DESIGN AND ANALYSIS OF TORSIONAL VIBRATION ON BEVEL PLANETARY GEAR

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Abstract: Gears are widely used in power transmission systems for small distances. Bevel gear is used for transmitting power of intersecting or angle shaft. For the vibration Analysis, it is necessary to consider tooth contact stresses and the forces that vary in direction of rotation, which increases the fatigue effect and causes the bending of the tooth. The precise model of bevel planetary gear used in vertical rolling mill is created in AUTODESK INVENTOR in the first phase. A physical gear pairs are fabricated from the 18CrNiMo7-6. The finite element analysis is carried out in ANSYS. Final results obtained from the analysis of the proposed fabricated gear pair are compared with the theoretical analysis of bevel planetary gears**.**

IndexTerms **- Torsional Vibration, Bevel Planetary Gear, Finite Element Analysis, Vertical Rolling Mill.**

I. INTRODUCTION

In engineering and technology the term “gear” is defined as a machine element used to transmit motion and power between rotating shafts by means of progressive engagement of projections called teeth. Gears operate in pairs, smaller of the pair being called the “pinion” and the larger the “gear”. For mechanical power transmission, gears are generally categorized into three distinct types, (a) those transmitting power and motion between parallel shaft, namely, spur and ordinary helical gears; (b) those for shafts with intersecting axes, the angle between the shafts being generally 90^0, e.g. bevel gear; (c) those where the shafts are neither parallel nor intersecting, the axes generally making 90^0 or some other angle to each other but in different planes. e.g.worm and worm wheel, crossed helical gears and hypoid gears. [1]

1.1 Planetary Gear

Planetary gear is also called as Epicyclic gear. Like a compound gear train, planetary trains are used when a large change in speed or power is needed across a small distance. The planetary gear set is the device that produces different gear ratios through the same set of gears. Any planetary gear set has three main components: The sun gear, the planet gears and the planet gears' carrier, the ring gear.

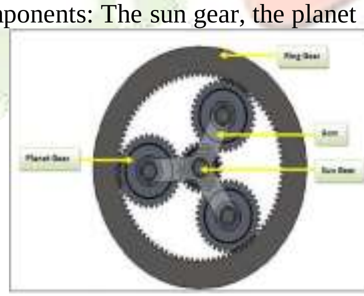

Figure 1 Planetary Gears

1.2 Spiral Bevel Gear

The most complex form of bevel gear is the spiral bevel. It is commonly used in applications that require high load capacity at higher operating speeds than are typically possible with either straight or Zerol bevel gears. The teeth of spiral bevel gears are curved and oblique (Figure 2), and as a result they have a considerable amount of overlap. This increases more than one tooth in contact at all times and results in gradual engagement and disengagement with continuous multiple tooth contact. [2]

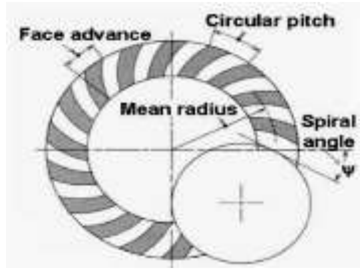

Figure 2 Illustration of spiral angle

1.3 Torsional Vibration of Mechanical System

Fundamentally, torsional vibration is an angular oscillation of rotating parts or rotors of the system. An inflexible or rigid body oscillates about particular reference axis. Each of the rotor in the system will oscillate about its rotational axis and follows a torsional disturbance to the system. In this way, the shaft is subjected to twisting. Torsional disturbance due to twisting can produce reversals of stress which cause fatigue failure. Hence, torsional vibration analysis is overwhelming in rotating machinery system.

1.4 Application

Bevel planetary gears are used in vertical rolling mill. Vertical rolling mills used for grinding in coal, raw and cement. Vertical roller mill is a type of grinder used to grind materials into extremely fine powder for use in material dressing processes, pyrotechnics, paints, cements and ceramics. It is an energy efficient alternative for a ball mill.

