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COMPUTATIONAL MODELING AND SIMULATION OF EPICYCLIC GEAR SYSTEM BEHAVIOR USING ANSYS FEA

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Abstract
This research paper delves into the structural analysis of epicyclic gear trains, employing Finite Element Analysis (FEA) as a pivotal tool for understanding their mechanical behaviour. Epicyclic gear trains, often employed in various mechanical systems such as automotive transmissions and industrial machinery, offer complex dynamics due to their arrangement of gears revolving around a central axis. The primary objective of this study is to investigate the structural integrity and performance of epicyclic gear trains under different loading conditions. The FEA analysis encompasses the application of loads such as torque inputs and external forces, enabling the evaluation of stress distribution, deformation, and contact pressures within the gear train. Through meticulous post-processing of results, areas of potential failure or stress concentration are identified, facilitating design optimization to enhance structural robustness and efficiency. Key findings from the analysis are presented, elucidating the critical factors influencing the performance of epicyclic gear trains. Insights gleaned from this research contribute to a deeper understanding of the structural behaviour of such gear systems and provide valuable guidance for design engineers in optimizing their performance and reliability. Overall, this research underscores the significance of FEA in elucidating the intricate mechanics of epicyclic gear trains, offering insights that can inform the design and development of advanced mechanical systems across diverse industrial applications.
Keywords: Epicyclic, gears, FEA, ANSYS.

I. INTRODUCTION

Epicyclic gear trains represent a fascinating realm of mechanical engineering, renowned for their intricate arrangement of gears revolving around a central axis. These gear systems, also known as planetary gear systems, find ubiquitous applications in various industries ranging from automotive transmissions to aerospace mechanisms. The complexity of their design and the interplay of forces within these systems necessitate thorough structural analysis to ensure optimal performance and reliability.

Finite Element Analysis (FEA) emerges as a powerful tool in unravelling the structural intricacies of epicyclic gear trains. By employing advanced computational techniques, FEA allows engineers to simulate the behaviour of complex mechanical systems under different loading conditions with remarkable accuracy. This enables a deeper understanding of the stresses, deformations, and contact pressures experienced by various components within the gear train.

Initially, a comprehensive 3D model of the epicyclic gear train is developed using CAD software, ensuring an accurate representation of all components including gears, shafts, and bearings. The model is then imported into ANSYS, a widely used FEA software, where meshing is applied to discretize the components into finite elements. Material properties are assigned to each component based on empirical data, and appropriate boundary conditions are imposed to simulate real-world operating conditions.

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In recent years, the integration of FEA tools like ANSYS into the design and analysis process has revolutionized the approach towards studying epicyclic gear trains. ANSYS offers a comprehensive suite of features tailored to tackle the challenges posed by these intricate systems, including precise meshing capabilities, sophisticated material modelling, and robust solver algorithms.
The significance of analysing epicyclic gear trains using FEA extends beyond mere structural evaluation; it encompasses the quest for innovation and optimization in mechanical design. By delving into the structural nuances of these gear systems, engineers can identify potential areas for improvement, mitigate failure risks, and ultimately enhance the performance and longevity of mechanical systems.
This introduction sets the stage for a detailed exploration into the structural analysis of epicyclic gear trains using FEA tools like ANSYS. Through a systematic examination of their mechanical behaviour, this research aims to unravel the mysteries of these intricate gear systems and pave the way for advancements in mechanical engineering design and innovation.

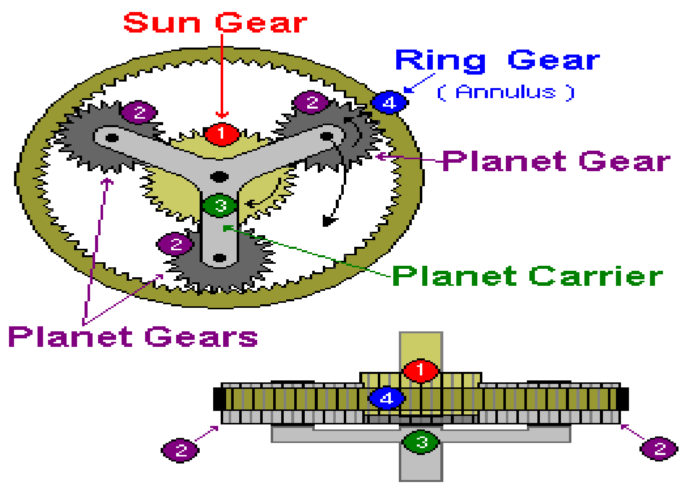

Fig. 1. Epicyclical gear train

A simple Epicyclic gear train consists of a sun gear (S) in the centre, a planet gear (P), a planet carrier or arm (C), and an internal or ring gear (R). The sun gear, ring gear and planet carrier all rotate about the same axis. The planet gear is mounted on a shaft that turns in the bearing in the planet carrier and meshes with both the sun gear and the ring gear. (Figure 1.3)

