Mechanism and Robot Kinematics

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Lecture – 02
Nomenclature

In the course of our discussions on Kinematics of Robots and other mechanisms; we will come across a number of terms, which are very specific to the subject. So, in this lecture I am going to go through these terms, make certain definitions and classifications.

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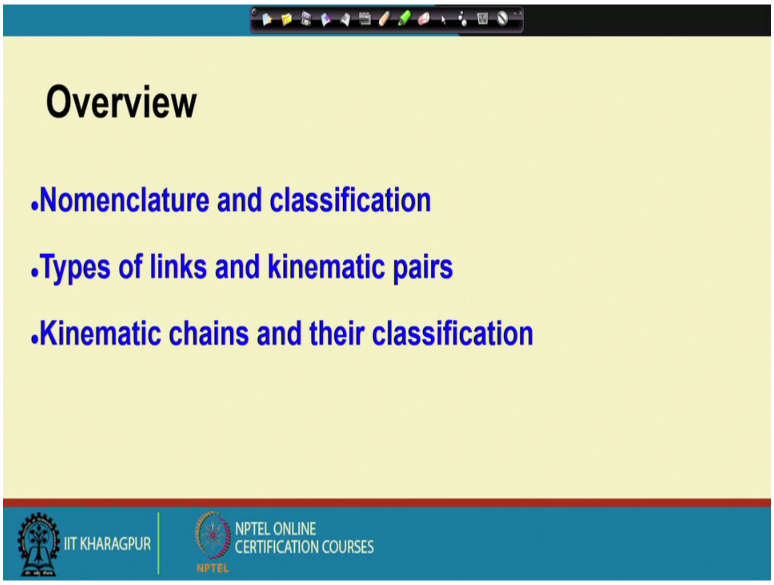

So, to begin with let me give you an overview of what we are going to discuss today. So, we have these nomenclature and classification, which I am going to discuss first. Then types of links and kinematic pairs, which I am going to define very soon, we are going to also look into what are known as kinematic chains and their classifications.

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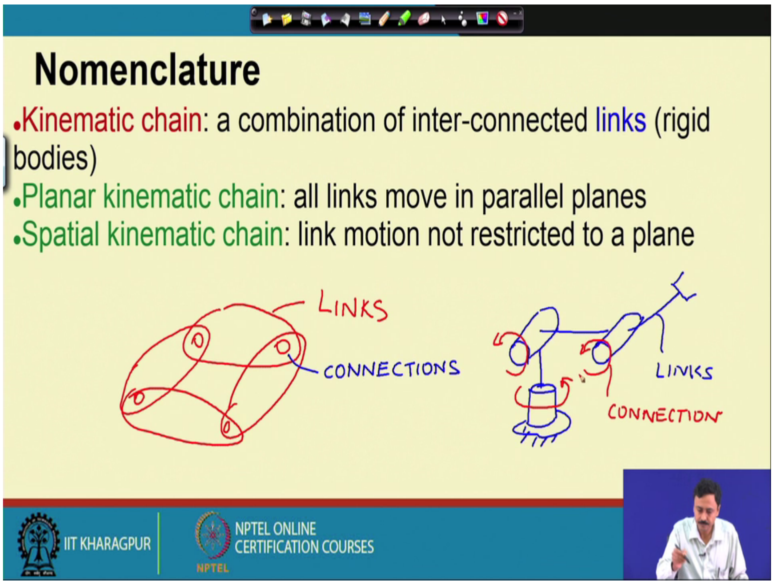

So, let us begin with nomenclature that we will come across. So, kinematic chain is a combination of interconnected links; these links are the rigid bodies which make up the mechanism of the robot. So, a combination of interconnected links is called a kinematic chain. Now there are can be two kinds of kinematic chains; planar kinematic chains, where all links move in parallel planes.

Or we can have special kinematic chain, where the link motion is not restricted to a plane. Just to give you an example; if you have a kinematic chain of this type, where these are connections between the links, so these are the links and these are the connections; so this can be a kinematic chain where links are connected by these connections.

Now, if the links move in the plane of the paper then it is called a planar kinematic chain or links move in parallel planes. Or you can have special kinematic chains, where links are not restricted to move in a plane. So for example, if you have; so in this figure these are the links and these are the connections. So, here these connections allow rotation; so, links need not move in a plane.

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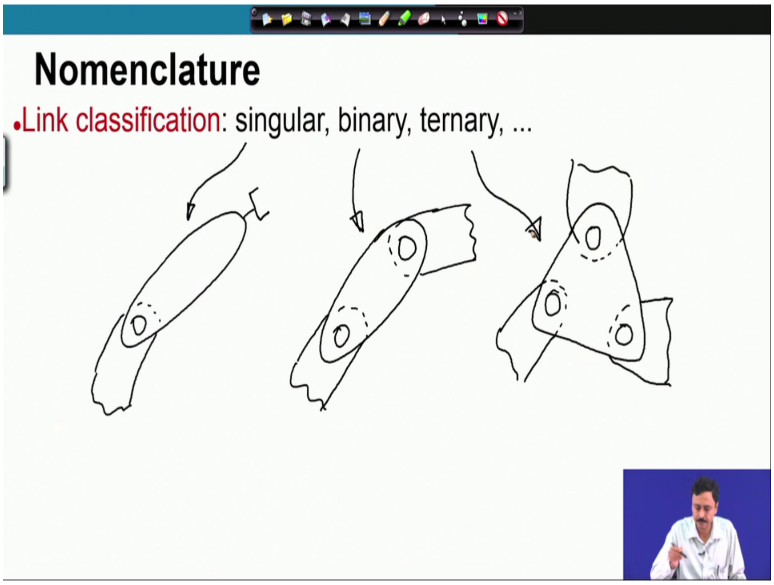

Now, we classify links into singular, binary, ternary; so, let us see what are these. So, a singular link is one where there is only one connection. So, there is only one connection; so possibly it is connected to something else; so there is only one connection. Typically open chain robots have singular links, so there will be something like an end effector here; some gripper, so this is a singular link.

