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A Review on Contact Stress Analysis of Spur Gear

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Abstract

Gears have a wide variety of applications. Their applications vary from watches to very large mechanical units like the lifting devices and automotives. Gears generally fail when the working stress exceeds the maximum permissible stress. Contact stress analysis between two spur gear teeth was considered in different contact positions representing a pair of mating gears during rotation. The contact stress in the mating gears is the key parameter in gear design. This review paper represents the stress analysis of mating teeth of spur gear to find maximum contact stress in the gear teeth. The results obtained from Finite Element Analysis (FEA) are compared with theoretical Hertzian equation values. The main objective of the study is to minimize stresses at maximum stress concentrated area. Design of spur gear can be improved by improving the quality of material, improving surface hardness by heat treatment, surface finishing methods. Apart from this stress also occurs during its actual working. Hence it is important to minimize the stresses. These stresses can be minimized by introducing stress relief features at stress zone.

Keywords— Contact Stress, FEA, Hertzian theory, Spur Gear

1. INTRODUCTION

Gears are the most common means of transmitting power in the modern mechanical engineering world. Gearing is one of the most effective methods for transmitting power and rotary motion from the source to its application with or without change of speed or direction. Gears will prevail as a critical machine element for transmitting power in future machines due to their high degree of reliability and compactness. The rapid development of heavy industries such as vehicle, shipbuilding and aircraft industries require advanced application of gear technology. Spur gear is a cylindrical shaped gear in which the teeth are parallel to the axis. It is easy to manufacture and it is mostly used in transmitting power from one shaft to another shaft up to certain distance & it is also used to vary the speed & Torque. e.g. Watches, gearbox etc. The cost of replacement of spur gear is very high and also the system down time is one of the effect in which these gears are part of system. Failure of gear causes breakdown of system which runs with help of gear. e.g. automobile vehicle.

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When gear is subjected to load, high stresses developed at the root of the teeth, Due to these high Stresses, possibility of fatigue failure at the root of teeth of spur gear increases. There is higher chance of fatigue failure at these locations. So to avoid fatigue failure of the gear, the stresses should be minimized at maximum stress. Spur gear is a cylindrical shaped gear in which the teeth are parallel to the axis. It is easy to manufacture and it is mostly used in transmitting power from one shaft to another shaft up to certain distance & it is also used to vary the speed & Torque. e.g. Watches, gearbox etc. The cost of replacement of spur gear is very high and also the system down time is one of the effect in which these gears are part of system. Failure of gear causes breakdown of system which runs with help of gear. e.g. automobile vehicle.When gear is subjected to load, high stresses developed at the root of the teeth, Due to these high Stresses, possibility of fatigue failure at the root of teeth of spur gear increases. There is higher chance of fatigue failure at these locations. So to avoid fatigue failure of the gear, the stresses should be minimized at maximum stress. concentrated area. Design of spur gear can be improved by improving the quality of material, improving surface hardness by heat treatment, surface finishing methods. Apart from this stress also occurs during its actual working. Hence it is important to minimize the stresses. These stresses can be minimized by introducing stress relief features at stress zone. Many simulation packages are available for checking the different values of stresses. Simulation is doesn't give exact results but gives a brief idea where stresses are induced. Hence experimental stress analysis method can also be adopted for studying stresses: Gears have a wide variety of applications. Their applications vary from watches to very large mechanical units like the lifting devices and automotives. Gears generally fail when the working stress exceeds the maximum permissible stress. Number of studies has been done by various authors to analyse the gear for stresses. Gears have been analysed for different points of contact on the tooth profile and the corresponding points of contact on the pinion.

In this study then the variation stress in root fillet region is found, which is then used for the study of variation of various parameters of stress reducing features. The effect and use of stress relief feature in geometry of gear is studied as reported by researchers. A study of the optimum size and location of the stress relief features for pinion and gear is proposed which help in reducing the fatigue failure in gears. Gears are the most common means of transmitting power in the modern mechanical engineering world. They vary from a tiny size used in watches to the large gears used in watches to the large gears used in lifting mechanisms and speed reducers. They form vital elements of main and ancillary mechanisms in many machines such as automobiles, tractors, metal cutting machine tools etc. Toothed gears are used to change the speed and power ratio as well as direction between input and output. Spur gear is a cylindrical shaped gear in which the teeth are parallel to the axis. It has the largest applications and, also, it is the easiest to manufacture. Spur gears are the most common type used. Tooth contact is primarily rolling, with sliding occurring during engagement and disengagement. Some noise is normal, but it may become objectionable at high speeds.

