A Review on the Design Aspects of Gears

Heshubh Sharad More[1], Dr. Rashmi Dwivedi[2]
[1]Heshubh Sharad More, MTech scholar, department of mechanical engineering, Sagar institute of science & technology, Bhopal, MP, India.
[2] Rashmi Dwivedi, Associate Professor, department of mechanical engineering, Sagar institute of science & technology, Bhopal, MP, India
[1]heshubh9091@gmail.com

Corresponding Author: Heshubh Sharad More

Abstract: *Gear is a mechanical rotating toothed part which meshes with other similar toothed parts to transmit torque and power. Gear tends to play a very vital role in all industries. This paper presents the overview of Gear and the bending fatigue in gear. Bending fatigue is one of the most common failure modes in spur gears. In carburized spur gears, subsurface failure initiation is characteristic for the high cycle fatigue regime, which is rather hard to detect and may cause rapid crack growth and complete failure of the tooth.*

Keywords: *Spur gears, 3D, POM, PM, shaft.*

I.INTRODUCTION

Gears are toothed, mechanical transmission elements used to transfer motion and power between machine components. Operating in mated pairs, gears mesh their teeth with the teeth of another corresponding gear or toothed component which prevents slippage during the transmission process. Each gear or toothed component is attached to a machine shaft or base component, therefore when the driving gear rotates along with its shaft component, the driven gear rotates or translates its shaft component. Depending on the design and construction of the gear pair, the transference of motion between the driving shaft and the driven shaft can result in a change of the direction of rotation or movement. Additionally, if the gears are not of equal sizes, the machine or system experiences a mechanical advantage which allows for a change in the output speed and torque.

Figure 1 Mechanical Gear

Gears and their mechanical characteristics are widely employed throughout industry to transmit motion and power in a variety of mechanical devices, such as clocks, instrumentation, and equipment, and to reduce or increase speed and torque in a variety of motorized devices, including automobiles, motorcycles, and machines. Other design characteristics, including construction material, gear shape, tooth construction and design, and gear pair configuration, help to classify and categorize the various types of gears available. Each of these gears offers different behaviors and advantages, but the requirements and specifications demanded by a particular motion or power transmission application determine the type of gear most suitable for use.

A.Gear Shape - Most types of gears are circular—i.e., the gear teeth are arranged around a cylindrical gear body with a circular face—but some non-circular gears are also available. These gears can feature elliptical, triangular, and square-shaped faces. Devices and systems which employ circular gears experience constancy in the gear ratios (i.e., the ratio of the output to the input) expressed—both for rotary speed and torque. The constancy of the gear ratio means that given the same input (either speed or torque), the device or system consistently provides the same output speed and torque.

On the other hand, devices and systems which employ non-circular gears experience variable speed and torque ratios. Variable speed and torque enable non-circular gears to fulfill special or irregular motion requirements, such as alternatingly increasing and decreasing output speed, multi-speed, and reversing motion. Additionally, linear gears, such as gear racks, can convert the rotational motion of the driving gear into the translational motion (or a combination of translational and rotational motion) of the driven gear.

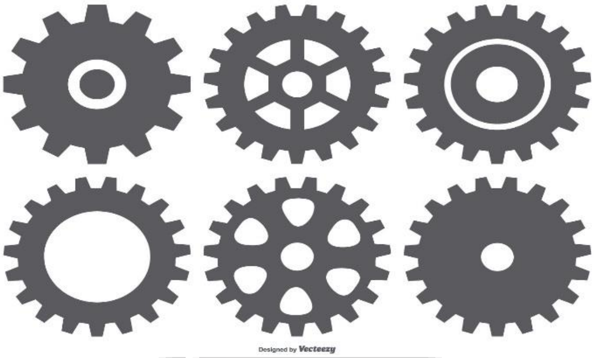

Figure 2 Different Shapes of Gear

Gear teeth are also referred to as cogs, hence why a gear is also called by the somewhat archaic term of cogwheel. While in the previous section, gears were categorized based on the overall shape of the gear body, this section describes characteristics relating to their tooth (i.e., cog) design and construction. There are several common design and construction options available for gear teeth, including:

