Tribological audit on gears

Tribology has been there since the beginning of recorded history. Tribology is the word basically derived from Greek in which ‘ tribos’ means rubbing. From this we understand that “ Tribology is the scientific study of interacting surfaces and of related subjects and practices”. [1] The 3 factors that are considered to be a major factor in tribology are friction, wear and lubrication. Friction is defined as the opposite force created when 2 surfaces are in contact. Friction can cause damage to the parts in contacts due to the heat generation and this can be studied using tribology. Wear is defined as the irregularities caused in a surface due to the external factors. Running a machine with weared parts can reduce the life of the machine. Lubrication is defined as the viscous liquid applied between two surfaces in contact for better performance and longer life.

Untitled. jpg Gears are means by which power is transferred from the source to the application. [2] In the present world it has been used in most of the mechanical machines so that power can be transferred in an easier and sufficient way. The gearing technology started at about 100 years before and it was carried out by the Europeans in the ‘ Dark Ages’ to bring out the development in the gears. [2] As years passed by more developed versions of gears were introduced which were lightweight, with high speed and gears that could withstand high loads. The gears are used as an important component in automobiles so that power is transmitted from the engine to the wheels to cause an increase in the speed of the vehicle. Hypoid gears are one of the common gears used in automobiles to do this operation. [2] Transmission which is defined as two or more gears working in tandem is used as an important principle in automobiles.

In today’s world many gears have been developed and these gears are being used for different purposes. These gears have been been divided into 2 such as:

External Gears: In these types of gears the teeth can be found outside the cylinder or cone.

Internal Gears: These types of gears have teeths in the inner surface of the cylinder or cone.

Spur GearsWith either internal or external gears a lot of gears have been developed for different purposes and these gears are explained below:

a) Spur gears: This is one of the most common types of gear. These gears have teeth perpendicular to the face of the gear and the edge of the tooth is parallel to the axis of rotation. The disadvantage of these types of gears is that they are a little noisy at low speeds and this reduces to a minimum at higher speeds. [7]

b) Rack and pinion gears: This type of gears consists of a rack more like a spur gear with infinite radius of curvature and a pinion gear which keeps on rotating over the rack. These types of gears are mainly used to convert circular motion into linear motion. Trains run on railway tracks based on this principle.

Racks Gears

c) Helical gears: Helical gears are almost similar to the spur gears. The difference is that the teeth’s are in a helicoids shape and are not parallel to the axis of rotation. [7] It is less noisy than the spur gears and is widely used

in industries. [7] Double helical gears are also used which has helical gears kept inversely on both sides.

Helical Gears

d) Worm gears: These are the type of gears that consists of a concave teeth profile and this teeth is usually engaged to helical gears. It is used where power is to be transferred at 90 degrees. Here sliding motion is caused rather than helical motion. [7] Heavy lubricants with good film thickness is used to prevent contact of the metals because since the teeth is small there is a chance in breakage of the teeth causing higher maintenance of the gears.

Worm Gears

e) Bevel gears: These types of gears have conical shaped teeths. It is mainly used to connect shafts to intersecting lines. The angle between 2 bevel gears can be between 0 to 180 degrees depending upon the purpose. Bevel gears with equal number of teeths and shafts at 90 degrees are called miter gears. Spiral bevel gears also known as hypoid gears are used in automobiles. These gears will always have shafts at 90 degrees.

Bevel Gears

f) Epicyclic gears: Here 2 or more external gears move inside an internal gear as shown in Fig. 8. These types of gears are mainly used in mechanical differentials.

In all the types of gears above due to their contact with each other a frictional force is created between them and due to these frictional forces it can cause wear to the gears. Here the tribological factors come into play and

reduce the life cycle of the gears. This can also cause the tooth of the gears to break. So lubricants have to be used to an extent to improve the life of the gears and materials have to be used according to the kind of environment in which the gears are to be used.

