

Introduction to Mechanical Micro Machining
Prof. Ajay M Sidpara
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 46
Components of Machine Tool (Contd.)

Good morning everybody, and let us discuss our a topic on a duplex bearing and the bearing mountings. And we have seen that the difference type of mounting configuration o-type, x-type and the tandem bearing type and we have seen the different advantages and disadvantages of each one of them. And we have also seen that because of the temperature rise there is a thermal growth of the system, mostly it is a shaft and how to take care of that particular thermal grow, so that there should not be any type of problem during the operation or the av after the operation. So, let us talk this thing further in these (Refer Time: 00:48).

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Spindle: Duplex bearing - Bearing Mounting

Motor-Spindle with Tandem Bearing Pairs and Spring Pre-Loading

Motor-spindles experience temperature increases due to bearing heat and motor losses. → Thermal growth of the spindle shaft → inner race is forced into the bearing → increase in pre-load → rapid failure

Mount the rear spindle bearings in a floating housing, with springs.

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Ajay Sidpara
Mechanical Engineering
IIT KHARAGPUR 137

So, here what we have seen in the last class that whenever there is a high temperature rise then heat will be generated; and because of that heat generation there is a growth of the spindle shaft. So, we have to do something new that is called floating housing with a spring. So, what is means that means let us see those things in detail right.

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Spindle: Duplex bearing - Bearing Mounting

Motor-Spindle with Tandem Bearing Pairs and Spring Pre-Loading

Floating housing is mounted in a precision bore, or ball cage → is free to move in an axial direction to the extent of clearance s .

Spindle grows → Rear bearings are free to move also.

In this way, the pre-load seen by the bearings does not change, and is maintained by the force exerted by the springs.

It is used for high speed milling spindles and grinding spindles.

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Ajay Sidi
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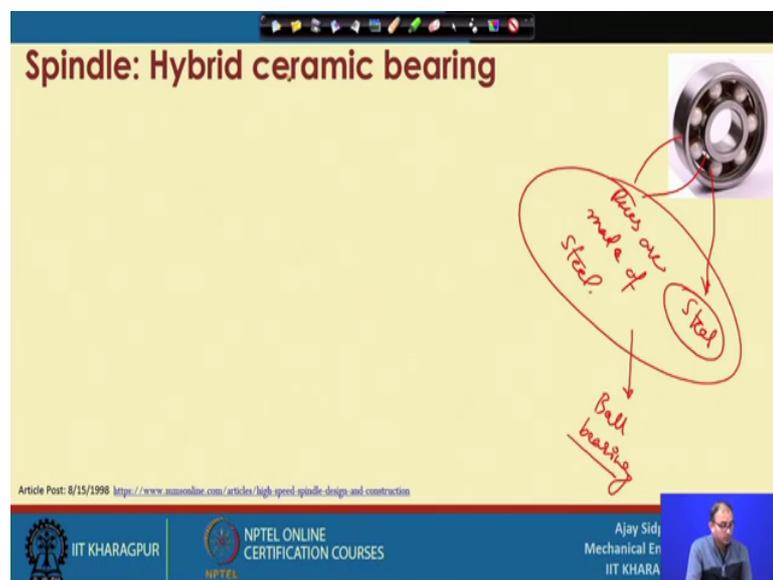
So, now, this is the same configuration here. Now, what we have to do here that floating housing is mounted in a precision bore or a ball cage and it is free to move in an axial direction to the extent of clearance s . So, this is called the clearance s . So, this is the clearance s . Now, this clearance is given to the rear end of the house. Now, this is the front end, this is actually opposite. Our tool is located here and this is the rear end. And we are giving a small amount of clearance to this direction that is because that we have to provide this additional space, so that whenever there is a thermal growth of the shaft at that time, this shaft will be accommodate within this particular dimension. So, you will not get any type of extra loading or compression or expansion of different components during the operation of the spindle right.

So, when the spindle grows the rear bearing are free to move also. So, now, this particular end part that we have seen that cantilever example that one end is fixed. So, now see this end is fixed see because we are using a cutting tool here. So, if there is a expansion in cutting tool (Refer Time: 02:23) then your z-axis will be compromised because your z-axis axis offset will be changed. So, we are not doing anything at that side, this old bearing is completely form the rigid. So, expansion will happened at the rear end only. So, your rear bearing are free to move. So, whatever your s that much amount of space you have and where your rear end will be moving in the direction correct.

So, in this way, the pre-load seen by the bearings does not change, and it is maintained by the force exerted by the spring. So, we are using spring preloading also here and we are providing that gap also. So, whenever there is an expansion at that time your spring will be further loaded, and then it will be compensated by that. And once the temperature comes down to the required level, again spring will this old shaft will again contract, but you have a spring loaded here. So, spring again actually release get release and then it will maintain to the original position, but it should be within this particular s will it will few micron only, so that much variation can be acceptable for a this particular type of settings right.

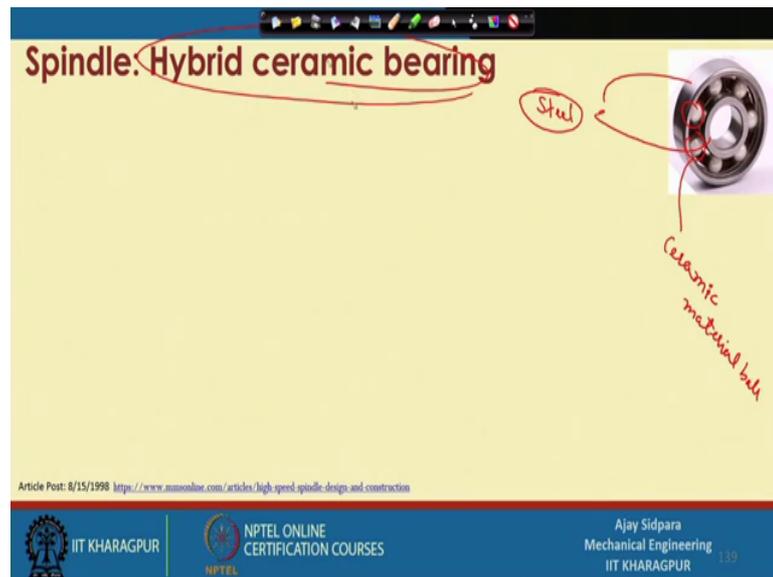
So, it is used for high speed milling spindle and the grinding spindle because here what we are looking that we do not want to disturb the system because of the heat because heat is one of the things which we have to maintain or we have to regulate in such a way that there is no any type of thermal deformation of the component or tool or any type of geometric x orthogonalities.

