Tribology

Prof. Dr. Harish Hirani
Department of Mechanical Engineering
Indian Institute of Technology, Delhi

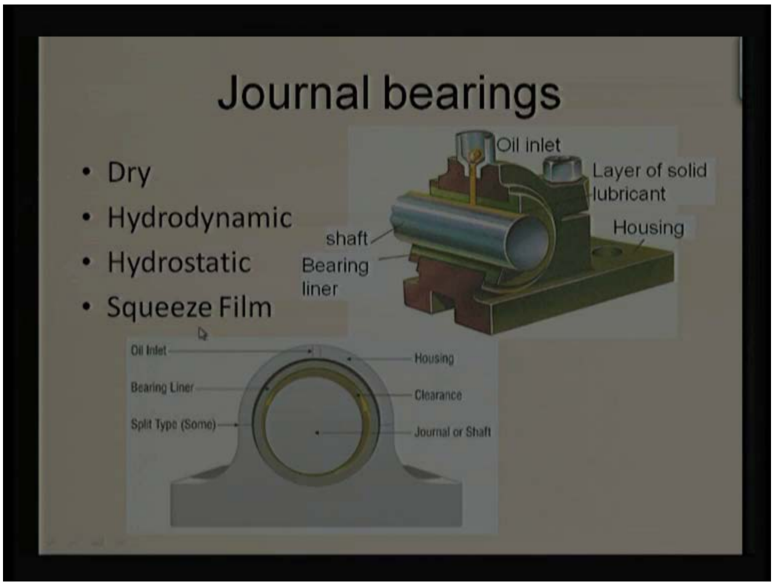
Module No. # 06

Lecture No. # 39

Journal Bearings

Hello and welcome to 39 th lecture of video course on Tribology, the title of the present lecture is Journal Bearing. We know bearings are required to support the load particularly, when there is a relative motion between components, we were talking about journal bearing is more like a we are trying to support some cylindrical shaft and the applied load may be in radial direction.

(Refer Slide Time: 00:56)



When we think about the journal bearing of rough picture of bears something like this, there is a shaft or cylindrical object known as a journal, housing which will remain a stationary, shaft is going to rotate, some intermediary component which will be called bearing, because housing can be treated as a bearing, but we want replacement housings are generally costlier, we will not be able to spare housing as a bearing.

So, we use some intermediate component, that is a bearing support and if you want to reduce the wear, reduce the friction we will try to use some lubricant that is the oil or air or grease some some lubricant in that case, that is what there is a some clearance. So, that we can accommodate, that lubricant in this clearances space and generally this clearances space is much lesser in dimension may be say 0.1 percent of the dimension of shaft, which is very very low dimension. Then, there is a some sought of the inlet it may, if we are using oil, oil inlet, if you are using grease that will be grease inlet, so that it can replenish, the lubricant, which has been removed from the bearing ends.

Housing may be splitted also, so that assembly and disassembly of the bearing is easier, it depends on the configuration we can think about bearings in or we say we can classify bearings. If we want to see this the split view or a better picture of this you can think like this, we say, there is oil inlet, there may be some oil reservoir also or continuous feeding of the oil. So, there is a oil is a passing through this, this is a shaft surface we try to keep shaft surface very smooth particularly, when we say surface of this may be lesser than 1 micron, 0.3, 0.2 micron, 0.4 microns. There is a housing and then, this is a bearing over here, but sometime we call as a bushing also, if it is a single piece what is a bearing in a two (( )) or the splitted one, then will be calling the bearing. And there is a nut and bolt connections to or may be, if it is threaded connection over here, then we can use directly clamping this splitted portion with this portion.

There is a other option also we can provide a layer of solid lubricant, if we do not want to use liquid lubricant greases and we do not want this kind of a oil reservoir, some passes like this, then we can think about a solid lubricants, but even in solid lubricants, we need to have a housing to restrict the motion of bearing.

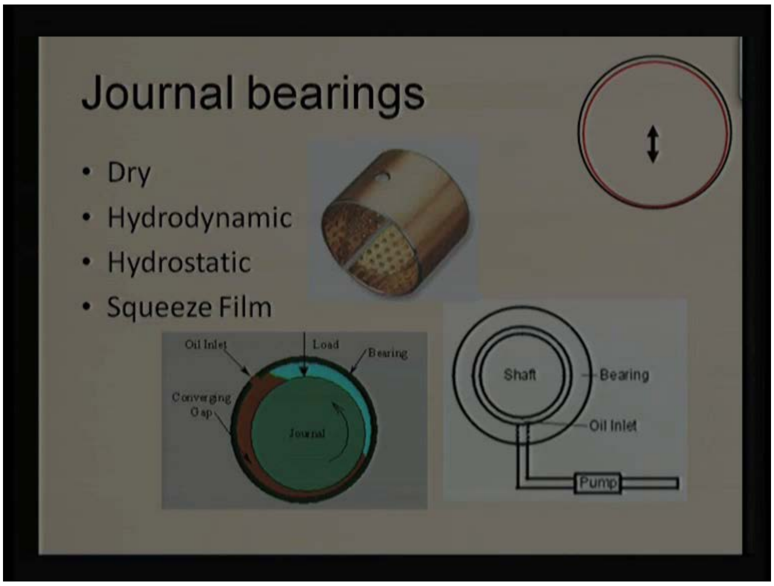
So, housing is essential, shaft is essential and bearing is essential and overall package overall assembly can be known as a journal bearing. If I do not use any liquid, assembly liquid then, I can say this is a dry bearing, dry bearing may be a natural oxide layer on a surfaces or we can use the dry lubricant also or solid lubricants, those things can be used and we can divide or we say classify journal bearing as a dry journal bearing.

Then, there is a possibility of hydrodynamic action, shaft is rotating related to the bearing, because of this relative motion, there will be pumping action and due to pumping action, there will be levitation of the shaft and that will be known as a hydrodynamic journal bearing.

There, is a possibility, we supply lubricant with a pressure. Under pressure, this shaft will be levitated or will be displaced from the oil hole in those situation naturally, oil hole need to be from the bottom side or from sides, so that shaft can be levitated. While in case of the hydrodynamic, generally we are providing from the top, in hydrostatic it will be just reverse, because we know wherever the shaft is going to touch the bearing surface, their lubrication is required and we need to palm the lubricant to levitate the shaft.