Materials used for making Gears:

Gears can be made from a wide variety of materials such as wood to high steel alloys depending on the requirements. Gears in different mechanical machines needs different materials to overcome the surrounding obstacles, for longer life of the equipment and the machine and also to reduce the cost. Due to these the design of gears will always depend on the accuracy level needed for the gears, load to be applied on the gears, speeds to which the gears will rotate, the noise limitations and the material to be used. So the cost of the gear will always depend on these factors. [2] So while selecting materials we should consider the tribological factors that would affect the gear while its operation like:

* Allowable bending and Hertz stress because as the bending stress is low there is a chance for the gear to get bend at higher temperatures.

* Wear resistance as the gears and gear tooth’s should not get weared at higher speed of rotation of the gears.

* Impact strength as the gears should not break when it is engaged with higher force with another gear.

* Water and corrosion resistance to resist against corrosion due to lubricant action.

* Manufacturing cost to make the gears profitable

* Size and weight so that the gears can be used in all machines

* Lubricant requirements to see that costly lubricants are not required to maintain the gears.

* Dimensionally stable and reliable.

* Stress free structure [3]

Depending upon these factors, different materials are used and the details about properties of the materials and the conditions on which these materials are used are given below:

1) Plastics: In the past, gears were made of wood or phenolic-resin impregnated cloth and as years passed by more light weight, low cost gears were required. With the invention of new polymers in plastics it gave more opportunities for the preparation of light weight, low cost gears. For this the most common plastics used today are acetate and nylon resins. This plastic gear reduces the cost of the gears when produced at large quantities and also is sometimes mixed with metals for longer and quieter operation of the gears. But since these acetate and nylon resins gears are limited to certain conditions such as strength, temperature resistance and accuracy it was required to make a different polymer for the preparation of the gears and a different polymer called ‘ Polyamide’ was developed. This polyamide molded gears could resist higher temperatures and could be used in certain situations in place of metal gears to overcome the tribological factors but due to its higher cost for production its still not used in all situations. [2]

2) Non-ferrous alloys: Titanium is also another material that can be combined with other metals to form a gear. Also the die cast materials like zinc, aluminium, brass, bronze are also used for gears due to its high corrosion property, high strength, less machining. These non ferrous alloys can be used for making gears because it can overcome most of the tribological factors. But these metals cannot be produced at large quantities due to its high cost of production. [2]

3) Cast iron: Cast iron is used for the preparation of gears because of its low cost, machinability and moderate mechanical properties. There are 3 types of cast irons differentiated basically depending on the structure of graphite in these irons. These are gray iron, malleable iron and ductile iron. Out of these the malleable and ductile irons have good shock resisting property and are mostly used in most of the gears by mixing it with other metals so that the gear made from this will be able to overcome most of the external factors affecting tribology. [2]

4) Sintered Powder Metals: These metals are used where high production is required with low cost. The process is simple where powder is put into the suitable high pressure die. A wide variety of selections of powders are available in this section of powdered metals. This sintered powder is also widely used in automotive industries by hot forming process which was recently developed to improve the mechanical properties of gears and resist against the effects of tribology. [2]

5) Hardened steels: This is one the most commonly used material in all industries for the manufacture of gears. These types of materials are used

based on the factors like load, time period for which the material will work, lubricants to be used and the surrounding conditions that affect tribology such as temperature, pressure and humidity. When the gears are to be run at moderate temperature a low alloy material will be used for the production of gear and if the work load on the gear is to be high a high alloy material will be used after case carburizing or case nitriding to increase the fatigue strength. Of the 2 processes the case carburizing will have more distortion than the case nitriding process and would require an additional grinding process that would cause an increase in the cost of the gears. [2] Steel alloy is mostly used for the production gears more than normal steels.