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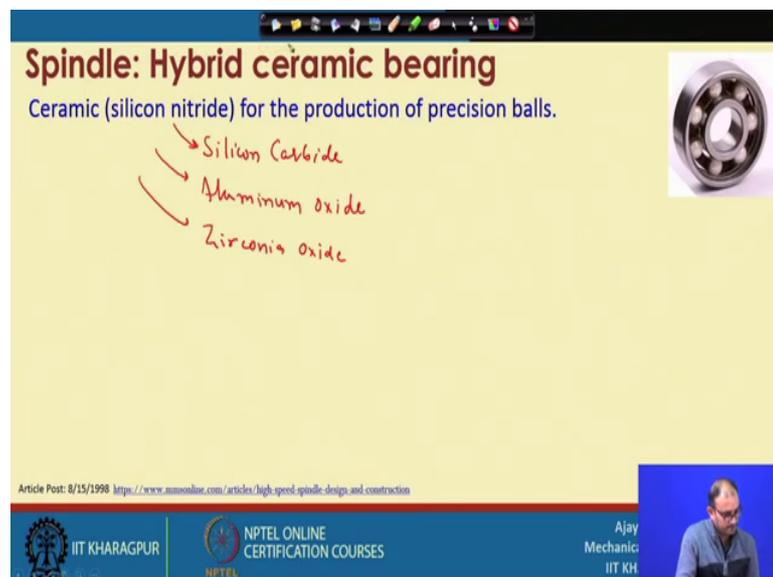
Now, coming to the hybrid ceramic bearings now till now what we have discussed thing that we have discussing about the ball bearings where this races, races are made of steel and ball is also made of the steel in the in case of ball bearing right. But now we are talking about hybrid ceramic bearings.

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Why we have talking hybrid ceramic because we are using ball of a ceramic material ceramic material ball. And then races steel we are using steel so that is why it is called hybrid ceramic bearings right. So, ceramic silicone nitrate not only ceramic silicone nitrate there are many also there let me name those things also.

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So, silicon nitrate is there, and silicon carbide is there, then aluminum oxide is there, zirconia oxide is one also there. So, these are the different, different type of ceramic materials which are mostly used for fabrication of these precision balls right.

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Spindle: Hybrid ceramic bearing
Ceramic (silicon nitride) for the production of precision balls.

The ceramic balls have 60% lighter than steel balls

High rotational speed → centrifugal force pushes the balls to the outer race, and even begin to deform the shape of the ball.

$F_c = m\omega^2 r$

mass Speed Radius

60%

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So, ceramic balls have 60 percent lighter than the steel balls are 60 percent lighter than the steel balls. Why this is important because now we know that if lighter the things you can actually increase the speed beyond a certain limit. Now, for the high rotational speed, centrifugal force pushes the balls to the outer race and even begin to deform the shape of the ball. Because now we know that centrifugal force F_c we can write that $m\omega^2 r$ correct. So, this is the radius, this is the speed, and this is the mass correct.

So, we are not actually doing anything with the radius now size is the same, wherever this is the thing from here to here r is not changing it. We are not changing the speed also, so speed is also same ω whatever we are rotating rotational speed is there, but we are changing mass right. So, now, it is a 60 percent less weight. Now, if you see these particular thing that if you use a centrifugal force with a steel bold. Now, what is going to happen that now you have a ball here and there then when you are rotating at the time it will go at this direction right.

So, what is happening that centrifugal force pushes the ball onto the outer race. So, you have a this particular ball and then this ball will be move towards this particular part because of the centrifugal force. So, you have outer race, and this is the ball and this ball is striking in this direction that means, it continuously pushing in this direction. So, you will get a additional force on the top part out inner face of the outer race. And because of

that what is happening you will get the deformation of the ball. So, which one is actually creating problems, so sometimes it will deforms the ball also some time it will deform the outer race also. So, in that is the reason for the particular ball bearing.

So, when you are using ball bearing at that time it will create a problem with the outer shape of the ball for the a surface profile of the in a outer race. So, because of that you are not able to go beyond a certain limit of speed, but now we know that we have 60 percent less weight. So now, you can go further because now centrifugal force will not play important that much because your aim is much small now correct.

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The slide features a yellow background with a blue header and footer. The title 'Spindle: Hybrid ceramic bearing' is in red. Below it, text describes ceramic (silicon nitride) for precision balls, noting they are 60% lighter than steel balls. It explains that at high speeds, centrifugal force deforms steel balls, leading to wear, while ceramic balls are less affected. A bullet point states ceramic balls allow for up to 30% higher speed. Images show a hybrid bearing and a full ceramic bearing. A red circle highlights the text 'Up to 30% higher speed'. Handwritten red text says 'Complete / Full ceramic bearings'. The footer includes IIT KHARAGPUR, NPTEL ONLINE CERTIFICATION COURSES, and a photo of Ajay Mechanic, IIT KH.

Spindle: Hybrid ceramic bearing
Ceramic (silicon nitride) for the production of precision balls.
The ceramic balls have 60% lighter than steel balls
High rotational speed → centrifugal force pushes the balls to the outer race, and even begin to deform the shape of the ball.
This deformation leads to rapid wear and bearing deterioration.
Ceramic balls will not be affected as much at the same speed.
• Up to 30% higher speed for a given ball bearing size, without sacrificing any bearing life.
Complete / Full ceramic bearings

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So, this deformation leads to the rapid wear and bearing deterioration because that is in case of the steel bear when you are using a normal ball bearing where was everything will made of steel. So, ceramic balls will not be affected as much as that particular same speed. So, now, you know that now you can expand the area of the that means, expand the particular speed that earlier it was a limited was range was fixed, but now you can expand that particular to a certain higher level without creating any problem.

So, for by using a ceramic ball only actually you can go up to 60 percent higher speed for a given ball bearing size without sacrificing any bearing life. So, what does it mean that do not without changing anything just by replacing the steel ball ceramic ball by a steel ball by the ceramic be balls you can actually increase the speed with the 30 percent without changing anything, you keep the application everything same and then you will

also still get the same bearing life, but increasing the speed. So, that is the a very good advantage because we know that the in micro machining our speed requirement is very very high and that is this is one of the best way to get the this thing done without changing so many other things correct.

