Tribology
Module 6: Application of Tribology

Q.1. Is the thrust sliding bearing same as tilted pad/Michelle's pad bearing?

Ans: Thrust bearing is a terminology used for "Axial bearing (load is along the axis of bearing)". If the relative motion is sliding and applied load normal to the face of the bearing, then bearing is named as "Thrust sliding bearing". If the relative motion is rolling and applied load is normal to the face of the bearing, then bearing is called as "Thrust rolling element bearing". Tilted pad bearing use the adaptive tilt of the pad and vary load carrying capacity as per the required. Tilted pad may be "Radial bearing" or "Thrust bearing". Michelle's pad bearing is titled pad (pad on pivots) sliding bearing.

Q.2. Where aerostatic/aerodynamic bearings are used?

Ans: Gas lubrication is recommended for high temperature, high speed and light load conditions. Aerostatic bearings require external pressure source and can support its designed load at zero speed. Aerostatic bearings are commonly used in grinding, machining, and micro positioning applications, where ever precision is required. Aerodynamic bearings, which are self acting bearings, generate load carrying capacity based on the relative motion between two very closely mating surfaces. Typical example of these kinds of bearings is magnetic read/write head-disk used in disk memory storage devices.

Q.3. Its said rotation is preferred over linear motion, but we know that sliding bearings are capable of more load carrying capacity, then why don't we prefer them?

Ans: Sliding bearings are preferred over rolling element bearings only if the continuous relative motion is sufficient to separate two surfaces, otherwise rolling element bearings (most commonly available in market) are common choice.

Q.4. What is the difference in the bearing when the shoulder is either on outer or inner ring?

Ans: Shoulder on outer or inner rings provides axial support and can tolerate some thrust load. Often the location of shoulder on inner/outer ring is decided from the convenience of rolling element bearing (filing of rolling element between inner and outer rings) assembly and bearing mounting.

Q.5. Can cages be replaced by lubricant which won't allow the roller to move from its position and only allow rotational motion?

<u>Ans</u>: We have not come across such lubricant which restrict sliding of rollers and allowing only rolling action of rollers. In other words lubricants cannot act as cage of rolling element bearings.

Q.6. Do we require seals for magnetic bearing?

<u>Ans</u>: Seals are used to prevent crossing of fluid from one region to other region. For example seal in rolling element bearings are used to prevent leakage of lubricant from bearings to outside environment and prevent dust (& moisture) to ingress in bearings. In common magnetic bearing applications we do not requires such sealing arrangement.

Q.7. Does magnetic bearing act as both thrust and radial bearing?

<u>Ans</u>: Magnetic bearings can be designed to support thrust load, radial load, and combined load.

Q.8. Do air bearings require same conditions as magnetic bearings? Do they act as both thrust and radial bearings?

<u>Ans</u>: Air and magnetic bearings are often recommended for oil-free high speed environment. Both kinds of bearings lack in damping and require active control system to handle instabilities. Air bearings can be designed to support thrust load, radial load and combined loads.

Q.9. If the spherical roller bearing has more friction compare to ball bearing then why in railways which require continuous use of the bearing we use spherical bearing? Give reason other than load carrying capacity?

<u>Ans</u>: Spherical roller bearings can handle misalignment and poor (i.e. contamination, starved) lubrication. Due to self aligning properties of these bearings, deviation in the centerline of railway axle relative to the railway tracks is possible. Therefore these bearings are suited for the railways.

Q.10. Why seals are increasing friction even when there is no contact with rolling element?

<u>Ans</u>: Seals, in rolling element bearings, remain in mechanical contact with inner and outer rings. Either inner or outer ring needs to relatively rotate, therefore seal sliding against rotating rings. Such sliding motion between ring and seal cause additional friction force in rolling element bearings.

Q.11. Can MR fluid act as ball bearing? What will decide the friction in such type of anti-friction bearing?