A binary link by extension is a link with two connections; this is a binary link. So, there are two connection points and hence by extension; we can have ternary links, quaternary links etcetera, so this is a ternary link where there are three connections and so, on.

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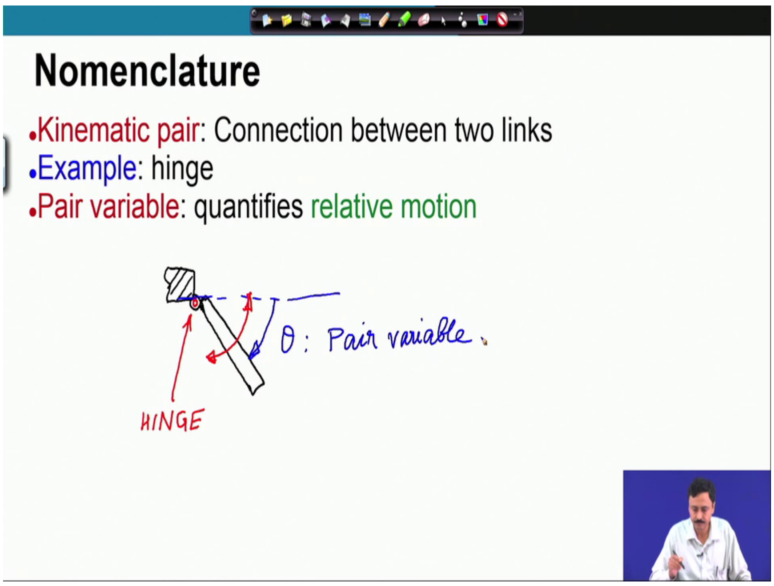

A kinematic pair is the connection between two links, so whenever you connect two links; see you can you can have two links and the connection can be a weld. Suppose you just weld two links, then it becomes an extension of a single link; it becomes an extension. So, it is not a very useful thing, so if you just weld two links; then it becomes one rigid body, it becomes one link; so it is not something very useful. But if you have a connection, which allows; some relative motion between the two links, then it is called a kinematic pair.

So, the connection between two links which allows some relative motion is a kinematic pair. For example, this hinge; so a door hinge for example, it allows the rotation. So, suppose this is the door frame and this is the door, so here I have the hinge. This hinge allows the door link to rotate, so this is the degree of freedom which the hinge allows, it just does not lock the door to the frame, it allows this relative motion between the frame and the door; hinge is an example of a kinematic pair.

So, therefore, with every kinematic pair; you have something called a pair variable which quantifies this relative motion between the links it connects. Therefore, in this particular example that I have shown you; what is the pair variable? Pair variable is the angle; let us say this angle that this hinge allows or this the angle by which the door has rotated. So, this rotation is quantified by this angle theta. So, I exactly know how much the door has rotated if you specify theta, so this theta is the pair variable.

So, theta is known as the pair variable, so a normal hinge has one pair variable because it allows only one rotation; about the axis of the hinge.

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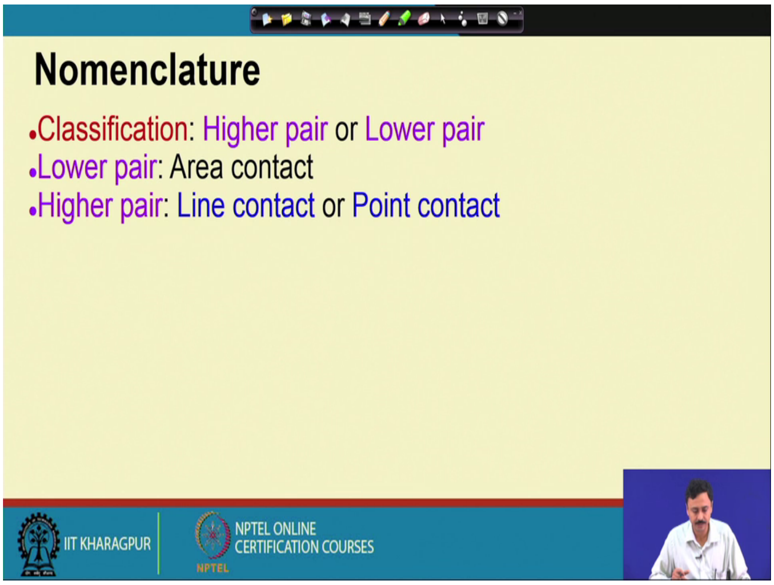

Now, we classify kinematic pairs as higher pair or lower pair. So, let us begin with the lower pair first; a lower kinematic pair is one in which we have area contact, I will very soon come to what this means. On the other hand, a higher pair has line contact or point contact; so whenever two bodies are connected by a kinematic pair. This kinematic pair can enforce certain restrictions in the relative motion of the two bodies by certain contacts.