And this is one of the things which is you can see here this particular part that we have just change the balls only correct, but still we are using the ceramic. So, that is why it is called the hybrid ceramic bearings. But bearings are available that are the fully ceramic bearings, so these are the called the full ceramic or complete right. So, if you see here the race outer race inner race everything in made of ceramic.

Now, if you consider these particular things, then this particular whatever advantage is you are getting for hybrid bearing that will be even higher in this particular case correct. So, these are the full bearings and they have very specific application for the mostly the high precision components where because the cost is also very, very high for this particular complete peramic ceramic ball bearing or the hybrid bearing compared to the normal bearing which we are get what we are getting in the market.

So, cost is the one issue where we have to actually do one type of optimized study that which one is better that by putting more cost what you are getting in terms of the spending money. So, cost versus amount of things which you have getting that is more important in this particular case, but there are lots of advantages associated with this ceramic bearing. So, let us see those things one by one. So, one thing is they are lighter.

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Spindle: Hybrid ceramic bearing
Ceramic Balls do not react with the steel raceways

One of the most prominent mechanisms of bearing failure is surface wear created by microscopic "cold welding" of the ball material to the raceway.

Temporarily attachment of ball with races

heat generation

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Second thing is that ceramic ball is do not react with the steel race because this are the ceramic material. And mostly they are inert with the either acidic environment or the other things that is the big advantage here, because one of when you are using a normal ball bearing, what was the problem that one of the most prominent mechanism of the bearing failure is the surface wear created by the microscopic cold welding.

So, what is this cold welding that is when you have a ball bearing, normal ball bearing what is going to happen that when you rotate at extremely high rpm, what is going to happen that this are the coin con context right. So, this are the contacts that is the mostly the point contact, but there are many point contact depending on the how many bolds are located in that particular material particular bearing.

So, when you are rotating at a extremely high rpm what is going to because there is a heat generation there is a heat generation right because of this heat generation what is going to happen that it is cold weld with the inner race and outer race. Cold welding means it is not like a permanent welding or like something that, but it is a temporally attachment with the ball and inner race, so this is a temporally attachment of ball with races right ok. So, it will temporarily it is because of this extremely high speed and the heat generation and that is creating problem that it will actually give a some type of removal of those parts.

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Spindle: Hybrid ceramic bearing

Ceramic Balls do not react with the steel raceways

One of the most prominent mechanisms of bearing failure is surface wear created by microscopic "cold welding" of the ball material to the raceway.

The cold welds actually break as the bearing rotates, creating surface roughness which leads to heat generation and bearing failure.

The ceramic material drastically reduces this mechanism, resulting in longer bearing life.



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So, when in this condition what is going to happen if you continue this operation this weld will be broken at the later stage when you are operating, and when the bearing rotates this weld will be removed from there and creating a surface roughness which leads to the heat generation in the bearing failure right. So, when you have a contact here. So, this is the contact part and then you further move in this direction, then what is going to happen that it will actually rotate. When it will rotate, so these particular cold weld it will either remove material from the work piece on the race it will remove material from the ball. So, in both the cases the roughness will be increase.

And because of that it will further because now your surface is something like this some if it is removed from this particular part or of it is removed from the ball then it would be something like this. So, now ball is not in same shape. And in this particular case, ball will have some additional material attached with this particular part correct. So, in both the cases this is what is the problem, but it will happen at the microscopically, but still it is enough to create a damage to the ball bearing. And finally, all the thing will be failed at the later stage right.

So, ceramic material drastically reduce this mechanism resulting in the longer bearing life because ceramic is different material and it has different properties compared to the metallic surface, because it is the ceramic part. So, it will not actually create this type of cold weld between the races and the ball so that is one of the advantage.

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Spindle: Hybrid ceramic bearing
Ceramic ball bearings operate at lower temperatures

Nearly perfect roundness → operates at much lower temperatures than steel ball bearings.

Glass like surface



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Ceramic ball bearing operates at the lower temperature, because if they are mostly near perfectly round because it is something like a glass like surface. Whatever you are getting here it is a glass like surface. So, its surface is very very shiny surfaces and looks almost a glass like. So, you will get a very very tight tolerances in terms of the roundness and the surface roughness. So, operates at a much lower temperature than the steel ball, because the polishing of this steel ball is difficult compared to the ceramic ball. So, dimensional accuracy is more controlled on the ceramic ball bearing. And because of that you may not get the temperature of zone in higher case it will operate at a much lower spread than the ball bearing.

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Spindle: Hybrid ceramic bearing
Ceramic ball bearings operate at lower temperatures
Nearly perfect roundness → operates at much lower temperatures than steel ball bearings.
This results in longer life for the bearing lubricant.

↑Temp → ↓Viscosity



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The slide features a yellow background with a blue header and footer. The main text is in black and blue. A handwritten blue oval highlights the text 'This results in longer life for the bearing lubricant.' and another blue oval highlights the handwritten text '↑Temp → ↓Viscosity' with an arrow pointing from the first oval to the second. A photograph of a hybrid ceramic bearing is shown on the right side of the slide.

This results in the longer life of the bearing lubricant because wherever you using bearing lubricant at that time if the temperature is very very high then holding lubricant will change its this property mostly it is a viscosity that higher temperature then lower viscosity right. So, because of that what is the happening, you are changing the property of the lubricant and sometimes lubricants is lubricant becomes very very in effective in the complete dissipation of the heat and the reducing the friction of this particular part. So, it will not create problem if you are using a ceramic ball instead of a steel ball right.

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Spindle: Hybrid ceramic bearing
Ceramic ball bearings operate at lower temperatures
Nearly perfect roundness → operates at much lower temperatures than steel ball bearings.
This results in longer life for the bearing lubricant.
Less friction generated in the bearings with increase in heat.
Low thermal expansion as compared to steel balls.



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The slide features a yellow background with a blue header and footer. The main text is in black and blue. A photograph of a hybrid ceramic bearing is shown on the right side of the slide. In the bottom right corner, there is a small inset image of a person, likely the presenter, against a blue background.

So, less friction generated in the bearing which increase eh with increase in the heat. So, when your stiff further go a down and a miss going high and high in terms of speed, it will generate the heat, but it will not create so much of friction in this particular because now the systems are different not is a steel bearing. Low thermal expansion is compared to the steel ball because metallic ceramics are very very low thermal coefficient of expansion compared to the steel. So, even if there is a high temperature you will not get the thermal growth of the system that means, mostly the different components of the bearings so that is the also advantages.

