Basics of Mechanical Engineering-1

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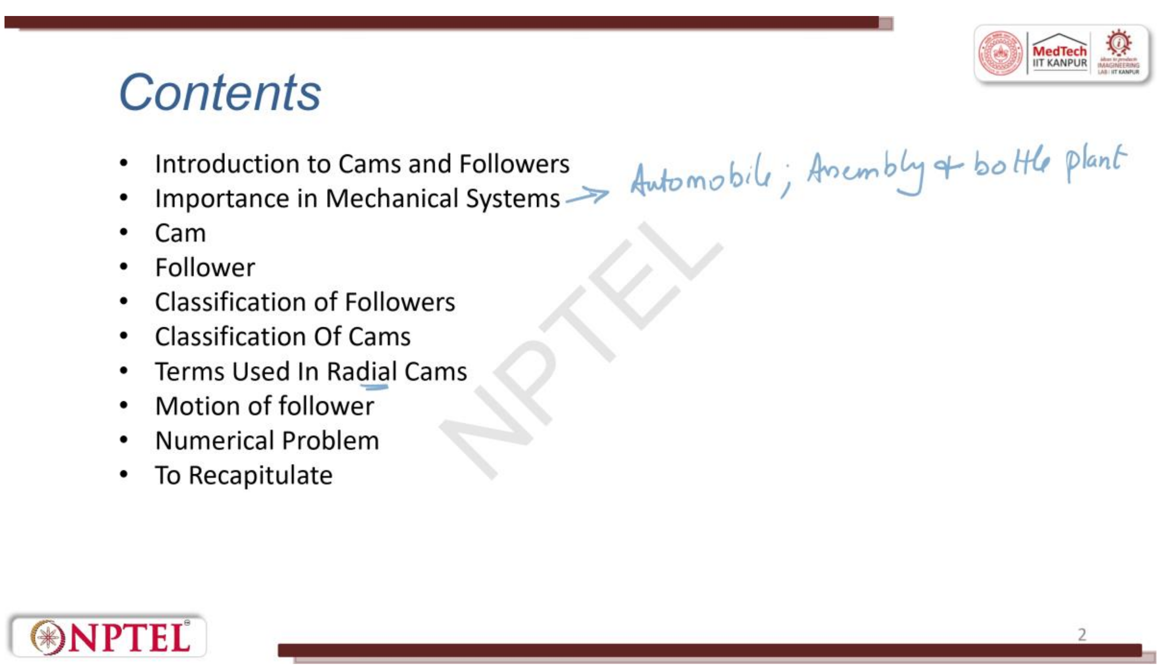
Week 10

Lecture 43

Cam and Follower Design

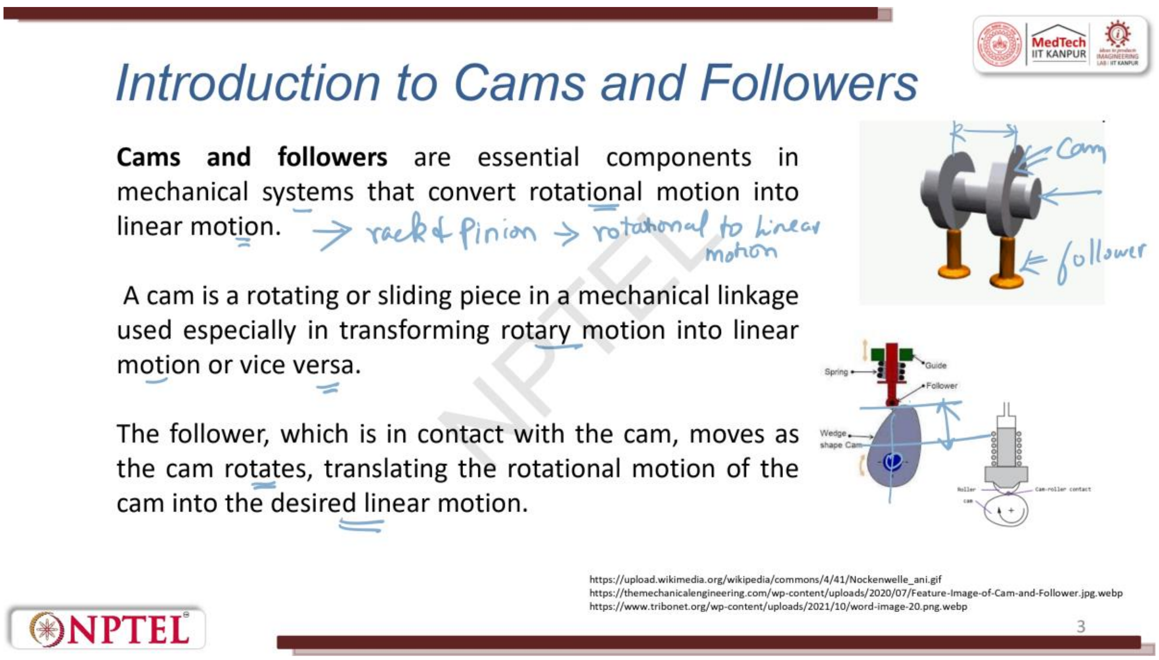
Welcome to the next lecture on Cam and Followers. We were looking into various mechanisms. So, we initially saw Rack and Pinion, then we saw Gear. Now, we will try to see Cam and Follower mechanisms or designs. Wherever you wanted to have varying displacement,

With varying velocity, cam and follower design is very important. When we are looking into mass production or in rigid automation, cam and follower plays a very important role.



So, in this lecture, we will try to cover Introduction of Cam and Follower Design. Then Importance of Cam and Follower in mechanical systems. Predominantly if you see it will be in automobile.

Automobile and sometimes it can also be in assembling and bottling plants. Where there is a time duration and filling can happen with varying velocity. Next we will see Cam and Follower. In Cam, there are different types of Cam, then different types of Follower, what are all the Terminologies used in a Radial Cam, then we will try to see motions of follower, numerical problems, one or two we will see, and finally we will try to have a recap.



This video clearly shows what is Cam and what is Follower. And why do you need it? When a rotation motion is given to a shaft and the cams which are all oriented in different directions and with different distance, you can see them in one circle, you can try to have 6 or 7 followers to be activated.

That means to say you can have 6-7 valves. These opening and closing of the valves can be controlled by rotating the shaft only once. So, the disc is called as a Cam and the plunger which is attached, which is in contact with the Cam is called as a Follower.

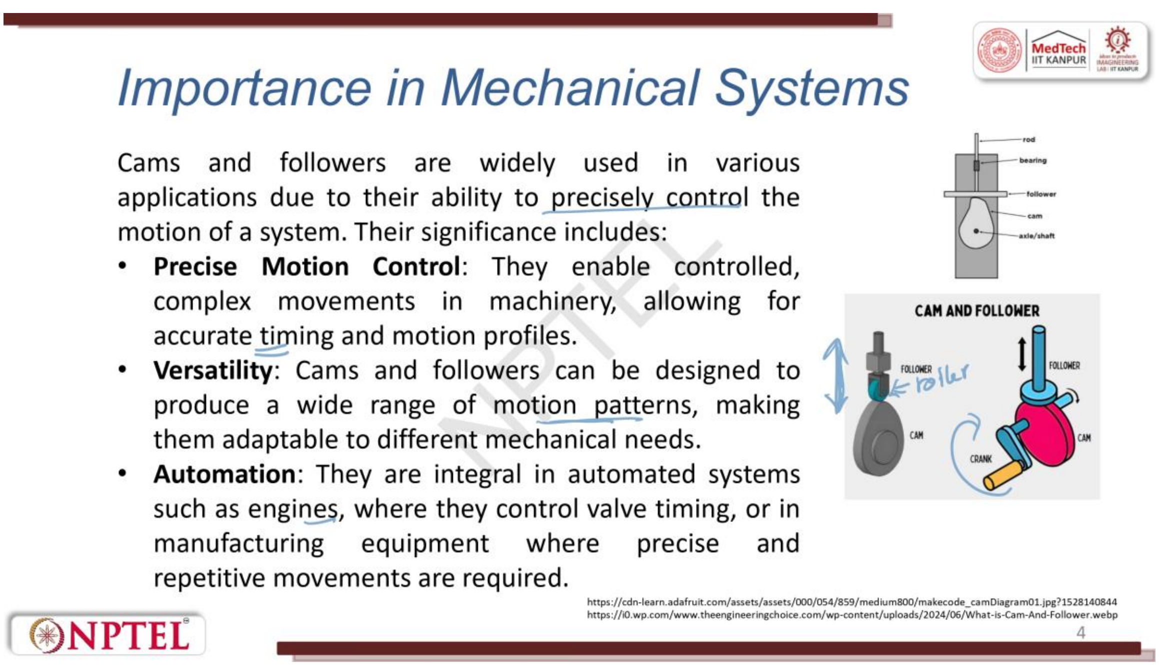
Cam and followers are essential components in mechanical systems which convert rotational motion into linear motion. We had a similar one in the past also we saw, which is Rack and Pinion mechanism, where they also used rotational to linear motion. A cam is a rotating or a sliding piece. in a mechanical linkage used especially in transforming rotary motion into linear motion or vice versa. A follower which is in contact, you can see the yellow portion which is in contact with the grey colour disc.