II. LITERATURE REVIEW

Ming Li et al. has created the model and highlighted the approach to predict the reliability of the helicopter planetary gear train under the condition of partial load. Firstly, the structure of gear system and partial load state are analyzed in detail, and the load histories of each gear are transformed into equivalent constant amplitude load spectrums to be as the load input variable for reliability model. At the same time, a tooth bending fatigue test is carried out with specific gears, and the statistical results of test data are as the strength input variable for reliability model. For the unequal load sharing of the planetary gear train leading from deformation of supporting members, an interference zone and a high stress zone on the running orbit of planet gear are formed, and they are not coincident. Due to the existence of a high stress zone, the reliability of the sun and planet gears is reduced, and 16% teeth on ring gear are sensitive to affect the reliability of the ring gear. The prediction results of the reliability model had shown that unequal load sharing among planet gears will reduce the reliability of planetary gear train. In the equal load sharing state ($K = 1$), the reliability of the gear system is 96.792%; while in the unequal load sharing state, it is reduced to 87.526% when the average unequal load sharing coefficient is 1.52. When the twin-engine helicopter are running with only one engine, the load environment in planetary gear train will be deteriorated, and this will increase the likelihood of tooth fatigue fracture. Because of a small number of teeth on planet gears leading to a large number of meshing, and with the double-sided loading, the planet gears are the main components that affect the reliability of the gear system. But ring gear is different, so in the pursuit of light weight design for planetary gear reducer, tooth width of the ring gear can be reduced to achieve the purpose of reducing weight. [3]

Changjiang Zhou et al. has established analytical solutions to calculate bending and contact strength for spiral bevel gears incorporating friction on the tooth surface, which are verified by ISO gear standard and finite element method (FEM). The bending strength is calculated based on Lewis cantilever beam approximation, utilizing the modified normal force and the friction component. The modified normal force is derived at the highest point of single tooth contact (HPSTC) in the normal equivalent gear. Follow Hertz contact theory, the contact strength is calculated when the modified normal force and the friction component are exerted at the lowest point of single tooth contact (LPSTC) in the normal equivalent gear. The calculated bending and contact stresses agree well with those obtained from the FEM analysis while considering the influence of friction. Both theoretical predictions and FEM analysis have shown that friction has a crucial effect on the load capacity of a spiral bevel gear drive, and that it exerts stronger influence on the bending strength (compared with the contact strength). When friction coefficients become larger (with the same input torque), the bending stress considering only the modified normal force decreases at HPSTC, whereas if it increases both the modified normal force and the friction component are included. In comparison, the contact stress will increase at LPSTC under both scenarios. [4]

Zhu Xioyuan et al. has described the different the tooth profile modification and proposed the design of the holey straight bevel. Based on the sphere involutes deduced with the engaging principle, the precise model is established by Pro/E in the first place. Then the finite element model is established in Hyper Works and the transmission error is analyzed. Finally taking transmission error together with the mesh impact as the dynamic excitation, the dynamic models of the holey straight bevel gears are built and the acceleration mean square of the dynamic steady state response is applied to express the vibration and noise subsequently. The results show that, the holey straight bevel gear can weaken the mesh impact under vibration process compared with the ordinary one in the same loading and constraint conditions. Under the same integrate excitation, the holey gears mean square root acceleration value of the dynamic steady state response is lower than the ordinary one, which indicates better vibration reduction performance has achieved. Moreover, the holey straight bevel gear is obviously lighter than the ordinary one, and the process method proposed is easier than the tooth profile modification. Therefore, the holey straight bevel gear has capacious engineering prospect on vibration and noise reduction of the vehicle transmission assemblies. [5]