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Spindle: Hybrid ceramic bearing
Ceramic bearings operate at much lower vibration levels
Spindle utilizing hybrid ceramic bearings exhibit

- higher rigidity and
- have higher natural frequencies,

making them less sensitive to vibration.

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The slide features a yellow background with a blue header and footer. A small image of a hybrid ceramic bearing is shown on the right side. The footer includes the IIT Khargapur logo, NPTEL Online Certification Courses logo, and the name of the presenter, Ajay S. Mechanical, IIT KHA.

And they operate a at a much vibration level because spindle utilize hybrid cera ball bearing exhibits a very higher rigidity because now they are very strong also in terms of the different type of mechanical properties. And there are higher natural frequency. So, you can go beyond a certain limit of a speed, so that your natural frequency is it will not reach to the resonance of the particular system. And making them less sensitive to the vibration, because if your system is not rigid then what will happen that after crossing a certain level of a speed at that time it will start (Refer Time: 17:18) because of the internal creation of the clearances and that is not happening fin this particular case.

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Spindle: Hybrid ceramic bearing

- Low thermal conductivity** → reduces the amount of heat absorbed which reduces cooling system requirements.
- Low deformation** → useful in the machines that work under extreme pressure.
- High temperature hardness** as compared to steel → retain their strength and hardness up to 1800 F.
- Low density** (3.2 g/cc), **high flexural strength** (1.0 GPa), and **high fracture toughness** (6 MPa/m²).

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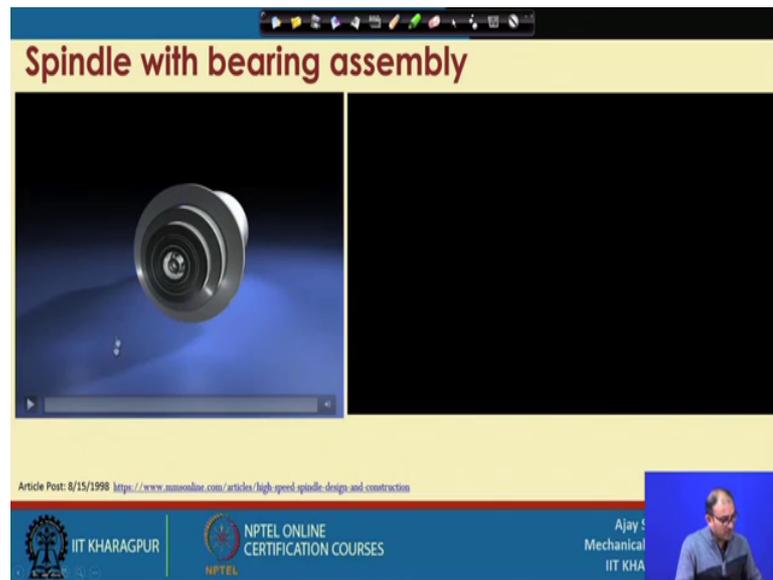
Ajay S
Mechanical
IIT KHA

Then some of the other advantages of the using ceramic ball it was a low thermal conductivity because of that that reduce the amount of heat observed within a which reduces the cooling system requirements. Because we will see in one animation that you have to cool the spindle also either by means of a air or by a water jacket. So, in this particular case if heat is not excepting or saving the heat within the body at that time it will mostly relieve the release the heat onto the atmosphere by different type of this cooling part systems, low deformation because it they are very very strong in terms of a stiffness. And use full for the machine that work under the extreme presures.

And high temperature hardness is compared to the steel because it retains the strength and hardness up to the 1800 fern degree. So, in this case Fahrenheit these particular cases you can get the very very high temperature operation without creating any problems. And some other properties the density is very very low because you can see that it is sixty percent lighter then the steel so that is what of the advantage here very high flexural strength volume as 1 gpa so that is under when it is under the flexural loading at that time, it will not create any problem and high fracture toughness 6 mpa per meter square.

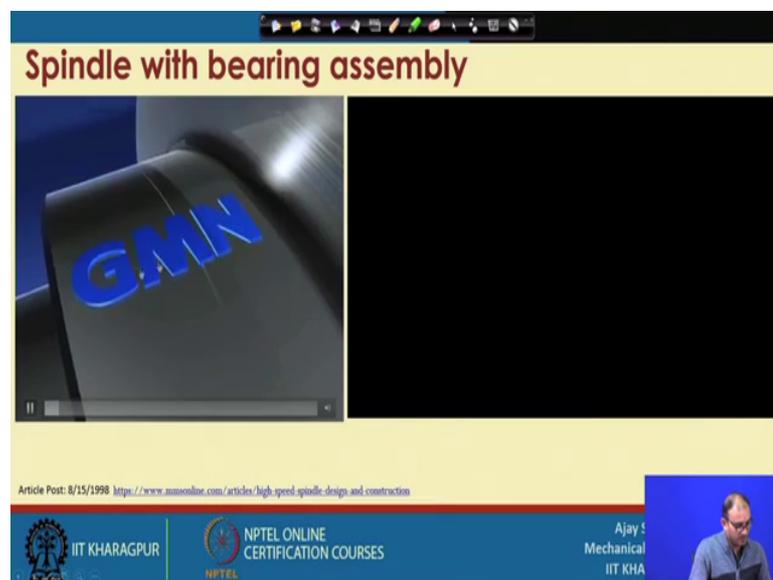
So, these are the some of the properties which are very very suitable for accepting these particular ceramic or hybrid ceramic bearings for the micro machining operation, so that is the reason that it is better to go with this type of ceramic bearings whenever you are using a spindle for the micromachining operation.