The follower which is in contact with the cam moves as the cam rotates. So the shaft rotates, the cam rotates. Moment the cam rotates, the contacting follower also rotates in the similar fashion of the cam. The follower which is in contact with the cam moves as the cam rotates. Translating the rotational motion of the cam into a desired linear motion.

If you try to see the cross section, you can see here a cam. How does it look like? It is not a circular disc. It is a disc which is offsetted with a distance. So you can see here there is a center.

So this is the center. So you will have a cam which has a throw. A linear distance displaced. So this will try to help in pushing the plunger up and down that can help in compressing or expanding the spring which is getting loaded. So this loading can in turn take care of opening or closing of the valve.

So this is a cam and then you can have spring follower is attached to a spring and then you can have a plunger or any other linear motion.



The cam and follower are widely used in various applications due to their ability to precisely control the motion of a system. So, in automobile, you can have where in which opening and closing of the valve where there is a cylinder, there is a combustion which happens inside the cylinder, then there is an expansion by the piston and this in turn has to be activated to opening and closing of the valve wherein which inside the engine combustion chamber, there is a spraying of diesel or spraying of any fuel. So, there we always try to use a cam where Precise Motion Control is there, they enable controlled complex movement in machinery allowing for accurate timing and motion profile.

So exactly at the time it opens and closes. Then Versatility. Cam and follower can be designed to produce a wide range of motion patterns. It need not be a single pattern. You can do multiple patterns.

You can have a disc type cam. You can have a cylinder type cam. You can have one cylinder, one cam and multiple followers can be there. So with single cam, single follower, multiple things can be activated. So multiple combinations can be done.

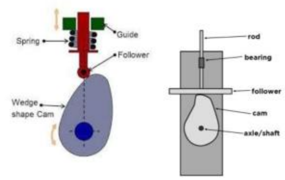
So, versatility cam and followers can be designed to produce a wide range of motion patterns making them adaptable to different mechanical needs. Automation, they are integral in automated systems such as engines where they control valve timing or in manufacturing equipment where precise and repetitive movements are required. So you can see here a crank is rotated. This crank in turn is attached to a cam. This cam will help the follower to move up and down and opening and closing can be done.

You can also have a motion like this. A cam rotates. This is a roller. This roller is attached to a shaft which is called as a follower. So the roller, so here you see the cross section area is large, cross section area is small.

For example, this is surface contact, this is line contact. You can also have point contact. So depending upon the sensitivity, the follower can be designed in multiple ways. So here you have a roller, this roller moves up and down, this roller moves up and down, wherein which it tries to open or close or do some operation as expected by the follower.

Cam

- A **cam** is a mechanical component used to convert rotational motion into linear motion.
- It typically consists of a rotating or sliding piece (the cam) that pushes against a follower, causing the follower to move in a controlled, predetermined path.
- The motion of the follower is determined by the shape of the cam's surface or profile.



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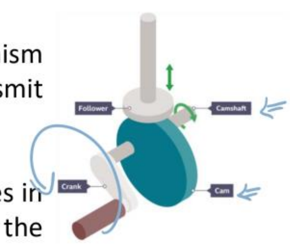
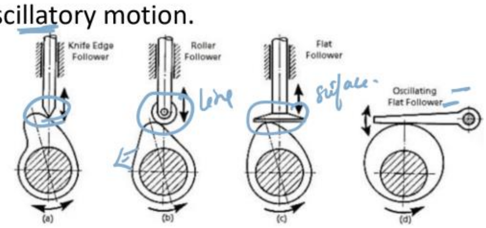
Cam is a mechanical component used to convert rotational motion to linear motion. It typically consists of a rotating or a sliding piece. You can have a cam either in rotation or in sliding that pushes against a follower causing the follower to move in a controlled predetermined path. The motion of the follower is determined by the shape of the cam surface profile. So, this is very important. Depending upon the motion, you can try to change the cam profile or the cam surface.

Follower

- A **follower** is a mechanical component in a cam mechanism that follows the contour of the cam profile to transmit motion.
- The follower is in direct contact with the cam and moves in a prescribed manner as the cam rotates, translating the cam's rotational motion into linear or oscillatory motion.



Cam → designed for a profile which can help in giving the desired o/p



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Follower, As I told you, there are different types of followers. Follower is a mechanical component in a cam mechanism that follows the contour of the cam profile to transmit a motion. So here if you see here, this is the follower, this is a crank which rotates and you have a cam, then you have a cam shaft attached to it.

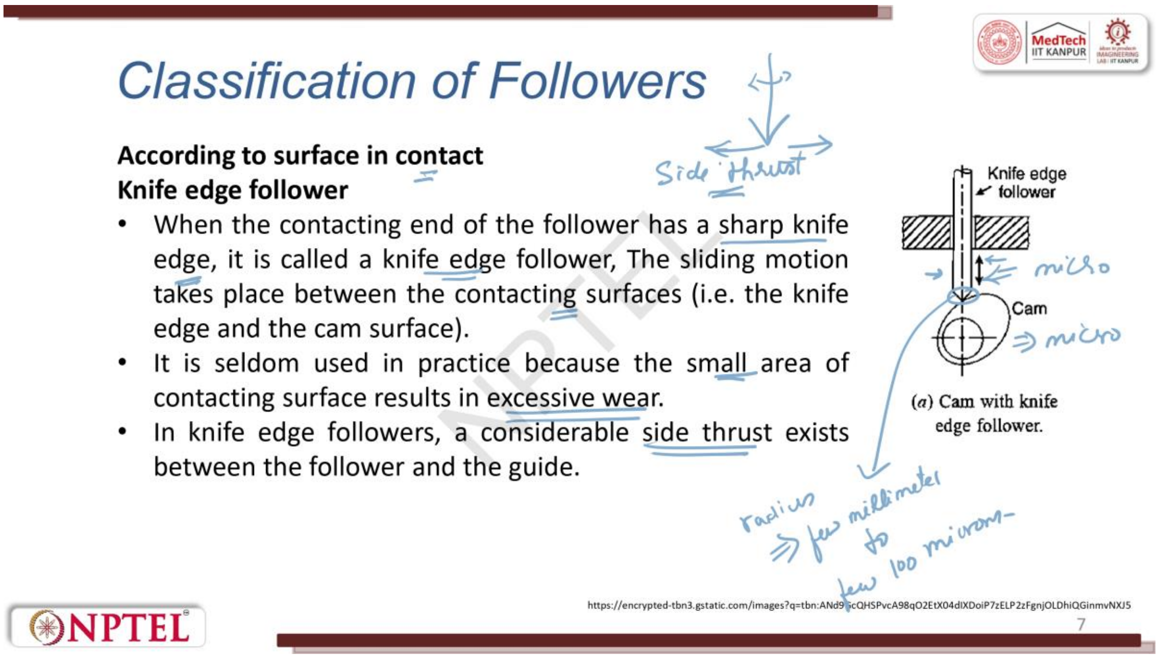
The follower is in direct contact with the cam and moves in a prescribed manner as the cam rotates, translating the rotational motion into linear or oscillatory. So you can have a knife edge, this is a knife edged follower, very precise you can try to have. You can have a roller type. This is almost like a point line. This is a surface.

Okay, you can have a flat follower. You can have a line follower, that is a roller follower. You can have a point contact, which is a knife edged follower. You can also have a oscillating flat follower. So here this goes up and down.

So if you see a cam, there is always an importance of the profile. So cam is dictated or is used or designed for a profile which can help in giving the desired output. So you can have oscillatory, you can have linear, you can have a point contact, very precision, line contact, flat contact. Why is it going from point to line to flat? When you have, the pressure is getting distributed.

So when the pressure is getting distributed, the wear and tear of the follower will be reduced and digging inside the cam also will be reduced. What can be the cam material? It can be a metal, it can be non-metal such as a polymer, you can have this too. Can I have ceramic? Yes, but the only difficulty with ceramic is it cannot take a toughness or it cannot take a fluctuating load.