Yinong Li et al. has proposed the 8-DOF(degrees-of-freedom) nonlinear dynamic model of a spiral bevel gear pair which involves time- varying mess stiffness, transmission error, backlash and asymmetric mesh stiffness. The effect of the asymmetric mesh stiffness on the vibration of spiral bevel gear transmission system is studied deliberately with numerical method. The results show that Firstly, the mesh stiffness for drive side has more effect on dynamic response than those on the coast side. The only double-sided impact region is affected considerably by mesh stiffness of coast side while single-sided impact impact regions are unchanged. Secondly, the dynamic response of the system is very sensitive to mesh stiffness of drive side. The change of mesh stiffness of drive side will affect response in the whole excitation frequency areas. Furthermore, the increase of drive side mesh stiffness tends to worsen the dynamic response especially in lightly loaded case. Thirdly, the vibration stability for heavy load case is far better than that for the lighter load case. And the mesh stiffness asymmetry affects the dynamic response more compared with heavy load case. [6]

Yuxin huang et al. has developed a program for torsional vibration in the form of a platform. The whole power train system torsional vibration model of a vehicle is built firstly with consideration of gear mesh stiffness and engine's excitation in it. The free torsional vibration mode analysis is made and the resonant torques of each lumped inertia in the transmission system are obtained. Secondly the forced vibration of transmission system with the engine's excitation is made and the dynamic torques of each lumped inertias are obtained. Thirdly the process for the torsional vibration analysis is integrated into the optimization process and the selection of the elastic coupling in the transmission system is made according the optimization and match results. Fourthly, in order to modify the design parameters in the structural design, the sensitivities of inertia and torsional stiffness with reference to Eigen values are obtained. At last the evaluations of analysis results have been made and some suggestions for structural modification for engineers are presented. According to the above study, the conclusion can be made that the new torsional modeling method, the elastic coupling selection method and integration, optimization method in the paper are practical and reliable and these methods play very important roles in torsional vibration analyzing, match and optimization of the vehicle transmission system. [7]

III. SOLID MODELING OF GEAR

From the design calculation, the solid modeling of gears is generated using AUTODESK INVENTOR (2017) software.

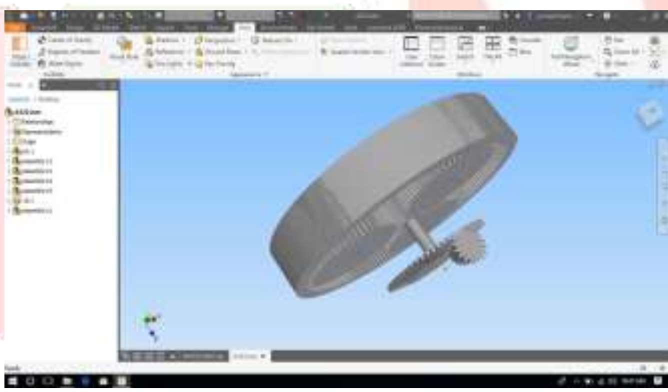

Figure 3 Solid model of bevel planetary gear

IV. ANALYSIS OF GEAR

After solid modeling, the finite element analysis is carried out using ANSYS 18.1 software to find out the harmonic response of all parts of gear pairs as follow.