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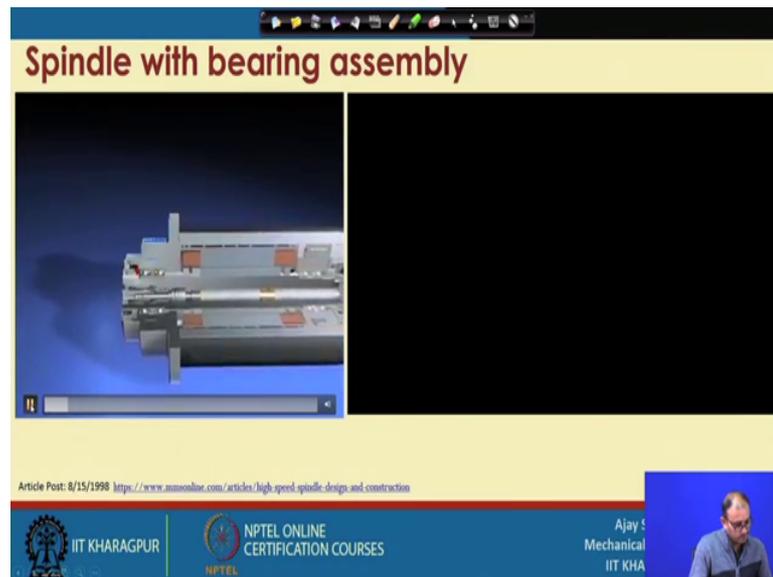
Now, let us see that what are the complete situation solo complete assembly of the bearing. So, these are the two things that what things we have to taken care we have to take care during the design of this part.

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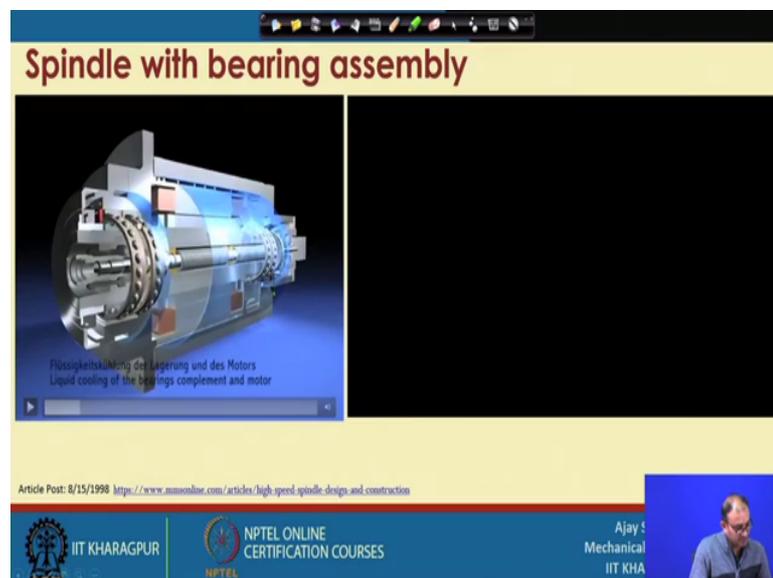
So, this is one of the company who are making this type of high precision spindle.

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And this is the cross sectional view and the cross sectional view of this particular spindle.

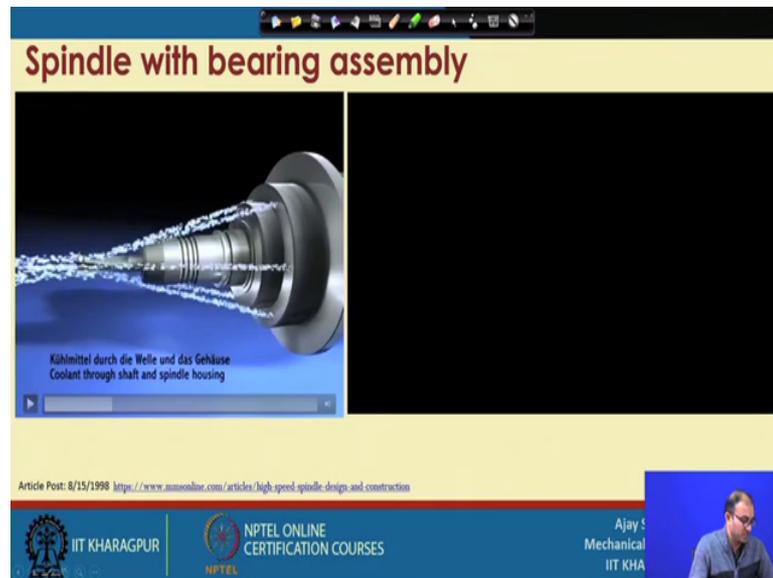
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Now, you can see that there are lots of bearings. So, these are the set of bearings. So, this is called a front bearing and this are called the rear end bearing right; so liquid cooling of the bearing components and the motors. So, now if you see this blue color, so this is called the liquid water jacket which is created within the system. Now, you can see that this particular thing is a one liquid jacket is given to the bearing also and there is the full

components here because this is the integrated or integral motor type spindle. So, everything is within the system motor is also there and then the transmission LU components also within the part right.

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So, this is one of the systems where what is going to happen that when you cut the material at that time we know that at chip are forming and they are spreading in the random direction. So, one of the way that you should make sure that chips are not actually attached with the tool here because we know that when you are working with a micro tool at that time flute space is also very very small; so if material is fixed or which is called the loading of the tool then the chip will stay on to the cutting tool here.

So, if we are folding a coolant through this particular part at that time you are actually focusing the coolant to the exact location where you are getting a material removed. So, chip will not come into contact with the fluids or any other direction and it will be spread away a very very quickly around the out of the machine area.

So, coolant to the shaft and the spindle housing, so this is one of the way. So, your spindle has also one of the ways by which you can provide the coolant. So, this coolant (Refer Time: 21:17) such a way that it will focused to the location of the machining. So, this is the machining zone. So, these particular coolant which is coming from this particular spindle housing, it will directly focus to the a cutting zone one is that you have a through coolant shaft.

So, shaft has also one of the passage through which you can supply the coolant. So, coolants are very concentrated around the machining zone that is called the interface between the cutting tool and the work piece. So, whenever you are doing machining at that time heating will be completely escape by the particular cooling element. So, heating will be most of the time taken care by this cooling media, and other then that chip will be also spreader away from the machining zone and the cutting tool.