So, we try to give a ceramic coating on top of a metal and sometimes they call that as ceramic cam and followers. But predominantly, we will try to use metals. Again in metals, it can be ferrous base, it can be non-ferrous base. For example, it can be brass, bronze, steel, multiple things are used. So, according to the surface in contact, we will try to see the classification of the follower.



Knife edge follower. When the contacting end of the follower has a sharp knife edge, it is called as knife edge follower. The sliding motion takes place between the contacting surface. It is seldom used in practice because the small area of contact results in excessive wear. But still wherever we wanted to have a very precision control, the cam size will get into the domain of micro and the knife follower will also be in terms of micro.

Micro means if you look at the tip, the radius can vary from few millimeter to few millimeter. 100 microns. Wherever you have a precise contact, knife if you want to have an analogy it is almost like a pen tip, nib. So, it is almost like that. In knife edge follower considerable side thrust exist.

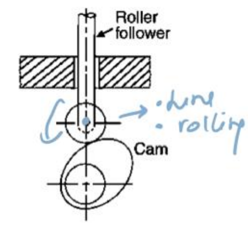
So, this is thrust, this is side thrust. Okay, side thrust. Okay, so that means to say it can oscillate. You press it, it can move left and right. So, it is called a side thrust.

So, when you are using cam, you have to make sure the side thrusts are not there. So, how do you arrest? You try to put a stopper in both sides and make sure that it does not go. So, in Knife edge follower, a considerable side thrust exists between the follower and the guide.

Classification of Followers

Roller follower

- When the contacting end of the follower is a roller, it is called a roller follower.
- Since the rolling motion takes place between the contacting surfaces (i.e. the roller and the cam), therefore the rate of wear is greatly reduced.
- In roller followers also the side thrust exists between the follower and the guide.
- The roller followers are extensively used where more space is available such as in stationary gas and oil engines and aircraft engines.



(*b*) Cam with roller follower.

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Next is Roller follower. Roller follower here when the contacting end of the follower is a roller. So here the advantages of two. One is line and the other one is rolling contact. So, when there is a rolling contact, this follower rolls about this axis. That can reduce the friction and wear loss.

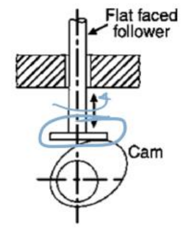
And second thing, there is a line contact. So, when the contacting end of the follower is a roller, this is called as Roller follower. Since the rolling motion takes place between the contacting surface, there is a rate of wear is greatly reduced. The roller can rotate about this axis and there is a line contact. The roller followers also has the side thrust exist between the follower and the guide.

The roller thrust are extensively used where more space is available such as in stationary gas, oil engines and aircraft engines. So, in automobile we always try to use roller follower only.

Classification of Followers

Flat faced or mushroom follower

- When the contacting end of the follower is a perfectly flat face, it is called a flat-faced follower).
- It may be noted that the side thrust between the follower and the guide is much reduced in case of flat faced followers.
- The only side thrust is due to friction between contact surfaces of the follower and cam. Relative motion between these surfaces is largely of sliding nature but wear may be reduced by off-setting the axis of follower, so that when the cam rotates, the follower also rotates about its own axis.
- The flat faced followers are generally used where space is limited such as in cams which operate the valves of automobile engine.



(c) Cam with flat faced follower.

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Then Flat roller. Shaped or Mushroom follower, this is a flat type follower when a contacting end of the follower is a perfectly flat face it is called as Flat faced follower. It may be noted that the side thrust between the follower and the guide is much reduced in the case of a flat faced follower this is the biggest advantage

There is a surface contact. Surface contact, it will also induce friction. But the advantage here is the side thrust contact is reduced to a large extent. The only side thrust is due to friction between the contact surfaces of the follower and the cam. The relative motion between these surfaces is largely of a sliding nature.

Rolling nature, sliding nature. Sliding, you have a wedge. Here, there is an object which slides, right. This object is in contact. It slides.

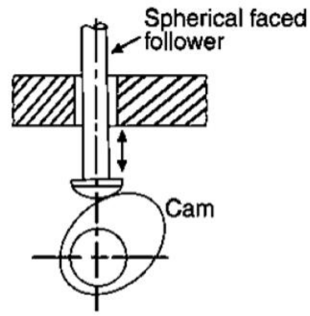
Next one is wedge. You have an object. You have a roller. So this is the wedge. So here we are talking about sliding nature.

But wear may be reduced by offsetting the axis of the follower. So that when the cam rotates, the follower also rotates about its own axis. It can rotate like this also. The flat-faced follower are generally used where space is limited, such as cams which operate the valves of an automobile engine.

Classification of Followers

Spherical faced follower

- When the contacting end of the follower is of spherical shape, it is called a spherical faced follower.
- It may be noted that when a flat-faced follower is used in automobile engines, high surface stresses are produced.
- In order to minimize these stresses, the flat end of the follower is machined to a spherical shape.



(*d*) Cam with spherical faced follower.

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Then you can have Spherical-Faced follower, flat-faced. Spherical is a combination of roller and flat-faced. When the contacting end of the follower is of a spherical shape, it is called as Spherical faced follower. It may be noted that when a flat faced follower is used in automobile engine, high surface stresses are produced. In order to minimize that, we always go for spherical faced follower.

Classification of Followers

According to the motion of follower

Reciprocating or Translating Follower

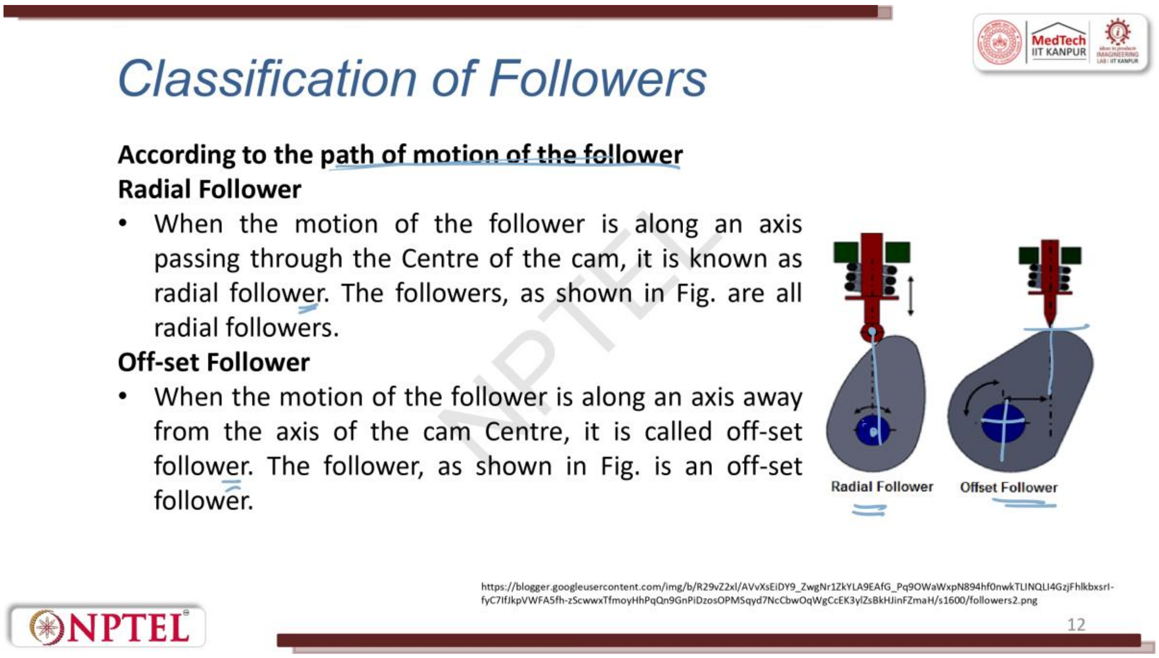
- When the follower reciprocates in guides as the cam rotates uniformly, it is known as reciprocating or translating follower. The followers are all reciprocating or translating followers.

Oscillating or Rotating Follower

- When the uniform rotary motion of the cam is converted into predetermined oscillatory motion of the follower, it is called oscillating or rotating follower.