And one more lubrication mechanism, that is a squeeze film lubrication can be utilized with this configuration, you can say the squeeze film journal bearing. So, journal bearing can be classified as a dry journal bearing, hydrodynamic journal bearing, hydrostatic journal bearing and a squeeze film journal bearing.

(Refer Slide Time: 06:06)



To give a better understanding, this slide is showing some sought of a sketches, I am assuming this red color circle is a shaft periphery outer surface and this black color circle as a bearing bow in a surface of the bearing, there is a some clearance and this arrow is indicating the motion of shaft, this motion of shaft is continuously changing, it is a center is continuously at a some distance from the bearing center and the distance is continuously changing with the time. So, that is going to give squeeze film action, what we have discussed in fluid film bearing topic? So, this is a known as a squeeze film bearing, shaft bearing clearance and the liquid lubricant may be there.

This is another sketch, which shows there is a pump, there is a pipeline and oil is getting pumped in this, so this is a oil inlet, this is a shaft surface, this is the bearing, because of the pumping action and pressure which is generated over this side, shaft will be levitated, it will be in air or we say that, it will not be touching the metal surface, there will be complete separation under pressure. Of course, when I use a complete separation, that means, apply load is balanced, it should not happen that, applied supplied pressure is much lesser than applied load, then naturally on that situation, this will not work and shaft will again touch the bearing surface.

So, for an equilibrium point of view, from design point of view we say that, shaft will be levitated, it will not touch the bearing surface, because of this pressure and the pressure will be designed as per the requirement, so this is hydrostatic bearing. Coming to the dry bearing we seen that, this is a typical dry bearing, split it so that, it can be fitted in some journal or it can be fitted in bearing housing and journal will be supported on this.

Now, there is some sought of, there are some sought of dimples on this. So, this bearing also can be utilized to store the lubricant, if there is a some lubricant available and we are not supplying continuous lubricant flow or we are not providing continuous flow. In those situation, this kind of bearing can restore the liquid lubricant for some time and can survive give the lesser coefficient of friction. Again, there is a hole to supply oil in this or there is a possibility that this hole can be used to fix the rotation or fix the degree of freedom of rotation of this bearing. So, depends on the purpose this hole can be utilized and this will be known as a dry bearing.

Finally, is a hydrodynamic journal bearing that is a most popular reasoning, but this is known as a self acting bearing, motion of the shaft itself is a used as a pump, we do not require external pump sources, that is a main advantage of hydrodynamic bearing, running cost will be lesser and in overall view, this coefficient of friction will be even much lesser than rolling element bearing.

However, there are some problems at the start and stop, those needs to be eliminated that is why, many times we combine hydrostatic bearing with hydrodynamic action. We use a pump to feed the lubricant, so that the shaft is a levitated and then, allow shaft to rotate.

So, the coefficient of friction is the lesser well within bounce much lesser than rolling element bearing, running cost is also slightly higher than rolling element bearing, but bearing life will be much larger.

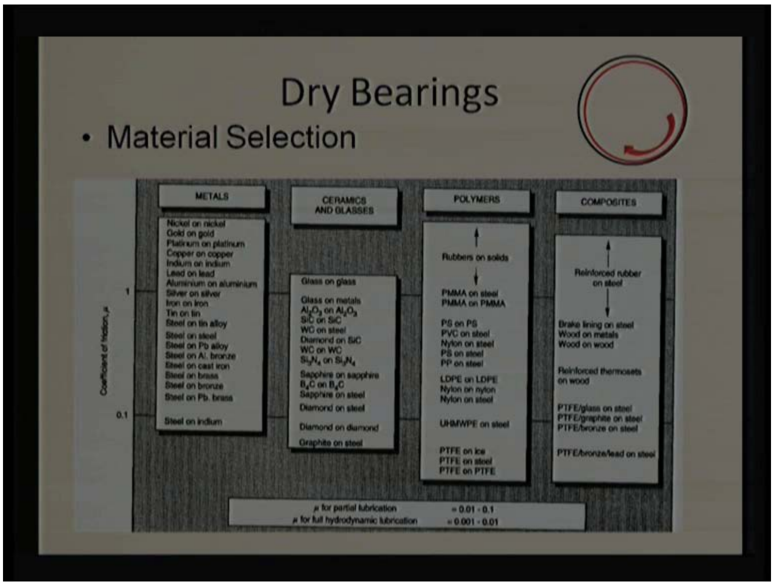
And it can be designed to control the vibrations, which in rolling element bearing are very difficult (( )) damping in rolling element bearing is almost next impossible, but this kind of bearing can eliminate all the vibration it can give complete support, very good damping.

So, this is a hydrodynamic bearing we are able to see there is a oil inlet, there is a shaft rotation and as a oil flow are start coming in, naturally there will be tendency to flow this side as well as this side, but there is a rotation, there is a pumping action going to happen in this convergent region.

So, most of the oil will be dragged in towards this direction, again there is a possibility this oil hole, oil can go in this region, but this is a diversion and there is a possibility the pressure whatever the pressure was generated it has come to back to the atmospheric and there is no pumping action. From here to here, the bearing may be star one and without lubricant or may be lubricant without much pressure in that or we call this is a cavitated source. So, most of the action is happening over here or we say we require a convergent gap for hydrodynamic journal bearing to make itself acting.

So, we can say the journal bearing can be classified as a dry bearing like this, hydrodynamic bearing like this, hydrostatic like this we require pumping source, this is one of the costly bearing and a squeeze film bearing, which mostly happens, because of the load action, typical example is (( )) engine, when the load is continuously changing and that is helping us to generate a lubrication mechanism.

