Introduction to Mechanical Micro Machining
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Lecture - 44
Components of Machine Tool (Contd.)

Good morning everybody and let us continue our discussion on the bearing of a high speed spindle. So, in the last class, we have seen that there are different types of bearings, we can use angular contact bearing and the roller contact bearing and we have seen that there is one particular parameter that is called contact angle which will actually dictate the what type of loading we are actually experiencing in the machine tool.

So, based on the different type of angular contact, we have to finalize the design of a bearing. So, let us continue this topic further.

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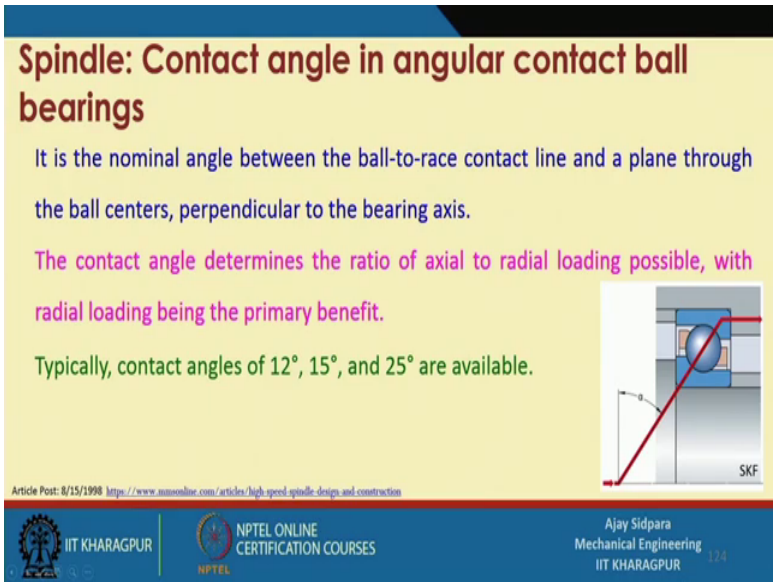

So, this was the slide in the last class, we have gone through that there are different type of contact angles and that contact angle, we have to finalize that which particular loading is important for our application.

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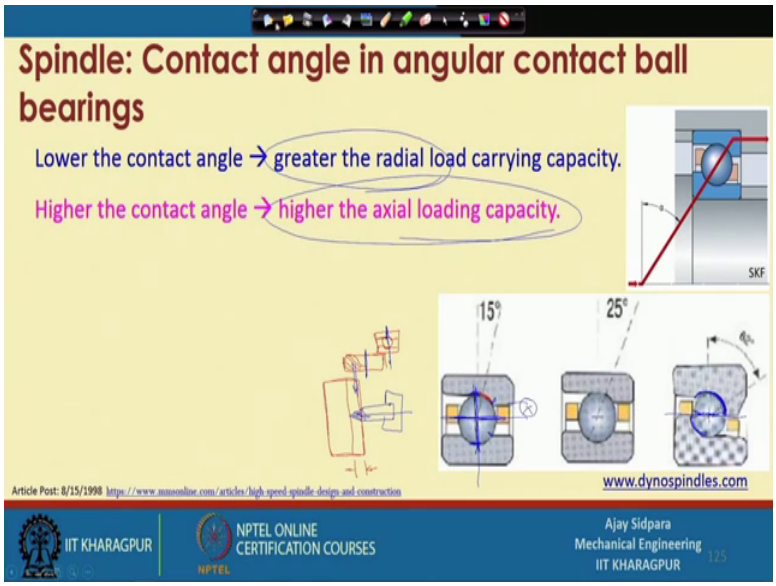

So, now these are this is what is going to happen with the different contact angle. Now, these are the 3 different angle is given 15 degree, 25 degree and the 62 degree. So, how this figures are different. Now, if you see this particular part; so, now, it everything depends on contact right and so now, here this is; what is the contact area. Now if you see if you are going with a higher contact angle, your contact angle area is increasing. Now contact area is even better then that correct.

So, what we are looking here that we are increasing the contact area here. So, in this particular case, what is happening that is if you increase the contact area what is going to happen here. So, let us see that part. So, what is going to happen that if it is a contact angle is lower. So, now, this is a lower contact area. So, greater is the radial load carrying capacity. Now, if you see in this case now contact is here.

Now, see this is the contact area correct. So, now, when you are rotating at a high rpm; now consider that you are cutting something from the phrase side. Now, suppose this is your work piece correct your spindle is here that you want to cut as through this surface, this is the amount of material, you want to cut and your spindle is located here; that means, cutting tool this is the cutting tool and this bore bearing is located here. So, this is the bearing.