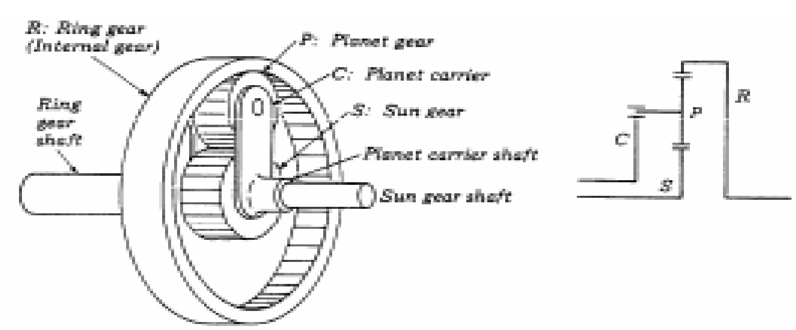

Fig. 2. An Epicyclic gear train and its associated terminology

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The general expressions pertaining to the gear train are given below:
For a gear train, if Ti = input torque, θi = input angular displacement, To = output torque, θo = output angular displacement, then,

Table 1. General expression values

Angular velocity ratio	$R_v = \frac{\theta_i}{\theta_o}$
Input work	Ti * θi
Output work	To * θo
Efficiency (h)	$\frac{Outputvork}{InputWork} = \frac{T_o\theta_o}{T_i\theta_i}$

If the input shaft tends to rotate in the direction of Ti, the gear train is balanced if
Ti θi = Mfriction + To θo
If there is no friction loss, the efficiency should be 1.0 and the output work equals to input work. The corresponding To is ideal and is equal to Ti Rv
To =Ti / Rv
Where To is the ideal output torque.

II. AIM AND OBJECTIVES OF THE STUDY

The aim of this research is to conduct a comprehensive analysis of epicyclic gear trains using Finite Element Analysis (FEA) tools such as ANSYS. By leveraging advanced computational techniques, the study seeks to gain insights into the structural behaviour of epicyclic gear trains under varying operating conditions. Through this analysis, the aim is to enhance our understanding of the mechanical complexities inherent in these gear systems and to provide valuable insights for optimizing their design and performance.
The following are the potential objectives of the study:

1. Develop a detailed 3D model of an epicyclic gear train, incorporating all relevant components such as gears, shafts, and bearings.
2. Import the model into ANSYS and perform meshing to discretize the components into finite elements, ensuring accurate representation of the geometry.
3. Assign appropriate material properties to each component based on empirical data or material specifications.
4. Apply boundary conditions to simulate real-world operating conditions, including torque inputs, external forces, and constraints.
5. Conduct FEA simulations to analyse the structural response of the epicyclic gear train under different loading scenarios.
6. Evaluate stress distribution, deformation, and contact pressures within the gear train to identify areas of potential failure or stress concentration.
7. Optimize the design of the gear train to improve structural robustness, efficiency, and reliability.
8. Validate the FEA results through comparison with analytical calculations or experimental data.
9. Provide recommendations for design improvements based on the insights gained from the analysis.

III. LITERATURE REVIEW

The dynamic behaviour of epicyclic gear trains was investigated using ANSYS Workbench in this research. Vibration characteristics, gear mesh dynamics, and noise generation were analysed to improve the performance of the gear train and reduce operational noise levels [1]. A structural optimization approach for epicyclic gear trains was presented using ANSYS Mechanical in this paper. The study was focused on minimizing stress concentrations and optimizing gear configurations to enhance the durability and efficiency of the gear train [2]. In this research, the focus was on the structural analysis and optimization of epicyclic gear trains using ANSYS Workbench. Design modifications were explored to improve the gear train's performance and reliability, with consideration given to factors such as stress concentration and deformation. The study examined how different design adjustments influenced the gear train's behaviour and sought to identify opportunities for enhancing its overall performance and reliability. [3]

In this study, the structural behaviour, stress distribution, and deformation characteristics of various gear configurations within epicyclic gear train systems were examined using ANSYS software. Different loading conditions were applied to assess the performance of the gear trains under realistic operating scenarios. The analysis involved simulating the interaction between gears, shafts, and bearings to understand how different design parameters and loading conditions influenced the structural integrity of the gear train. Additionally, the study aimed to identify potential areas of stress concentration and deformation, providing insights for optimizing the design and enhancing the reliability of epicyclic gear train systems. [4]