(Refer Slide Time: 12:20)



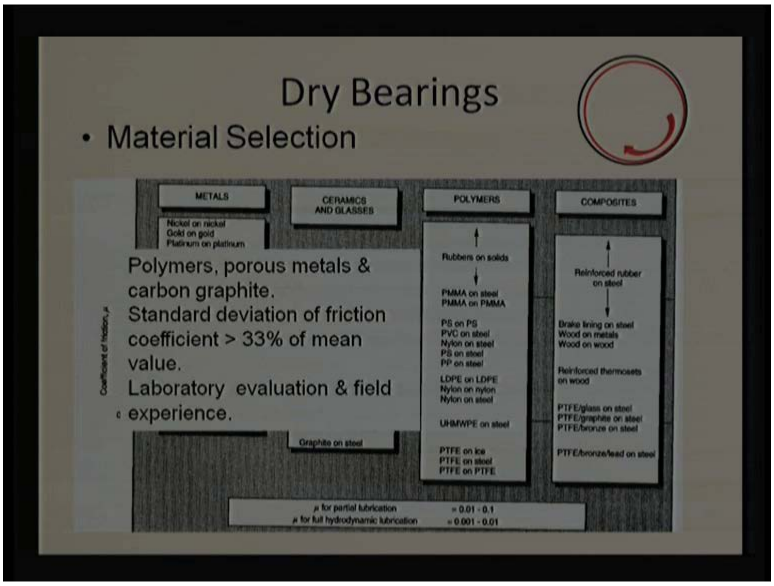
Now, start with a dry bearings what we are going to see, how to design this bearings and there again the red color circle and the black color circle, red color circle is indicating shaft surface, black color circle is indicating bearing bow and this arrow is showing the rotation; in this case, rotation will not be a major problem for us either in clockwise or in anti-clockwise, what is going to happen, when there is a direct contact, metal to metal touch will be there or if there is a natural oxide on this surface, then those surfaces also will come in a contact. So, contact will be there and whenever there is a contact, there will be wear and excess of friction naturally, when there is a excess of friction and wear we need to think about a materials. Materials in those situations need to be carefully selected otherwise, there will be high wear rate, lesser life and no use of using the tribology.

So, tribology is essential from material selection point of view, we should choose proper lubricant material, so that we can get desirable service from the bearing. When we talk about the material selection, naturally first choice comes on the friction; coefficient of friction need to be lesser, if coefficient of friction is a lesser, wear rate will be also lesser that is because of the direct contact, coefficient of friction is very high, there should not be any addition, because that is going to additional wear, there should not be too much vibration otherwise, it will be (( )) of the wear; so, that is why we need good material or we say coefficient of friction is plotted on y axis and x axis or we say showing the blocks metal, ceramic glasses, polymers and composites.

From friction point of view, I can say that this kind of a combination will be a better option; PTFE on PTFE, PTFE on steel, PTFE on ice, of course ice we are not going to use, so may be steel, or PTFE this combination is going to give better results from friction point of view. And naturally, there is a possibility lesser wear, if the hardness is well contained otherwise, when we talk about the composites we can think about the PTFE bronze or combinations whatever using with a fillers, PTFE can be make a stronger. So, this combination also can be recommended from coefficient of friction point of view.

And this figure is clearly indicating, when we talk about the full film lubrication, coefficient of friction is much lesser if I say 0.1 here, coefficient of friction here is a 0.001 almost hundred times lesser than this. So, hydrodynamic bearing will be always recommended, when we require more reliable performance, but the cost of the assembly will be on higher side we require a bigger size well, in case of the dry bearing we are not using any liquid lubricant, no pumping source. So, overall system will be much lesser we say in volume.

(Refer Slide Time: 15:33)



When we talk about the materials we say that, from this chart we are able to see the graphite on the steel is also good, PTFE is good also, most of the polymers are showing going to show the better performance either direct polymers or filled polymers using some sought of composites.

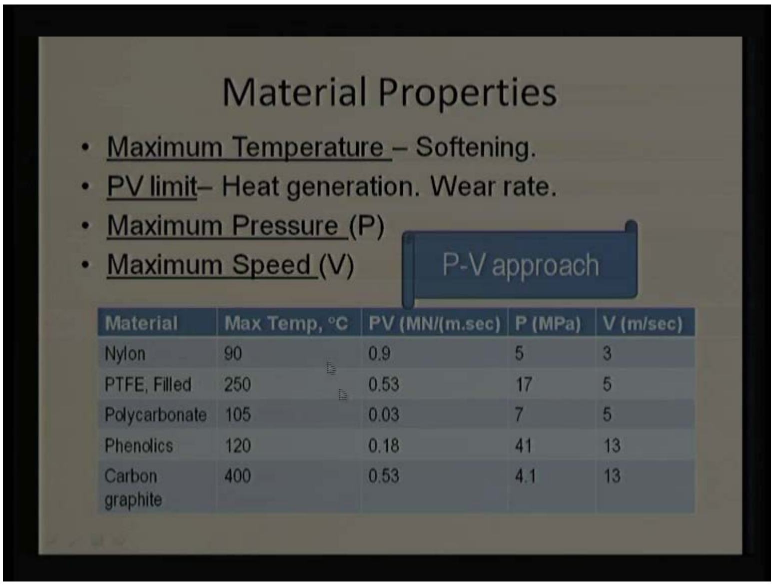
So, polymers and there is a possibility we can make about a porous materials, the porous materials, which have a some sought of white and they can act as a good reservoir for the particles, wear particles and they keep over all surfaces under mild wear condition.

Then, what is the problem, can we really design this kind of bearings that is the big question reason being; in the dry condition, coefficient of friction does not remain constant, if I plot and find out extended deviation, most of the time extended deviation is a more than 33 percent of mean value, which we cannot rely on any coefficient of friction to be one instant may be say in one situation coefficient of friction is 0.2 in next situation it may be 0.3 or may be 0.1. So, there is a huge variation in coefficient of friction that is why most of the time we say that, this cannot be generalized cannot be scientifically generalized.

So, what we require, whatever the component we are choosing, what is the material we are choosing at elementary level we will do the calculation, but final this should be checked against the experiments that is why we say that, laboratory evaluation and the field experience comes more compared to mathematical modeling of this system.

We can choose empirical relation we can use empirical relations get the results, but do not rely completely on those results we need to fabricate that particular setup and test it or we directly apply those components and test in field testing, that will give overall confidence and some more modification, if it is a required. So, we do not go ahead with this kind of dry bearing just based on the signs, just based on the mathematical calculations you may take some sought of experimental scope or experimental methods or the experimental test setups we use to find out, what will be the best for the particular configuration.

(Refer Slide Time: 18:07)



Material	Max Temp, °C	PV (MN/(m.sec)	P (MPa)	V (m/sec)
Nylon	90	0.9	5	3
PTFE, Filled	250	0.53	17	5
Polycarbonate	105	0.03	7	5
Phenolics	120	0.18	41	13
Carbon graphite	400	0.53	4.1	13

Now, when we talk about the material and important of material for the dry bearing; naturally question comes, what are the material properties, how do we select proper material, is there any definite property so I should look for that part of property? yeah if it is we have four important properties say maximum temperature, PV limit, maximum pressure and maximum speed.