2. LITRATURE REVIEW

Dhavale A.S. , Abhay Utpat [1] paper explores when gear is subjected to load, high stresses developed at the root of the teeth, Due to these high stresses, possibility of fatigue failure at the root of teeth of spur gear increases. There is higher chance of fatigue failure at these locations. So to avoid fatigue failure of the gear, the stresses should be minimized at maximum stress concentrated area. Hence it is important to minimize the stresses. These stresses can be minimized by introducing stress relief features at stress zone. Many simulation packages are available for checking the different values of stresses. Simulation is doesn't give exact results but gives a brief idea where stresses are induced. Hence experimental stress analysis. Single stress reliving features did not improve gear stress. stress reduction by means of introducing of stress reliving feature is possible. Stress redistribution is highly sensitive to the change in size, Location and Number so select size, Location and Number very carefully. Using two holes as a stress reliving features gives more stress reduction. Small variation in size, location and number gives large difference in equivalent stress. Introduction of stress reliving feature at specific location of specific size and number gives maximum reliving of stress otherwise strength of gear reduces.

Mr.Bharat Gupta, Mr.Abhishek choubey [2] explains that Current Analytical methods of calculating gear contact stresses use Hertz's equations, which were originally derived for contact between two cylinders. So for CONTACT STRESSES it's necessary to develop and to determine appropriate models of contact elements, and to calculate contact stresses using ANSYS and compare the results with Hertzian theory. The finite element method is proficient to supply this information but the time required to generate proper model is a large. Therefore to reduce the modelling time a pre-processor method that builds up the geometry required for finite element analysis may be used, such as Pro/Engineer. Pro/Engineer can generate three dimensional models of gears. In Pro/Engineer the generated model geometry is opened in ANSYS for analysis. It is also shown that the development of finite element analysis model of the Spur gear assembly to simulate the contact stress between two gears reasonably and obtained result is compared with the Hertzian theoretical equation. Based on the result from the contact stress analysis the hardness of the gear tooth profile can be improved to resist pitting failure: phenomena in which small particles are removed from the surface of the tooth that is because of the high contact stresses that are present between mating teeth.The module is important geometrical parameter during the design of gear. As it is expected, in this work the maximum contact stress decreases with increasing module and it will be higher at the pitch point. As a result, based on this finding if the contact stress minimization is the primary concern and if the large power is to be transmitted then a Spur gear with higher module is preferred.

Ruben D.Chacon , Luis J Andueza [3] In this paper a study of the stresses in the contact zone among a couple of spur gears is realized using the finite elements method. The analysis is done by using a plane model involving the contact between two teeth. The geometry is defined according to the standards of the American Gear Manufacturers Association (AGMA). The results obtained are compared with the value given by two others approaches. The first is the theory of Hertz when it is applied to two curved segments in contact. The second approach is the AGMA procedure for calculating contact stresses in spur gear. Theresults obtained are very similar either using FEM and Hertz´s theory. The contact pressure obtained by FEM is lower than the one obtained by means of Hertz´s theory, this fact reflects the influence of the geometry profile which allows the occurrence of contact zones with greater area, and therefore lower pressures. The ability of the FEM for the simulation of mechanical spur gears contact have been proved, presenting estimates of contact pressure and stress states with similar results and tendencies to those obtained by the contact theory of plane models of Hertz and AGMA. The contact pressure and stress state are highest for higher points on the involute and lower were a single pair of teeth assumes the full load transmitted, and minimal for the contact at the pitch point.

Ali Raad Hassan [4] This paper explains that Contact stress analysis between two spur gear teeth was considered in different contact positions, representing a pair of mating gears during rotation. A programme has been developed to plot a pair of teeth in contact. This programme was run for each 3° of pinion rotation from the first location of contact to the last location of contact to produce 10 cases. Each case was represented a sequence position of contact between these two teeth. The programme gives graphic results for the profiles of these teeth in each position and location of contact during rotation. Finite element models were made for these cases and stress analysis was done. The results were presented and finite element analysis results were compared with theoretical calculations, wherever available. The presentation dealt with contact stress, considering contact ratio, approach angle, recess angle, contact and length of contact. The stress was more than the correct value of contact stress obtaining from approximating tools. This search was certainly not easy and cannot be carried out without the use of finite element analysis. To apply finite element method in contact stress a special technique was used rather the regular elements, to distinguish between the contact regions which were in two parts. One was the first body named target region and the other body was named contact region. For target region, target elements were used and in contact region contact elements were used. ANSYS software presents a significant technique for this purpose which was used here.