The materials used for gear preparation are an important factor for the preparation of gears as the working, the life of the gear, strength of the gear will all depend on the material. The material chosen must also be able to withstand the friction, wear and lubrication and have to be overcome to have long lasting and strong gears. If correct material is not chosen according to the criteria the machine can be of a complete failure and may not work properly. While selecting the materials the following factors have to be considered:

Surface of the gears:

The surface of gear has an important part in the life cycle of the gear as it must be able to withstand friction, wear and it must be able to properly engage with other gears and provide the required power to the required output shaft. For gears the surface texture which is defined as “ the combinations of imperfections on a surface” [11] must be smooth and the gap between two teeths must be of proper size so the the 2 teeths are

engaged correctly to each other. Eventhough gears now produced are with poor geometrical perfection or quality of surface texture companies is trying hard to produce gears with reduced surface texture by processes such as honing, lapping and super finishing methods.

This is the opposite force caused when one body moves tangentially over another. The force can cause heat between the surface and can lead to the wear of the parts. The quality of the material used and the surface roughness decides the amount of friction that would occur on the surface of gears and this inturn decides the depth of wear that would occur on gears. The different types of wears that occurs on the surface of gears are given below:

Ø Adhesive wear: This type of wear occurs on the tooth surface and is very difficult to find. Here the surface of the tooth gets a quashed look due to the long running of the gears. A moderate adhesive wear can also be caused on the gear surface due to variable loading of on the gear at different times. [15] The moderate adhesive wear will appear bright and can be seen with the naked eye 9as shown in fig. 11).

Ø Abrasive wear: This type of wear occurs on gear surfaces when fine or severe dust particles are present in the lubricant used to reduce friction between the engaging gear surfaces. This type of wear is mainly seen in machines used at cement factories, road laying machines, mining machineries etc. The abrasives can cause the surface texture of the gear to change which in turn causes the application of more lubricant to the surface for the smooth running of the machine. [15] The abrasives in the lubricant

can be of 2 types and cause wear to the gear in 2 methods which are classified as mild abrasion and severe abrasion.

· Mild Abrasion: This type of wear is caused when mild or fine particles are present in the lubricant and this causes wear on the surface of the gear. This cause only small marks on the surface of the gear and wear increases in the longer run of the gears. [15]

· Severe Abrasion: This type of wear is caused when large particles are present in the lubricant. It causes a larger wear in the gear and also can cause the breakdown in the machine. [15]

· Corrosive Abrasion: This type of abrasion is caused when the chemicals in Lubricating oil reacts with the surface. [15]

Conformity: It is defined as " the degree of agreement between the surfaces".[1] The degree of conformity must be maximum for gears to exactly engage and run for a longer period of time. Initial wear can increase the conformity between the gears. If the right amount of lubricant is added during the initial wear period the initial wear will stop by itself and increase the conformity between the gears. High conformity is found mostly between 2 flat surfaces. The lowest conformity is found between a flat surface and a ball.[1]

Surface Texture: It is surface condition that depends on the material of manufacture, the way in which the material was processed, the lubricant used on the surface and the type of wear that occurs on the surface. Surface texture is an important factor for gears movement of the gears and the

degree at which the gears touch each other depends on this property. Below the shows the terms that are used for defining the surface texture:

The irregularities in the surface of gears must be reduced to minimum while making a gear so that the thin film lubricant can run smoothly between gears and reduce the tribological factors between the gears. The surface finish should be smooth and must be free from sharp irregularities to increase the fatigue strength of the gear and this should be maintained throughout the gears to have a quieter operation. [3] The surface of the gear which is to be in contact with the other gear has to be of higher strength so the tooth don’t get weared out easily. The precision of the gears structure should be considered for long lasting of the gears. The surface of the gears can be improved using methods like polishing, heat treatment methods,

Lubrication for smoother operation of gears:

Lubricants are a viscous fluid applied between 2 gears for reducing the heat generated between them and to lubricate the teeth to reduce the friction between the gears. The selections of lubricant have to be correct to in order to provide high efficiency, good reliability, low maintenance and long life for the gears. [4] Generally the gear operates in 3 modes of lubrication mainly boundary, mixed, full film and hydrodynamic lubrication. The boundary condition is attained when the gear is started or stopped. With increase in relative motion the mixed lubrication condition is obtained and with further increase in speed the gear is said to run at full film lubrication.[3] “ If there is a lubricant between the 2 contact surfaces and it is sufficient to protect the gears from contact then the lubrication is called as hydrodynamic lubrication”. [1] The lubricant differs from the normal liquid by the property

of viscosity. Viscosity is defined as “ the measure of the fluids resistance to flow”. [13] Since gears would be under high pressure and sliding it would require a medium to high grade lubricant. As the viscosity of lubricant increases the lubricant is said to be more reliable for the gears. A gear lubricant is said to have the below factors for obtaining a good performance from the gear:

* thermal and oxidative stability

* thermal durability

* compatibility with seal materials

* protection against excessive gear and bearing wear

* high-temperature extreme pressure protection

* gear and bearing cleanliness

* emulsibility characteristics

* rust and corrosion protection, especially to yellow metal components

* antifoaming characteristics [5]

The major tribological factors of the lubricant are:

· Viscosity: It is a property of the lubricant for providing the lubrication affect to the engaging gears. The viscosity of the lubricant can protect the gear from friction. Higher the viscosity greater the protection to the gears.

· Additives: It is a chemical substance added to oil to increase the property of oil and protect the gear against wear. Additives can protect the gear from wear and overheating. Better the additives greater will be the protection for the gear.

· Contamination: It is the addition of an external component in the lubricant that could reduce the property of the lubricant. This is a disadvantage for gears. If the contaminated substance is large it can cause a breakdown to the gears.

· Degradation: It is the wearing out of some parts of the gear due to chemical reactions. This is also a disadvantage to the gears. More the degradation more the chance for the tooth to break off.

The below table explains the factors affecting selection of industrial gear lubricants:

Factor
Requirement

Gearing Type

* Spur and bevel

* Helical and spiral bevel

* Hypoid

* Worm

Low slide, low speed

Moderate slide, moderate to high loading

High slide, high loading

Excessive sliding, moderate to high loading

Loading

High loaded industrial gear drives requires the use of extreme gear pressure gear lubricants.

Surface finish

Rougher surfaces requires high viscosity oils

Smoother surfaces can use low viscosity oils

Transmitted power

As load is increased viscosity must be increased.

Gear speed

The higher the speed of the gear drive the lighter the viscosity needs to be

Materials compatibility

Some types of extreme pressure additives can attack yellow metals like brass and bronze

Temperature

The industrial gear lubricants viscosity must be selected based on the lowest and highest operating temperature.

Types of gear lubricants:

There are lots of oil used as lubricant for gears to reduce wear, to protect against corrosion, to protect the gear against oxidation and to prevent the formation of foam between the 2 gears. [12]

· Inhibited oil: This is a lubricant used to prevent the corrosion and foaming between the gears. [12]

· Extreme Pressure Oils: These oils contain inhibited oils and chemically active substances and are used for modifying the friction acting between the 2 engaging gears.[12]

· Compounded oils; These are oils made from steam cylinder stocks compounded with fatless additives. The purpose of this oil is also to reduce friction.[12]

· Open gear compounds: This lubricant consists of additives and is used for high, slow speed heavily loaded gears. This lubricant protects the gear teeth from damage.[12]

· Greases: This is one of the commonly used lubricants. It consists thick soap contents. It can only be used on low speed gear surfaces.[12]

Methods of lubrication:

· Grease Lubrication: This type of lubrication is used at gears with0 to 6 m/s tangential speed. It can be applied on all types of gears operating at low speeds. Excess of this lubricant can lead power loss and viscous drag.[5]