It is interesting we are saying the PV limit and we are talking about independently pressure and V. So, this p and V, I can have a separate thing, but a combination or product is also been as a material property or in other words, when we are talking about the p, when the velocity is 0. We are talking about the V, when the pressure is 0. So, these two parameters will matter, it will give some results whether bearing is going to survive upto that pressure, bearing is going to survive upto that velocity, but PV is also important because, that is going to decide what will be the heat generation or we say PV factor can be converted to heat generation relation and that is going to say that with a bearing is going to be fine or soften or will there be any micro structure change or we say that, whenever there is a heat generation than naturally the temperature will also come or we say heat distribution capabilities.

So, PV is one of the most important parameter in this case, because that is going to count, what will be the coefficient of friction, what will be the maximum temperature and what will be the allowable pressure and velocity that is why we say most of the time we use PV limit or PV approach to design the dry bearing.

In addition, PV limit also can be related to the bearing we will discuss this in next few slides, while maximum temperature we know that is a limit of the softening or elastic limit will be converted to the plastic limit or there is as softening of the material, elastic limit will not be valid. So, in those situations we need to go ahead with the temperature below that maximum temperature, operating temperature at any time need to be lesser than maximum allowable temperature otherwise, whatever the relation we use, whatever design we use that will not be useful at elementary stage; however, if we require maximum temperature than may be, we want to control than there may be, there is a possibility of external cooling we can think in that direction.

So, what has been discussed we require four material properties; maximum temperature, what is a maximum temperature with bearing can sustain, PV limit what is a overall maximum value of this product, individual maximum pressure, individual maximum speed. And as I mentioned most important is a PV limit we need to see, what will be the maximum value bearing can sustain or we call as a PV approach and if we see the couple of the table particularly, we know the polymers and some time, the carbon graphite has been used as a dry bearing, because of the low coefficient of friction, low coefficient of friction was a first choice and then, we are going out with the other material properties and I mentioned that, coefficient of friction which is not a material property, it is a the more like a system property.

While here the maximum temperature we can see the nylon this is the one of the polymer, PTFE filled PTFE along cannot sustain very high temperature is generally saw from material. So, PTFE filled is 250 degree centigrade and polycarbonate that is a 105 degree centigrade lesser than PTFE, but may show the better performance phenolics and carbon graphite.

We are able to see the carbon graphite as a distinctly very high temperature here we are talking about the 100, 250 temperature, while here we are talking about the 400 degree centigrade. Naturally, for high temperature application, it should be able to utilize carbon graphite; it has a more advantages compared to any of the bearing. Talking about the PV limit that is the given in mega Newton per unit meter second, this is a nylon is going to show only the 0.9, but this is better than PTFE, is better and far better than polycarbonate, is better than phenolics.

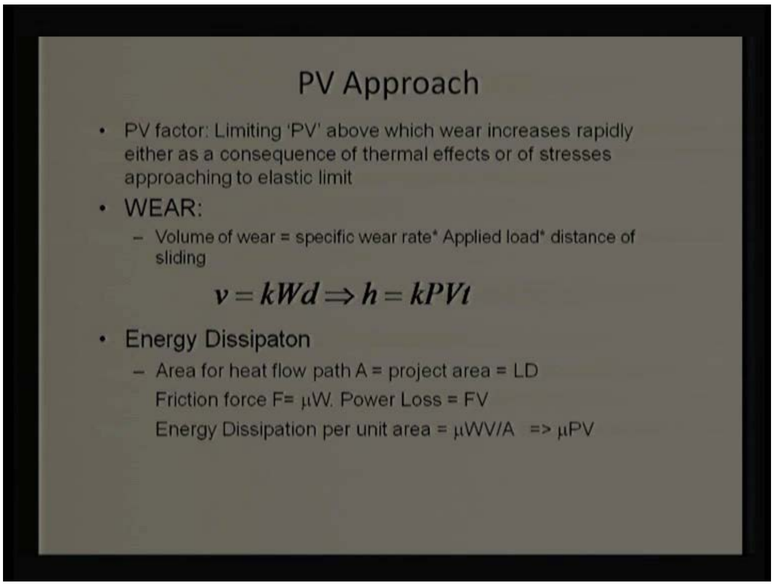
So, that is a showing a better results even though, my temperature point of view, nylon is showing the worst result in whole group, but it is showing the good results from the PV point of view, except we say that, high temperature this limit will continuously change right. So, that is why whatever we have application we need to see whether the low temperature application we can think about the nylon is a first choice, PV is going to decide what will be the bearing dimension.

Now, coming to the pressure, maximum pressure will it can sustain, nylon is not able to sustain very high pressure. Now, while carbon graphite is also 4.1 is a lower side, while phenolics is a giving a best results in this.

So, every case different material is giving results in case of maximum temperature; carbon graphite, in case of PV limit; it is a nylon, in case of maximum pressure; it is a phenolics, which is giving the best result. While maximum velocity point of view again the two materials are giving the best result, the phenolics and carbon graphite, this material table shows that, whichever the requirement we can decide or we can choose a proper material, but there is a problem these materials are been tested in one lab, may not give always the same results, there may be some fluctuation in these values, because these values are depending like PTFE, when we talk the field one, it is a glass field, it is a carbon field or any other material this properties will change naturally. Whenever we talking about the carbon graphite, (( )) carbon graphite is made that again will change properties.

So, it is not this material manufacturing process also plays important role. So, we need to check material with a manufacturing process and may be go through the catalog to choose proper values, this table has been shown just to indicate how to choose a proper material may be, when we have a temperature requirement we want to go for high temperature naturally, there is a bunch of option carbon graphite. Then, we want to go for the high PV limit naturally we have option of nylon, when we talk about maximum pressure and lesser velocity then, naturally we can talk about the phenolics, this is what we are trying to convey, but again these are not a 100 percent correct results, may be this is tested in one lab, then we try to apply on real object we need to see what materials are available and we need to choose a proper table corresponding to that, which is been given by the manufacturer or we say that, we can think about the designing dry bearing using PV approach.

(Refer Slide Time: 25:43)



Some few lines on the PV approach some description on PV approach we say, the PV approach is basically it gives a factor it gets affected it is the product and this product has been decided, so that we keep bearing wear within my domain we can use orchid equation, if we cross this PV limit still the bearing will survive for not forever may be say, few seconds, few minutes few hours, but not longer time. Again those that kind of life will be difficult to predict, because already cross domain that is why for a mild domain point of view; it is a PV approach is need to be used, because if we go ahead across this PV limit, wear rate is going to be increased drastically.