B.Gear Teeth Structure : Depending on the gear structure, gear teeth are either cut directly into the gear blank or inserted as separate, shaped components into the gear blank. For most applications, once a gear succumbs to fatigue, it can be replaced in its entirety. However, the advantage of employing gears with separate tooth components is the ability to individually replace the teeth as each becomes fatigued rather than replacing the whole gear component. This capability may help to reduce the overall cost of gear replacement over time as individual cogs are available at a lower cost compared to that of a complete gear. Additionally, it allows specialized, custom, or otherwise difficult to find gear bodies to be retained and preserved.

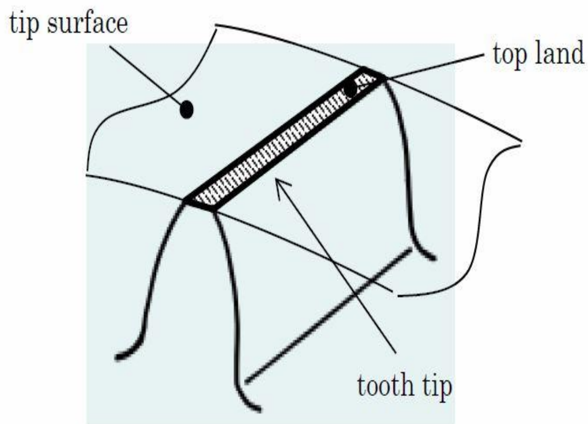

Figure 3 Gear Tooth Structure

C.Gear Teeth Placement: Gear teeth are cut or inserted on the outer or inner surface of the gear body. In external gears, the teeth are placed on the outer surface of the gear body, pointing outward from the gear center. On the other hand, in internal gears, the teeth are placed on an inner surface of the gear body, pointing inward towards the gear center. In mated pairs, the placement of the gear teeth on each of the gear bodies largely determines the motion of the driven gear.

When both gears in a mated pair are of the external type, the driving gear and driven gear (and their respective shaft or base component) rotate or move in opposite directions. If an application requires the input and output to rotate or move in the same direction, an idler gear (i.e., a gear placed between the driving gear and driven gear) is typically employed to change the direction of rotation of the driven gear.

If one of the mated gear pair is an internal gear and the other is an external gear, both the driving gear and driven gear rotate in the same direction. This type of gear pair configuration removes the need for an idler gear in applications which require the same direction of rotation in the driving and driven gear. Additionally, configurations which employ an internal-external gear pair are suitable for limited- or restricted-space applications as the gears and their shaft or base components can be positioned closer together than is possible with a comparable external-only gear pair.

Figure 4 Example of an internal-external gear pair

Gear Tooth Profile: The tooth profile of a gear refers to the cross-sectional shape of the gear's teeth and influences a variety of the gear's performance characteristics, including the speed ratio and experienced friction. While there are a large number of tooth profiles available for the design and construction of gears, there are three main types of tooth profiles employed—involute, trochoid, and cycloid.

Involute gear teeth follow a shape designated by the involute curve of a circle, which is a locus formed by the end point of an imaginary line tangent to the base circle as the line rolls along the circle's circumference. Throughout industry, the majority of gears produced employ the involute tooth profile both because of its ease of manufacturing and its smoothness of operation. Compared to some of the other profiles, the involute profile consists of fewer curves, making the manufacturing of involute gear teeth simpler and, consequently, the manufacturing equipment necessary cheaper, which reduces the overall cost of production.

II. SPUR GEARS

Spur gears are common for transmitting motion between parallel shafts. They are visualized easily and classified as cylindrical gears as a result of their shape. Their tooth surfaces are placed parallel to the axis of mounted shafts and this leads to no thrust force being generated in axial direction. Spur gears can be manufactured to very high degrees of precision as their production is an easy process.