Now if this contact is an area contact, then it is a lower pair; if it is a point contact or a line contact then it is called a higher pair.

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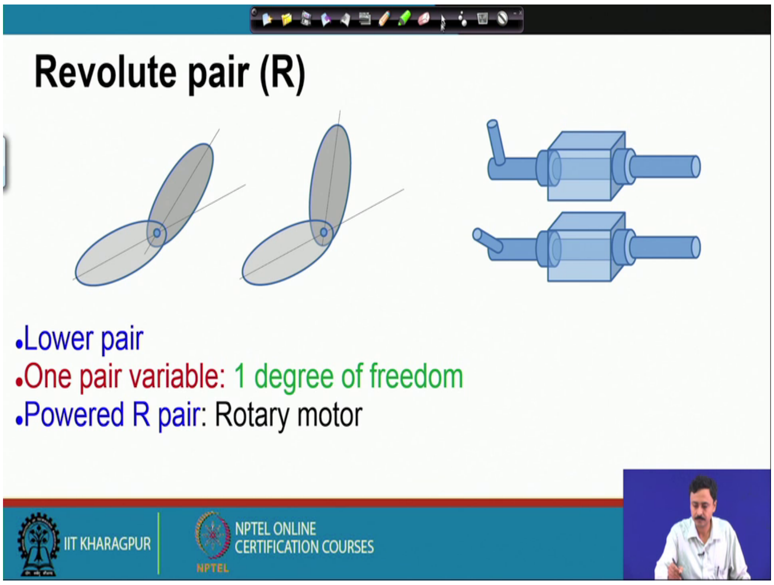

Let us look at the types of kinematic pairs we come across very often. So, to begin with this is a simplest thing that we have just now discussed; this is called a revolute pair, what we normally call the hinge. Hinge in the technical parlance is known as the revolute pair; so in this kinematic pair, our pair variable is this angle; we call it theta, so this angle as you can see changes.

So, a hinge allows change of this relative angle between the two links. This figure shows on the right; the figure shows a three dimensional visualization of a revolute pair. So, here as you can see; this kinematic pair allows, this relative motion between the cylinder and the block. So, is a rotational motion; relative rotational motion, so this is the revolute pair or R pair. In this, you can very easily see that you have area contact here.

So, the restriction that the block produce provides on the motion of the cylinder is through area contact. So, there is area contact between the cylinder and the block therefore, we categorize or classify this revolute pair as a lower pair. There is one pair variable, so we say a revolute pair has 1 degree of freedom. Because, by specifying this theta; you can exactly specify the relative configuration of the two links.

If you specify theta, the two links will get fixed; so that there will not be any ambiguity. A powered R pair is a rotary motor, so when you have a rotary motor connected to one of the links and the shaft is connected to the other link. So, that forms a revolute pair and it is a powered revolute pair; so, a rotary motor is a powered revolute pair.

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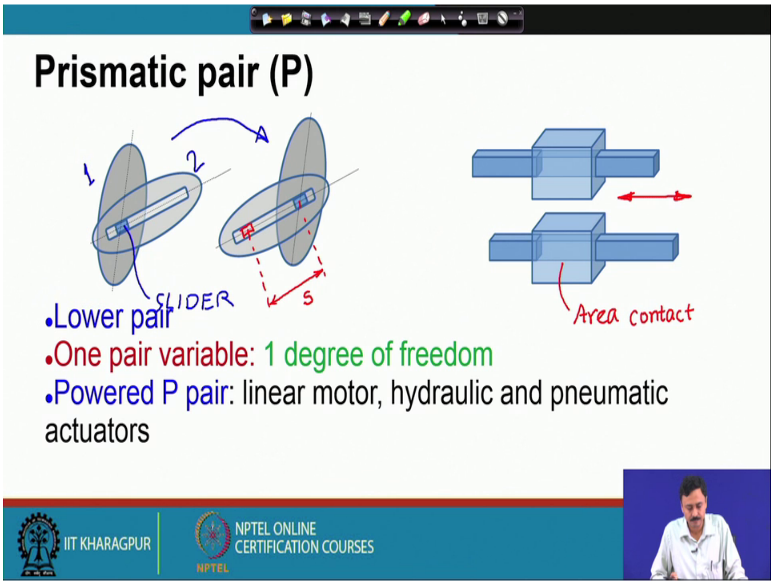

Next, we come to this prismatic pair or P pair; so, what is the motion allowed by the P pair? As you can see, there is a slider; so here we have a; the slider is connected to body 1 and body 2 has a slot. This slider as you can see is of a rectangular shape therefore, this slider cannot rotate inside the slot, it can only slide and that is what I have shown in the next figure.

So, the body 1 or link 1 is sliding inside the slot without rotating. So, if you specify where the slider is from certain; datum position, if you specify this distance; the sliding distance, then the location of the slider related to the datum position is completely specified.

So, in a prismatic pair as well; you have a pair variable which is S; then there is only one pair variable. This is a three dimensional visualization of the prismatic pair; as you can see the slider can only slide without rotation; so there cannot be any rotation. Here also there is area contact; therefore, a prismatic pair is a lower pair; it has got one pair variable S, so this allows 1 degree of freedom between the two links.