When the wear rate is increasing, it may be because of the excess of thermal heating, because the PV is also using energy distribution capabilities of the material that is why the, it is different from one material to other material, even the pressure and velocity we are giving, but this PV limit is different.

And there is a possibility of excess stresses we say stresses are going beyond elastic limit naturally bearing will deform, it will not be remaining in shape and it will turn out to be useless. So, we need to design bearing from PV limit point of view. I mentioned about that, PV can be converted in the wear rate or we say that, this approach can be utilized to estimate the wear rate or mild wear rate we know, where wear we have studied the wear. So, volume of the wear can be given as the constant k or we can use the word, specific wear rate into applied load and distance travel into product this.

In this case, the specific wear rate is also involving the hardness otherwise, we use a separate k and divide by hardness, but by most of the polymer cases we use a specific wear rate more commonly, now this relation can be given as a volume of the wear specific wear rate applied load W and distance of sliding.

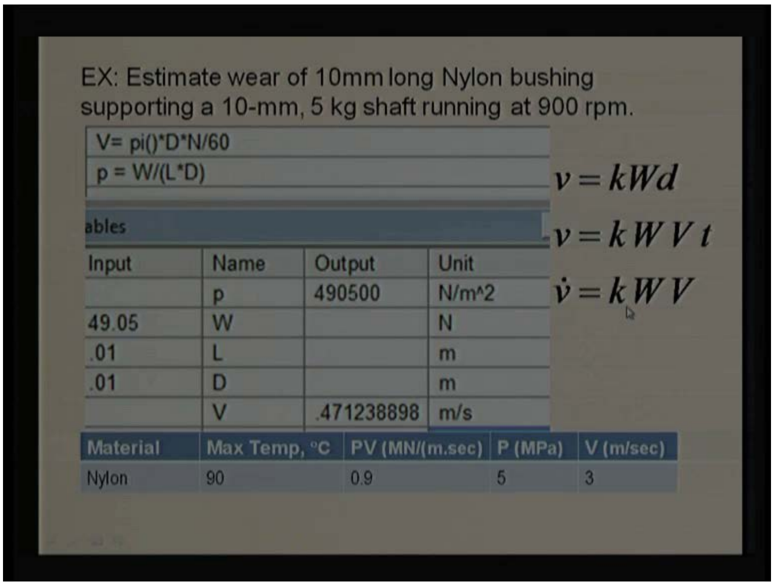
Now, if I assume the volume, is product of depth of wear into area or we say, h into a and a can be brought on this denominator side, now which is W by a can be given as a P right I will just repeat it we say volume can be given as a h into a and a can be transferred to this side, right hand side. So, W by a, will turn out to be P, d distance traveled can be given as a velocity into time. So, that is why the d is been given as a velocity into time, P as a W by e, load by area, k remains as it is. So, this is going to give the depth of wear or material we should assume that, there is a uniform wear this is a also involving PV factor.

So, this PV permissible factor can be given, if it is a crossing some limit naturally this wear rate cannot be or this equation this orchid equation cannot be used. So, that is why that PV approach will be utilized and to find out, k, it is well with the limit and the h can be figured out or we can estimate the bearing life.

In addition, as I mentioned that this is also involving heat distribution capabilities, what we can relate in this we say that, area for the heat flow can be given as a projected area I am assuming the bearing length L and diameter as a D. So, projected area will be L into D, friction force we know very well that it can be given as a normal load into coefficient of friction and normal load can be given in terms of pressure into area, when we talk about the power loss, power loss can be given as a friction force into velocity.

Now, what will happen we say we try to find out, energy distribution this is the power loss per unit area that is mu into W into velocity divided by area. So, this is energy distribution area, which is giving us a mu PV. So, again PV is related to energy distribution, is related to the overall temperature raise. So, that is why the PV factor which is been given at a catalogs can be utilized to find out, what will be the wear rate, it can be utilized also to find out, what will be the energy distribution or what will be the overall heat generation based on that, whether again this is a related to the mu most of the time, coefficient of friction is not given in the catalog we that is why we relate only the PV, even the PV is where in within the limit, even this energy distribution will be within the limits, that is why see this is the indirectly whole design criteria, PV pressure into velocity at any time, it is not a maximum value of pressure, it is not the maximum value of velocity, it is a product which is going to decide the design of bearing.

(Refer Slide Time: 31:19)



Let us take one example, you see example says, whether the estimated wear rate (( )) in this case, estimated wear of 10 mm long, the length is been defined, material has been defined as a nylon, nylon bushing instead of bearing we are using the word bushing, because that is the solid piece supporting a 10 mm shaft, which has a weight of 5 K g. So, it is a dead weight of the shaft, no external load has been applied. So, that is a slightly loaded bearing and nylon bearing should give better results over here, say 5 K g shaft, which is running at a 900 R P M. If I know the shaft diameter, I know the R P M we can find out, what will be the relative velocity? Assuming this bushing is a having fixed or is a it is fixed in a housing, no relative velocity, no velocity related to the housing, naturally related to the velocity, related to the shaft will be there. Now, we do the calculation only two formulas are required; first is the V that is a we say three formulas will be required; first, is the V, V is a pi D N divided by 60, because N is given in R P M.

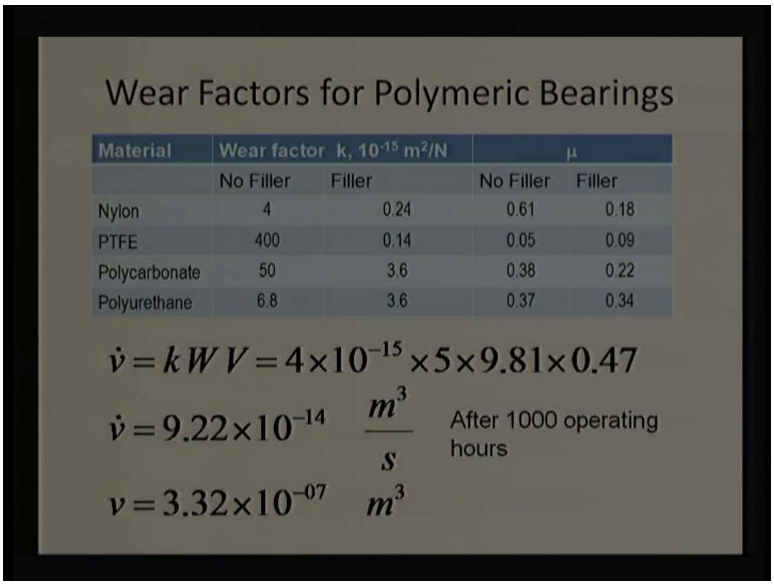
So, we required velocity in meter per second, D is a mentioned to us that is a 10 mm diameter and pi we know, is the 3.14. Now, P is a pressure can be calculated by normal force that normal force we assuming the 5 K g, that if you convert the Newton, it will be 5 into 9.81 that is a W divided by L into D that is the length of the bearing and diameter of bearing we assume in the shaft diameter is a same as a bearing board diameter, even though there will be clearance, but that will be microns.