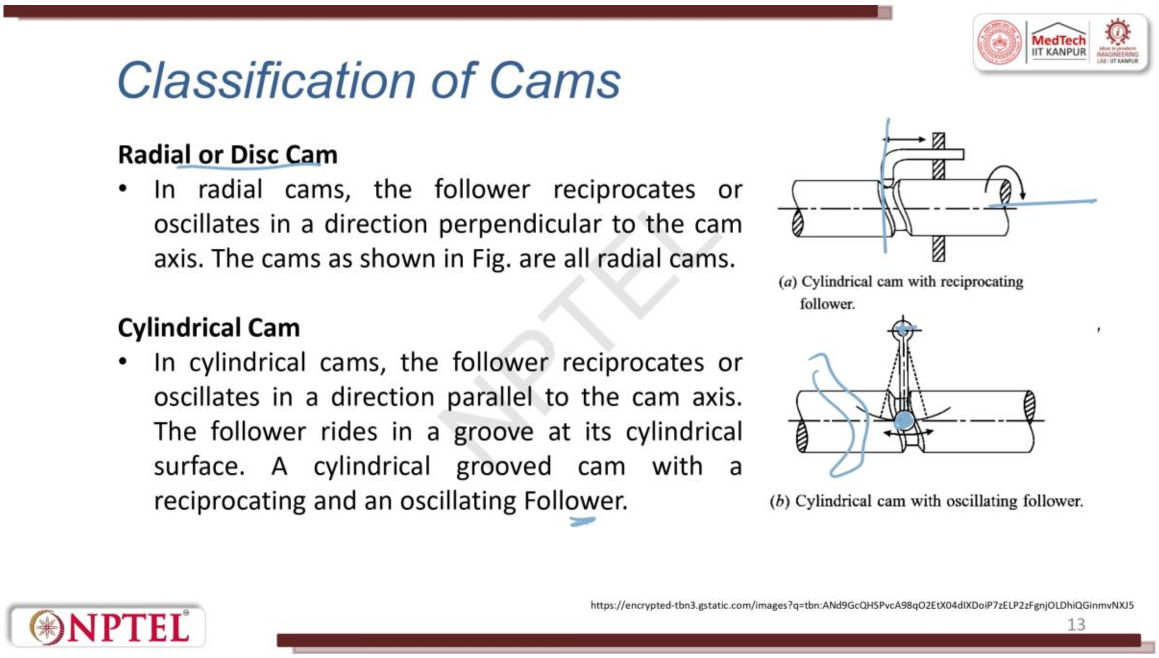
So, classification of the follower based upon motion. So, the motion can be two types. One is reciprocating, the other one can be oscillating. Okay. So, according to the motion of the follower, reciprocation or translation followers can be there. When the follower reciprocates in guides, what are guides? Supports which are there.

These are guides. When the follower reciprocates in guides, as the cam rotates uniformly, it is known as reciprocating or translating follower. The followers are all Reciprocating and Translating followers. Oscillation or Rotating followers. When the uniform rotatory motion of the cam is converted into predetermined oscillatory motion of a follower, it is called Oscillating or Rotating follower. So, earlier we saw motion of the follower.



Next, according to the path of motion of the follower. You can have radial follower, you can have Off-set follower. When the motion of the follower is along an axis passing through the center of the cam, so this is called as Radial follower. So here this is the axis of the follower, axis of the cam, they are passing.

Is along an axis passing through the center of the cam, it is known as Radial follower. It is shown in the figure. Off-set follower, you look at it, the cam axis is here, the follower axis is here. When the motion of the follower is along an axis away from the axis of the cam center, it is called as Off-set follower. The off-set is shown in the figure, is an off-set follower.

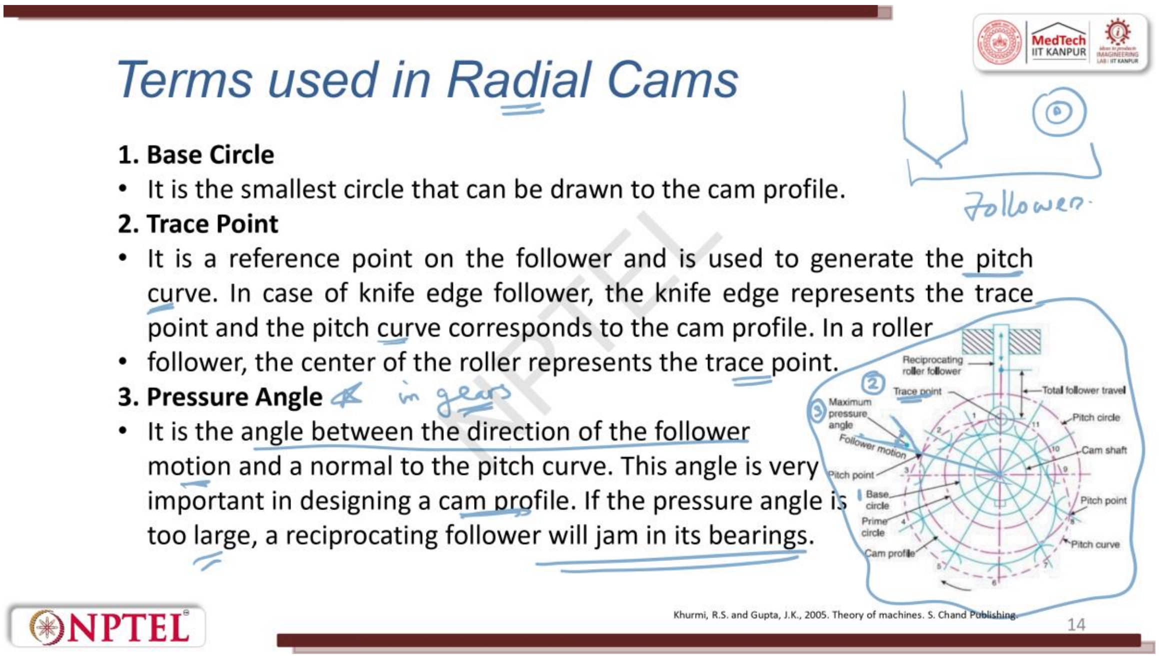


You can also have a Radial or a Disc cam. In radial cam, the follower reciprocates or oscillates in the direction perpendicular to the cam. So, this and this. In radial cams, the follower reciprocates or oscillates in a direction perpendicular. So, rotation is there, perpendicular to that it can go.

So, this thing is called as Radial cams. In Cylindrical cams, the follower reciprocates or oscillates in a direction parallel to the cam axis. The follower rides in the grooves at its central surface. The cylindrical grooves cam with a reciprocating or an oscillatory motion. So here there are grooves.

Inside the groove, this is a follower. This follower can oscillate. It is fixed here, so it can oscillate. So it will go like this, something like this. It will oscillate or it can reciprocate.

A cylindrical grooved cam with a reciprocating and an oscillatory follower is shown here. Till now what we saw was disc type. Now whatever you are seeing is a cylinder type.



So now let us look into some of the Terms in a Radial Cam. So the most important thing is the base circle.

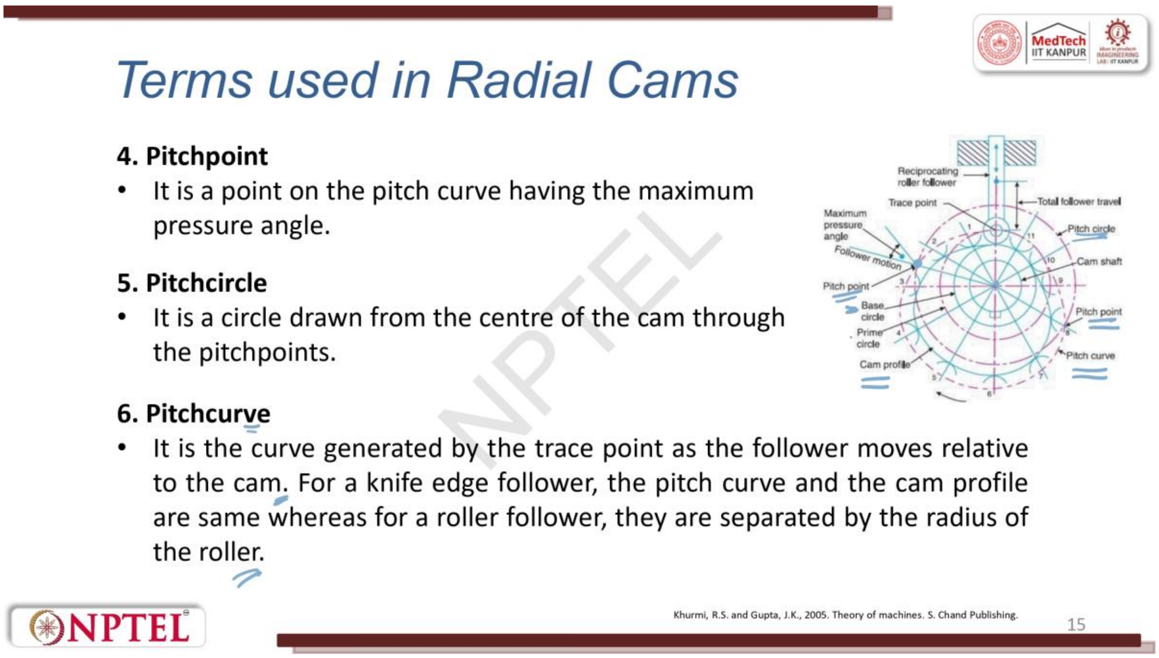
So, you can refer this figure where all the details are given. So, first we are trying to talk about the Base Circle. Base circle, it is the smallest circle that can be drawn to the cam profile. Trace Point, this is the second thing we are talking about, Trace Point. It is a reference point on the follower and is used to generate the pitch curve.