A powered P pair is a linear motor or a hydraulic or pneumatic actuator, they are classified as powered P pairs. So, normally in a linear motor; it produces only the extension of the motor or a hydraulic or pneumatic actuator as you know, it produces only extension of the actuator; there is no rotation.

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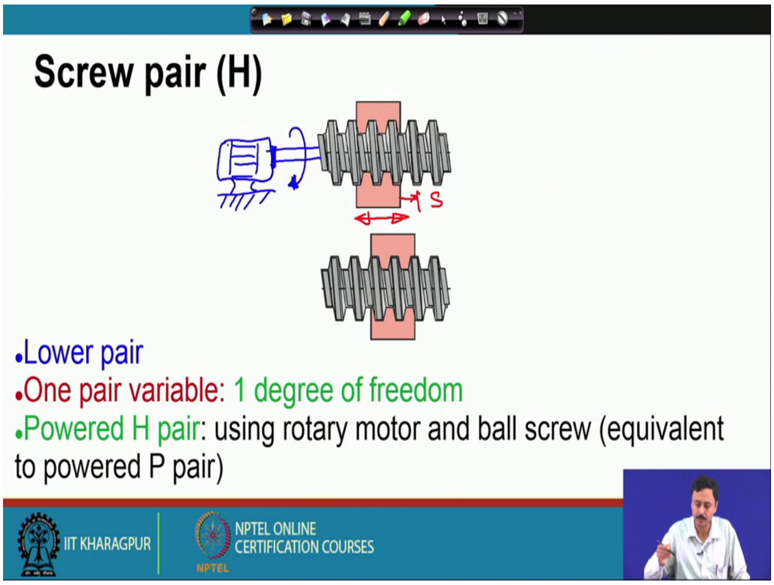

Next is the screw pair or H pair as you can see here, here is a figure of a screw; which is usually powered by a motor. So, if you rotate the motor the nut can translate; usually this is the arrangement that the screw is rotated by a motor and the nut can translate. So, you can realize that the translation of the nut is intimately connected to the rotation of the screw, it is very well related to the lead of the screw.

So, therefore I have only one pair variable; if I say that this sliding distance, let us say this sliding distance is the pair variable. Then corresponding to that how much should be the rotation? I can easily calculate, if I know the lead of the screw.

So, therefore this is a lower pair because as you know that within a screw and a nut; the contact is an area contact. So, this is also a lower pair; it has got one pair variable as I just now mentioned either you can take it as the sliding distance or the corresponding rotation of the screw, so it has got 1 degree of freedom. A powered H pair using rotary motor and possibly a ball screw or a square threaded screw is equivalent to a powered P pair. The only thing is the input is rotary motion and the output is translatory motion and this is very often used in machine tools.

So, you can treat a powered H pair; just like a powered P pair.

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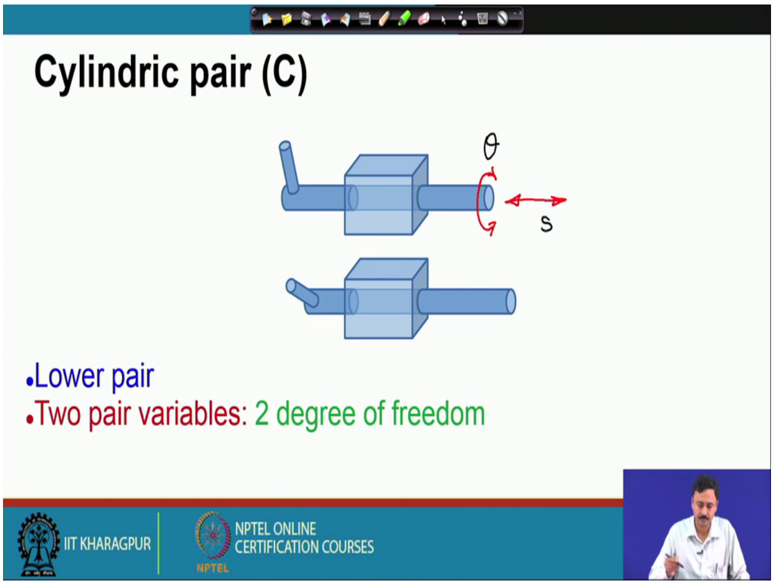

Then we come to the cylindric pair; so as you can see here, this here we have a cylinder which can rotate, as well as translate within the block. So, the cylinder here can rotate with respect to the block and it can also translate with respect to the block; this is called a cylindric pair. So, you can make a guess again it has got area contact between the block and the cylinder.

So, therefore this is a lower pair; lower kinematic pair, it allows two motions; one is the translation the other is a rotation. So, I can have the sliding and I can have the angle, so this has two pair variables. If I specify these two pair variables, then the relative motion between the block and the cylinder is perfectly fixed; it is fixed and there is no ambiguity.

So, therefore, I need to specify two things theta and S; to completely specify the cylinder inside the block. So, we say that there are two pair variables and hence we have 2 degree of freedom for a cylindric pair.