<u>Ans</u>: The aim of MR fluids is to provide controllable rheological properties. On one hand MR fluid should provide very low friction, so spherical shape of MR particles provides desirable results. On the other hand MR fluid must provide very high friction on demand, so high magnetic saturation limit and irregular particle shape is desired. However, to minimize wear rate of contacting surfaces spherical shape of particles is preferred. In other words due to spherical shape of particles, MR fluid in off-state (zero magnetic field) may act as ball bearing by allowing particle to roll compared to slide. In such case viscosity of carrier fluid, relative sliding speed and applied load shall decide the friction force.

Q.12. What is the use of Tandem bearing? Give three practical applications of Tandem, O and X bearings.

<u>Ans</u>: Tandem is an arrangement of bearings where a team of bearings are lined up one behind another all facing in the same direction. For example double row tandem angular contact ball bearing is required to sustain high axial load in one direction. To support axial load in both the directions O or X arrangement of double row angular contact ball bearing is used.

Q.13. The table for coefficient of friction in bearing does not shows the dependence on material used, how will the coefficient of friction change with material? Will the trend remain same for different materials?

<u>Ans</u>: Material of commonly available rolling element bearings is SAE52100. The operating hardness (i.e. hardness during bearing operations) ranges between 55HRC to 64 HRC and bearing surfaces are very smooth. Due to these characteristics friction force, under normal operating conditions, the friction force is negligible. The trend of friction force shall remain same for different materials.

Q.14. Can instead of steel balls we can use hard rubber balls? What will be the complications with this design?

Ans: Rubber is known for its elasticity and deformability. With increase in elastic deformation, roll to slide ratio is reduced. Therefore bearing will not act as rolling bearing, but act as sliding bearing. Further increase in hardness of rubber increase its brittleness and chances of cracking. Therefore instead of increase the hardness of rubber we prefer to reduce the applied load. Under very low load condition rubber balls may provide rolling action.

Q.15. What does PV limit means physically? Is it possible that bearing is exceeding PV limit yet still works?

Ans: PV limit is a useful parameter in the section of Tribo-materials used for dry lubrication, which is related to heat dissipation capabilities of material. This limit defines a boundary line between “mild wear” and “severe wear”. In other words material experience operating conditions exceeding PV limit will be subject to rapid wear or overheating.

Q.16. Can hydrostatic and hydrodynamic bearings be used in outer space?

Ans: Lubricants in outer space are subject to radiant energy, temperature extremes and ultrahigh vacuum environments, therefore solid lubricants are preferred over liquid lubricants. In other words rolling element and dry bearings, which can be lubricated with solid lubricants, are better choices compared liquid based hydrodynamic and hydrostatic bearings.

Q.17. Why lubricant gets ruptured? Why is there discontinuity of lubricant in long bearing?

Ans: In divergent region of lubrication, the fluid pressure may decrease below the ambient pressure. Under sub-ambient pressure conditions liquid experiences tensile stress, which cannot be sustained by liquid lubricant and rupture of lubricant-film occur. The discontinuity of lubricant also occur in short and finite bearings, it is not restricted to long bearing.

Q.18. What is the optimum location of oil inlet with respect to the shaft rotation direction?

Ans: The location of oil inlet is referred with respected to load line. Sixty to ninety degrees (in the direction of rotation) with respect to load line is a preferable choice.

Q.19. How the flow of lubricant affects the temperature dissipation?

Ans: An increase in the flow of lubricant enhances the convective heat transfer, therefore increases the temperature dissipation. To simplify the calculation, often we consider bulk flow and average temperature approach (same body temperature at any instant of time) to estimate the temperature dissipation.

Q.20. Why the railway lines are not lubricated?

Ans: Lubrication of railway tracks reduces the lateral force (increase fuel economy), the wear of rails, the noise and ground born vibration. Due to these advantages railway lines are grease lubricated. Relatively thick bio-degradable grease mixed with solid lubricants is used to lubricate railway lines.

Q.21. What is negative friction?

Ans: Negative friction is just a concept to prove the importance of friction. In reality negative friction does not exist.

Q.22. How will we determining the coefficient of friction for a magnetic bearing?

Ans: Ideally the coefficient of friction for a magnetic bearing is zero, however there will air drag on the rotating shaft that cause the friction loss. In addition to this energy loss, active magnetic bearings (control + bias current required for electromagnets; power supply for control unit) require drive energy to float the shaft. As required drive energy is a loss, therefore often it is treated as friction loss. By evaluating these losses coefficient of friction can be estimated.