When we talk about the 10 mm and may be say 10 micron clearance we will not be able to think about 10.01 that is not going to change a significant results that is why we use inter (( )) whatever the dimension over here that will be (( )) directly will not be worrying much 10.01, it is not going to change a much results right. So, this is what, this is variable list. So, pressure which is been calculated by using this formula is turning out to be around 0.49 mega Pascal. Similarly, velocity is turning out to be 0.47 meter per second we can check that, whether this this product or this parameters are well within limit or not for nylon.

And we what we get a nylon, yes pressure permissible pressure is a 5 mega Pascal or what we are getting 0.5 mega Pascal, 10 times lesser. So, that is right we are able to see the right result. Coming to the velocity, this velocity is 0.47 meter per second, permissible 3 meter per second, 6 times higher, no problem from velocity point of view; it is a clean check from pressure point of view; it is a clean check.

Now, we talk about the product say 0.49 into 0.47 naturally, it will be lesser than 0.4 and permissible limit is 0.9 that is again from that point of view, this product is fine obviously, the design the bearing is fine it can survive without much problem. The question comes, how to estimate wear rate this is say, bearing is fine, it can survive the load, there will not be excess of temperature raise, but when this bearing be able to survive (( )) we are not estimating wear rate how to do that, we can use some formulation we say we know very well, the wear cannot be given as the specific wear rate into normal load into distance travelled, distance travelled can be given in terms of velocity into t, velocity we know very well what is the value of velocity. And wear rate can be we say the, v divided by t will give me us a wear rate or wear rate can be given as specific wear rate into normal load into V we know W we know, where V, only unknown for us is a k again that is related to material parameter or related to the condition in which it is been utilized. So, we can take a rough estimation from the bearing catalog naturally, we need to refer bearing catalog and we need to see what is this value for the nylon.

(Refer Slide Time: 35:58)



And there is table, which shows wear factor wear a specific rate that is a 10 is to minus 15 in terms of 10 is to minus 15 it appears to be very low number, but when you calculate turnout to be very high number. So, in nylon when we are using in no filler and of course, in (( )) nothing has been mentioned this is only nylon; it does not say there is a filled or unfilled. So, we should take this values say, we say the k factor in our case will be taken as the 4 into 10 is to minus 15, there is other possibility if we use the filler in a nylon with a fillers may be coming fillers, when the glass (( )) fillers depends, any material fillers that, wear rate is turning out to be lesser again this will not be 100 percent correct, because the difference on the filler the rate will change.

Now, coefficient of friction also is there, coefficient of friction in the case of the nylon load in this case very high hardness, it is given as a 0.61, when it is a filled, coefficient of friction is given in a 0.18 again this values are again cannot be directly used, because coefficient of friction is a system property, is not a individual material properties; however, it can give some guidance, but not final value, for final value we need to iterate properly we need to manufacture and then, we need to test in reality.

There are some other material also PTFE, polycarbonate, polyurethane that is a like in this case, particularly wear factor for PTFE was significantly high that is a 400, almost

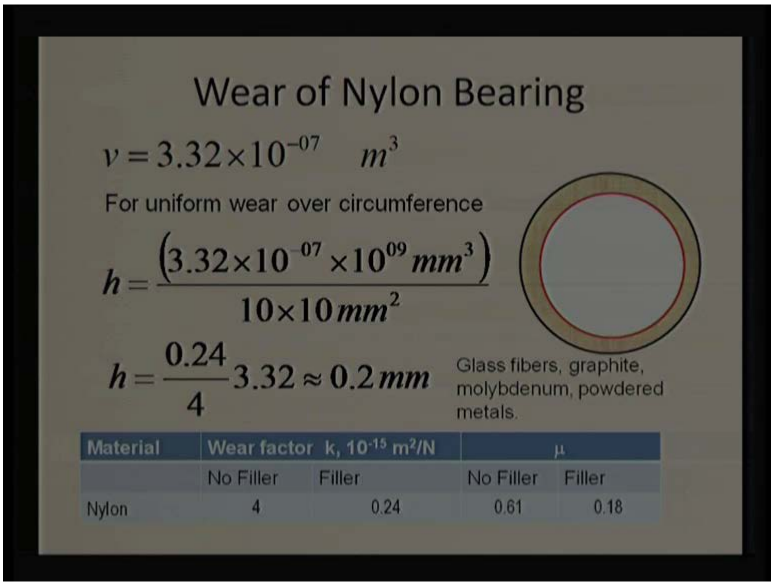
100 times compared to nylon, pure PTFE should not be used, it should be always used with a fillers and that is says with a fillers significant decrease in wear rate, huge decrease in a wear rate (( )) coefficient of friction here the penalty comes, PTFE is preferred from friction point of view, coefficient of friction is very low say the 0.05. But with the mixture of say, we are trying to fill it with a some sought of fillers, some long fibers than coefficient of friction is increasing almost a two times, but again if we compare decrease in a wear rate is much higher compare to the increase in the coefficient of friction. So, we need to see that (( )) if we when application is only for coefficient of friction we are not worrying of the wear rate, then we can use a pure PTFE, but when we say overall balance, overall economics then we need to think about filled PTFE.

Similarly, we have other materials so for in our case, we have a nylon we can take example of initially the no filler, it is not filled completely or it is not filled at all and then, this wear rate will turn out to be 4 into 10 is to minus 1, value of k will be 4 into 10 is to minus 15 use that value in the relation, which we drive in last line.