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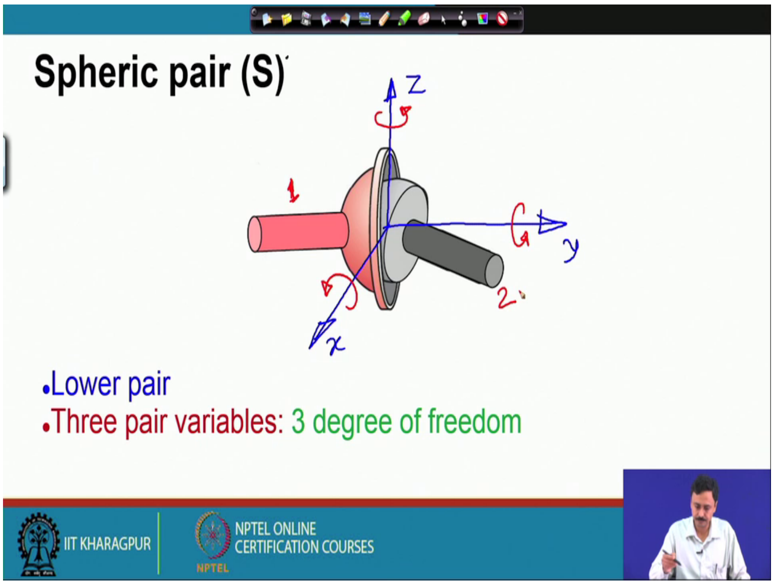

Then we come to the Spheric pair which is another very common kinematic pair. As you know that; this definitely has area contact, so this is the lower pair. It has got three pair variables; now what are these pair variables? So, these pair variables can be understood like this; I can have one axis like this, another axis like this, the third axis orthogonal to the two. So, this spheric pair can allow rotation about the X axis; it allows rotation about the Y axis, also allows rotation about the Z axis.

So, this has got three pair variables; I must specify these three angles of rotation that will fix the relative orientation of the two links. So, these are the two links, this is 1; you can remember this as 1 and this as 2. So, the relative orientation of the two links is specified once you specify these three rotations, so these are got three pair variables so this has 3 degrees of freedom.

So, the most common example of a spheric pair is the ball and socket joint we all have.

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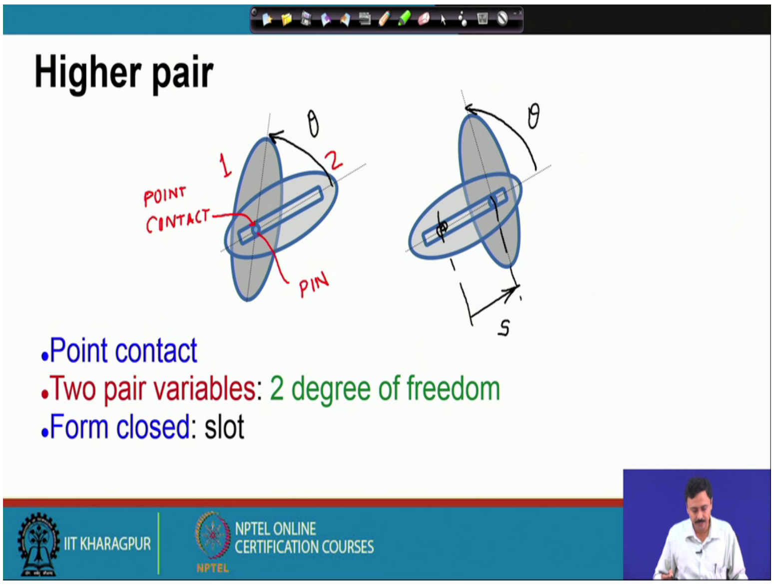

Next we come to higher pairs; so as I have mentioned higher pair is one in which we have point or line contact. So, you can very easily see; this is a pin that can move in this slot, so pin is on link 1; slot is on link 2. Now, the pin can not only slide within the slot, but can also allow rotation; the pin also allows rotation this pin is a circular pin. And the contact points are points; these are the contact points. So at the top and at the bottom; so the contact is a point contact. So, we have a point contact at the top and the bottom of the pin with the slot; this is a higher pair.

So, we have point contact; there are two pair variables. So, what are these? One is the rotation, you see the angle can change, the angle has changed. The other is the sliding; so the pin started from here, went up to this point. So, if you specify theta and S; that will completely specify the relative orient location and orientation of the two links. Therefore, we have two pair variables and hence 2 degrees of freedom.

Now one thing to note in this is that; this slot is restricting the motion of the pin in the perpendicular direction. Such kinematic pair which is closed by geometry, you see the geometry of the slot is restricting; this is called a form closed kinematic pair. So, this is a form closed higher pair; why form closed? Because it is restricted by the geometry of the slot in certain situations, such point contact can occur which are forced by some external force which might be due to a spring or gravity etcetera.

So, let us look into some more examples to clarify this point.