Spur gears have always been accepted as highly efficient types of gearing solution, particularly when you have to apply transmitting power and rotary motion from a parallel shaft to another. Spur gears generate functioning speed with a steady drive as they are determined by the distance at the center. This driving speed can be increased or decreased by the varied numbers of teeth which are there in the driving gear.

Spur gears are cut straight and are considered as the simplest kinds of gears. They are made up of a cylinder or a disk that has projecting teeth which are radial. The left and right surfaces of spur gears' teeth are generally made symmetrical and are regarded to be basic when the thickness of the teeth when measured along the circle of the pitch is half of that circular pitch.

A.Types of Spur Gears - There are three main classes of spur gears: external tooth, internal tooth, and rack-and-pinion. The external tooth variety shown in Figure 5 is the most common. Figure 6 illustrates an internal gear and Figure 39.3 shows a rack or straight-line spur gear.

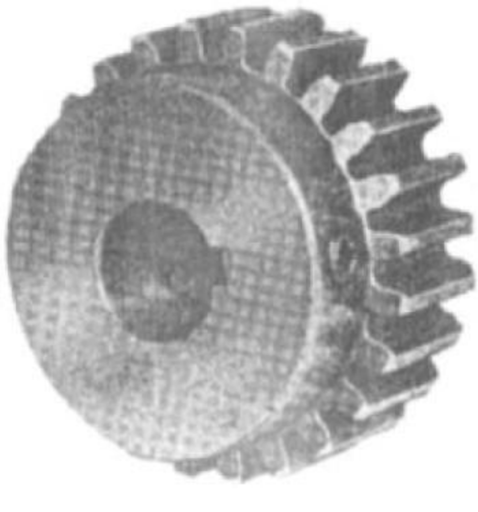

Figure 5 External Tooth of Spur gear

The spur gear is cylindrical and has straight teeth cut parallel to its rotational axis. The tooth size of spur gears is established by the diametrical pitch. Spur-gear design accommodates mostly rolling, rather than sliding, contact of the tooth surfaces and tooth contact occurs along a line parallel to the axis. Such rolling contact produces less heat and yields high mechanical efficiency, often up to 99 per cent.

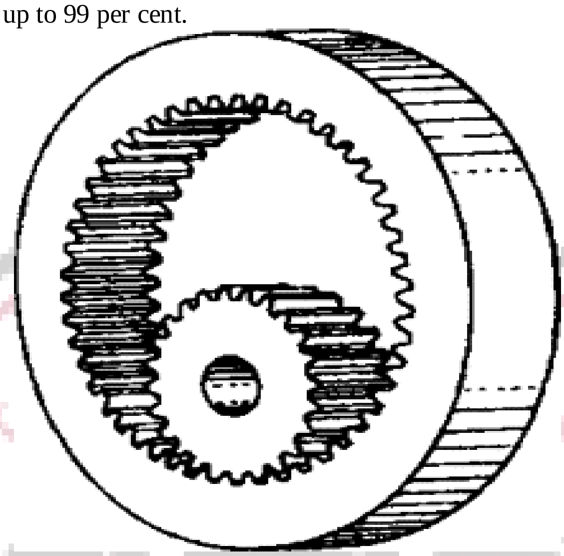

Figure 6 internal spur gear

An internal spur gear**,** in combination with a standard spur-gear pinion, provides a compact drive mechanism for transmitting motion between parallel shafts that rotate in the same direction. The internal gear is a wheel that has teeth cut on the inside of its rim and the pinion is housed inside the wheel. The driving and driven members rotate in the same direction at relative speeds inversely proportional to the number of teeth.

