A REVIEW OF DESIGN AND ANALYSIS OF A 3-STAGE PLANETARY GEARBOX

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Abstract:

Planetary Gear System is an assembly of gears where one or more planet gears revolve around a gear placed at centre named Sun gear and a ring gear encircles the whole system. It is capable of achieving high reduction ratios in a very compact package. Large number of manufacturing errors can influence the stresses induced onto the gear system. In this paper, a detailed study of the design of a planetary gearbox is done at first. After designing, this research utilizes the finite element method to investigate the variation of stresses occurring due to misalignments. Here, the stresses analyzed are occurring due to misalignments resulting from the tolerances on centre distance between gears and also from the tolerances on parts. In this paper, we have reviewed the research papers mainly dealing with the designing and analysis of a planetary gearbox.

Keywords-*Planetary Gearbox, Stress Analysis, FEM Analysis, Misalignments, Tolerances*

Introduction

A Planetary Gearbox consists of one or more rotating gears revolving around a central gear. The aspects which characterize a planetary gear system are its compactness, co-axial arrangement of driving and driven shafts, large speed reduction possibilities in relation to its overall size, possibilities of a number of combinations of driving and driven inputs and outputs, large torque conversion possibilities and different possibilities of orientation of drives [1] .

The principal advantages of planetary gears over parallel axis gears are considerable savings in weight and space, these advantages stem from the fact that the use of multiple planets allows the load to be transmitted by several tooth contacts and the co-axial arrangement of input and output shafts gives a more compact layout. A second advantage of using multiple planets is that when two or more planets are spaced symmetrically on the carrier, the radial loads of the planets offset each other. Therefore, the bearings and the gear housing for the co-axial elements must be designed only to maintain proper alignment of the gearing and withstand loads imposed by external conditions [2].

It depends upon the how many planets are there in a planetary system for it to distribute the transferred torque through several gear mesh points and what this means is a planetary gear with 3 planets can transfer three times more the torque for a very similar sized fixed axis gear system.

For applications where elevated positioning accuracy and repeatability is required, high rotational stiffness and also minimum elastic windup is important and especially under fluctuating loading conditions. The load distribution among various points also means that the load is divided among N contacts thus increasing the torsional stiffness of the planetary gearbox [3].

Planetary gear system is vulnerable to instabilities as they are subject to constantly applied torques. Critical speeds in them separate the boundaries from divergence instabilities, if any divergence instabilities occur. High-speed planetary gears gyroscopic systems do not conserve energy and thus may experience instability [4].

One of the advantages of planetary gear transmissions is that the input torque is divided in a number of parallel paths. For n planet planetary gear system, each sun–planet–ring path is to transmit 1/n of the input torque. However, this is only true in the ideal case when there is equal load sharing between all the planets in the planetary gear systems. In planetary gearing system, one of the three basic components is held stationary; one of the two remaining components is an input, providing power to the system, while the last component is an output, receiving power from the system. The ratio of input rotation to output rotation is dependent upon the number of teeth in each gear, and which component is held stationary [5].

The most attractive features of planet gears are their load distribution capability and very light weight. Moreover, the compactness of these gears maybe attributed to the sharing of the load by several planets and internal balancing of external gear tooth loads by rollers that support the rim . Under the influence of tooth loads, the planet gear rim elastically deforms to equalize the load within. The distribution of externally applied tooth loads by the gear and its thin rim significantly affects and magnitude and location of critical stresses around the gear circumference [6]. In transmissions in the presence of errors in pinion positioning, it is found that there is unequal load sharing between the parallel paths.