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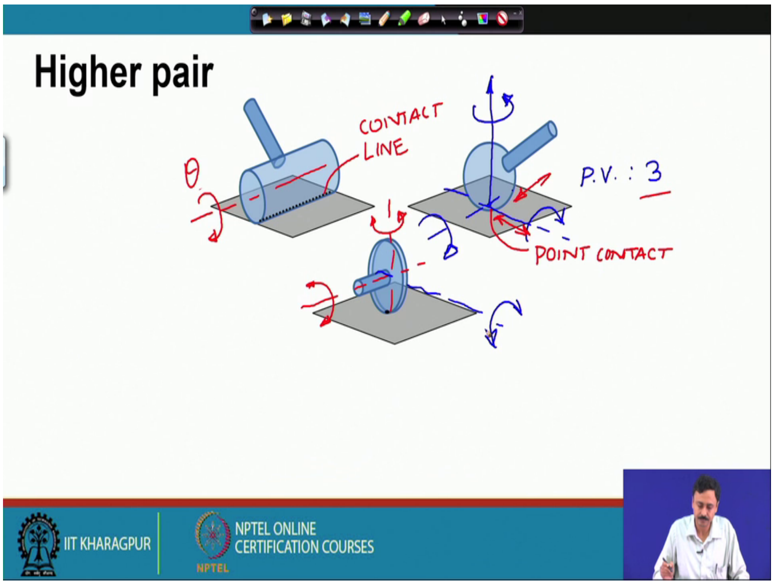

So, here I have some examples; we look at them one by one. First is a cylinder on the ground, this is the line of contact; this is a contact line and if you say that there is friction there cannot be any slip, then this cylinder can have only the rolling motion. In that case the cylinder has only one pair variable which is the rolling angle. If you have friction, then you have only theta.

Similarly, in the case of this ball on the ground; so this is a point contact. So, this is also higher pair and if you look at the pair variables; I can have rotation about this axis and I can have rolling about these two axis. So, this has three pair variables; if you do not allow sliding, if it is purely in rolling, but if you allow sliding then it can slide into two more directions, it can slide this way and this way; in which case the number of pair variables become 5.

That is if you allow sliding, but if you do not allow sliding then it has got 3 degrees of freedom. The third example is that of a wheel; so again it has got a point contact with the ground. Now, if you do not allow sliding; then this can roll in this direction and it can spin which is the steering of this wheel; in this direction.

So, in this discussion we are assuming that this wheel is something like a car wheel, but if this is a motorcycle wheel; then in addition you can have the tilting motion of the motorcycle field. In that case, the number of pair variables will increase to 3; for the car this has got two pair variables or 2 degrees of freedom. But in case of motorcycle, you have three pair variables allowing 3 degrees of freedom.

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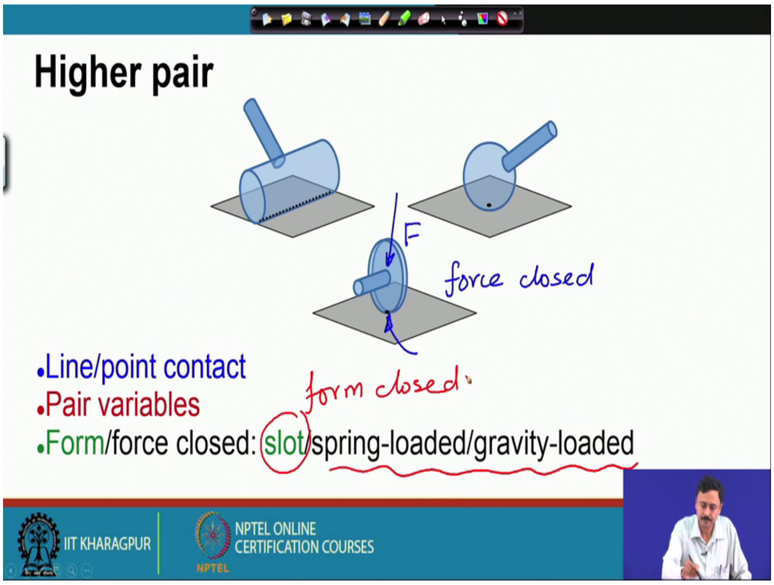

So, you have line or point contact in all these examples, I have discussed about the pair variables under various situations. In the case of car or motorcycle you know the contact is maintained; this contact is maintained by gravity; under the weight. So, here the contact is maintained by force; external force which is the weight or the gravitational force.

So, we call such a kinematic pair as force closed; so in this case it is force closed. So, here it is force closed, but had it been inside a slot, then it becomes form closed. So, force because of spring loading or gravity loading and form closed is because of the geometry of the slot.

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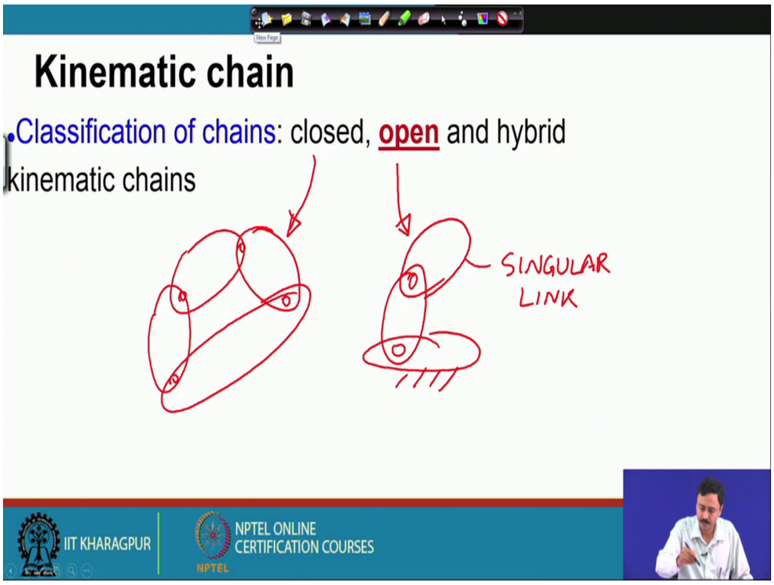

Now, we classify chains as closed open and hybrid kinematic chains. So, closed chains are those which are something like this; so as you can see, there is no singular link in a closed chain. Whereas in an open chain, you will have a singular link; so, this is an open chain; we have a singular link. A closed chain has either binary ternary, but no singular link and hybrid chain is a mixture of closed and open chains.