Spur gears could be manufactured as internal gears and rings and as cluster gears. Internal spurs have cylindrical pitch surfaces and teeth that are parallel to their axis. The teeth are formed on inner surfaces of the cylinders. The cluster gears are manufactured through a cluster or precision array of spur gears. This is done with the help of contrasting bores on shafts or gear blanks. These gear assemblies are used by original equipment manufacturers of automotive, marine industry and off-highway niche applications.

The teeth form of spur gears is generally shown as plane curves on cross section perpendicular to the shafts. Hence, pitch circles are used in the place of pitch cylinders. The contact points of two pitch circles are known as the pitch points. These are points that two pitch circles touch during the rolling contact. These are spots that have no relative motion between gears. The process of tooth forming is divided into two types known as gear form milling and gear form generating methods. The gear form generation is a method that is used widely and it allows for mass production of involute gears with high precision.

Most spur gears and helical gears are manufactured with the help of cutting. Yet, there are many other methods like casting, rolling and forging. In the case of plastic spur gears, in addition to tooth cutting such as with metal gears, injection molding is used depending on the quantity of production.

The steps of manufacture for metal spur gears generally involve cutting off round rod materials, turning blacks on lathe machines and tooth cutting screw keyways and holes that can be added whenever required. This is generally the case when hardness and high accuracy are not required. After cutting of gears, grinding of tooth surface and shaving process is used often to enhance strength and accuracy. Gear grinding is done to enhance the surface roughness and accuracy of gears. It will indicate the grinding process of gear tooth surfaces after tooth cutting and treatment by heat with a polishing stone that rotates at very high speeds and this is done on special tooth grinding machines.

B.Carburizing Spur Gears -Carburizing is a widely used, effective technique to increase surface hardness of steel used in gears, and achieve a compressive residual stress. There are several methods, and hotter isn't always better. Carburizing is the addition of carbon to the surface of low carbon steels. It is generally accomplished at temperatures between 850-1,000°C. Once quenched, the high-carbon surface layer yields a high hardness martensitic case with excellent wear and fatigue resistance. This carburized case surrounds the tough, low carbon steel core.

The case hardness is primarily a function of the carbon content. There is little advantage increasing the carbon content beyond 0.65% to increase hardness. Higher carbon content can increase microstructural properties such as wear, sliding contact fatigue, and rolling contact fatigue. Too high carbon content can result in excessive carbide networks or massive carbides. The case depth is a function of time temperature and chemistry, of the process, and the available carbon (carbon potential) at the surface of the steel.

III. LITERATURE REVIEW

(Lin et al., 2018) [1] An FEA model of an input spur gear pair found in the 4LZ-2 combined harvester gearbox was developed to investigate the bending fatigue life of the pinion gear. A novel fatigue life prediction methodology incorporating the concept of power density was presented to estimate the fatigue crack initiation life under high cycle fatigue. A classical LEFM approach was then followed to determine the propagation of fatigue crack to ultimate physical failure. It was seen that the primary failure mode of the gear pair was the fatigue of the pinion gear's tooth root. A fatigue life prediction methodology based on the novel concept of power density was demonstrated that estimated crack initiation life by considering the coupled effects of the loading stress and loading frequency. The method- ology is particularly viable for addressing high cycle fatigue when loading stresses are both non-stationary and broadband.

(Singh & Singh, 2017) [2] The article has provided a review on various design features and performance characteristics of polymer and polymer composite gears. Techniques based on the modification in the profile of the gear tooth and their effects on the performance of these gears are also discussed. It is evident from survey that much work has been done on polymer-based spur gears only. The polymeric materials that can be used in gearing phenomenon have not been explored much except nylon and POM. Fibers have been extensively used as rein- forcing materials, and filler reinforcement has not been adequately addressed for polymer composite gears. Studies carried out on polymer gears are largely based on experimental approach, and less number of articles are based on simulation approach.

