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Design and Analysis of Planetary Drive Speed Reducer: A Review

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Abstract

An integral part of every planetary gear system is the sun gear, which rotates in the centre, and a series of planet gears that surround it. There is a ring gear that goes around the system. Despite its little size, it manages to achieve impressive reduction ratios. There is a vast spectrum of manufacturing error that may affect the affects on the gear system. The inquiry begins with a thorough examination of the design of planetary gearboxes. In order to investigate the stress variation produced by misalignments, this research uses the finite element technique after the design process. As a result of tolerances on the centre distance between components and gears, misalignments have occurred, leading to current stresses. A survey of research on planetary gearbox analysis and design is presented in this publication.

Keywords: Planetary Gearbox, Stress Analysis, FEM Analysis, Misalignments, Tolerances

Introduction

The gears that make up a planetary gearbox revolve around a central gear. Among the many defining characteristics of planetary gear systems are their diminutive stature, the co-axial arrangement of driving and driven shafts, the capacity to decrease speeds in relation to their total size, the many input/output combinations that may be realised, and the orientation of the drives [1]. When compared to gears with parallel axes, planetary gears are much smaller and lighter. Because the input and output shafts are positioned co-axially, the load is passed over many tooth contacts in planetary gears, which makes the gearbox smaller. When several planets are uniformly distributed on the carrier, their radial weights balance each other out, which is an additional advantage of employing multiple planets. In order to maintain proper gear alignment and external stress support, the bearings and gear housing of the co-axial components are limited in design [2]. The ratio of transmitted torque to gear mesh points is directly proportional to the number of planets in a planetary gear system, so a three-planet gear may transmit three times as much torque as a fixed-axis gear system of same size. For uses requiring improved positioning accuracy and repeatability, a low amount of elastic windup and strong rotational stiffness are essential. When loading conditions are uncertain, this is especially the case. The distribution of load across many locations increases the torsional stiffness of the planetary gearbox, which is achieved by distributing it over N connections [3]. A planetary gear system's instability might be due to the constant

the pressure that is applied. If divergence instabilities occur, their critical speeds will separate the boundaries. Rapidly spinning planetary gear gyroscopic devices waste energy and might be unstable [4]. By splitting the input torque into several parallel paths, planetary gear gearboxes provide a number of advantages. Each sun-planet-ring path in an n-planet planetary gear system transmits the input torque in 1/n stages. However, this is most accurate in planetary gear systems when the weight is distributed uniformly across the planets. In a planetary gearing system, one component remains stationary while the other two act as inputs and

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outputs, transferring power accordingly. The input rotation to output rotation ratio is determined by the number of teeth in each gear and the component that is maintained fixed [5]. Planet gears are attractive due to their lightweight design and load-distributing capabilities. Furthermore, the tiny size of these gears might be due to the fact that their weight is shared across many planets, with the rollers supporting the rim helping to equalise the pressures applied to their outside. As a result of elastic deformation caused by tooth loads, the load within the globe gear is balanced. Distribution of externally applied tooth loads by the gear and its thin rim effect critical stresses across the gear's circle [6]. The parallel channels fail to properly transmit the weight when transmissions have pinion positioning problems.

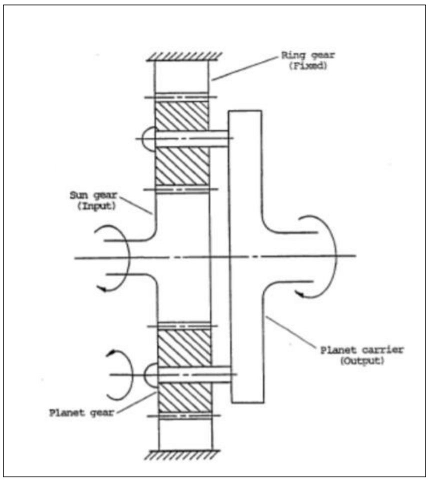

Figure 1. A Planetary Gear Train [2]

The fact that planetary gears share the load is an important issue for gearbox construction and torque ratings. Misaligned pinions have the potential to drastically change the forces acting on the system. Planetary gear systems are subject to strains due to the way loads are distributed within them [7]. In a gear system, contact stresses and fillet stresses are the most common types of stresses. Stress analysis in planetary systems may be impacted by manufacturing or placement errors of planet gears, in addition to stresses induced by contact and fillet forces. Surprisingly, when one considers gear gearbox via the lens of load gearbox, they see that there are sudden changes in load. That is to say, the stiffness of the meshing between teeth directly correlates to the amount of force acting on those teeth. This being the case, a

variations in the distribution of loads at various sites of contact. Stress analysis for gear teeth is one limitation that designers encounter. The primary objective of stress analysis is to pinpoint regions of high stress in order to detect possible failure or fracture spots. Using the finite element technique (FEM), we may see stress fluctuations at the sites of high stress created by meshing gear teeth and the misalignments that cause additional stresses, as well as the change in contact stress.