Vivek Karaveer , Ashish Mogrekar [5] This paper presents the stress analysis of mating teeth of spur gear to find maximum contact stress in the gear teeth. The contact stress in the mating gears is the key parameter in gear design. The results obtained from Finite Element Analysis (FEA) are compared with theoretical Hertzian equation values. For the analysis, steel and grey cast iron are used as the materials of spur gear. The spur gears are sketched, modeled and assembled in ANSYS DesignModeler. As Finite Element Method (FEM) is the easy and accurate technique for stress analysis, FEA is done in finite element software ANSYS 14.5. Also deformation for steel and grey cast iron is obtained as efficiency of the gear depends on its deformation. The results show that the difference between maximum contact stresses obtained from Hertz equation and Finite Element Analysis is very less and it is acceptable. The deformation patterns of steel and grey cast iron gears depict that the difference in their deformation is negligible. Here the theoretical maximum contact stress is calculated by Hertz equation. Also the finite element analysis of spur gear is done to determine the maximum contact stress by ANSYS 14.5. It was found that the results from both Hertz equation and Finite Element Analysis are comparable. From the deformation pattern of steel and grey cast iron, it could be concluded that difference between the maximum values of steel and grey CI gear deformation is very less.

Nidal H. Abu-Hamdeh, Mohammad A. Alharty [6] studied that stress reliving features to reduce the root fillet stress in spur gear. A pilot model was established to predict von Mises stress at the root fillet of the gear without holes and was used as a reference model. Finite element modeling was adopted using Abaqus® package. The predicted stresses were compared with stresses obtained by AGMA analytical solution. A good agreement was found in the comparison between the calculated and predicted stresses. The first model was performed by creating hole/holes in the gear body with various diameters, various centre distances, and various hole/holes orientation angles from Z-axis. Three cases were used in this model; one hole, two holes, and three holes. The second model was performed by creating hole/holes in the face/profile of the gear with various diameters and center distances. The finite element modeling was performed using Abaqus/CAE 6.10. Firstly, a pilot model with no holes created in the gear body was established to predict stresses at the root fillet of the gear and the results were compared with stresses obtained by AGMA analytical solution. A close agreement in stresses obtained analytically with those obtained from simulation was found. Consequently, the other two models were constructed to examine the effect of creating holes in the gear body as stress relieving features on root fillet stresses. For one hole case, it was found that the best results were obtained when one hole as a stress reliving feature was created at 60° angle from Z-axis. Furthermore, increasing the diameter of hole/holes resulted in higher percentage of stress reductions compared to the pilot case. For the two- and three-hole cases, increasing the number of holes resulted in higher percentage of stress reductions compared to the pilot case, but gear rigidity in this case was questionable. The second model did not produce any reduction of stresses in the root fillet area. On the contrary, stress increased because of the reduction in contact area.

3. Contact Stress analysis of Spur Gear by Hertz theory

The contact stress in the mating gears is the key parameter in gear design. The transfer of power between gears takes place at the contact between the acting teeth. The stresses at contact point are computed by means of the theory of Hertz . The method of calculating gear contact stress by Hertz's equation originally derived for contact between two cylinders . Figure 1 & Figure2 shows the contact stresses between cylinders.

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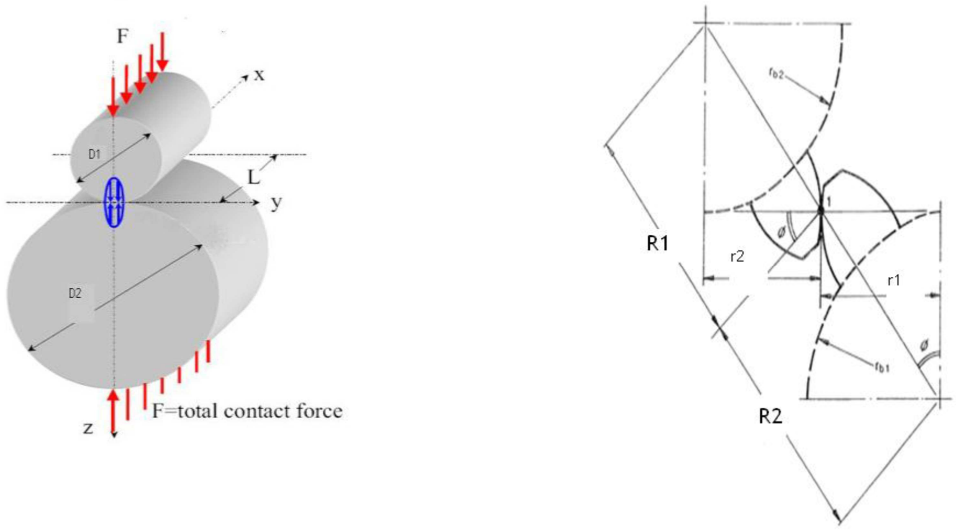