(Spur et al., 2019) [3] The present paper is aimed at investigating the effect of porosity and microstructure on tooth root bending fatigue of small-module spur gears produced by powder metallurgy (P/M). Specifically, three steel variants differing in powder composition and alloying route were subjected either to case-hardening or sinter-hardening. The obtained results were interpreted in light of microstructural and fractographic inspections. On the basis of the Murakami √ area method, it was found that fatigue strength is mainly dictated by the largest near-surface defect and by the hardness of the softest microstructural constituent. Owing to the very complicated shape of the critical pore, it was found that its maximum Feret diameter is the geometrical parameter that best captures the detrimental effect on fatigue.

(Čular et al., 2019) [4] In this paper, analytical model for bending fatigue prediction of carburized gear steel specimens based on strain-life approach was proposed for low and high cycle fatigue regimes. Hardness method and multilayer method were used to acquire strain-life fatigue properties of material layers. Through rule of mixture, average cyclic stress-strain curves for carburized specimens were obtained. In addition, an approach was suggested for translating axial to bending fatigue data through Neuber's rule and modifying factors.
(Review, 2020) [5] A review about the practical design of gears, their tolerances, and drawings is presented in the paper in order to propose a guideline for the designer. All the proposed formula, as well as the full methodology, has been used and in-field tested for several years in the framework of gear design in the machine tool industry. The described tools may be regarded as a comprehensive method to guide the engineer from the white paper to final design and gear drawing, following the required steps for gear parameter calculation and verification. From this point of view, this paper is particularly novel, as it is a full-comprehensive collection of all the tools supporting gear design. Furthermore, the proposed method is particularly suitable for automatic computation by electronic datasheets.

(Publication, n.d.) [6] Based on the finding of various researchers for analyzing the bending stress generated in spur gear, it can be concluded that three methods namely, analytical methods, experimental methods and numerical methods using FEM are equally important. Various parameters such as tooth contact ratio, addendum modification, gear rim thickness, etc. affect nature of stress generated in gear body and gear teeth. While analyzing stress on one gear teeth, adjacent tooth also must be considered because its presence affects the nature and quantity of stress. Stress on gear tooth can be calculated by FEM. First is directly applying concentrated load on single gear tooth. Only bending stress can be calculated by this method. Adopting the larger pressure angle on the drive side bending stress decreases on the gear teeth. Thus, load carrying capacity increases. Hence while designing asymmetric gears it is advisable to consider most of the parameters, so that strength and performance of the gear would be enhanced.

(Natali et al., 2021) [7] Several methodologies for the mesh stiffness calculation in spur gears have been found in the literature, in the last decades. Based on a bibliographical analysis and the research activities of the authors, attention has been devoted to three methodologies, which ap- peared as the most employed and cited. A critical review of such methodologies, FE-based method, hybrid analytical-FE method, and analytical approach, has been undertaken, highlighting some crucial aspects regarding the mesh stiffness estimation process. Within this framework, useful information related to the critical choice of parameters needed for the implementation of the methods are presented, in order to provide further guidelines for their application. Furthermore, the methods are compared in terms of results accuracy and computational time for full blank and lightweight gears. This comparison leads to useful guidelines regarding the definition of the most suitable approach depending on the spe- cific requirements. Finally, two variants of an examined hybrid method are presented. They are based on linear, nonlinear FE analyses and analytical formulation. Their purpose is to compare the use of different analytical formulations against the FE formulation for the computation of the local deformation of gear teeth.

(Patil & Kale, 2020) [8] The gears used for analysis in present investigation are made by using rapid prototyping . The determination of the contact area utilizes one of the RP techniques, like fused deposition modeling (FDM).RP techniques like FDM enables the making of gears with complex profile A model of simple spur gears with circular arc profile of teeth is applied as an example for testing . Material used for manufacturing the gears include ABS (Acrylonitrile Butadeine Styrene). This research investigate the characteristics of an involute spur gear system mainly focused on bending and contact stresses using Finite Element method (FEM) and analytical method.