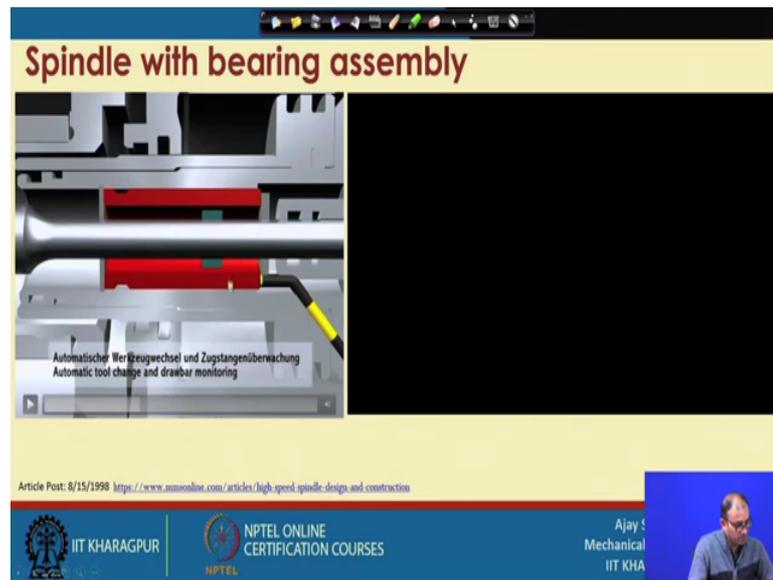
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So, now, coming to this is called the tool retention mechanism or the tool holder mechanism right. So, when you are putting this particular tool, and we have discussed some time there (Refer Time: 22:13) that is called as drawbar mechanism. So, this is called the drawbar mechanism. So, how this will work that when it is expanded at that time, you can push this particular cutting tool holder into it right. So, it is going down and then it is actually getting inserted inside it.

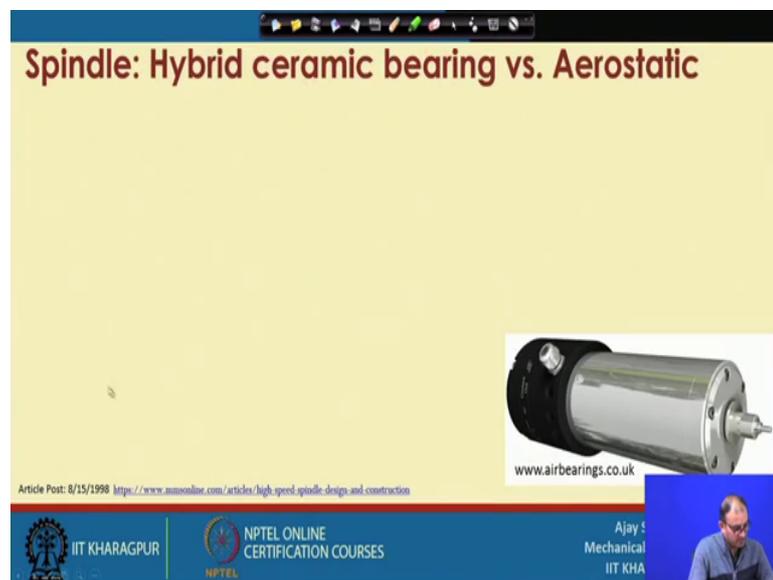
So, this is called the automatic tool change and drawbar monitoring system. So, here it will tell you that you are actually measuring the forces and the contact forces. So, once everything is firmly contacted, then you will get the signal also right.

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So, this is the automatic tool by monitoring system. So, the rear end of the draw bar where you are actually moving this particular bar to grip the tool.

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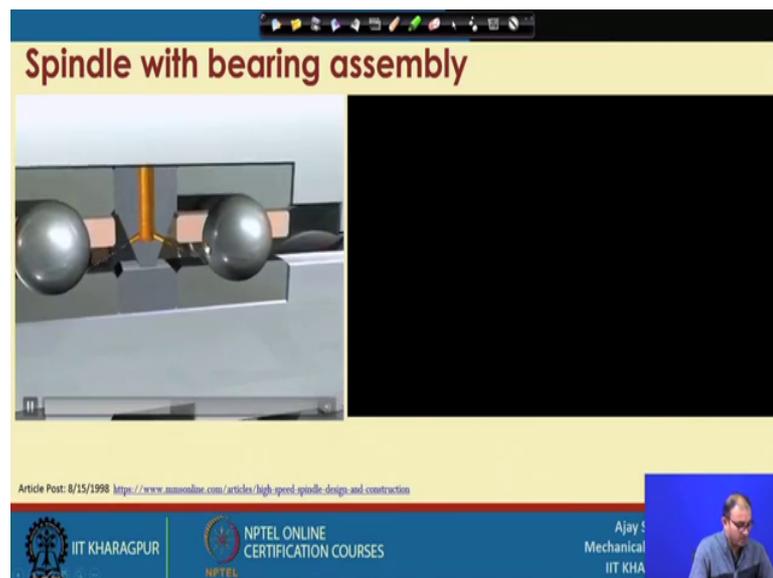


So, now you are releasing the system right. So, now it is gripped. Now, you can remove these parts. So, now, it is released from this part. So, for attaching and relieving, you can do the same thing. Now, another thing that once when you put it inside and when you relieve it at that time what happen sometime some micro chips or some for a dot particles some time it will stick to the surface. So, if you do not clean this part the next time when

you are added a attaching another tool from here, it will not be fix completely here and because of that you will get the run out. So, that is called the periodic run out or the static run out.

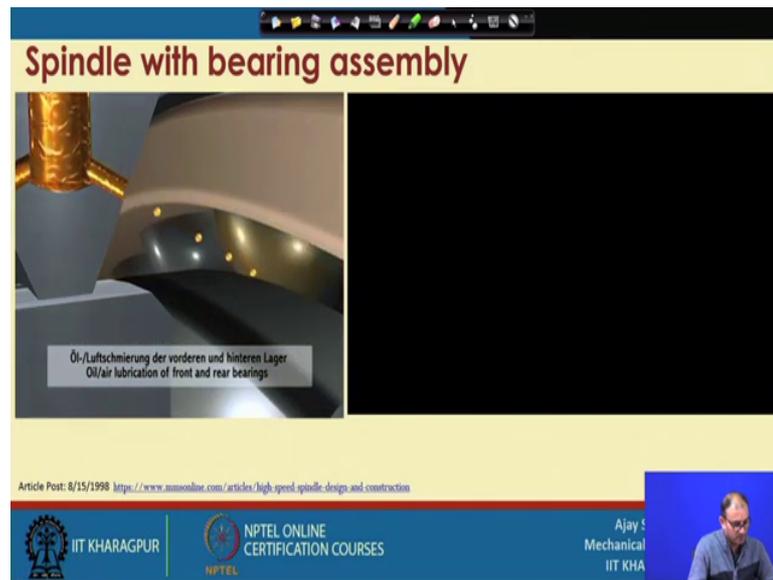
So, here some spindle has this type of additional mechanism by which once the spindle or the tool holder is release after that you provide one type of taper cleaning of the tool interfaces by the air you supply the air. So, air will actually get a positive pressure. So, it is pressure is very, very high here. So, when you pushing the air here, so air will be coming out from this particular passage to that atmosphere. So, even if there are some dirt particles or some foreign element which will create some problem at the interface it will be expelled away from the particular joints, so that is the automatic tool cleaning of the tool interface by the air.