Q.23. Explain the reason why we are using high viscosity at lower pitch velocity and vice-versa?

Ans: In hydrodynamics a combination of higher velocity and higher viscosity causes thick lubrication, but this combination will cause high friction loss. Therefore to maintain sufficient film thickness and lesser friction at high pitch velocity lesser viscosity lubricant and at low pitch velocity high viscosity lubricant is recommended.

Q.24. Wear factor vs. friction coefficient, which will be preferred more? Why?

Ans: It depends on the application. For example in writing with pencil lesser friction and moderate wear of graphite is preferred. Similarly during walking moderate friction but minimum shoe wear is desired. Typically reduction in wear is preferred over reduction in friction.

Q.25. Is PV approach only for journal bearing?

<u>Ans</u>: PV approach is for every Tribo-pair operating under dry lubrication conditions.

Q.26. How can the wear be uniform when we know that the bearing will usually be in contact at the same position?

<u>Ans</u>: Uniform wear is an assumption. In reality it does not happen. In bearings, on surface wear local clearance changes, therefore equilibrium position of shaft changes.

Q.27. "Two well-spaced short bearings are better than one long one" what about misalignment?

<u>Ans</u>: In short bearing, the resistance to lubricant leakage (from ends) is relatively lesser compared to long bearing, which means for same supply pressure and relative velocity, lubricant leakage will be more in short bearing compared to long bearing. This will help avoid metal to metal and reduce misalignment of the rotating shaft.

Q.28. Compare "splash lubrication" with "completely immersed lubrication"?

<u>Ans</u>: Immersed lubrication, often termed as "Oil bath lubrication", is widely used for low to medium speeds application. Major drawback of this type of lubrication method is churning loss, which restricts usage of this lubrication method to lubricate rotating components lying on one horizontal line. With an increase in speed the churning loss increases and level of oil requires a reduction to decreases the churning loss. Splash lubrication is used where relatively high speed rotating components are on various levels, rendering the bath method useless. Higher peripheral speeds of rotating component helps to generate the oil mist, required for lubrication.

Q.29. What does graph contact stress vs. Brinell hardness signify?

<u>Ans</u>: Graph of contact stress vs. Brinell hardness is Contact stress is of compressive nature; therefore an increase in surface hardness can tolerate higher contact stress. This behavior of typical gear materials was plotted by published by AGMA (American Gear Manufacturer's Association) as a graph for gear designers.

Q.30. Give five criteria which will tell that the bearing has been mounted properly? Are there any standard techniques and guidelines for mounting of a bearing?

Ans: Bearings are designed with a specific internal clearance to allow free rotation of rolling elements, to compensate the thermal expansion, and to distribute load on rolling elements. If after bearing installation, the internal clearance remains same as the designed clearance, then one can state with confidence that bearing is mounted properly. Apart from maintain designed clearance it is a must to retain bearings rings on their seating surfaces (shaft for the inner, housing bore for the outer). Relative motion of inner with respective to shaft surface or/and relative motion of outer ring with respective to housing lead ring-wear and reduce bearing life. The internal clearance, running noise, vibration, heat build-up and radial retention of bearing rings on their respective seats are typical measurable criteria which indicate whether bearing is mounted properly or not. For proper mounting of rolling element bearings, following guidelines shall be useful:

- Anything that may come into contact with bearings should be kept clean, including worker's hands and tools.
- When bearings have to be mounted in unprotected places, steps should be taken to protect the bearing and mounting position.
- Depending on bearing type and size, mechanical, hydraulic or thermal methods are used in mounting. Make every effort to avoid nicking bearings.
- Prevent loose particles entering into bearings while being mounted.
- In heating bearings for easier mounting, heating temperature should not exceed 100°C.

Q.31. Why did we choose NLGI 2, what is the criteria of choice?

Ans: NLGI (National Lubricating Grease Institute) grade is a qualitative measure to classify lubricating grease. There are nine grades (000, 00, 0, 1, 2, 3, 4, 5, 6) and NLGI 2 average of these grades. "NLGI 000" grease will bleed (requires extra sealing measures) and "NLGI 6" cause high resistance (pumping loss), therefore until unless there is specific demand "NLGI 2" is the first choice.