It is generating the pitch curve. It is very important. Pitch curve. In case of knife edge follower, the knife edge represents the trace point of the pitch curve corresponding to the cam profile. In a roller, the center of the roller represents a trace point.

So, knife and roller, followers, these two are followers. Pressure angle. The similar concept of pressure angle we saw in gears also. So, here is the pressure angle. So, you can see here pressure angle is this is a line which is drawn and an angle line pressure angle.

So, this is normal an angle. It is the angle between the direction of the follower motion and the normal to the pitch curve. This angle is very important in designing the cam profile, very important detail. If the pressure angle is too large, a reciprocating follower will jam in its bearings. So, you have to be very careful the pressure angle.

A similar analogy is pressure angle in gears also we saw how important it is. So, pressure angle here we are talking with respect to roller.

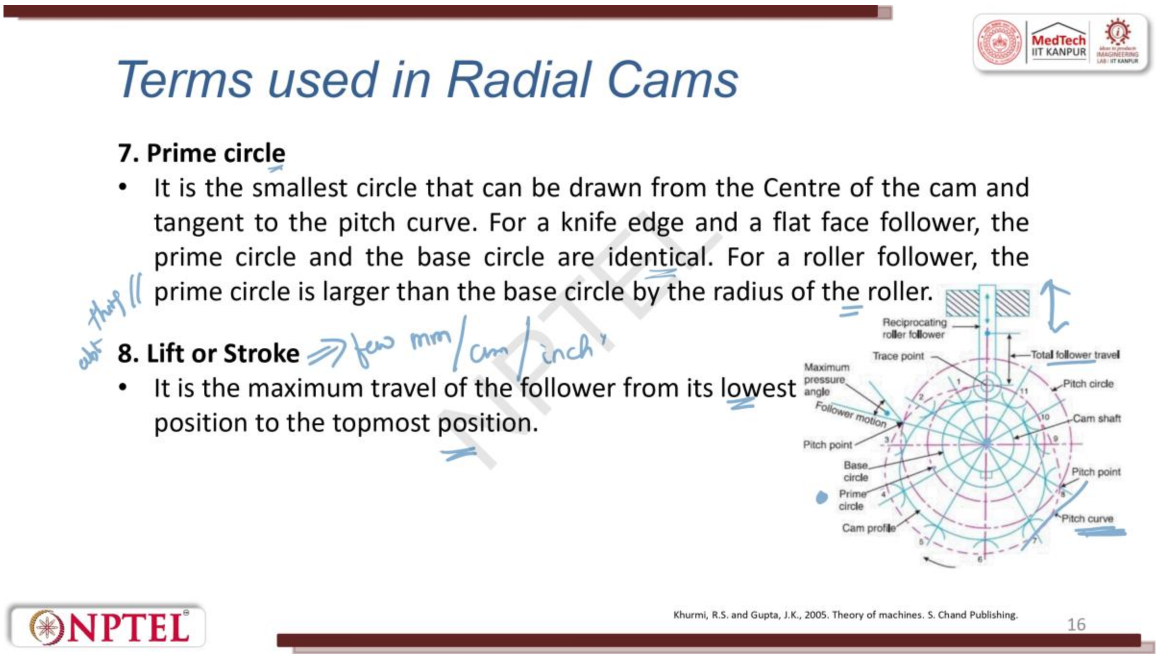


Next, Pitchpoint. It is a point on the pitch curve having the maximum pressure angle is called as the Pitchpoint. Pitchcircle, it is a circle drawn from the center of the cam through the pitchpoint.

So, center of the cam to the pitchpoint, it is called as a Pitchcircle. Then, it is most important thing is the Pitchcurve. So, this is called as the Pitchcurve. See, pitchpoint is here. You can see a pitchpoint here.

So, pitchcurve. It is the curve generated by the trace points. Trace points are the dotted lines. Trace points as the follower moves relative to the cam. For a knife edge follower, the pitch curve and the cam profile are the same.

Whereas in roller, they are separated by the radius of the roller. So, you can see a cam profile, you can see base circle, pitch curve, pitch point.

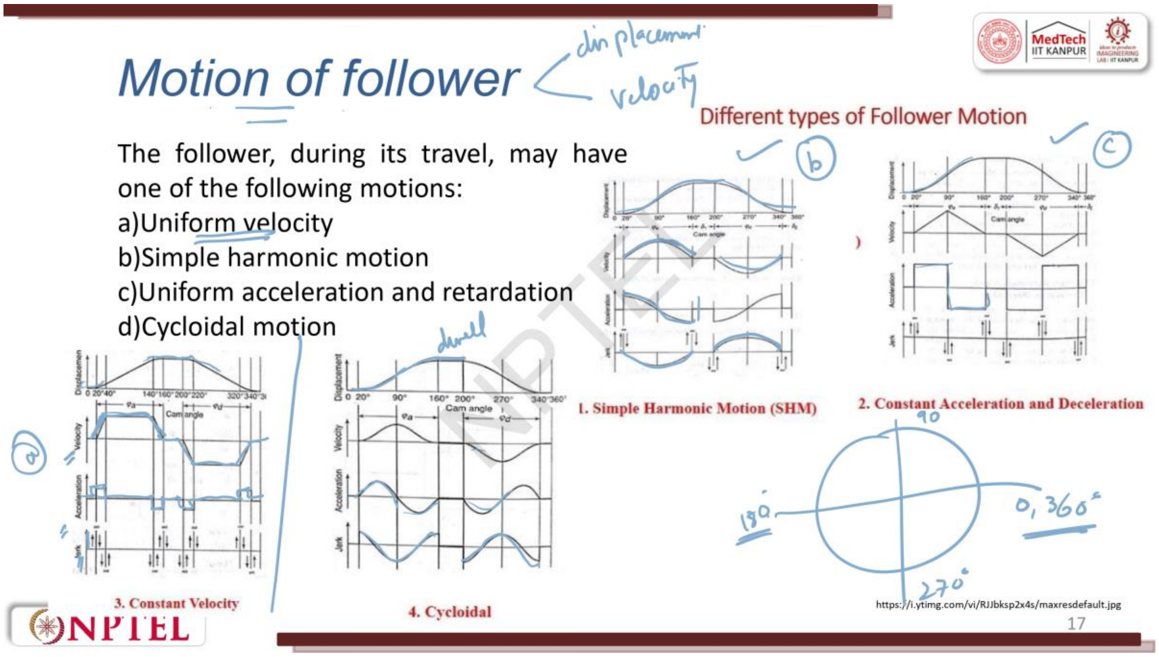


What is a Prime circle? Prime circle is here. This is called as a Prime circle. It is the smallest circle that can be drawn from the center of the cam and tangent to the pitchcurve. Where is your pitchcurve? This is your pitchcurve. A tangent. It is the smallest circle that can be drawn from the center of the cam and the tangent of the pitchcurve.

For a knife edge and a flat face follower, the prime 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. So, please think about this point. Then stroke, this is called as the Stroke. Stroke is the maximum moving up and down.

Lift or a stroke, it is the maximum travel of the follower from the lowest portion to the highest portion. Lowest portion to the highest portion. When this fellow rotates, it will rotate like this. So the lift will be minimum to maximum. So this is called as the Lift.

Sometimes it will be in few millimeters slash centimeters in a heavy engine. Like where we are using in mining and machinery or other heavy industries, we can use it in inches to the Lift of a Stroke.



So the Motion of the Follower. So in the follower there are two things. One is displacement. The other thing is the velocity of the motion. So these two things are very important in cam and follower. The follower during its travel may have one of the following motions, it can have one of the following motions and today, of course, if they are making lot of complex mechanisms where in which you can have half in uniform (half in simple harmonic) they can also have combinations, right. So the motion of a follower can fall in any one of these type. It can have uniform velocity.