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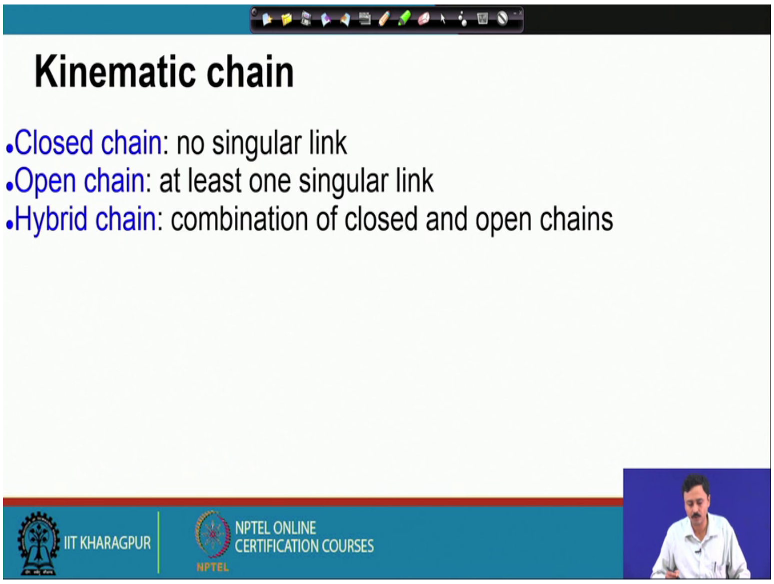

So, let us look at some examples now; so to summarize closed chain, no singular link open chain atleast one singular link and hybrid chain is a combination of closed and open chains.

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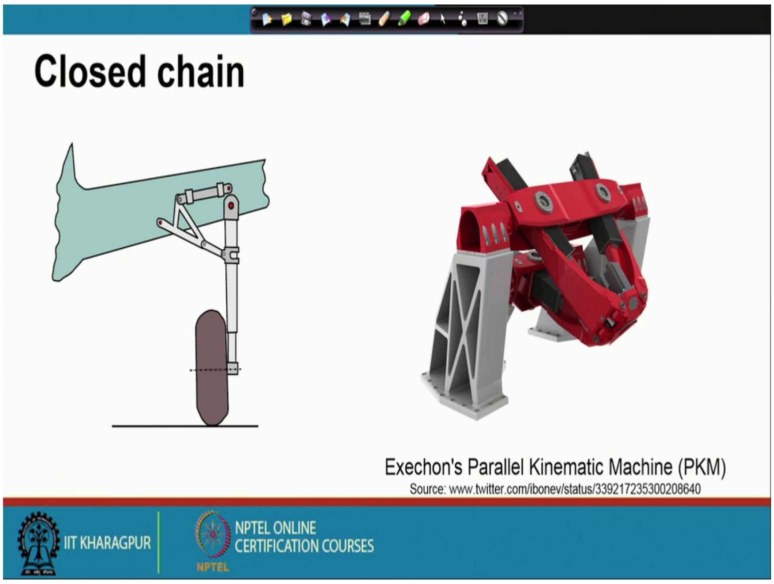

So, here is an example of the closed chain; this is the landing gear of an aircraft. So, there is no singular link, this is the Exechon's Parallel Kinematic Machine, there is no singular link; they are all closed chain.

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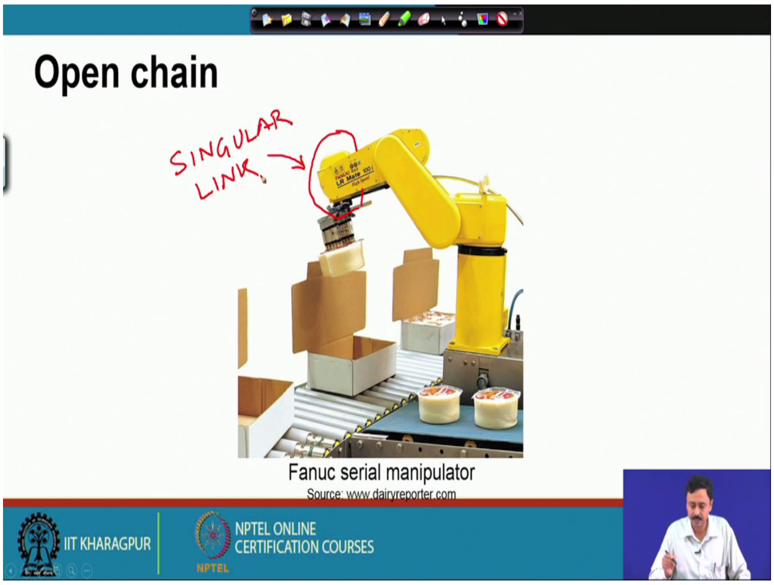

Whereas this robot; the serial manipulator from Fanuc; this has got a link which is partially visible here, it is on the other side; which is connected to the end effector and there is nothing after that. So this is a singular link, so here we have a singular link and therefore, this is an open chain.