(Agarwal et al., 2018) [9] In this examination, a writing audit was led to distinguish late limited component models of goad adapt. On ground of geometrical model, numerical model of goad equip is performed utilizing limited component. Goad adapt tooth profile utilizing explanatory bend as its line of activity the outcomes affirm that the proposed outline strategy is more adaptable to control the state of the tooth profile by changing the parameters of the parabola line of activity or root filet span of apparatus profile The quality including the contact stresses and life cycle, of the rigging drive planned by utilizing the proposed technique is broke down by a FEA reproduction. The most recent research results a lessen contact stressup to15 % without undermining and obstruction any decrease of torque.

IV. TOOTH BENDING FATIGUE

Gear Failure occurs in different modes. Many modes of gear failure are there, for example fatigue, impact, wear, or plastic deformation. Of these, one of the most common causes of gear failure is tooth bending fatigue. Fatigue is the most common failure in gearing. Tooth bending fatigue and surface contact fatigue are two of the most common modes of fatigue failure in gears.

A.Bending failure - Gear tooth behaves like a cantilever beam subjected to repetitive bending stress. The tooth may crack due to repetitive bending stress. To avoid such failure, the module and face width of the gear is adjusted so that the beam strength is greater than the dynamic load.

B.Pitting - It is a surface fatigue failure due to repetitive contact stresses. Pitting starts when total load acting on the gear tooth exceeds the wear strength of the gear.To avoid the pitting, the dynamic load between the gear tooth should be less than the wear strength of the gear tooth.The initial or corrective pitting is a localized phenomenon, characterized by small pits at high spots. Such high spots are progressively worn out and the load is redistributed. Initial pitting is caused by the errors in tooth profile, surface irregularities, and misalignment.

The remedies against initial pitting are precise machining of gears, adjusting the correct alignment of gears so that the load is uniformly distributed across the full face width, and reducing the dynamic loads. This is a major cause of gear failure accounting for nearly 60% of the gear failures. Pitting is the formation of craters on the gear tooth surface. These craters are formed due to the high amount of compressive contact stresses in the gear surface occurring during transmission of the torque or in simple terms due to compressive fatigue on the gear tooth surface.

Surface contact fatigue of gear teeth is oneof the most common causes of gear operational failure due to excessive local Hertzian contact fatigue stresses. Generally, there are two types of surface contact fatigue, namely, pitting and spalling. The pitting of gear is characterisedbyoccurrence of small pits on the contact surface. Pitting originates from small, surface or subsurface initial cracks, which grow under repeated contact loading. Pitting is a three-dimensional phenomenon and strongly depends on contact surface finish, material microstructure and operating conditions, such as type of contact, loading, misalignment, lubrication problems, temperature, etc. Spalling, in general, is not considered an initial mode of failure but rather a continuation or propagation of pitting and rolling contact fatigue. Although pitting appears as shallow craters at contact surfaces,spalling appears as deeper cavities at contact surfaces. Gearboxes are generally robust and reliable devices. However, problems do occur particularly due to application error. Application errors can be caused by a number of problems, including mounting and installation, vibration, cooling, lubrication, and maintenance. Misalignment is probably the most common, single cause of failure, Due to misalignment; the pinion does not mesh properly with the gear during operation, and this lead to a high stress concentration at the surface ofgears.

The misalignment also leads to severe wear and excessive heat generation at the mating surface. In gears, it is exhibited as premature pitting at one end of the tooth. There are many causes of misalignment, both static (manufacturing or setting-up errors) and dynamic, due to elastic deflections of components under load, and also due to thermal expansion. Also, damage to and failures of gears in gearbox can and do occur as a direct or indirect result of lubrication problems [11].

V. CONCLUSION

In this paper we have discussed about the rolle of gear, its types and also the defects caused inside the gear. Furthermore we have discussed about the spur gear and technique of carbonizing steel in the manufacturing of gear. Additionally the work done by several researchers in finding the binding stress in spur gears was also discussed in the literature review.

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