· Splash Lubrication: This type of lubrication is applied to gears with speed of 4 to 15 m/s tangential speed. Here the lubrication is done by running the gear through an oil bath. The lubricant is effective only from 3 m/s speed of the gear and the oil should be prevented from mixing with some other liquid or particles which could cause a damage to the gear teeth.[5]

· Spray Lubrication: This type of lubrication is applied to gears with more 12m/s of tangential operating speed. Here the oil for lubrication is sprayed through a nozzle. The nozzle should be engineered properly as there is a chance for the oil to get deflected out of path of flow by centrifugal force or by the air that is flowing out. [5]

Lubricants can protect the gears from the tribological factors such as friction and wear. We know what are the types of lubricants to be used, their applications and the types of lubrication processes. It is important that we select the right amount and quality of lubricants for the gears so that they have a longer life and don’t get weared out easily. Engineers are still now researching to find the best lubricant for gears so that defects in gears like scoring, scuffing, pitting doesn’t occur at all for gears. The gear noise is also prevented to an extend by lubrication.

Operating Conditions for Gears:

Operating conditions are important tribological factors for gears as this will determine the lubricant to be used, the material to be selected for making gears. The operating conditions of gears are determined by the factors like load applied on the gear, the speed at which the gear is about to rotate, relative motion between the gears, environmental condition, the product of

pressure and velocity acting on the gears and the temperature on which the gear is about to work. These operating conditions which are to be considered for operation of gear are applied below:

1) Load: Load is the determining factor for the strength of a gear which determines the material to be used for the gear production, the amount of rubbing that would occur between the gear surfaces, the whole network of surface stresses that would occur in the contact zone of the gear surfaces and the coefficient of friction that would occur between the gears. The load also influences the behaviour of a lubricant or the abrasive particles present in the lubricant which would cause an impact on the gear tooth directly. The other area where the load influence is known is at the bonding between the gears that is directly dependent on the degradation of the surface films, increase in contact area and on temperature. In fact loading has a major impact on the change, age and wear characteristics of the materials. The schematic diagram of the influence of load on the operation of gear is given in the fig. 11. the explains the stresses produced due to load applied and the effects of these substances on the element. So in order to keep the gear in good condition and free from wear the following points have to be taken into account:

* To keep the gears in good condition progressive loading of gears is a best way.

* Decrease in load variation as it would reduce the rise of cavitation in the gears

* Decreasing fatigue loading in gears to prevent surface fatigue wear.[14]

2) Speed: Speed of gear is an important factor as it varies from one mechanical component to another and is an important factor for the working of the machine. The parameter of the gears that are greatly influenced by the speed of gears are :

a) Temperature: Temperature is a factor which is greatly influenced by the speed of the gear. As the speed of the gears increases the temperature between the gears also increases leading to more heat dissipation. Inorder to maintain the temperature between the gears we have to consider a good coolant and a good heat conducting surrounding medium.

b) Friction coefficient: The effect of speed on the friction coefficient comes into play especially in a lubricated circumstance, where this factor determines the hydrodynamic load carrying capacity. At very low speed of the gears there is a chance for the stick-slip phenomenon due to the fluctuation in friction coefficient. [14]

3) Relative motion: The relative motion involves motions like sliding, rolling, spinning and bouncing. These motion can decrease the performance of the gear and also can cause wear in the gear. The use of correct material, lubricant and designing the gear correctly can increase the performance of the gear and also give longer life to the gear. [1]

4) Environment: Environment can cause a decrease in performance of the gear. This is caused by the contamination of the lubricant and also due to the chemical reaction of the lubricant with the gear metals. [1]

5) Product (PxV): Here the quantity of heat generated by friction is calculated from the energy at the contact which is given by the equation E = QVf (where Q = load applied to the contact, V = displacement velocity, f = friction coefficient). Here the term PxV is used as a reference to estimate the limiting conditions for materials such as polymers, solid lubricants, self lubricating sintered materials etc. This in turn can be used as a basis for the selection and comparison of materials. Thus we are able to know the maximum PxV for certain materials and us them for the production of gears. [14]