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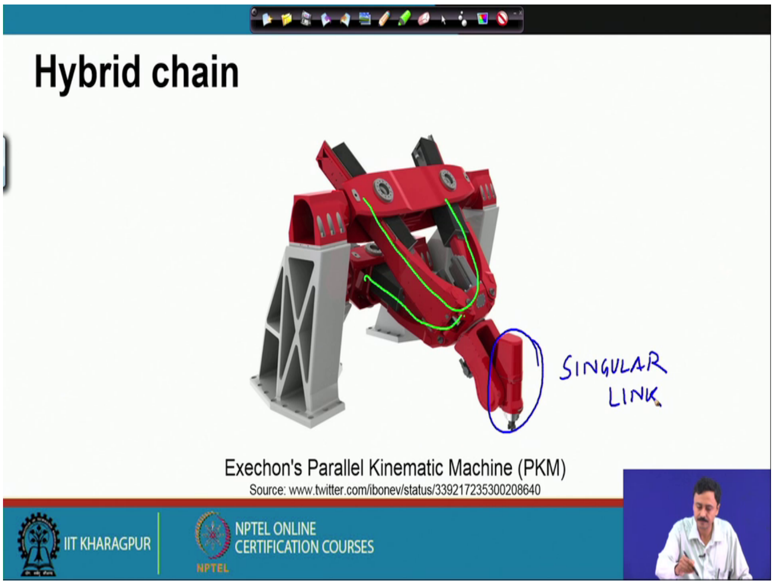

Now this is a hybrid chain; why a hybrid chain? You can see these are all closed chains, but here you have a singular link. So, it has both closed chains and a singular link, so this is a hybrid chain.

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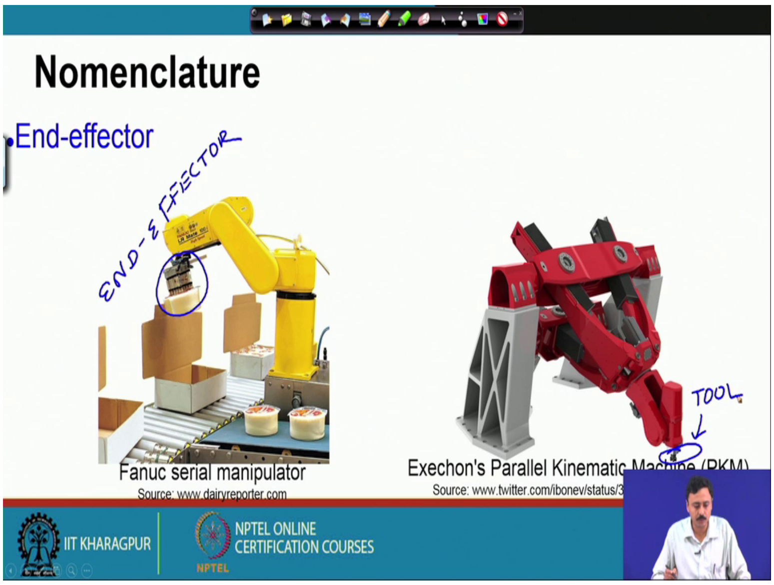

Now, we will come across this term end effector; specifically in the case of robots. The end effector is something like a gripper, so this is the end effector; which grips, holds something else; it could be even a tool. For example, in this parallel kinematic machine; the end effector is a tool. So, that does the operation that this manipulator is supposed to do, so end effector is either a gripper or a tool; at the end of the singular link of the robot.

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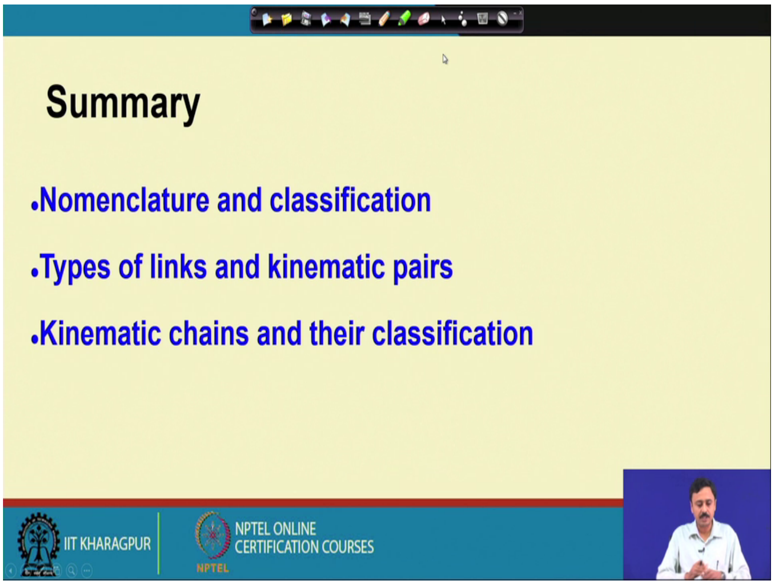

So, let me summarize; we have looked into nomenclature and classification of links, kinematic pairs etcetera. We had looked at kinematic chains, their classifications and we have defined that degree of freedom of various kinematic pairs. And we have looked at what is known as the end effector of a robot manipulator. So, with that I will close this lecture.