Figure1: Cylinders in contact under compression

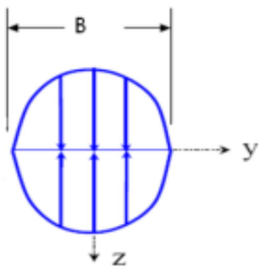

Figure2: Elliptical stress distribution across the width

In machine design, problems frequently occurs when two members with curved surfaces are deformed when pressed against one another giving rise to an area of contact under compressive stresses. Of particular interest to the gear designer is the case where the curved surfaces are of cylindrical shape because they closely resemble gear tooth surfaces. In Fig.1 two gear teeth are shown in mating condition at the pitch point. Referring to Fig.2, the area of contact under load is a narrow rectangle of width B and length L. The stress distribution pattern is elliptical across the width as shown in figure 3.

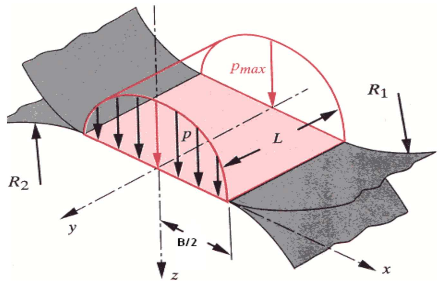

Figure 3: Ellipsoidal–prism pressure distribution value is given by

$$P_{c\ max} = \frac{4*F}{\pi*B*L}$$

where,

$$B = \sqrt{\frac{8 \times F}{\Pi \times L} \times \frac{\frac{1-v1^2}{E_1} + \frac{1-v2^2}{E_2}}{\frac{1}{D_1} + \frac{1}{D_2}}}$$

Here, F is the applied force,v1and v2 are Poison's ratio of the two materials of the cylinders with diameters D1 and D2, E1 and E2 are the respective modulii of elasticity.
Putting the values of B and assuming a value of 0.3 to poison's ratio , and by replacing diameters by respective radii,

$$p_{c\,max} = \sqrt{0.35 \times \frac{F}{L} \times \frac{\frac{1}{R_1} + \frac{1}{R_2}}{\frac{1}{E_1} + \frac{1}{E_2}}}$$

The Hertz equations discussed so far can be utilised to calculate the contact stresses which prevail in case of tooth surfaces of two mating spur gears. Though an approximation, the contact aspects of such gears can be taken to be equivalent to those of cylinders having the same radii of curvature at the contact point as the load transmitting gears have. Radius of curvature changes continuously in case of an involutes curve, and it changes sharply in the vicinity of the base circle.

4. Contact Stress analysis of Spur Gear by AGMA

The contact stress of spur gear pair is studied through the finite element method and AGMA (American Gear Manufactures Association) Stress formulas. The contact stress σ_H based on AGMA standard is represented as follows

$$\sigma_H = Z_E \sqrt{F_t K_o K_v K_s \frac{K_H}{2 r_1 W Z_I}}$$

where,

(F_t) is Transmitted tangential load , (K_0) overload Factor , (K_v) Dynamic Factor ,(K_s) Size factor ,(k_H) Load distribution factor, (r_1) pitch radius of the pinion, (w) Face width ,(Z_1) Geometry factor for pitting resistance.

5. Conclusion

This Study presents theoretical maximum contact stress is calculated by theory of Hertz and AGMA standard also we have to find contact stress of spur gear by finite element analysis .The results obtained from finite element analysis , Hertz theory and AGMA standard are comparable. we also minimize the contact stresses by FEM and different shapes of hole can also be studied for relieving stress.

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