You can have simple harmonic motion. You can have uniform acceleration and deceleration. Then it can have a cycloidal motion. When we say uniform velocity, it is constant velocity. So, you can have, this is the displacement and we are trying to talk with respect to, this is maybe 0, 90, 180, 270 degrees, when a cam rotates, then again it comes to 360 degrees.

When a cam rotates one rotation, it can go like this. So, when we talk about it in the x, you can see, they will talk about degrees. For example, 0, 20, 40, 140, 160, 200, 240. So, here you can see 0 to 20, there is no displacement. And after that from 20 to 40 there is a rise and then from 40 to 140 there is a uniform rise.

Afterwards there is a dwell where there is no rise in the lift and then onwards it falls down. So if we try to, this is a displacement. When I try to take the displacement divided with respect to time, I get the velocity. You can see a lean uniform velocity. This is what they are saying.

Uniform velocity and then the velocity is the same. Then when it hits the dwell, it falls down and then when it goes down. So the rotation happens, right. So it is first half is up to 180 and then 180 to 360 it falls down. So, this is displacement and here you can have velocity.

The rate of change of velocity leads to acceleration. You can see here it is a step function. So, it goes like this, this, then it follows this, then this way, then it goes like this, then acceleration. So you can see here what is the jerk. It can go up, down, up.

So all these things are given. So when we are trying to have uniform velocity, we are trying to talk about a cam which can have this profile. When we are trying to have a simple harmonic motion, we are trying to talk about this type. So, you can see here same way, this is the displacement you have, right. And this is where you have the velocity, right.

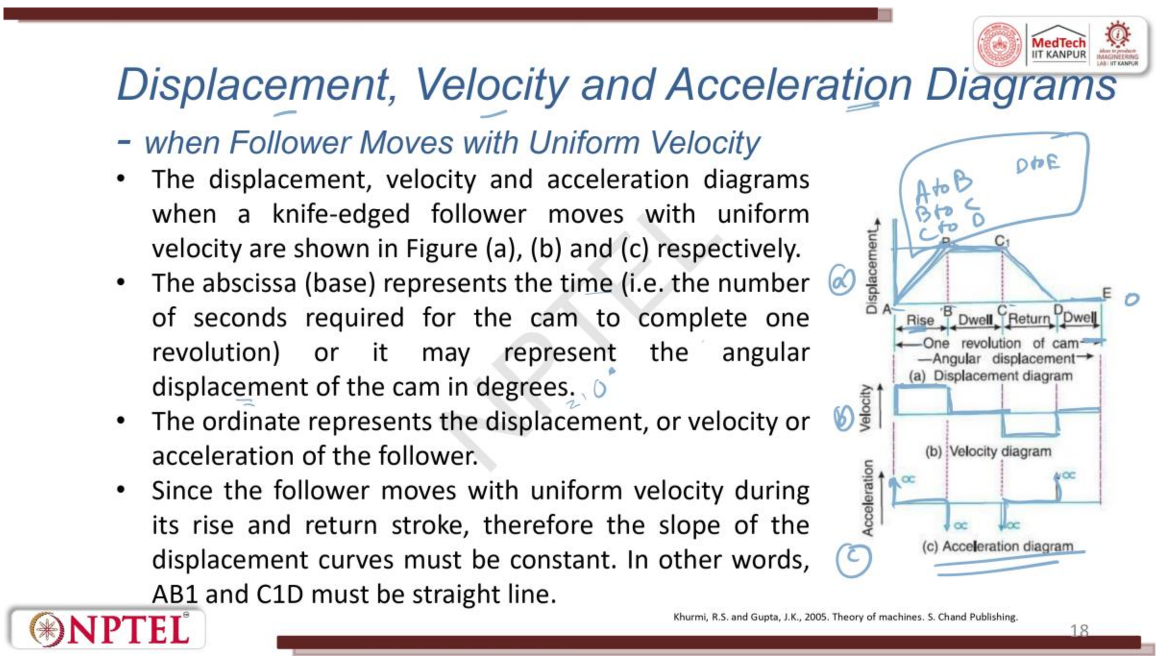
It goes in a sinusoidal wave, positive side, negative side. When I try to take the acceleration of this, it becomes like this and the jerk motion will happen something like this. Up, down, up, down. So, when we try to have uniform acceleration and deceleration, this is what is the third one, this is the c type, this is b, this is a. So, here you see uniform acceleration. So, here acceleration was something like a step function.

So, we wanted to have a uniform acceleration and deceleration. So, the cam profile displacement will be here; you can see this and then you will have velocity. Then for that you can have uniform acceleration in positive and negative and you can see the jerk motion. Why is it important? Because you know what is the ultimate application you want.

Based upon the ultimate application, you will have to choose whether I wanted to have a uniform velocity, whether I wanted to have a uniform acceleration, whether I wanted to have a sinusoidal motion. So sinusoidal motion means in 0 to 180 you can say open and 180 to 360 you can say close. Or 0 to 180 you can have partial opening or primary opening and 180 to 360, you can try to have something like a precise opening and closing, whatever it is that is left to it. The last motion is called as Cycloidal motion. Cycloidal motion you can also try to have a displacement curve like this.

There is a displacement which increases from 20 to 90 then there is a slow increase to 180 or 160 then 160 to 200, there is a flat plateau. So this is called as a Dwell cycle and then you can have a fall down or a displacement which is coming in the negative direction. When we try to plot it you can try to see it is like a Gaussian distribution happening. So, here it was not a Gaussian distribution, it was up and then down, right. So, and then if you try to see the acceleration, it is a sinusoidal motion.

And then the jerk, if you see, it happens like this. You can choose any one of this motion, then choose a cam, then choose a follower to meet or to the requirements.



So, Displacement, Velocity and Acceleration Diagram; so the y axis is the displacement and x axis is that we talk from 0 to 360 degrees. So here you can see here it is divided into 4 segments, the entire so A to B, B to C, C to D. And all these things A to B, B to C, C to D and then it can also be D to E. It all represents when you try to sum it up it represents one revolution of a cam.

So now the displacement is divided into four parts. One is called as the rise of the displacement. Then we call it as a dwell of the displacement, then we call as a return of the displacement, then we call a dwell of the displacement. So, here D to E is a dwell where the displacement is 0 and where B to C again, we call it as a dwell where that is a maximum. So, between these two, we have a rise and then we have a fall because when you rotate, it has to be divided 0, 90, 180, 270, 360.

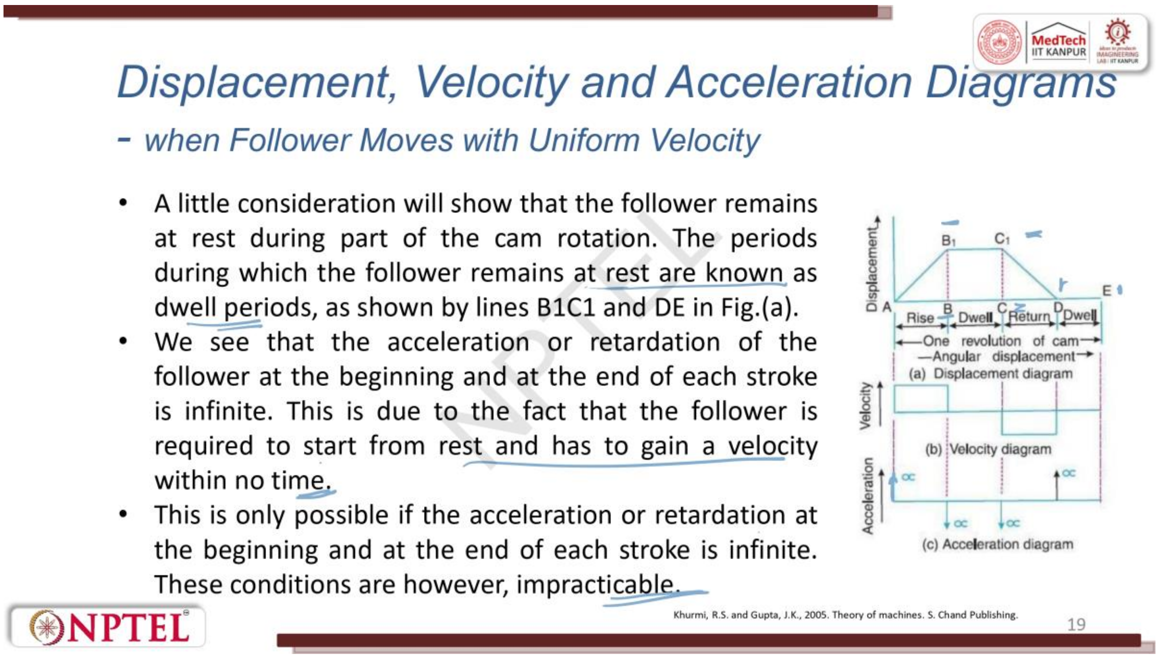
So, that is what it is given here. So, the corresponding of this displacement, what is the velocity response? You can see here the slope increases. When you differentiate with respect to time, it becomes a straight line. Then as and when it reaches B, there is no change in slope.