Correct. So, now, in earlier case what we had seen in the last example that our tool was actually penetrating inside. So, at that time you need actually the radial load thru thrust

loading also that is axial loading or right now what we are doing we are actually not penetrating inside, but it is we are actually creating the same amount of depth of cut outside of the work piece. So, you do not have any loading on the axial direction. Now, you are penetrating your tool into the work piece yeah. So, you are moving in this direction now. So, what is happening here that you will not experience any type of axial loading right now, but you will get the radial loading here?

So, when you are moving in this direction what is going to happen your ball will actually move in opposite direction because you consider this is the one particular load and you are giving the load in this direction your bearing will experience the load in the other direction. So, if you see this thing that whenever you are looking at the centre of this part. So, it is better do a contacts here because now you are getting a force in this direction.

So, if you are getting this particular force at that time you have a very very high radial load carrying capacity, but not the axial one because if you see in this particular part your contact is far away from the center of this particular part.

So, at that time you will not get a more amount of stiffness in the axial direction, but you will get the high load carrying capacity in the radial direction. So, that is what is thing here, correct, if you increase the contact angle, what is going to happen that what you are doing actually you are actually securing your axial angle also. Now, you consider this particular figure, this and this. So, now, contact area is from here to here correct this is the contact area.

So, now whatever we here told in. So, now, you consider you are doing drilling operation here correct. So, now, you have to penetrate your tool into this. So, when you are penetrating at that time, it will create one force in this direction also. So, for that particular case, now you know that our contact area for in this case, this is the very large contact area in this case. Now consider this area; you do not have any type of support, but here if you see this thing, it is in full contact up to this and for the other half, you will get support from this particular part correct.

So, if you increase your contact angle; that means, from lower to higher one at that time you are increasing the axial loading capacity. So, this thing is very important when we are talking about the drilling operations and both things, you will need when you are

talking about the slot cutting or some type of machining or the pocket cavity cutting in the milling operation correct.

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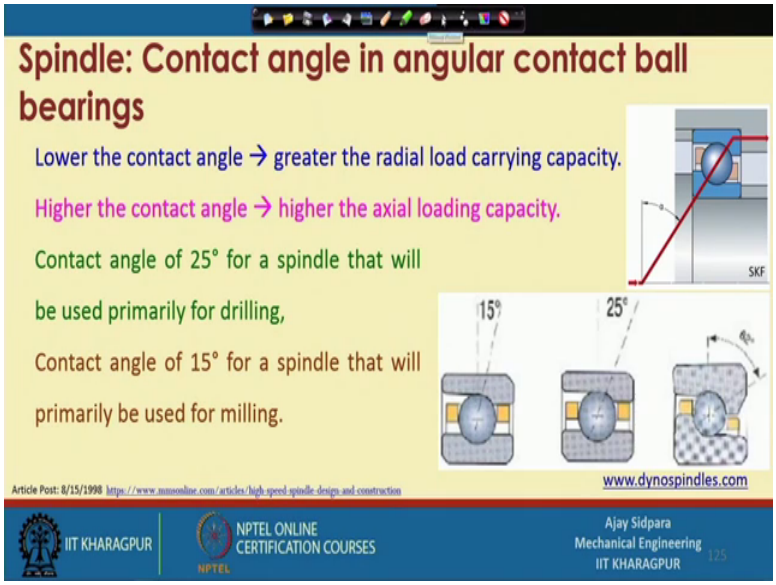

So, angle contact in 25 degree for spindle that will most probably used for drilling operation. Now, you can see this particular thing because we know that what is our objective that when you are going with a higher contact angle this type of thing at that time our object use to increase the axial loading and we know that when you do drilling operation at that time mostly our we are talking about the thrust and the torque only.

So, if you are giving the more and more depth inside at that time, you have you should have very high axial loading capacity otherwise bearing will fail at the later stage. So, 25 degree or higher for that at that time mostly, it is used for drilling operations and when you are talking about 15 degree, then what we are doing actually, we are actually maintaining both the things in this case because now we have to think about radial load also you cannot just go with the drilling only.

So, now, for milling operation we have to also pay importance to the radial load here in this case. So, for lower contact angle, what we are doing that we have to sacrifice some of the things for the axial loading here.

So, to take care about the radial loading; so, at that time the 15 degree contact angle is appropriate for a milling operation, right.