A handful of literature reviews focused on this gear system's analysis and design, leading to these findings: Planetary gear systems are more compact, lighter, and torque dense than conventional gear systems. This study mainly aimed to better understand planetary gear systems with just one stage. Planetary gears have been the focus of much research on both design and analysis in the past. Although single-stage differential planetary gears don't excel at high-torque tasks, they may nonetheless accomplish significant reduction ratios when called upon. Dr. Alexander Kapelevich [8] pointed out that if there were less than three stages, the gear system would be excessively large and complicated, which would lead to high reduction ratios. Forces

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that badly destroyed the whole planetary gear system were produced by manufacturing flaws and assembly variations [9].

Design of a 3-Stage Planetary Gearbox

A total of three stages were considered, with the first stage consisting of helical gears and the latter two stages being planetary gears, after taking into account the power input to the gear system and any other pertinent characteristics. Due to the high power input and the need for a larger reduction ratio, the planetary gear system was the ideal choice due to its compactness compared to other gear systems. In the beginning, design characteristics that characterised a planetary gear system included the number of planets each gear stage would have, the number of teeth on each gear, the gear module, the pitch circle diameter, and the torque transferred in each gear stage, as stated in the Handbook of Gear by G.M. Maitra. The rationale for maintaining a constant number of planets at 4 per planetary stage was that, with each planet at right angles to each other, the radial forces would be anti-symmetrical, preventing any imbalance caused by centrifugal forces cancelling each other out. All the other gear parameters are computed once the number of planets is rounded off [1]. According to Robert G. Parker's study, one of the most important goals in many sectors is to maximise power density and increase load sharing across planets. To do this, thin ring rings are necessary, which causes the ring gear to be elastically deflected. The ring gear is particularly vulnerable because to its absence of extra restraint from the bearings [10], but the sun and planets might potentially undergo elastic deformation. According to G.G. Antony, a lightweight and compact package with a high torque capability is a must-have for automation applications. In order to prevent extra system inertia caused by changes in high dynamic loads, planetary gearboxes spread the torque to be transferred over numerous gear mesh points, which means that high torque density is necessary for automotive applications. The number of planets chosen determines this distribution. This indicates that four-planetary gears may transmit four times the torque of a regular gear system of the same size. [3].

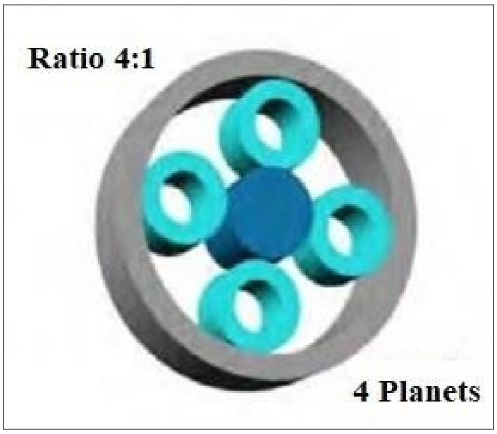

Fig. 2 Simple Planetary Stages with 4 Planets [3]

Tobias Schulze's research confirms that. While planetary gear systems have received little experimental attention, Christopher G. Cooley found that high-speed planetary gears have not yet yielded any results. In his analysis, he just needed to measure the housing; calculating the motions of the individual gear bodies was unnecessary. He investigates the operation of a manufacturing planetary gear's sun and ring gears experimentally using inductance vibrometers.

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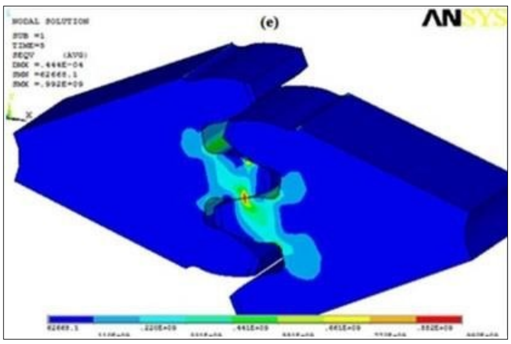
Furthermore, he checks the operation of stationary planetary gears using modal testing. It can detect vibrations in each gear separately thanks to accelerometers attached to each gear. [12]. Costopoulos presented a novel design for asymmetric gear teeth in his paper with the aim of minimising the fillet bending stress. In his essay, he suggested a few different ways to construct the gear teeth, one of which was to make them as thick as possible at the root fillet area and as thin as possible at the tip. On top of that, staying away from sharp and pointed teeth helps preserve the normal 20 involute's beneficial operating properties. Aside from having standard-rated pitting and scoring resistance, the involute working area of the driving side of the gear is insensitive to centre distance inaccuracies, as he also said. An alternative to the conventional trochoidal root fillet was suggested for the root of the working side; this design was based on the idea of using the circular tip of the producing hobbing tool. The old trochoidal gear teeth had less bending resistance, thus this modification was made to increase it. [13]. Fuchun Yang studied up on the subject so he could show how the proposed method affects power flow analysis, torque, and velocity. How simple and successful is the method described in the article was shown by the results of the power analyses. Each node and system's efficiency was examined in this article, along with the effect of certain attributes. The results demonstrated that power loss on specific nodes dominates when the system efficiency is positive, and that partial shafts may self-lock. These results guided suggestions for improving system and node efficiency in the design phase [14].