So, it becomes a dwell almost like a dwell flat. Then it decreases in the negative direction. So, it comes falls in the negative direction. Then it comes back. Then there is a dwell.

So, when you differentiate dx by dt, then what you get is acceleration. So, the acceleration will happen here. Then it is 0. Then it will happen here. Then it will happen 0, then it will happen here, then it will happen 0.

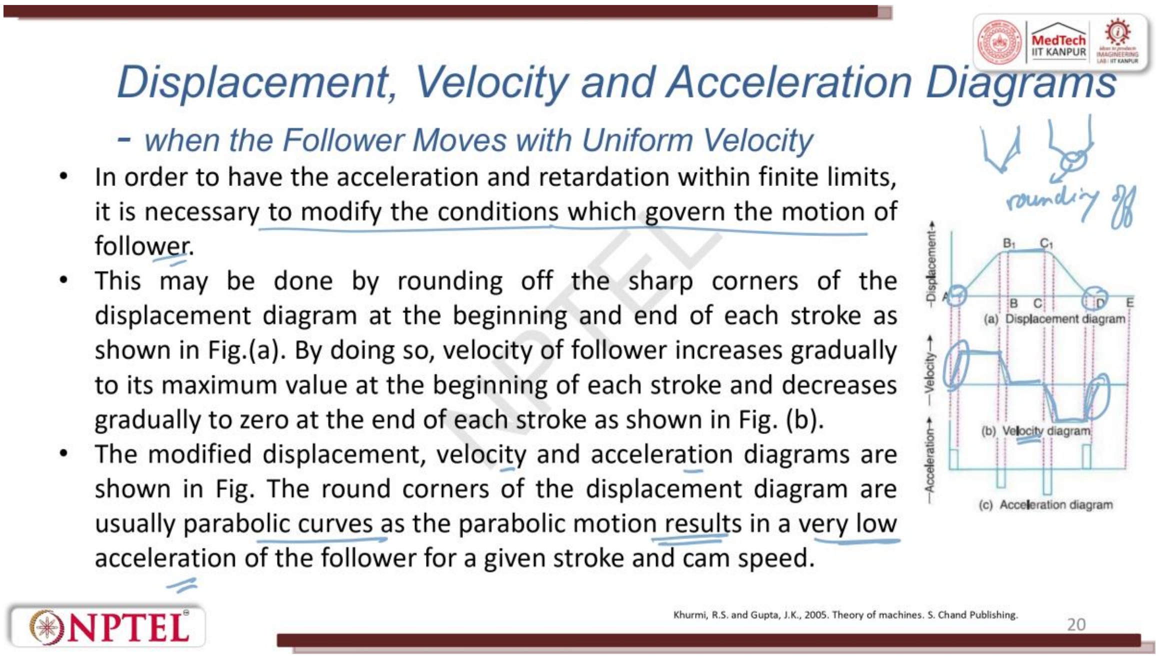
So, it is almost like a point you can have. This is the acceleration diagram. So, it will be like a straight line like this, then like this, then this it will happen. So, when follower moves with uniform velocity, the displacement, velocity and acceleration diagram when a knife edge follower moves with uniform velocity are shown in A, B and C. The abscissa base represents the time.

So, time rpm, (rpm to time). So, represents the time either the number of seconds required for a RAM to complete one revolution or it may be represented in a angular displacement of a cam in degrees. Generally, we do it with cam in degrees. The ordinates represents the displacement in the y-axis, velocity or acceleration. Since the follower moves with a uniform velocity during its rise and during its return, the slope of the displacement curve must be constant. In other words, A1, B, AB1 and C1D must be straight lines.



A little consideration while showing the follower remains at rest during part of cam rotation, the period during which the follower remains at rest are known as dwell period or at a highest peak. So, it is shown in B to B1, C1 to C1 and again D to E. We see that the acceleration or retardation of the follower at the beginning and at the end of each stroke is infinite. This is due to the fact that the follower is required to start from rest and has to gain velocity within no time. Instantly it has to do.

It is only possible if the acceleration or retardation at the beginning and at the end of the stroke is infinite. These conditions are however impractical. So it goes instant up and instant down is not possible. So that is what we are trying to say.



In order to have the acceleration retardation with a finite limit it is necessary to modify the condition you see here modify the condition which governs the motion of the equation.

So what do we do is we do not start at a instantaneously we give something called as a small dwell. So during the small devil, you see the velocity increases and then it tries to A to B then the velocity is uniform, it becomes a straight line then B to B1 again, there is a deceleration, then you continue to be in the flat, then again it is coming down. So you have a deceleration negative side flat then increase. So, this is called as a velocity diagram. I said like a nib of a pen.

You can have something like this, but it is always advisable to have a small. This is called as a rounding off. This may be done by rounding off the sharp corner of the displacement diagram at the beginning and the end of the stroke as shown in figure A. By doing so, the velocity of the follower increases gradually to the maximum value at the beginning of each stroke and also decreases gradually at the end of the stroke. The modified Displacement, Velocity and Acceleration diagram are shown in the figure.

The rounded corner of the displacement diagram are usually parabolic curves or a parabolic motion results in a very low acceleration of the follower for a given stroke of a camp speed.

Displacement, Velocity and Acceleration Diagrams

- when Follower Moves with Simple Harmonic Motion

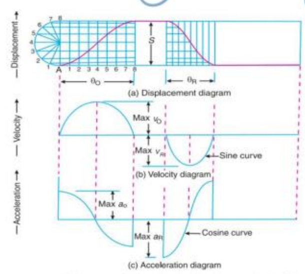
The displacement, velocity and acceleration diagrams when the follower moves with simple harmonic motion are shown in Fig. (*a*), (*b*) and (*c*) respectively. The displacement diagram is drawn as follows :

1. Draw a semi-circle on the follower stroke as diameter.

2. Divide the semi-circle into any number of even equal parts (say eight).

3. Divide angular displacements of cam during out stroke and return stroke into the same number of equal parts.

4. The displacement diagram is obtained by projecting the points as shown in Fig.(*a*).



Displacement, velocity and acceleration diagrams when the follower moves with simple harmonic motion.

Khurmi, R.S. and Gupta, J.K., 2005. Theory of machines. S. Chand Publishing.

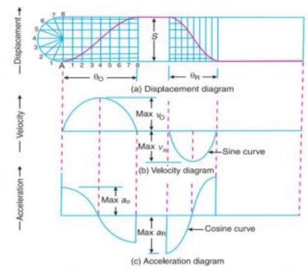
So, the displacement, velocity and acceleration diagrams when the follower moves with a simple harmonic motion is shown in figure A, B and C. So, this is figure A, figure B and figure C. So, here draw a semicircle on the follower stroke. As diameter, so this is what they are saying, right. Divide a semicircle into any number of equal parts, say 8, so this they are dividing into 8.

Divide the angular displacement of the cam during out stroke and return stroke in the same number of equal parts. So, you can see they are dividing in the same number of equal parts. The displacement diagram is obtained by projecting these points as shown in A. Circle, 8 parts, then you try to draw straight lines, then you try to have this angle, this is also into 8 parts, so then they try to meet. So, wherever they meet, then you try to join them to get the displacement diagram.

Displacement, Velocity and Acceleration Diagrams

- when Follower Moves with Simple Harmonic Motion

- The velocity and acceleration diagrams are shown in Fig. (*b*) and (*c*) respectively. Since the follower moves with a simple harmonic motion, therefore velocity diagram consists of a sine curve and the acceleration diagram is a cosine curve.
- We see from Fig. (*b*) that the velocity of the follower is zero at the beginning and at the end of its stroke and increases gradually to a maximum at mid-stroke.
- On the other hand, the acceleration of the follower is maximum at the beginning and at the ends of the stroke and diminishes to zero at mid-stroke.



Displacement, velocity and acceleration diagrams when the followe moves with simple harmonic motion.

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The velocity and the acceleration diagram are shown in B and C. Since the follower moves with a simple harmonic motion, therefore the velocity diagram consists of a sine curve and the acceleration will always try to have a cosine curve. So this is a sine curve and this is a cosine curve. So we see that from B, the velocity of the follower is 0 at the beginning and at the end of the stroke and increases gradually to maximum and minimum. On the other hand, the acceleration of the follower is maximum at the beginning and the end of the stroke and demises to 0 in the middle of the stroke.