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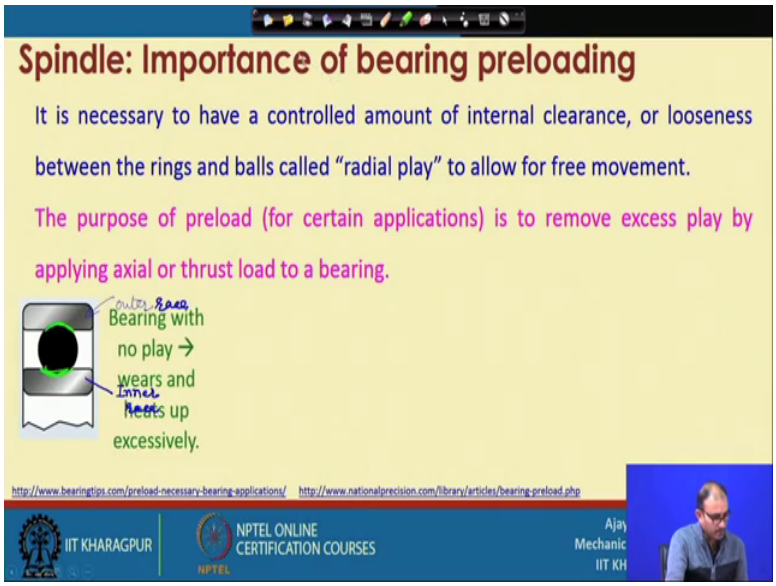

So, what is the importance of preloading? So, because we have seen in one animation also in lo long time before that if there is a unavailability or you are not preloading the bearing at that time, there is a allowance between the or the clearance between the races and the ball. So, what is happening because of that let us see it that it is necessary to have a controlled amount of internal clearance or the looseness between the ring and the ball called the radial play to allow for a free movement.

So, the purpose of the preload for certain application, you do not require preloading for all the application that also you have to consider that purpose of preload is to remove this excess play whatever we are telling here by applying axial or the thrust load to a bearing. So, now, what is happening here? So, now, this is one of the bearing what is happening here he here at this location this is the outer race this is the inner race and this is the ball. So, now, here what we are doing it is firmly grip between the two things, right.

So, there is there is a full contact here what you were thinking a looking here at this location. So, this is very very much penetrated inside the races. So, it is the full contact here. So, you do not have any type of radial play or any type of free movement here right now. So, what is problem with this particular thing that bearings with no play. So, it does not have any play you do your not providing any radial play or any type of excess play which is required for free movement.

So, what is happening because of that you will get a wear and heat up excessively? So, why it is happening here because why we are using bearing here because we have to rotate this bearing a our object is to rotate this bearing in between the races a outer race and the inner race.

Now, if you are shu firmly gripping these thing what is going to happen you are not getting free motion here at this location. So, at that time what is going to happen here that it will not rotate, but it will actually skid only correct?

So, when it will skid at that time, this contact will be under friction, there is a high amount of frictions generated here when there is a friction, it will heat up when there is a heating at that time there is a chances of wear because we have seen in that roughness is that even though it is it looks like a very very fine surface, but microscopic scopically there are lot of roughness indulaces are there.

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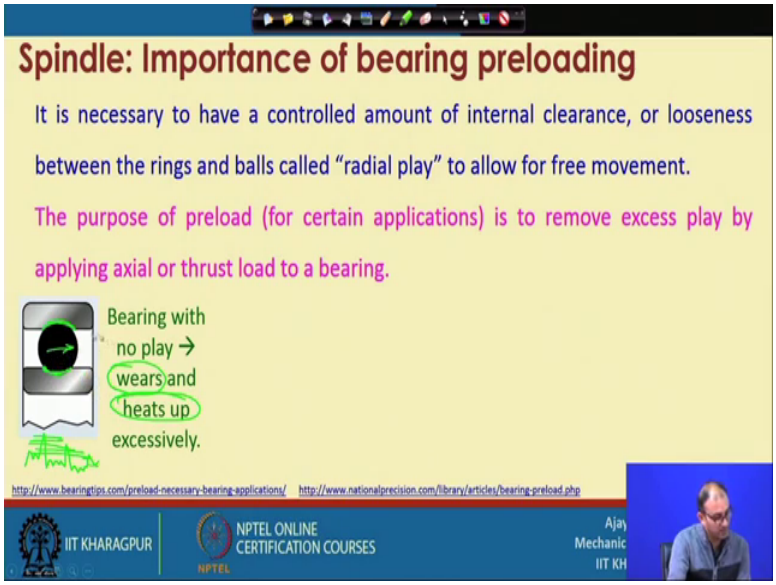

So, these are the roughness profile. So, because of that what is happening that when it is sliding or skidding on the surface instead of rotation at that time there is a removal of these material and because of that you have to you will get one additional clearance that is actually you have not intended to do that.

So, that is the reason for a what is going to happen with this particular part and when you operate this thing for longer time ultimately clearance will increase and this bearing will fail in that particular application.