Q.32. If NLGI 3 and 4 are hard, then why are we using them as lubricants? What type of grease is used in spherical roller bearing which is used by railways?

Ans: To lubricate any Tribo-pair, lubricant needs to be maintained at the interface of Tribo-pair. This can be achieved by pumping lubricant at the interface or increasing its resistance against its leakage from the interface. "NLGI 3" and "NLGI 4" are resistant against their leakage from the Tribo-interface, which allow maintenance team to lubricate Tribo-interface intermediately (i.e. once in a day, once in a week, etc.). Hence "NLGI 3" & "NLGI 4" can be used as lubricants. "NLGI 3" is preferable choice for spherical roller bearings used in railways.

Q.33. Which NLGI would be suggested in robotic arms?

<u>Ans</u>: Robots have many moving elements. Using grease to lubricate robotic arms allow smooth proper function of robotic arms. Often low NLGI grade greases ("NLGI 00" and "NLGI 0") with proper sealing arrangement are recommended for robotic arm. For example molygrease (NLGI 00) which contains solid lubricants is recommended for planetary gear reduction units if robotic arm.

Q.34. Do we have magnetic gears like magnetic bearing?

<u>Ans</u>: Yes. The repulsive magnetic forces are used to transmit power without any mechanical contact. A magnetic gear uses rare earth permanent magnets to transmit torque between an input and output shaft without any mechanical contact.

Q.35. Hypoid gears the axis perpendicular or just offset? Why there will be more sliding in this gear?

<u>Ans</u>: Hypoid gears are type of spiral bevel gears (bevel gear with helical teeth) whose axes do not intersect with the axis of the meshing gear. In other words axes of pair of hypoid gears are perpendicular (generally, angle may be other than ninety degrees) with an offset. As there is offset in axes, sliding is bound to come.

Q.36. How will we stop lubricant bleeding?

<u>Ans</u>: To reduce lubricant bleeding, effective viscosity of lubricant needs to be increased. To complete stop leakage, effective sealing arrangement is essential.

Q.37. What will happen to solid lubricant after getting sheared?

<u>Ans</u>: Solid lubricants, after getting sheared, either squeezed out from interface or acts as soft debris between Tribo-surfaces. To re-utilized sheared solid lubricant often liquid lubricant is used along with solid lubricant. Liquid lubricant acts as carrier fluid.

Q.38. Can we give lubrication to open gear system?

<u>Ans</u>: Low speeds and very high torque are typical operating characteristics of open gear drives. Due to such extreme operating conditions there is hardly any possibility of hydrodynamic lubrication, so grease mixed with solid lubricants (i.e. graphite) is preferable choice.

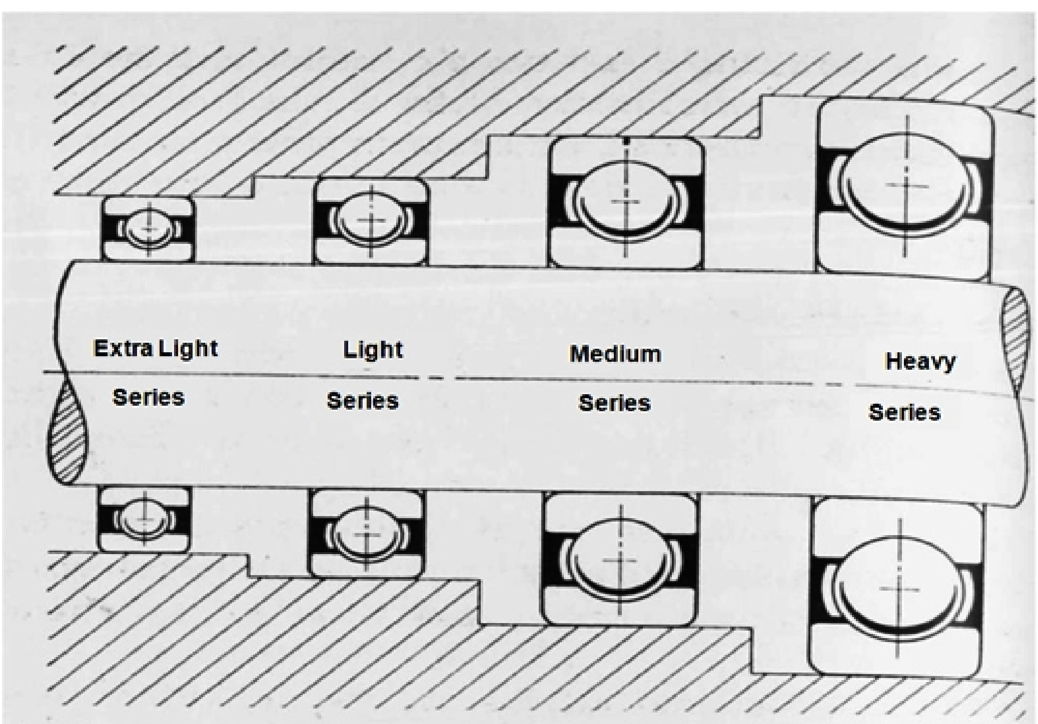
Q.39. What is scuffing? How many types of failure mechanisms are there for gears? Discuss some.