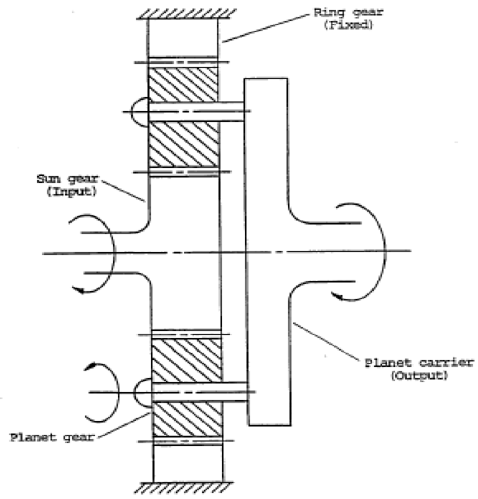

Figure 1 A Planetary Gear Train [2]

This load sharing of planetary gears has significant implications for transmission design and torque ratings. The errors in pinion positioning can have major effects on stresses induced on to the system. Stresses in a planetary gear system gets induced on how the load is getting distributed inside the gear system [7].

Contact stresses and fillet stresses make up for the most of the stresses induced onto a gear system. In a planetary system apart from the stresses coming out from contact and fillet forces, manufacturing errors and positioning errors in a planet gears also make an impact on stress analysis. In practice, in gear transmission, sudden load changes occur from the viewpoint of load transmission. That is, the load acting on a pair of teeth depends on the meshing stiffness of that pair. This leads to a variation in the load distribution across contact points.

Stress analysis for gear teeth is regarded as a limiting factor for designers. Stress analysis focuses on the determination of the regions of stress concentration where failure or fracture may be initiated. The present work concentrates on the change in the contact stress that is generated in meshing gear teeth along with the misalignments that leads to further stresses been induced and finite element method (FEM) is utilized to see the variations in stresses at the places where high stresses are induced.

Literature Review

Few literature reviews on the design and analysis of this gear system were studied and following conclusion were made out of them:

- Planetary gear system is compact, light weight and have higher torque density than the conventional gear system.
- Studies were mainly based on single stage planetary gear system
- The extensive research in the field of planetary gear design and analysis have already been done
- In single stage differential planetary gear high reductions ratios are possible but it will also work for low torque applications

Dr. Alexander Kapelevich [8] in his study presented few research gaps, for high reduction ratios if less than 3 stages were selected would result in bulky and large gear system. It was also found that stresses getting induced due to the manufacturing errors and assembly variations brought major damage to the whole planetary gear system [9].

Design of a 3-Stage Planetary Gearbox

Considering the power input to the gear system and all the other relevant parameters, the number of stage was rounded to be three with the first stage being that of helical gears followed by two planetary gear stages. Since the power input was high to go with higher reduction ratio required, to opt for planetary gear system was the best decision considering the compactness planetary gearbox will provide over all other gear systems.

According to the Handbook of Gear from G.M. Maitra, Design parameters that defined a planetary gear systems were at first, the number of planets each planetary gear stage would carry, the number of teeth on every gear, module for gears, pitch circle diameter the torque transmitted in each gear stage. It was found that number of planets for each planetary stage should be kept 4 and the logic behind that decision that since each planet would thus be at 90˚ to each other, so the radial forces will be opposite to each other and thus there wouldn't be any case of unbalancing as centrifugal forces will cancel out each other. After rounding on number of planets, all the other gear parameters are calculated [1].

As Robert G. Parker presents in his research that In many industries, it is of highest priority to maximize the power density and improve load sharing among the planets and for that it is imperative to have thin ring rings and what this does is, it leads to elastic deflection of the ring gear. There is also a possibility that sun and planets might also get deformed elastically but the ring gear is especially susceptible because it lacks the backing of any additional constraint from the bearings [10].

G.G. Antony presents that an important requirement for automation applications is high torque capability in a compact and light package. High Torque density is required for automotive applications because with change in high dynamic loads in order to avoid additional system inertia and depending upon the selected number of planets, planetary gearboxes distribute the torque to be transmitted through multiple gear mesh points. This means planetary gears with four planets can transfer four times the torque of a similar sized conventional gear system. [3].