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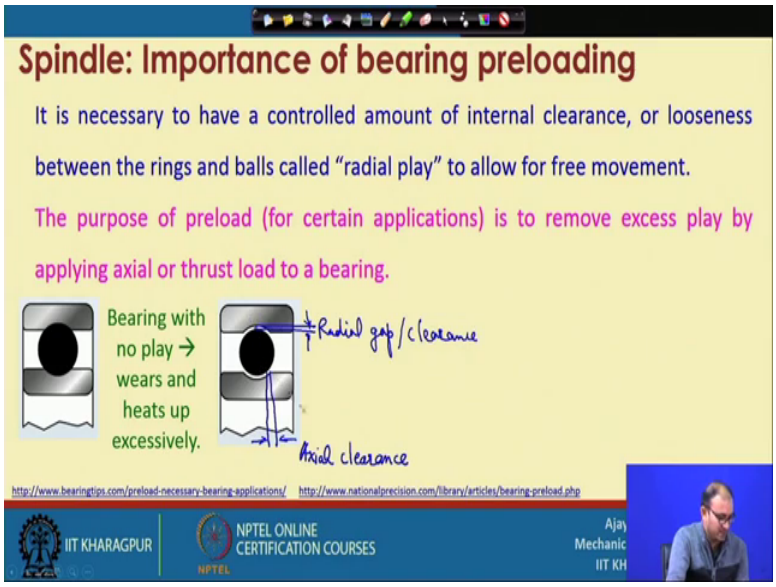

Second one is that it is exactly opposite to the first condition now here that you have a clearance and there clearance is this is the resilience now what is happening here that this particular dimension whatever you are thinking that this particular bearing will move in the two direction. So, now, you consider this is the axial.

So, this is the ax radial gap or we can say clearance correct and when it is moving in this way or this way what is going to happen that it will shift in the radial direction axial direction also. So, let us consider these one that whatever; this two points are there, let it be small, but that is enough to destroy this particular bearing under applications. So, that is axial clearance right. So, both the way it is like that. So, here what is happening that you are not getting a reasonable contact between the be ball and inner race and the outer race.

So, what are the problem? Here also problems are there.

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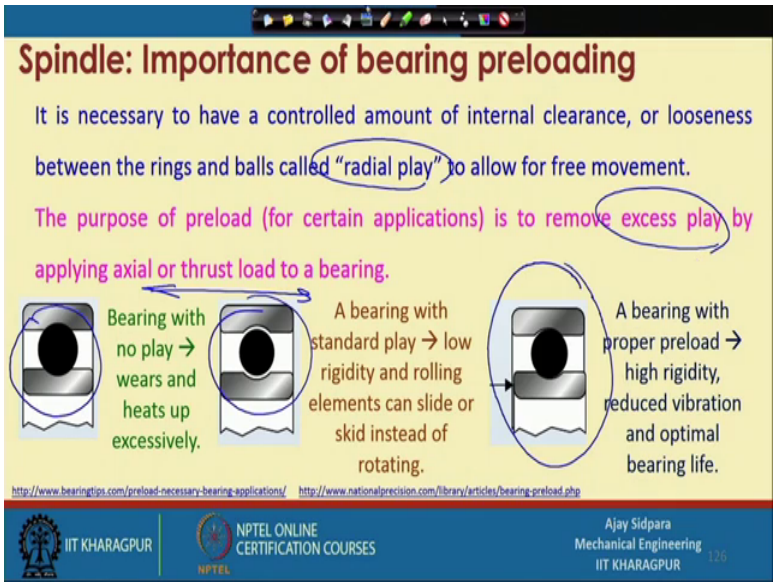

So, bearing with a standard play; so, here the rigidity is low because you have gap in both the direction one is this radial gap one is in radial gap and another one is in axial part. So, you do not have rigidity because system is not perfectly stabilized; that means, whenever there is a loading at that time instead of passing that motion to the bearing first it will deform itself; that means, it will loosen between these particular gap whatever it this precision micron fifty micron or hundred micron whatever it is there it will actually move within that part. So, you will not get any additional.

So, rolling element may a can slide or skid instead of rotating here now what is going to happen that here it is a firm contact. So, mostly it will happen a sliding here and here what is happening the loading is; that means, contact is not at all in the both the surfaces. So, what is going to bearing will move randomly, it does not have any type of control motion here. So, it may happen that in slide only because in for rotation, what is going to happen that first whenever there is a contact at one particular race whether it is a in outer race or the inner race.

If one of the thin thing is rotating at that time if bearing is in contact with that rotating element bearing will rotate, but right now here actually there is a standard play between these two. So, initially it may rotate also, but after the contact is loosen from that; then it will slide also some time it will skid also because it is not doing anything, it will just sliding on the top surface.

So, this is what is going to happen with this part and we know that rigidity is very important for micro machining application for you cannot have any type of a play within the system, let it be in a 1 micron or 2 micron because when you are talking about the dimension control is point one micron then these thing are very very dangerous for the final job operation.

