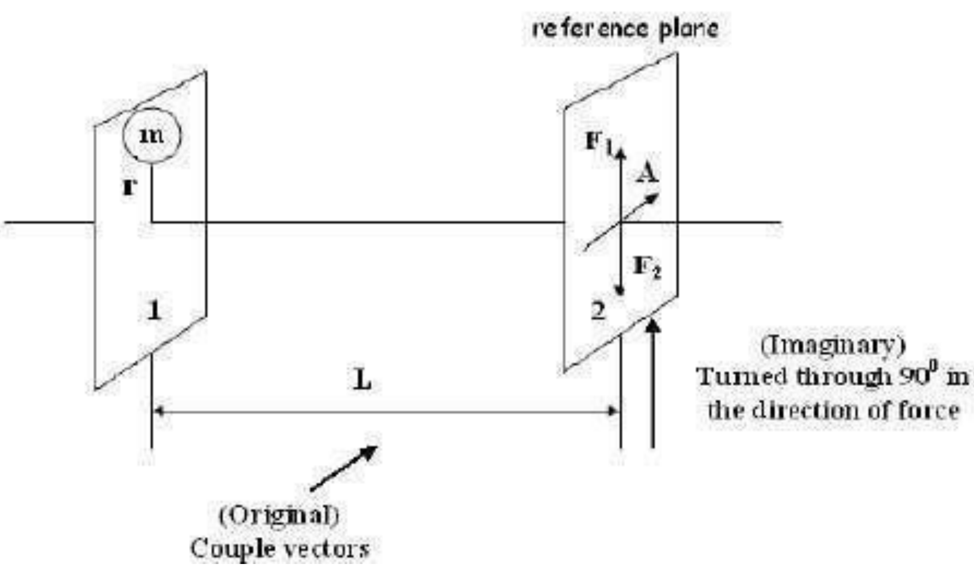
$$m_1 r_1 + m_2 r_2 +$$

The magnitude
In general,

CASE 4:

BALANCING OF SEVERAL MASSES ROTATING IN DIFFERENT PLANES

When several masses revolve in different planes, they may be transferred to a reference plane and this reference plane is a plane passing through a point on the axis of rotation and perpendicular to it.



Whenarevolvingmassinoneplaneistransferredtoareferenceplane,itseffectisto cause a force of same magnitude to the centrifugal force of the revolving masstoactinthereferenceplanealongwithacoupleofmagnitudeequaltothe product of the force and the distance between the two planes.

Inordertohaveacompletebalanceoftheseveralrevolvingmassesindifferentplanes,

1. theforcesinthereferenceplanemustbalance,i.e.,theresultantforcemustbe zero and

2. thecouplesaboutthereferenceplanemustbalancei.e.,theresultantcouple must be zero.

Amassplacedinthereferenceplanemaysatisfythefirstconditionbutthecouple balance is satisfiedonly by two forces of equal magnitude in different planes. Thus,ingeneral,twoplanesareneededtobalanceasystemofrotatingmasses **balanicingofreciprocatingengine**

UNIT6:VIBRATIONOFMACHINEPARTS

Introduction

When elastic bodies such as a spring, a beam and a shaft are displaced from the equilibriumpositionbytheapplicationofexternalforces,andthenreleased,they execute a vibratory motion.

Classifyvibrations

Longitudinalvibrations.Whentheparticlesoftheshaftordiscmovesparalleltothe axis of the shaft, as shown in Fig (*a*), then the vibrations are known as ***longitudinal vibrations*.**

When no externalforceactsonthe body,aftergivingitan initial displacement, thenthebodyissaidtobeunder***freeornaturalvibrations*.**Thefrequencyofthefree vibrations is called ***free or natural***

frequency.

2. ***Transversevibrations****.*Whentheparticlesoftheshaftordiscmove approximately perpendicular to the axis of the shaft

3. ***Torsionalvibrations****.* When theparticles of the shaftordisc move in acircle abouttheaxisoftheshaft,as showninFig.(*c*),thenthevibrationsare knownas ***torsionalvibrations*****.**Inthiscase,theshaftistwistedanduntwistedalternately and the torsional shear stresses are inducedin the shaft.

2- Forcedvibrations.

Whenthebodyvibrates undertheinfluenceofexternalforce,thenthebodyissaidto be under ***forced vibrations*****.**The external force applied to the body is a periodic disturbingforcecreatedbyunbalance.Thevibrationshavethesamefrequency as the applied force.

3- Dampedvibrations.

Whenthereisareductioninamplitudeovereverycycleofvibration,themotionissaid to be ***damped vibration*****.** This is due to the fact that a certain amount of energy possessed by the vibrating system is always dissipated in overcoming frictional resistances to the motion.

DefinewithrespecttovibrationCycle:

Amplitude:

TimePeriod:

1. ***Periodofvibrationortimeperiod*****.**Itisthetimeintervalafterwhichthemotionis repeated itself. The period of vibration is usually expressed in seconds.

2. ***Cycle*****.**Itisthemotioncompletedduringonetimeperiod.

3. ***Frequency*****.**Itis the numberofcyclesdescribedinonesecond.InS.I.units,the frequencyis expressedinhertz(briefly writtenas Hz) which isequaltoonecycle per second.

StatethecausesofVibration

Unbalance: This is basically in reference to the rotating bodies. The uneven distribution of mass in a rotating body contributes to the unbalance. A good example of unbalance related vibration would be the —vibrating alert in our mobilephones.Hereasmallamountofunbalancedweightisrotatedbyamotor causingthevibrationwhichmakesthe mobile phone tovibrate. Youwouldhave experiencedthesamesortofvibrationoccurringinyour frontloadedwashing machines that tend to vibrate during the —spinningmode.

Misalignment: Thisisanothermajorcauseofvibrationparticularlyinmachinesthat are driven by motors or any other prime movers.

BentShaft: Arotatingshaftthatisbentalsoproducesthethevibratingeffectsinceit losses it rotation capability about its center.

Gearsinthemachine:Thegearsinthemachinealwaystendtoproducevibration, mainly duetotheirmeshing.Thoughthismaybecontrolledtosomeextent,anyproblemin the gearbox tends to get enhanced with ease.

Bearings: Last but not the least, here is a major contributor for vibration. In majority of the cases every initial problem starts in the bearings and propagates totherestofthemembersofthemachine.Abearingdevoidoflubricationtendstowear out fast and fails

quickly, but before this is noticed it damages the remaining components in the machineandaninitiallookwouldseemasifsomethinghadgonewrongwiththeother components leading to the bearing failure.

Effectsofvibration:

(a) BadEffects: Thepresenceofvibrationin anymechanicalsystemproduces unwantednoise,highstresses,poorreliability,wearandprematurefailureof parts.Vibrationsareagreatsourceofhumandiscomfortintheformofphysical and mental strains.

(b) GoodEffects: Avibrationdoesusefulworkinmusicalinstruments,vibrating screens,shakers,relive pain in physiotherapy• -unbalanceis its maincause, so balancing of parts is necessary.

- usingshockabsorbers.
- usingdynamicvibrationabsorbers.
- providingthescreens(ifnoiseistobereduced)