So, wear rate is given as a k into normal load into V, we know from this table this is specific wear rate is a 4 into 10 is to minus 15, apply load is a 5 K g. So, 5 into 9.81 Newton and the velocity which we figure out from the previous slide is a 0.47, 0.4721 something, but just to make it rounding of the 0.47 that is a wear rate. And this wear rate in mm cube per second is showing as a value of 9.22 into 10 is to minus 14, how do we know that, this wear rate is good or very high or see from this table, we can say this wear rate is very high compared to filled nylon, but in obsolete sense when we are designing bearing we will not be able to figure out as it is.

So, lets take example we say, we want this bearing to survive for 1000 hours, 1000 operating hours that is why we say, if we want this bearing to survive for 1000 hours what we are going to do this multiply this time 1000 hours into 60 minute into 60 seconds that is going to give us, what will be the wear, overall accumulated wear after 1000 hours. So, we will do that and you say, the wear is a can be represented as 3.32 into 10 is to minus 7 meter cube, again it is not going to give us complete indication, whether that is fine for us or not, should we recommend this kind of bearing design or we need to change material, it is not going to give a complete solution from here. So, we need to go ahead one step further to find out are we right or there is some mistake and we should change the material. For that purpose we can think about wear with as a uniform wear or not.

(Refer Slide Time: 41:02)



So, is the bearing (( )) shown, which is the bearing bow and there is a some thickness of the bearing, there is a possibility, there is a uniform wear almost average circumference every point on a circumference is a experiencing the wear. So, there is a continuous decrease in the thickness, regular thickness change that is why I say that, in this black color sign this black color is turning out to be red color having a slightly lesser thickness in this case.

So, it is a uniform, but there is a possibility that, this portion is a (( )) compared to any of that portion, there is a possibility, but on those situation we need to go ahead with a complete simulation and dynamic simulation go with the time to time and we say the how point of contacts are continuously changing over whole circumference and how wear rate is going to change, but for time being we can assume, there is a uniform wear, what is the meaning of that say if uniform wear over complete circumference or in other words, we can say h into a, area is a constant c area that is a projected area and h is a depth, whatever the initial board diameter and this board new board diameter difference divided by 2 that will be the increase in or decrease in thickness, the decrease in a thickness is going to give as h.

So, this will be same 3.32 into 10 is to minus 7 that is in a meter cube. So, we should change to the mm cube and that is a that is why this multiplication comes to 10 is to 9 divided by area we know the projected area is a 10 into 10, 10 mm is a length and 10 mm is a diameter, so that projected area, again we are not taking this decrement whatever the happening that is a decimal point we are not taking reason being that, is not going to affect overall results to significant level, there will be (( )), there will be some delta variation in that, but we are not much worried about that.

So, for a this case we are with yeah in this case, the straight forward calculation there is a 3.32 10 is to minus 7, 10 is to plus 9 of course, this is going to give 10 is to minus 9, 10 is to minus 2 from here that is why this will turn out to be 10 is to minus 9, this is 10 is to plus 9 this will be cancelled out, overall wear weight will turn out to be 3.32 mm at the significantly high value.

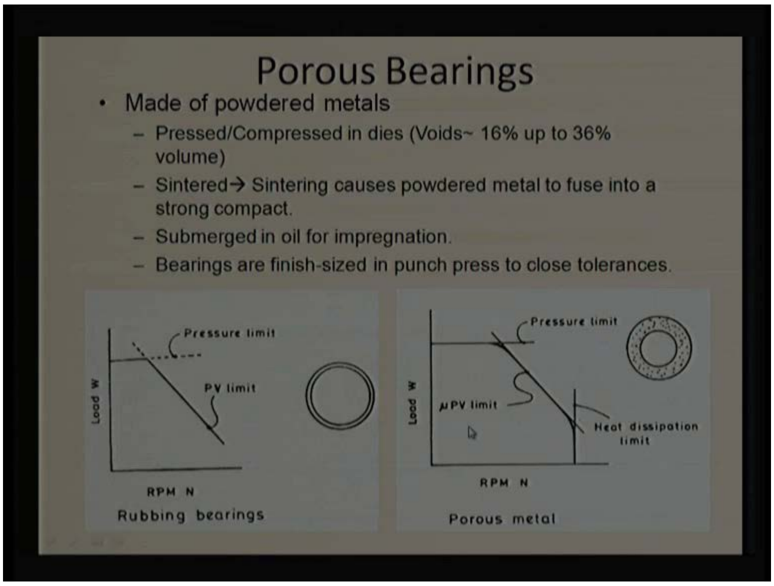
We have a bearing board diameter 10 mm, there may be thickness of 5 mm, 6 mm, 7 mm and out of that 3.3 wear, 2 mm wear is going to wear out. So, that is a highly undesirable. 10 mm is a maybe say with a keeping a thickness of 5 mm, 6 mm and more than half of thickness is been removed.

So, in that case the impact loading will start bearing will not be able to support this system, there will be complete (( )) jump from one corner to other corner, bearing will turn out to be instable of course not at the initial stage, but at the latter stage. So, that is why the bearing need to be replaced much lesser than 1000 hours may be, say even 10 hours, 20 hours, 30 hours we need to find out, what is the wear rate and how the vibration level is going to increase in other side you can think about, replacing this non filled nylon with the filled nylon, the wear rate in that situation is much lesser that is a 0.24 compared to 4, almost 16 times difference and that is a case, we can choose that kind of material, we can do calculation instead of 3.32 wear we are going to get only 0.2 mm wear rate at the rate. So, the depth of wear has a 0.2 mm, which is most of the case is acceptable.

So, when we choose the bearing having this kind of a wear constant or we say wear factor 0.24 bearing is going to survive for 1000 hours without much problem yes after that, we should replace it because of depth of the wear has reached to 0.2 mm and it will start vibrating and there will be some sought of a instability and wear rate may increase after that, because wear phenomena is going to change, wear rate may increase further.

So, in that situation we say that, if we go through this kind of exercise we can choose bearing properly that will be good for us. So, this is a of course, when we are talking about the fillers we can think about number of combination, the glass fibers, graphite molybdenum disulphide, some power metal surfaces, not surfaces, in the fibers we can be using those to the get a lesser wear rate from a nylon and that is important to make this kind of bearings.