So, this is what is happening with the bearing with the standard play. So, this is also not good for the micro machining operation this is also not good for micro machining. So, what is good for this both the things, then what we have to do that you use this particular standard play and then what you have to do that you have to apply one force here at the this direction. So, once you put the force what is going to happen you are shifting this inner race little bit inside when you are shifting what is going to happen these particular point will contact. So, you will get a contact here and when you are shifting ball in this direction you are getting contact here also correct.

So, now what we are talking we are talking about that angle alpha here correct. So, if you want to increase this contact angle what you have to do that you have to increased the you have to change the design of this particular outer race inner race. So, have will get additional contact between these two different surfaces. So, in that way you can actually think about the different different contact angle. So, this is called the preloading of the ball bearing.

So, bearing with a proper preload; so, what is going to happen that you will get rigidity because now balling is contact with both the races outer race and inner race, it reduces vibration because now it does not have play ball the surfaces and in contact and again steel, it is not in full contact. Now, if you see this particular gap here located here contact is here only not at this location, right.

So, it is actually in contact, but not like a no play. So, this is not the condition. So, this t whatever we are talking here, this whole thing is actually in between these two right you have a contact, but not the firm is this one you have little bit of play, but not like these correct. So, this is what is happening that you have to shift either the inner race or the outer race in such a way that you will get a contact between this two. So, that there is no any type of radial play or the excess play whatever we are talking here at this location. So, that is why preloading.

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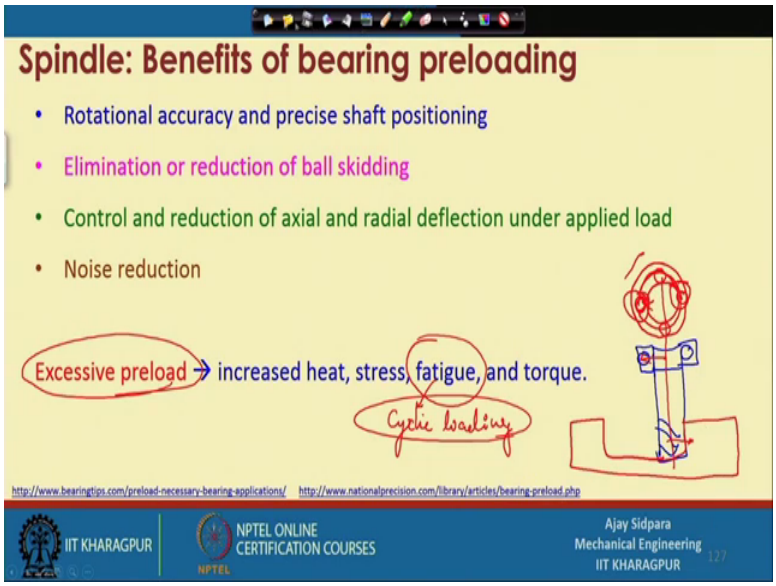

So, what are the benefits of preloading? So, one is the rotational accuracy and precise shaft positioning possible if you see that earlier case where was a play was there at that time the few microns here and there that dimensions size not in your control ball may run in any location in axial direction or the radial direction with a few micron of allowance is or the clearance.

So, you do not have exactly precise shaft positioning within that dimension rotational accuracy is now perfect because now ball is in contact with both the surfaces elimination or reduction of the ball skidding. So, now, ball will not skid because now it is getting the both the surface and that is also not full contact it is contact is enough to make sure that the ball is there is a reductional skidding or either, it is a completely elimination of the skidding control and reduction of the axial and radial deflection under the applied load. Now you have to play with the angular contact angle.

So, based on that actually you can see that which one is good that we have seen that you can control the excess and radial deflection or you can reduce that deflection under a certain amount of loading.

Noise reduction is there because if there is an a full contact what is going to happen there is a temperature rise and the wear because of that you gel gea clearance will increase and that will create a huge noise in between the surfaces because whatever the amount of

surface which is removed from the ball either from the ball or the races that is still within that part.

So, it is further increase the wear of the components and then you will get a very very high noise and if it is a full normal contact; that means, the normal clearance between the two surfaces ball is actually free to move in axial direction as well as radial direction. So, because of that unintentional motion you will further get the noise, but that is not happening in the preloading bearing. So, that is the advantage.

But there are thing that if you excessively preloaded; what is going to happen that it will increase the heat excessive preload means that is the first example that your ball is completely fixed between the inner race and the outer race. So, same thing will happen that you will increase the heat stresses will be very very high and fatigue load and torque will also increase why we are getting fatigue loading here.

Because we know that is our shaft is here suppose this is our cutting tool right and we are putting bearing here consider these are the bearings correct and now what is going to happen that you are cutting a slot here. So, now, this is your work piece right, you are cutting this particular slot within this part. Now when you are cutting a slot what is going to happen you have to apply load in this direction when you apply load in this direction your bearing will actually experience forces in the opposite direction in this direction, right.