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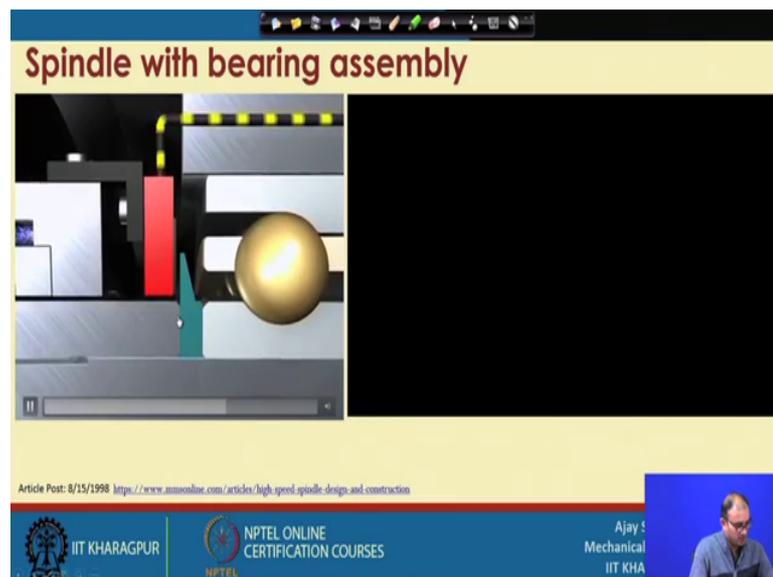
Now, coming to the bearing lubrication, now there are different methods are available. So, this is one of them which is showing here.

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So, it is oil or air lubrication of the front and the rear bearing. So, it is you provide one completely oil monitoring system here. So, it will provide the continuous air supply to the bearing races here, and then it will drop by drop everything will be lubricated within the system. Now, you can see here the once the bearing is rotated then you will get the lubrication of the balls as well as some other components continuously right.

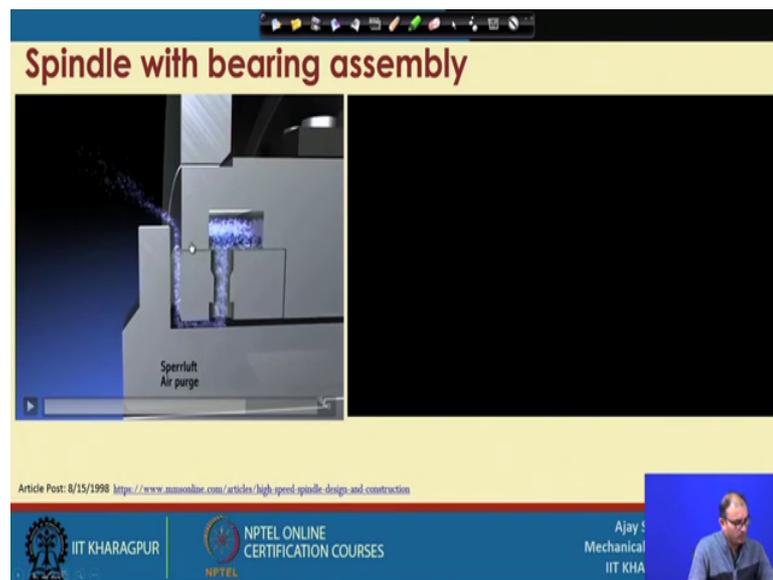
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So, this is the sensor of all measuring the axial shaft movement. Now, the shaft is in this direction. So, how much is the shaft move in this direction that is mostly we and we are

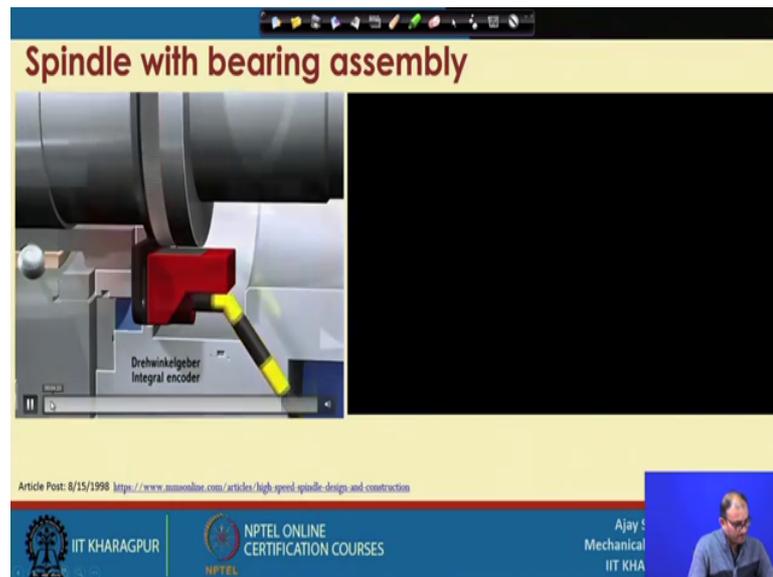
talking about the drilling of a hole or doing a micro drilling or other operation where it will create some problem at the later stage. So, this is the sensor for measuring the axial shaft movement. So, it is mostly some type of capacitive type of sensor or the whole effect sensor which will actually monitor the how much is the axial displacement of the shaft. And every time it will give a signal to the system, so that you can maintain or you can monitor this particular signal right.