(Refer Slide Time: 46:11)



Now, we will talk about the dry bearing and the one in similar category we can keep porous bearings, what is a porous bearing? See, porous bearing are generally made of the powder, we were talking about the non metallic bearing, the dry bearing non metallic polymer as a non metal, carbon graphite is non metal. Now, we want to use the metal, because that is the more popular most commonly used materials and mostly a manufacturing process are established, well established well understood. So, we can think about the porous bearing, why we are using the word porous? Because, these bearings many materials have generally the porous or voids and the percentage of the volume percentage of those voids may range between 16 to 36 percent substantially high value and how to make this, we are not going to manufacturing process just an over view, so that this bear bearings can meet by pressing pressing in a press.

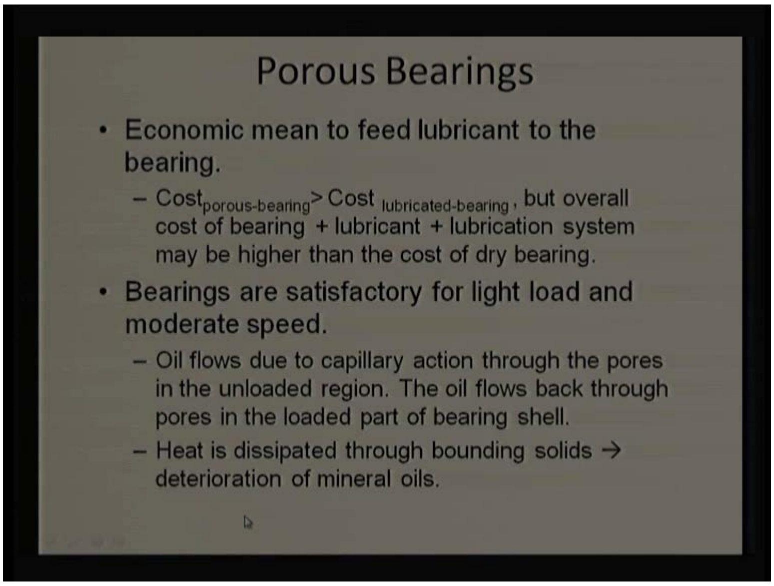
So, that it can be say that, compressed. So, it is a pressed or compressed in dies particularly shape, the bearing need to be compressed on that, once that is done naturally next process will be sintering; so, that particles they get engaged make a one bulk material, it should not happen on always powder form that is why the sintering is essential, after sintering this powdered metal will fuse and to the make a strong compact unit.

As this material or this bearing materials have a porous. So, when we sum it, we dip this material in the oil, what will happen, oil will get observed in this material and porous which are 16 to 36 percent volumes will be filled with oil. So, we are going to get advantage bearing filled with oil, we do not have to supply separately and of course, final finish again we need to go ahead with a finishing operation to get the tolerance, close tolerance or whatever the tolerance we require, so that we can maintain proper clearance.

Now, this figure is going to give competitive say in the one end bearing is initially rubbing bearing, allowable limit load is some W, allowable RPM we say some RPM, when talk about the porous one and compare with the rubbing one, we are able to see velocity limit is increasing, heat dissipation capabilities also increased or we say that, area occupied by this curve is much lesser than the area occupied by this curve.

So, while making the bearing porous we are able to provide better life, higher pressure limit, higher velocity limit or this will require lesser dimension overall lesser dimension compared to the dry bearing for the same life (( )) that is why the porous bearing are preferred in this situation, wherever there is a restriction of all supply we need a compact unit naturally, we can go ahead with a porous metal bearings.

(Refer Slide Time: 49:23)



Now, some time we say that, if I say the general sentence is the economic benefit of a porous bearing it is going to give a cost effectiveness, but when we go to market we find porous bearing cost is higher than dry rubbing bearings, the question comes how we are saying, these are the these bearings are the cost effective bearings, when you go to market we find this bearing at the higher price compared to dry bearings or compared to the normal bearings. Even though, we know the cost of the porous bearing is higher than cost of a normal we say dry bearing or lubricated bearing, but when we compare compare the cost of the bearing plus lubricant cost plus lubrication system cost and the piping and pump and all we find, initial as well as a running cost is much lesser in porous bearings.

So, if load is permitted, velocity is permitted we should prefer porous bearing compared to other bearings reason being; does not require much space lesser volume, more compactness, lesser running cost, lesser initial cost for the overall system that is why we say, the bearing if bearings are satisfactory for the application, then we should choose it and these bearings are satisfactory for the light load applications and moderate speed, light to moderate speed, they are not recommended for high speed, they are not recommended for medium on high way load of course, these are the relative types for the nano scale or the moderate scale every thing is a light load and this one will certain speed naturally we can think about all porous bearing for the nano or micro bearing.

Now, how these bearings are really operated we say that, in this bearings oil flows due to capillary action; there are small pores, the length of the pores or the depth of the pore is much larger than the diameter naturally, it will act as a capillary and due to this capillary action, whatever the oil which is stored in the pores or in voids, it will come out of that and it will be flowing on a surface say, oil flow due to the capillary action through pores in unloaded rolling naturally, the bearing is loaded it will apply opposite pressure, it will not allow the capillary tube to bring oil out.

So, under pressure oil goes back and no load case, only some oil will come out, it will not be continuous supply, but if it is not been removed, then flow will stop that is a simple flute mechanics thing we say that, it will reach to the surface, but if it is not wiped off from the surface, further oil will not come. So, that is a overall benefit of a porous bearing, their secret oil, they give the oil other surface and if there is a shaft, it can wipe it again some oil will come out and whatever the oil comes that can be go back or can be redeposit in the bearing under pressure. So, under no load condition oil comes out the surface and the load condition is go back in the bearing, so this story is happening.

However, we know very well that in this kind of bearings again will be subjected to the friction slightly hard friction compared to liquid lubricated bearing and lesser friction compared to the dry bearing. So, only heat dissipation capabilities need to be accounted or again, a short we can use the same PV approach which we have used for the dry bearing for this kind of application.

So, this kind of a thing can be utilized or we say that depends on, if the oil which we are filled is the mineral oil, then that temperature limit should come otherwise, if you are operating this kind of bearings for the high temperature application, then we should account that for high temperature application of the metal is supporting us, then we should use some sought of synthetic oil, which does not (( )) with the temperature or which has a high viscosity index, it does not change much performance. So, the we need to choose what the application is and how to select proper bearing for that. We will continue with this porous bearing in our next lecture and after that, we will try to start with the hydrostatic bearing in next lecture. Thanks, thanks for your attention.