So, when you are looking at this direction let us see this in a top view. So, this is the shaft and this are the bearings let us consider four balls only right now, but balls are located a enough amount of uniformly distributed here. So, when force is in this direction. So, this ball will be in the compression here because of this particular force right and this ball will not experience any type of forces right now here, but we know that this is in rotation. So, this ball will go and this reaction this ball will come to this location right. So, it is a within a and you are consider rotating at a 10,000 rpm or 5,000 rpm.

So, within a fraction of a second or fraction of fraction of minute in few seconds the same ball will experience two different type of forces one is in the compression and there is suddenly release of that particular load. So, that is because of that you are experiencing the fatigue loading fatigue loading is the cyclic loading, right. So, because of that what is going to happen that you may get a premature failure in the bearing because it will not

about not able to compensate that particular thing because you have tightly fixed these particular ball within the two races.

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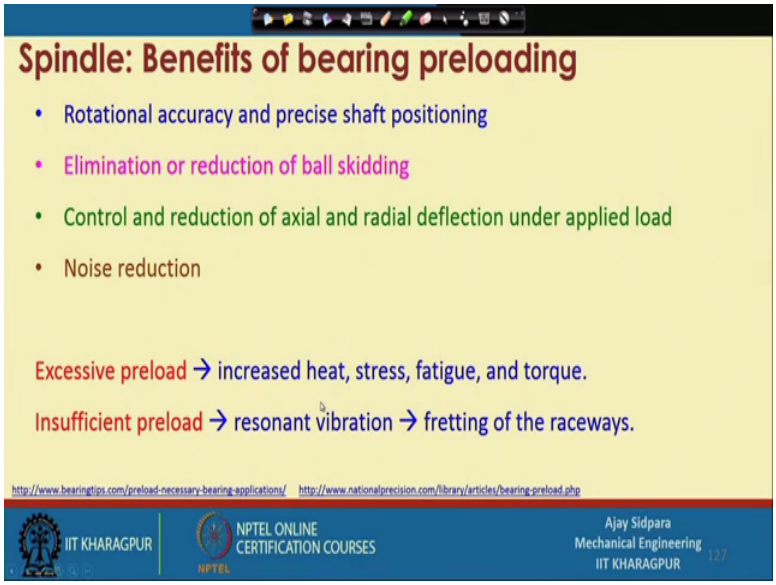

In sufficient preload; Now, consider that is there is a preload, but that is not sufficient then resonant vibration have come and because when there is a vibration at that time it will actually fix with the matches with the nature of frequency and you will get a extremely high vibration and fretting of the race way will happen; because whenever there is a gap at that time what is happening because of the centrifugal force ball will try to heat the races it will not rotate around the races and because of that it is a fretting of this particular race ways and that is creating a problem at the later stage.

So, you should know that what is the limit of the preload; in such a way that you can avoid both of these problems at the later stage when; your system is under operation right.

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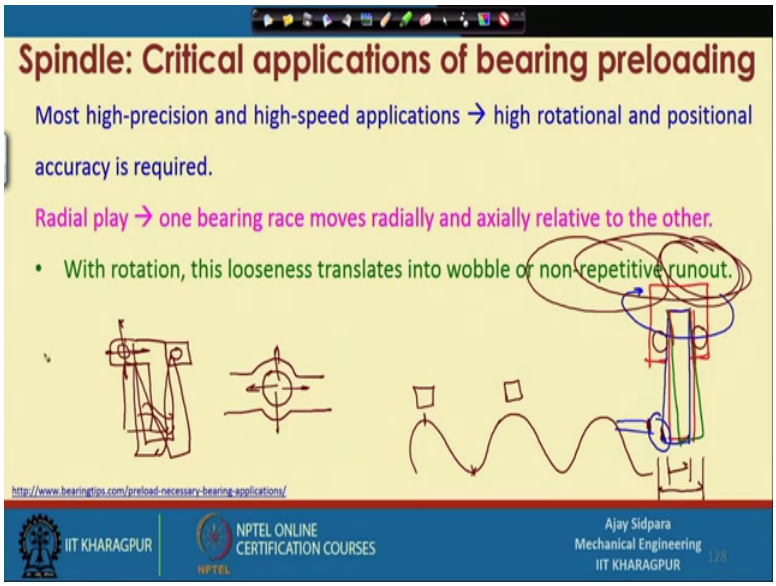

So, what are the critical application of bearing preloading because we know that when we are using for a high spa precision high speed application what we need we need a high rotational positional accuracy otherwise it will create a lot of problems at the later stage.

Because your tool run out is also one of the problem because of this improper fixings of the bearings and improper design of the spindle it is not only because of the fixing of your tool to the tool to the tool holder, but because of this internal problems also, it may not get the high rotational and positional accuracy at the later stage.