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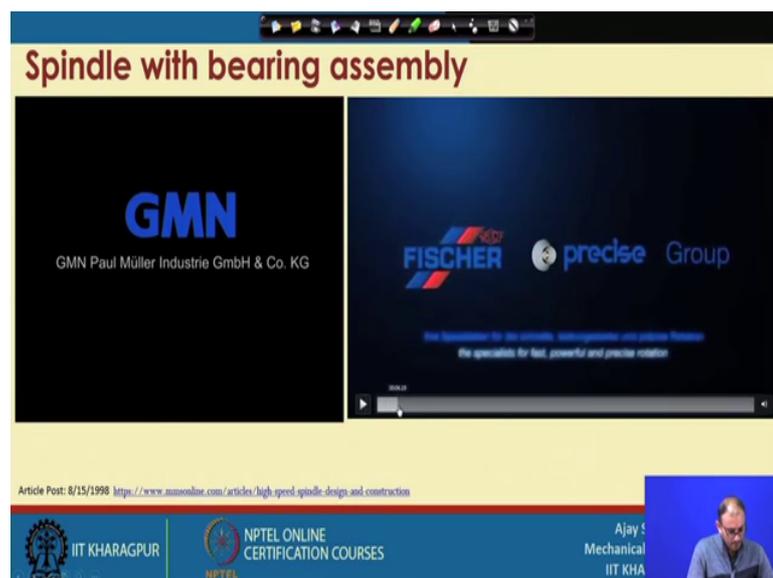
So, this is the air purge because whenever you are doing machining, you will may get the very very fine amount of particles because of the machining also as well as some of the chip also. So, this air purge will make sure that none of these things will actually getting inside the system. So, you are continuously providing the this air purge, so that nothing is come out inside the system, and system is completely secured from the coolant as well as the external element like a chip or dirt or some type of other microscopic elements.

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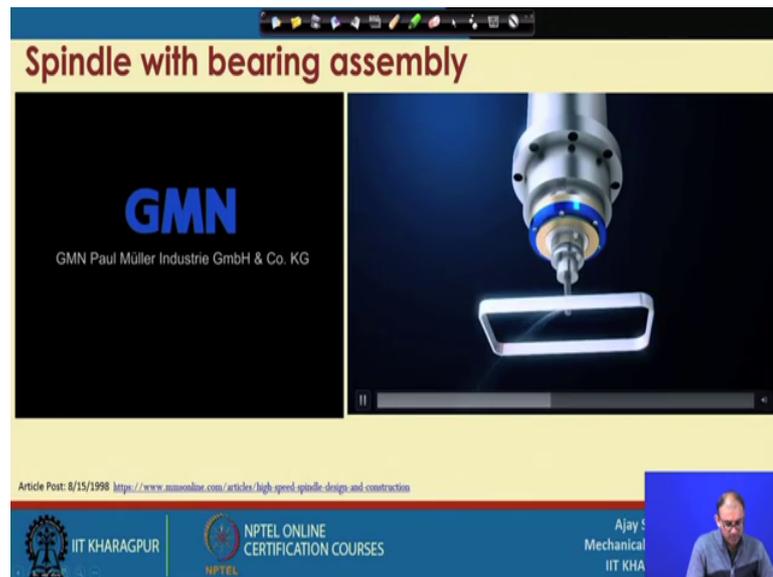
And this is the rotary encoder which is used for measurement of or the calculation of the rotational speed of the shaft, but here we are using rotary encoder because we want to measure the rotational on set that is the best way for doing these things. And temperature sensors are also attached here, so that whatever there is a com any type of axial movement or something that will be compensated within the part. So, this is all about one system.

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Now, let us see this one more. So, this is also one other company Fischer right.

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So, whenever you do machining or something you always get some heat generated within the system.

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So, what we have to do to count the right those type of thing so you will get some type of z displacement because of the heat right.

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The slide features a yellow header with the title "Spindle with bearing assembly". On the left, the GMN logo is displayed above the text "GMN Paul Müller Industrie GmbH & Co. KG". On the right, the text reads "Fischer hat die Lösung. Fischer has the solution." Below the main content, there is a URL: "Article Post: 8/15/1998 <https://www.amsonline.com/articles/high-speed-spindle-designs-and-construction>". The footer includes the IIT Kharagpur logo, "NPTEL ONLINE CERTIFICATION COURSES", and the presenter's name "Ajay Mechanical IIT KHA" next to a small video feed of the presenter.

So, what are the solution for that so, this is again the cross section of the whole system.

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This slide shows a 3D cutaway model of a spindle assembly. The title "Spindle with bearing assembly" is at the top. The GMN logo and company name are on the left. The main image is labeled "Wellenkühlung Shaft Cooling". Below the model, there is German text: "Über mehrere Kanäle wird die Welle gekühlt; Temperaturveränderungen und Längenänderungen werden nahezu eliminiert." followed by its English translation: "Several channels cool the shaft; Temperature changes and axial growth are almost eliminated." The footer contains the same information as the previous slide: "Article Post: 8/15/1998 <https://www.amsonline.com/articles/high-speed-spindle-designs-and-construction>", "IIT Kharagpur", "NPTEL ONLINE CERTIFICATION COURSES", and "Ajay Mechanical IIT KHA" with a video feed.

So, now, this is the cooling channel. Now, see several channel cools the shaft temperature changes and the axial growth are almost eliminated. So, these are the shaft cooling system because we know that we have seen that the thermal growth is mostly happen to the shaft. So, if you want to avoid the thermal growth what you have to do that you have to cool the shaft during the operation, so that you will not get any type of thermal expansion right. And this is for the bearing and the motor. So, again you are getting the

same water jacket cooling or the air cooling by means of that you can maintain the temperature within the system. right.

So, another is optimize air or oil lubrication guarantees the minimum losses maximum speed and available reliability. So, you can maintain these things, your system you can operate continuously without any problem. So, this is the greasing unit. So, you continuous the greasing also to the bearing and different other components, so it can reduce the friction. And this is the sealing of the spindle. So, this is one of the wear through which through the tool actually you can provide.

So, this is the different kind of for the fluid called the internal tool cooled to a maximum. So, even without actually restricting the speed of this spindle, you can provide cooling lubricant through this particular spindle. So, this is the cooling lubricant. You can go with the minimum quantity lubrication also where you can actually give a very very minor amount of a supply cooling coolant, so that you can do some type of cost cutting in that. And another one is that you can supply air also.

So, these are the different ways you can actually control the see some. So, now, we have in different components of bearing and the installation of the bearing within the system also. And this particular whole system will tell you that how the bearings and all the things are actually assembled within the qu system of the spindle and how things you have to take care during the operation.

So, let me stop at this location. We will continue our discussion on this spindle component or the machine tool component in the next class.

Thank you very much.