Ans: Gear teeth are subject to wear, bending fatigue and surface fatigue. The sliding motion, below and above pitch line, causes wear of gear teeth, which in turn increases clearance and reduces contact ration; and finally leads to failure of gears. Gear teeth also flex as they go in and out of mesh, which leads to bending fatigue of gears. Surface fatigue may be moderate, localized or destructive. It can be caused by failure of the lubricant film (i.e. due to overheating in the mesh area, misalignment, excessive load, etc.). The resulting metal to metal contact produces alternative welding and tearing that quickly removes metal from the gear surfaces. Destructive surface fatigue, often termed as "SCUFFING", occurs due to high meshing temperature. In this failure material may be displaced radially over the tip of the gear teeth. Material may be missing from above and below the pitch line, causing the pitch line itself to stand out prominently. At this stage, the gear is unfit for further service.

Q.40. While finding pressure in spur gear, why didn't we consider the pressure applied due to lubricant? What will be the pressure due to lubricant included?

Ans: The contact pressure in spur gear is generally very high compared to lubricant supply (ranging between 2 to 5 bar)pressure, therefore accounting supply pressure does not affect the contact pressure.

Q.41. Consider the figure below:



Is it necessary that the size of bearing has to increase with the increase in load carrying capacity? Would change in the material of the bearing helps in reducing the size of the bearing while keeping the load carrying capacity same?

Ans: Load carrying capacity can be increased by increase width, increase diameter or increasing number of rolling elements. Therefore based on the dimensional constraints bearings can be selected. Generally change in material, just for load carrying capacity is not recommended.

Q.42. In Elasto-hydrodynamic lubrication does $h_{min} \propto W^{-0.075}$ mean that very high load can be supported in this case?

Ans: Yes, very large load can be supported in EHL lubrication regime.

Q.43. What is the physical/scientific reason for the $h_{min} \propto W^{-0.075}$ and $h_{min} \propto U^{0.68}$?

Ans: Elastohydrodynamic lubrication is based on the elastic deformation of asperities and relative velocity of sliding surfaces. Increasing load on the sliding surfaces causes elastic deformation of new asperities which did not play load support earlier and only marginal deformation of asperities which were supporting the applied. Therefore minimum film thickness value does not significantly with increasing applied load ($h_{min} \propto W^{-0.075}$). On the other hand, relative velocity is the source of pressure generation between two sliding surfaces. Due to fluid pressure two surfaces get separate and minimum fluid film exists. Therefore in hydrodynamic lubrication $h_{min} \propto U^{0.5}$ is used. In Elastohydrodynamic lubrication we consider the viscosity thickening due to increase in pressure, which in turn increases the fluid pressure. Therefore the effect of velocity is more dominant in Elastohydrodynamic lubrication ($h_{min} \propto U^{0.68}$) compared to velocity effect in hydrodynamic lubrication mechanism ($h_{min} \propto U^{0.5}$).