So, when you are talking about the high precision and high speed you always look for the high rotational in the high accuracy. So, radial play is problematic because one bearing race moves radially and axially related to the each other that we have seen in that thing that whenever ball is not in contact with either outer race or the inner race at that time, you will get both the motion radial motion as well as axial motion.

So, with this motion if you do not compensate this part any continue operation then because of this looseness translate into wobble and the non repetitive run-out. So, what is this non repetitive run out? Now we can say that there is two different type of things. Now consider this is your spindle, consider this is your tool and this is your tool holder correct and by chance what is happening that this things is perfectly align, but because of the problem in the mounting what is happening that this is little bit of axis.

Correct. So, this is the of axis of this part now you rotate this system correct; so, what is going to happen that suppose you have cutting edge here. So, when you rotate at that time at that time you will find that this is the cutting edge every time which is coming at this location when right and this particular cutting edge when you are talking here at that time, it will not come into that part.

So, if you put one sensor here that is capacity sensor and if you want to find out that what is the situation of these part. So, now, what is going to happen that your rotation will be something like this? So, this is the one rotation and other way, it will be exactly opposite to that. So, this is what is going to happen let me change this color first.

Correct. So, what is the thing here. So, this is your intended diameter right the red color whatever is there this is the thing what you are getting, but what you are getting you are getting this additional motion. So, this is what you are getting additionally, but this is called the repetitive run out why it is repetitive run out because it will not change with respect to time if you see if you put one capacitive sensory into a find out that how many times, you will get this particular movement here. So, it is you will get one signal something like this right because your sensor is located here.

So, whenever this age will come here in a one rotation you will get a signal here because it is very close to it after that it will stay away at this green position you will not get this signal it; that means, signal stand full reduce again after this green again it will try to move in this again strength of the signal will increase and you will get one signal here that is by some type of non contact type of sensor.

So, this is called repetitive because it will not change with respect to time or it will; you can also it will not a random thing, but here this is a random thing because here what is happening that our ball is here our race is here and now we do not know here which way your ball will move whether, it will move in the axial directions or it will move in the radial direction right. So, that is the reason that whatever run-out is happening because of this that suppose you have a balls here and in this direction, but you have straight complete system.

So, now this is the two cutting tool and these are the consider this are the bearing this is the same thing right. So, now, what is happening that you do not know that your ball is moving in this direction or it is moving in this direction, but it has freedom to move in

both the direction? So, now, this whatever our the run-out, you will get here because of this motion because here also it may come in this way also come or may come in terms of dimension in the z axis also because it can move in this direction also.

So, these whatever run out you are getting here that is because of that is why it is called the non repetitive run out not in the cyclic loading in this way or other way where you can actually get the perfect or uniform pattern of the run out signal, but that is not happening here in this case correct.

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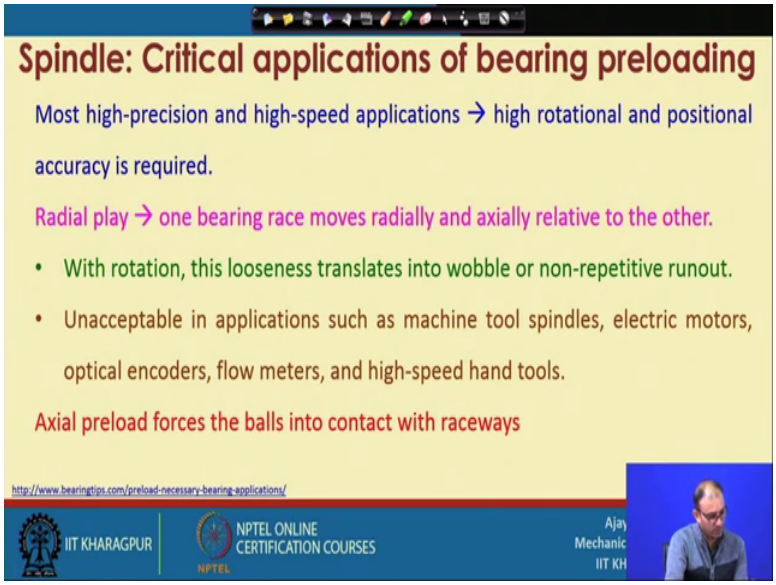

So, what is happening because unexpectable on the application such as machine tool spindle electric motor optical encoder flow meter and high speed hand tools. So, this are the application where you actually do not want this type of uncertain things which are very difficult to move in the other direction.

So, why this is required because then axial preload force is the ball into contact with the race way. So, that is why we need a preloading of that.