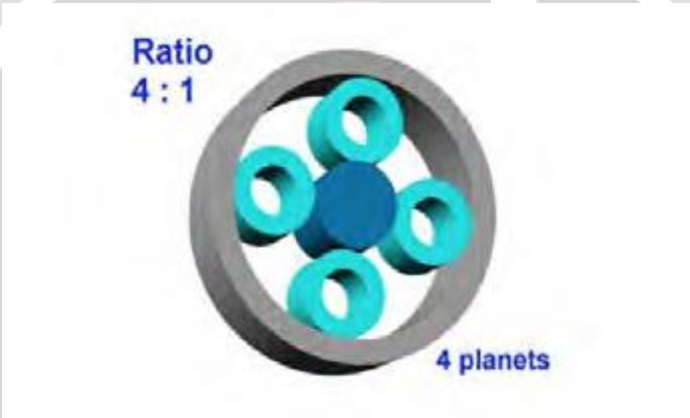

Figure 2 Simple Planetary Stage with 4 Planets [3]

As Tobias Schulze puts it in his research paper that the product design process of a gearbox begins with the load calculation, followed by gear designing with the help of certain parameters and component layout to the point of structure analysis [11]. Christopher G. Cooley found out currently there aren't any experimental results for planetary gears operating at high speeds but few experimental research do exist for planetary gear system. In his paper he has taken cases where only measurements of the housing were taken and no information on the motions of the individual gear bodies were to be determined. He experimentally investigate the sun and ring gear motions of a production planetary gear using inductance vibrometers and also perform modal experiments on stationary planetary gears. It measures individual gear vibrations by instrumenting each gear with accelerometers [12].

Th.Costopoulos in his paper presented a novel design for asymmetric gear teeth aiming at the minimization of the fillet bending stress. In his paper he put forward the following design concepts , firstly the gear teeth are made as thick as possible at the root fillet area and consequently the mating teeth are made as thin as possible at the tip. Secondly the sharp and pointed teeth are avoided in order to retain the good working properties of the standard 20 involute. He also talked regarding its insensitivity to center distance errors and its standard rated pitting and scoring resistance, the working portion of the driving side of the gear is involute. It was also suggested that the root fillet of the working side be replaced by a circular fillet and not the standard trochoidal generated from the circular tip of the generating hobbing tool and the idea behind that the circular root fillet been introduced was to increase the bending resistance of the gear teeth compared with the conventional trochoidal one. [13].

Fuchun Yang studied how to illustrate the velocity, torque and power flow analysis based on the method proposed. It was shown that the method presented in the paper is so convenient and efficient for the power analyses. The influence of certain parameters on efficiency of each node and system were also analyzed in this paper. The results showed that the power loss on certain node is dominant and partial shafts may bear self-lock when the efficiency of system is positive. Based on these results, suggestions on design were given for the improvement of the node and system efficiencies [14].

Stress Analysis

Seok-Chul Hwanga showed that there are two methods for analyzing the stress generated in meshing gear teeth. The first is to apply the concentrated load at the load position directly. Then, the bending stress of the gear can be calculated. This metho d is being widely used owing to its simplicity [15]. Apart from that certain variations in manufacturing parameters and assembly variations can really hamper the gear system. Each of these errors and variations influence the position of the planet tooth flanks that mesh with the sun gear and the internal gear. If the errors or variations are such that a certain planet is pushed ahead of the rest in its relative tangential position within the carrier, it is likely that it will carry more load than the others [16].

Toni Jabbour in his paper aims to calculate the bending stress distribution at the tooth root and the contact stress along each line of contact. With that, the critical load conditions are been considered and both the tooth-root stress and the contact stress under these conditions are determined. The modeling of the pair of gears for different angles of rotation leads to the determination of the critical configurations for which the bending and contact stresses are maximum the following observations were made : For spur gears, the position of the point of contact which leads to the critical tooth-root stress depends on the contact ratio of the pair of gears which increases with the number of teeth. The critical contact stres s is obtained at the radius of the pitch circle. For helical gears, the critical tooth-root stress is obtained when the point of contact is located at a distance of 1.65 mm, while the contact stress is located at a radius equal to the radius of the pitch circle of the gear. Both stresses are obtained when the total length of lines of contact is minimum. [17].