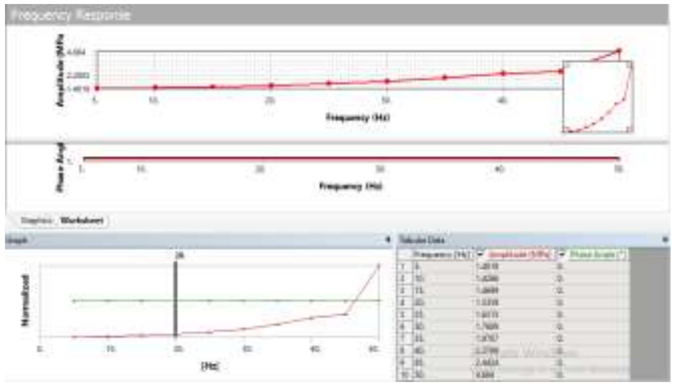

Figure 4 Frequency vs. amplitude graph of bevel pinion

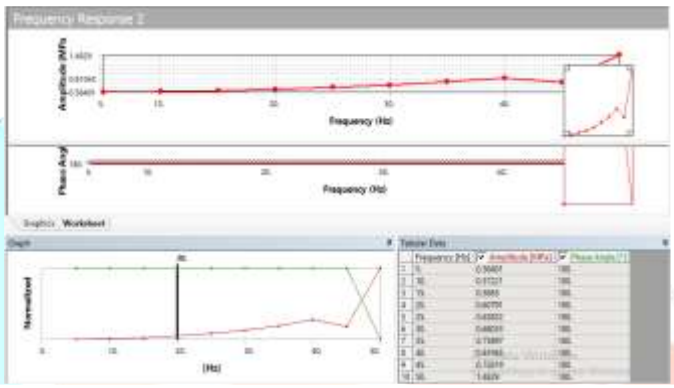

Figure 5 Frequency vs. amplitude graph of bevel gear

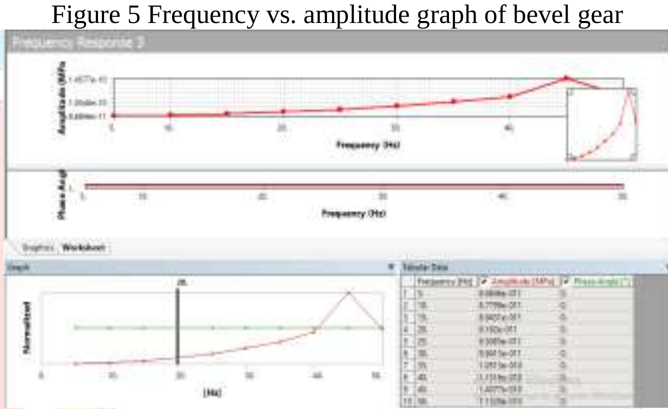

Figure 6 Frequency vs. amplitude graph of sun gear

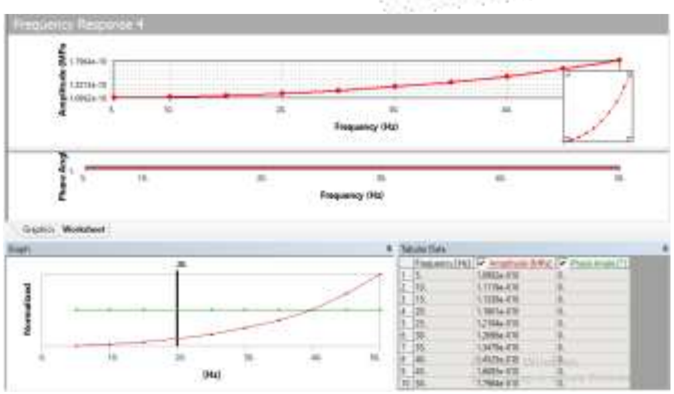

Figure 7 Frequency vs. amplitude graph of planet gear 1

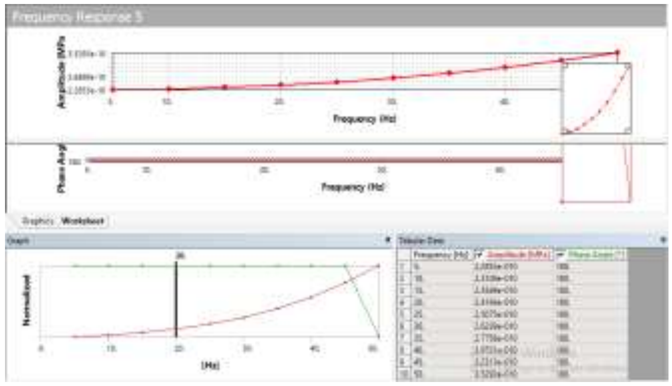

Figure 8 Frequency vs. amplitude graph of planet gear 2

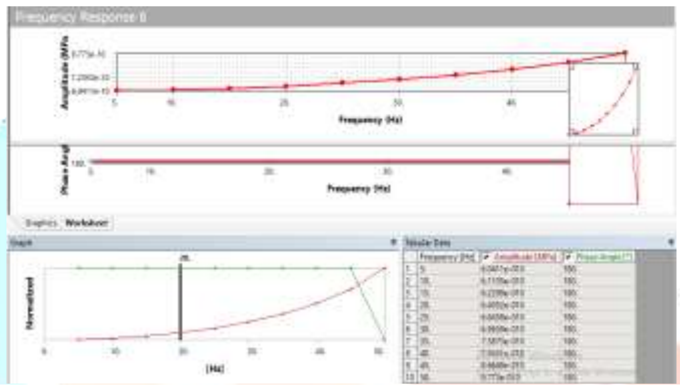

Figure 9 Frequency vs. amplitude graph of planet gear 3

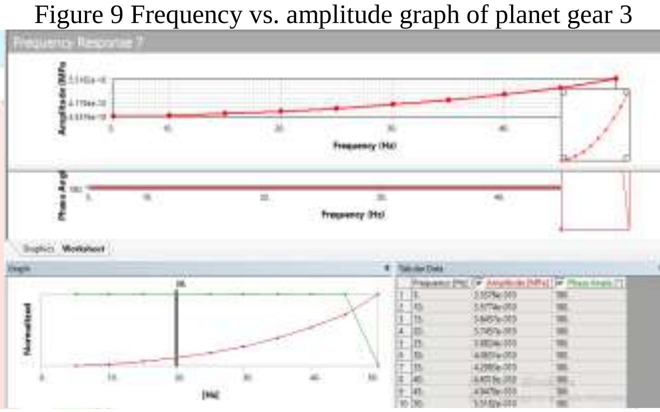

Figure 10 Frequency vs. amplitude graph of internal gear

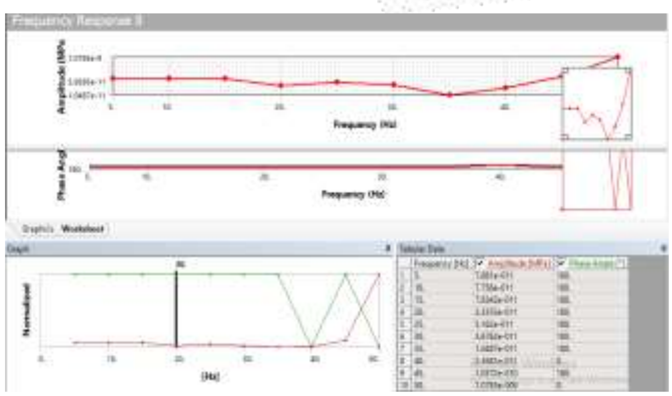

Figure 11 Frequency vs. amplitude graph of supporting plate

From the above graphs, to get the information regarding the design safe or not. The highest frequency of bevel planetary gears is 16.5 Hz. Above all graphs is frequency vs. amplitude. In all graphs get to the high value of amplitude got at 50 Hz frequency which is far away from model frequency.

V. CONCLUSION

In this work, the 3D model of bevel planetary gears is created with the help of Autodesk Inventor (2017) and the finite element analysis is carried out using the ANSYS 18.1. The AGMA standard provides brief details about the design by rule as well as a standard design procedure for gear. FEA analysis seems to be a good tool to replace costly and time consuming experimental work. In this work it is attempting to find out the natural frequency of all gears and data is used to find out harmonic response of all parts. The result of harmonic response highest amplitude is far away from input frequency. Hence, gearbox is safe for these input parameters.

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