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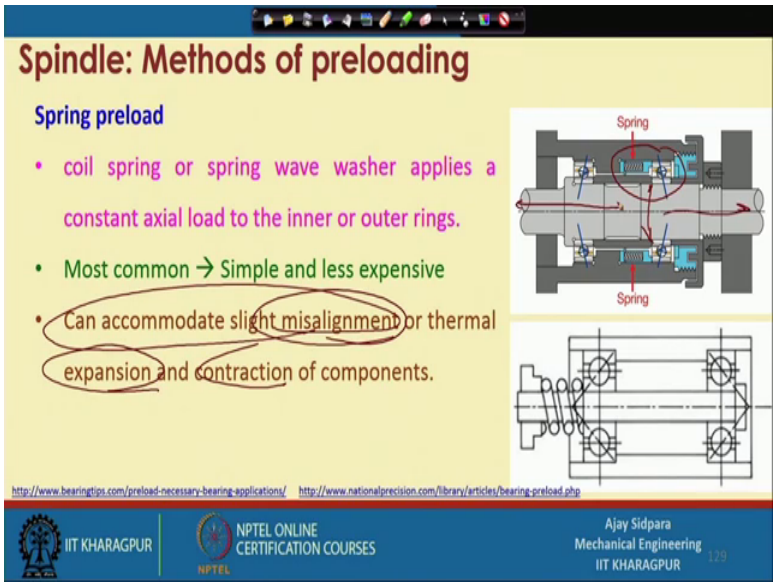

So, that you can avoid that all these problems at the later stage; so, what are the different methods of pro leading there are two methods; one is spring loaded. So, what is we are doing here in these case that this is our bearing. So, now, our objective is to fee move either inner race or outer race in such a way that it will create a contact at a certain location.

See if you put a spring here and then you tight it from this particular part. So, wherever this spring is touching; so, this string spring is touching at the outer race right now. So, when you are pushing these part your spring will push the outer race in this direction. So, you will create a contact at this part right. So, this is the contact by the spring, right.

So, this is called spindle spring preload. So, what you have to do that you have to use a coil spring or spring washer that apply constant axial load to the outer ring or the inner ring that is up to you that which particular things you want to district the motion and most common, it is a simple and less expensive method because you have to mount a spring here and then it will actually create a contact between the ball and the particular race.

And can accommodate the slight misalignment or thermal expansion and the contraction of the components because now we know that even though, we are telling that heat is less here, but still it is a physical contact right let it be line contact or the point contact.

So, when you rotate at a high rpm, you have lot of loses because of the motor roll current also as well as there is a mechanical fiction.

So, after a certain duration of time when you are rotating at a thousands of rpm then there is a what is going to happen that there is a expansion there is a thermal growth of the shaft. So, when there a thermal growth of the shaft, what is happening that a small amount of misalignment this particular thing will accept because we are using a spring it is not a hard mechanical contact. So, if you are getting a thermal growth of your system then what is happening that spring will care of a certain amount of misalignment. So, that is one of the advantages of the spring preloaded.

Because now, we know that if there is a excess misalignment expansion of contraction your spring will actually response accordingly because it is already preloaded. So, if you are expanding, then further preload a further loaded or if it is a contraction, then it will actually release little bit.

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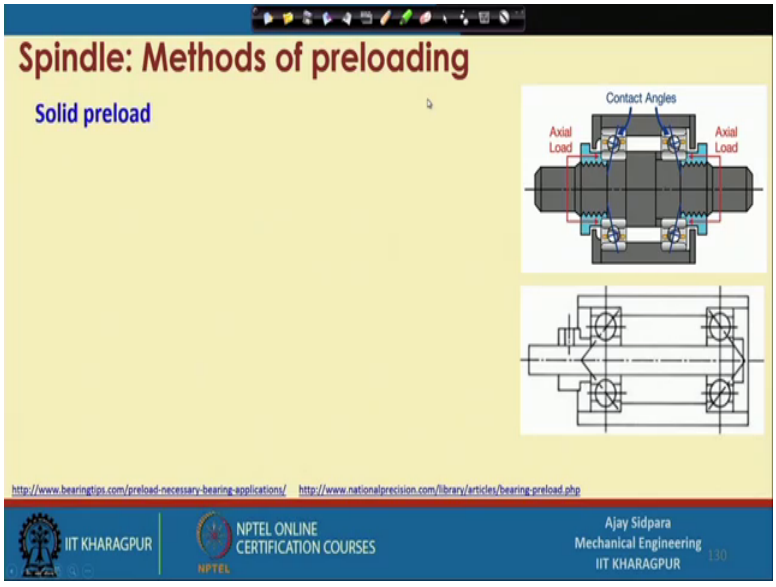

So, small things here and there will not make much more difference to the particular this type and then another type is the solid preload type these thing, we will discuss in the next class because this will take further more time.

So, let me stop this lecture, here we will continue this particular topic in the next class.

Thank you very much.