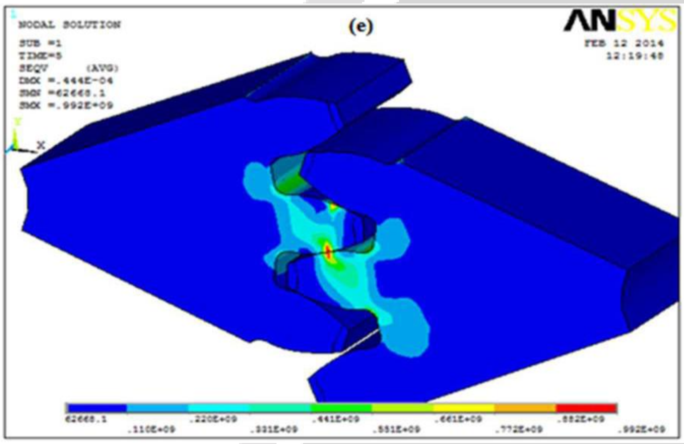

Figure 3 Contact Stresses [18]

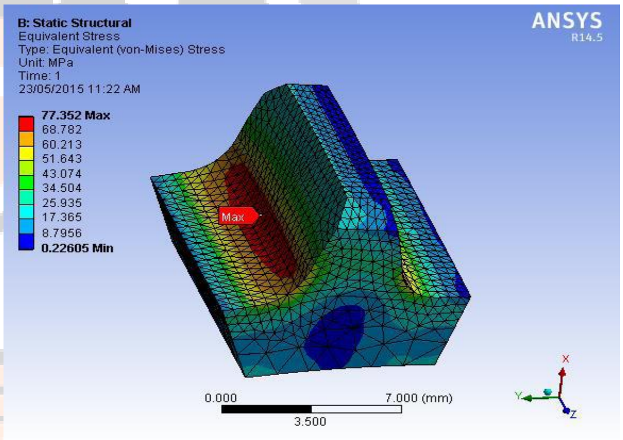

Figure 4 Tooth Stress Analysis [19]

Sarfraz Ali N in this paper showcases a general view of geometry optimization of spur gear under static loading. In here the application of Lewis bending equation is carried out for the stress calculation of a gear tooth at the fillet and and it is validated further with Finite element analysis method using ANSYS 14.5. The results shows the effect of root fillet on the bending stresses of the gear tooth and suggests the best optimized radius considering the combined effect of von-mises stresses and deformation [19]

Seok-Chul Hwanga presents in his research work that if any change is brought in the contact stress of spur and helical gears in relation to the contact position than its effects are seen on the stresses at that particular regions. Regarding changes in the contact stress, the maximum value is measured at the lowest point single-tooth contact and is compared with the contact stress calculated based on the AGMA standard and also by Hertzian contact stresses method [15].

Li Shuting presents in his work the effect that the tooth profile modification, lead relieving and transmitted torque will have on tooth contact stresses, load-sharing ratio and mesh stiffness of a pair of spur gears used in planetary gear system is investigated in this paper. The study of the effect of misalignment errors of the gear shafts on the plane of action and lead crowning on tooth mesh stiffness is also done. It is also found that the tooth profile modification has much more significant effect on tooth load-sharing ratio and mesh stiffness. During the analysis it is also found that the lead relieving has no bearing on load-sharing ratio of the gears but it reduces tooth mesh stiffness to a greater extent [20]

Hassan made it clear that, considering contact ratio, approach angle, recess angle, contact and length of contact was of very importance while calculating the contact stresses. The stress was more than the correct value of contact stress obtaining from approximating tools. This analysis of stress was certainly not easy and cannot be carried out without the help of finite element analysis. In this particular study, To apply finite element method in contact stress a special technique was used rather the regular methods, 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. And all this was done in ANSYS APDL software which provides a significant technique for this purpose. A computer program was developed to plot one pair of teeth in contact at different positions of contact depending on the formulation. The selected angular interval value was 3°, the progress of contact was studied at each 3° interval, which means that there were 10 cases of contact under consideration. These 10 cases were used to build 10 finite element contact models and contact finite element analysis was done under the load and material conditions were named [21]

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