6) Temperature: Temperature has a major effect on the contact zone of the 2 surfaces of a gear. The temperature increase in the tooth of the gear can cause geometric distortion or loss of clearance in the tooth. It can also cause an increase in the coefficient of friction and wear to the gear. Temperature can also cause deterioration in the mechanical properties of the materials and change the properties of the lubricants. An increase in the interfacial bonds is also caused which lead to a chemical reaction between the materials. [14]

Conclusion: Thus the audit of gears using the tribological factors such as material, surface, lubrication and operating conditions was conducted. It is found that gears are useful in most of the mechanical applications and also have a lot of properties that are to be taken care of while the operation of the gear. In today’s world, a lot of materials are available for the manufacture of gears. These materials can only be used in different conditions and have their own advantages and disadvantages. So in future a much modern material with zero wearing property and that provides longer

life to the gears have to be developed. In the case of surfaces of gears smooth finished gears are already been produced these days. A surface with normal surface texture and conformity will provide smoother running of gears in future. A lots of lubricants are available in todays world. In future a more advanced lubricant can be developed that can reduce wearing of gears completely and also help to increase the performance of gears to the fullest. All gears today are developed for performing at a particular load and temperature above which the gear can get damaged. So in future gears have to be developed that can operate at maximum temperature and load so that wear of gears due to these characteristics can be reduced to minimum.

References:

[1] J. A. Williams, Oxford Science Publications, OUP, 1994, pp. 1.

[2] Coy, J. J., Townsend, P. D. and Zaretsky, E. V., " Gearing", NASA RP-1152, December 1985.

[3] Gear Materials, Ashoka Group [online].[Accessed on 6th December, 2009]. Available from: http://www. gearshub. com/gear-materials. html#selection

[4] Gearology, Boston Gear [online].[Accessed on 2nd December, 2009]. Available from: http://www. bostongear. com/training/gearology. asp

[5] Gear Lubrication [online].[Accessed on 4thDecember, 2009]. Available from: http://www. roymech. co. uk/Useful_Tables/Drive/Gear_lubrication. html

[6] Lawrence G. Ludwig, Jr., Schaeffer Manufacturing Company, " Lubrication Selection for Enclosed Gear Drives". Machinery Lubrication. January 2005

[7] Gear Types, Engineers Edge [online].[Accessed on 4th December, 2009]. Available from: http://www. engineersedge. com/gears/gear_types. htm

[8] Precision Gears, Inc [online]. [Accessed on 4th December, 2009]. Available from: www. precisiongears. com

[9] Gears, Monarch Bearing [online]. [Accessed on 4th December, 2009]. Available from: http://www. monarchbearing. com/gears. html

[10] Surface Finish [online].[Accessed on 6th December, 2009]. Available from: http://www. mfg. mtu. edu/cyberman/quality/sfinish/index. html

[11] Surface Texture –Definition [online].[Accessed on 6th December, 2009]. Available from: http://www. toolingu. com/definition-350140-22499-surface-texture. html

[12] Gear Systems – A Tribological Review [online].[Accessed on 6th December, 2009]. Available from: http://www. chunbotech. co. kr/techinform/ti-13. pdf

[13] Viscosity [online].[Accessed on 6th December, 2009]. Available from: http://www. princeton. edu/~gasdyn/Research/T-C_Research_Folder/Viscosity_def. html

[14] Neale. M. J, Polak. T. A., Priest. M, “ Handbook of Surface Treatments and Coatings”, Professional engineering Publishing Limited London and Bury St Edmunds, UK, 2003, pp. 24-27.

[15] Gear Failures[online].[Accessed on 6th December, 2009]. Available from: http://www. nptel. iitm. ac. in/courses/IIT-MADRAS/Machine_Design_II/pdf/2_7. pdf