Stress Analysis

Two approaches to the analysis of stress in meshing gear teeth were shown by Seok-Chul Hwanga. One option is to apply the focused force directly to the load location. It is thus possible to determine the gear's bending stress. The ease of use of this approach has led to its widespread adoption [15]. The gear system is also vulnerable to assembly-related and manufacturing-parameter fluctuations. All of these mistakes and differences affect where the planet's teeth sides interact with the solar gear and the internal gear. Because of its relative tangential location inside the carrier, a planet is likely to bear greater burden than the others if the mistakes or variations cause it to be pushed ahead of the others [16]. The goal of Toni Jabbour's research is to determine the distribution of bending stress at the tooth root as well as the contact stress along each contact line. Then, under these circumstances, the tooth-root stress and the contact stress were calculated, taking into account the critical load conditions. The critical configurations for which the bending and contact stresses are highest are determined by simulating the pair of gears for various degrees of rotation. These findings were recorded: As the number of teeth rises, the contact ratio of the pair of gears determines the location of the point of contact that causes critical tooth-root stress in spur gears. Finding the critical contact stress at the pitch circle radius is possible. At a distance of 1.65 mm from the point of contact, the critical tooth-root stress for helical gears is attained, and the contact stress is placed at a radius equal to the gear's pitch circle radius. Both stresses are achieved when the sum of the contact lines is at its shortest [17].



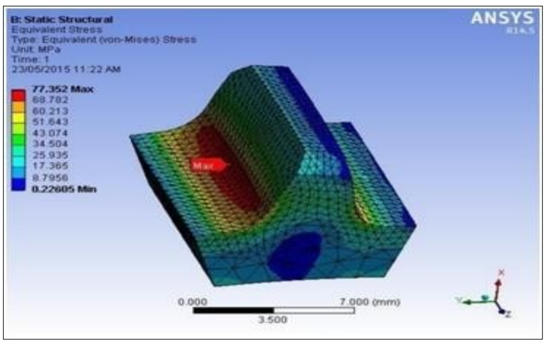


Fig. 3 Contact Stresses [18]   Fig. 4 Tooth Stress Analyses [19]

An overview of improving the geometry of spur gears exposed to static stress is presented by Sarfraz Ali N in this work. In this case, we use the Lewis bending equation to compute the fillet stress of a gear tooth, and then we use ANSYS 14.5's finite element analysis method to assess it. By considering both deformation and von-mises stresses, the results show how the root fillet affects the bending stresses on the gear tooth and suggest the ideal radius. In the year 19. Findings from the research by Seok-Chul Hwanga indicate that variations in the contact stress between spur and helical gears in relation to the contact position influence stresses in certain regions. We assess the maximum contact stress at the point where single teeth touch the ground and compare it to the maximum contact stress calculated using the AGMA standard and the Hertzian contact stresses method [15]. The impacts of changing the tooth profile, releasing lead, and transferring torque in a planetary gear system with two spur gears are studied in this work by Li Shuting. The pressures on tooth contact, load-sharing ratio, and mesh stiffness are considered. The effect of lead crowning and gear shaft misalignment on the stiffness of tooth mesh is also investigated. It is also shown that the tooth load-sharing ratio and mesh stiffness are significantly affected by the tooth profile change. Lead relief considerably reduces tooth mesh stiffness but has no influence on the load-sharing ratio of the gears, according to the experiment [20]. As a means of calculating the contact stresses, Considering the approach angle, recess angle, contact, and length of touch was of utmost importance, according to Hassan. The stress levels above the threshold at which these methods would provide a reliable assessment of contact stress. It would not have been feasible to do this stress study without finite element analysis; it was not an easy task. This study used a novel strategy to distinguish between the two separate contact zones before using the finite element technique to contact stress, rather of relying on the conventional methods. The first structure was known as the contact area, and the second as the target region. We used components that were assigned for the contact zone and those that were intended for the target area. For this, we relied on the ANSYS APDL tool, which provides a robust solution. One set of teeth in contact at different places was mapped using a computer software that was developed depending on the formulation. Ten contact cases were used to investigate the progress of contact at each 3° interval, with an angular interval value of 3° selected. With these 10 instances as a basis, ten finite element models were built for use in contact finite element analysis according to the given load and material conditions [21].

Conclusion

Research publications that focused on planetary gearbox design and analysis were carefully evaluated in this report. Using the finite element approach, this paper considers the design of a planetary gearbox and conducts stress studies to evaluate the variation of stresses caused by misalignments.

Misalignments, which may be the consequence of tolerances on the centre distance between gears or on components, are the source of strains, according to the examined data.

- It packs a lot of reduction power into a small footprint.

- A considerable number of manufacturing mistakes might impact the stresses introduced into the gear system, according to the major finding from the studied results.

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