So, you can see here, middle of the stroke it goes to 0. Now, you have seen what is the displacement velocity acceleration diagram for a uniform velocity and for a sinusoidal velocity, right, for a simple harmonic motion. Two we have seen. In the similar way, you can try to draw a cycloidal one and you can also try to have uniform acceleration one.

So, now let us try to write down little bit of math behind it. When the follower moves with simple harmonic motion, let us take S as the stroke of the follower. The angular displacement of the cam during out stroke and return stroke of the follower are represented as theta O and theta R where omega is the angular velocity of the camp which is defined in radians per second. Then time required for the outstroke of the follower in seconds t is equal to theta divided by omega. So, you get this t naught. Consider a point P moves at a uniform speed.

Omega P radians per second around the circumference of a circle with the stroke S as the diameter as shown in the figure. Stroke is S. So, now P is a point. Omega is the angular velocity shown in the figure. The point P dash executes a simple harmonic motion as the point P rotates. So, the peripheral speed of the point P dash is nothing but vp is equal to pi by 2 into S by 1 by T naught.

So, it is velocity vp is pi by 2 into stroke divided by time. So, this can be vp can be represented as pi s by 2 into omega into theta 0. Maximum velocity of the follower at the outward stroke is going to be v equal to vp, which will be represented as omega pi s to theta 0. So, the acceleration, the maximum acceleration of the follower on the outstroke will be a, which will be represented by this and a equal to a naught, we will be represented by this way. Similarly, maximum velocity of the follower on the return stroke and the maximum acceleration of the follower on the return stroke are given by this.

So, VR and aR. Okay, in this slide, we saw how do we calculate vp, how do we calculate v naught. Here, we will try to see how do we calculate a naught and then how do we calculate ap. So, it is acceleration that is velocity. So, here we are trying to do for a simple harmonic motion. So, we can also see how do we try to do the design for a follower which moves in uniform acceleration and deceleration. So, the displacement velocity and acceleration diagram is shown here.

So, we try to have this is what is a displacement which happens, then we will try to have a b c d e which is cut into pieces, then we will have these lines which meet them. So, we try to get the a b1, c2, d3 something like that. So, here it is the angular displacement we have. So, which is from here mid of this to mid of this. So, when we try to differentiate, we try to get the velocity profile like a hill.

So, a dwell then a hill. So, this is maximum a vo vp then acceleration vo vp, right. So, the displacement velocity acceleration diagram when the follower moves with the uniform acceleration and deceleration is shown here in figure a b and c. We see that the displacement diagram consists of a parabolic curve which may be drawn by the following. Divide the angular displacement of the camp during the outward stroke into any equal number of parts and draw vertical lines through these points as shown in the figure A. So you draw A, B, C, D here, right?

So you draw it. Divide the stroke of the follower S into same number of equal parts. So, you are dividing into equal parts. Then join Aa to intersect the vertical line, join Aa which will try to intersect the vertical line. So, you see here ABCD is given, right.

So, be Aa to intersect the vertical line through a point 1. So, you see a point 1 is here, point 1, A is here, this is A. So, obtain the point 1 at B. Similarly, you do for other points C, D, E, F, whatever it is and now join these points to obtain a parabolic curve. This is a parabolic curve you get. Since in a simple way as discussed above, the displacement diagram of the follower during return stroke may be drawn.

So this is forward, this is return. Since acceleration and retardation are uniform, therefore the velocity varies directly with respect to time. The velocity diagram is shown in B. So the stroke length s, so theta o and theta r are the angular displacement of the curve during the outstroke and the return stroke. Omega is the angular displacement, time is equal to theta by omega.

So the return stroke it is taken as theta r, tr is the return stroke time. Theta r by omega. So, the mean velocity of the follower is s by t naught and the mean velocity of the follower is going to be s by tr. So, this is for outward stroke and this is for a return stroke. So, since the maximum velocity of the follower is equal to twice the mean velocity, therefore, the maximum velocity of the follower of the out stroke is going to be 25 by T, so 2 omega times. This is for the maximum velocity of out stroke, return stroke will be this.

So, we see that the acceleration diagram as shown in figure C, that during the first half of the outward stroke, there is a uniform acceleration and during the second half, you can see uniform acceleration and uniform deceleration. Second half of the outstroke, there is a uniform retardation. Thus, the maximum velocity of the follower is reached after the time called t0 by 2. So, the maximum acceleration of the follower by substituting all is represented as a naught during the outward circle, outward stroke is going to be 4 times omega square S divided by theta out square. So, the maximum acceleration of the follower is going to be this ar.

So, when we try to do a follower with a cycloidal motion, so you will try to have displacement, then velocity, acceleration, there is a roller or a diagram, a small circle, which we will try to divide it into 8 parts and draw straight lines. The displacement velocity acceleration diagram, when the follower moves with a cycloidal motion, A follower is moving in a cycloidal motion is shown in A, B and C respectively. We know the cycloid is a curved traced by a point on a circle. A curve traced by a point on a circle.

So this is a circle, this is a point on a curve. Point on a circle when the circle rolls without slipping on a straight line. So, the displacement of the follower after time t seconds is x is equal to s is represented by theta by theta and theta o minus 2 pi sine. 2 pi theta by theta naught. Now, velocity of the follower after a time of t seconds, we differentiate it with this.

So, this can be represented by this way. And then, we try to differentiate equation 1, we try to get it. Then, we try to differentiate the equation 2, we try to get the acceleration. So, the maximum, the velocity is maximum when theta, cos theta is equal to minus 1 or theta equal to theta pi is equal to this or when theta equal to theta not by 2. Substituting theta not into 2, we try to get the velocity.

So, the maximum velocity for the return stroke is going to be this. So, the acceleration when we try to take this, we try to differentiate, we try to get the same acceleration for the out and acceleration for the in. So if you draw the profile for velocity, you can see since it is cycloidal, it will have its maximum and then it will try to fall into this peak. So this is called as a maximum velocity. So this is done in theta naught by 2.

So if we try to differentiate it, so here it comes like a sinusoidal pattern. So I have given three problems for you to solve like a tutorial. You can try to solve it. We will display the results during the discussion hours. So the three problems are going to be one on SHM, one on cycloidal and the other one we will see.

The first problem goes the cam lifts the follower by 120 degrees with a simple harmonic motion followed by a dwell of 30 degrees. Then the follower lowers down during 150 degrees of the cam rotation with a uniform acceleration and deceleration followed by a dwell period. If the cam rotates at a uniform speed of 150 rpm, calculate the maximum velocity and acceleration of the follower during the descent period. This is the descent period, right. The next problem is following the data related to a cam profile in which the follower moves with uniform acceleration and deceleration during the ascend and descend.

The maximum cam radius is given, the roller diameter is given, the lift is also, lift is nothing but the stroke length. The offset is also given 12 towards the right, the angle of ascend is 60 degrees, the angle of descend is 90 degrees. The angle of dwell for both ascend and descend is given 45. The speed of the cam is also given. So what are they asking?

Draw the profile of the cam. Determine the maximum velocity and the uniform acceleration of the follower during the outstroke and return stroke. So this is how the profile will come. You can try to solve this problem. However, in the examination, we will not give you such a big problem.

We will try to give you a piecemeal. So small sections of this problem can be asked. The third problem is the flat face mushroom follower is operated by a uniform rotating cam. The follower is raised through a distance, stroke is given, 120 degrees is given and the rest is also given. So after the rest it rotates 120 degrees.

The raising of the follower takes place with a cycloidal motion. And the lowering of the uniform acceleration and deceleration happens. However, the uniform acceleration is two-third of the uniform deceleration. The least radius of the cam is given. And finally, what we ask is draw the cram profile and determine the values of maximum velocity and maximum acceleration. during the rise and the maximum velocity and uniform acceleration and deceleration during the lowering of the follower.

So, we are trying to ask in this portion and in this portion. Friends, such big problems will not be asked. We will try to segment one portion and solve it. Why I am giving you the complete problem is so that you can understand how will it happen in real time. So, to recap, we saw what is a primary function of a cam.

Different types of cams and followers. What are the different types of cam and follower used in mechanical application? The importance of displacement, velocity, acceleration diagram. Then we derived the displacement equation for uniform motion cam and explained how to use it to calculate velocity and acceleration. Finally, we saw the importance of pressure angle.

In this lecture, we have used the following reference material. I hope this lecture would have been useful to you. Thank you. Bye.