Finite element analysis, particularly ANSYS, was employed in this study to analyse the structural integrity and performance of epicyclic gear trains in automotive transmissions. The effects of gear geometry, material properties, and loading conditions on gear train behaviour were investigated. The research aimed to understand how variations in these factors impacted the structural integrity and performance of the gear trains, providing insights for optimizing their design and enhancing their reliability in automotive applications. [5]

IV. VIRTUAL ANALYSIS

ANSYS mechanical, a general-purpose finite element analysis (FEA) computer-aided engineering software tool developed by ANSYS Inc., was commonly utilized. Within ANSYS mechanical, a self-contained analysis tool was employed, encompassing pre-processing tasks such as geometry creation and meshing, as well as solver and post-processing modules, all within a unified graphical user interface. ANSYS served as a general-purpose finite element modelling package, facilitating the numerical resolution of a diverse array of mechanical and other engineering issues, including both linear structural analysis and non-linear contact analysis.

In this work, ANSYS was employed for conducting the analysis, among various finite element method (FEM) packages available.

The solution procedure utilizing ANSYS involved the following steps:

1. The geometry of the gear slated for analysis was imported from the solid modeler Pro/Engineer in IGES format, which was compatible with ANSYS.
2. The element type and material properties, including Young's modulus and Poisson's ratio, were specified.
3. The three-dimensional gear model was meshed, generating a meshed 3D solid model of the gear, as depicted in Figure 6.2.
4. Boundary conditions and external loads were applied to the model.

5. Based on the previously defined input parameters, the solution was generated.

Finally, the solution was observed through various display options:

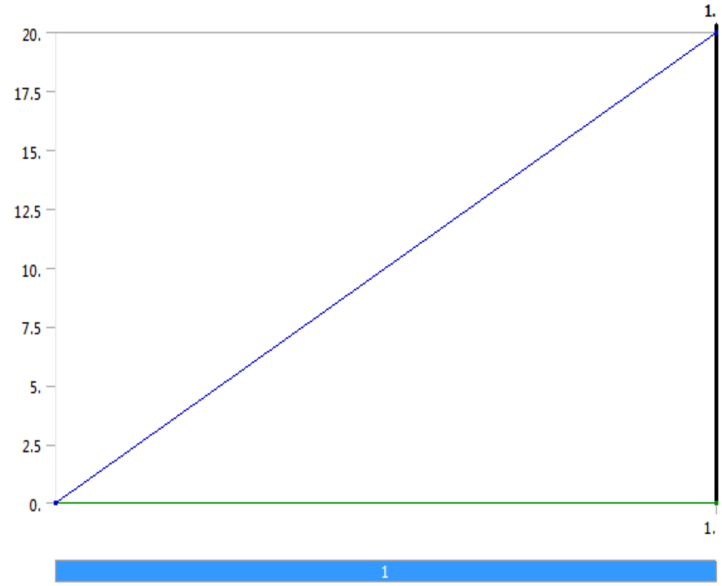


Fig. 3. Rotation velocity

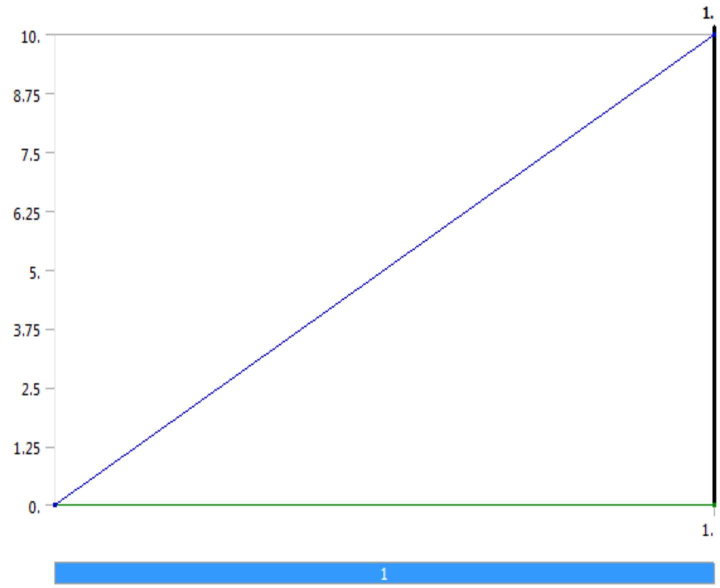
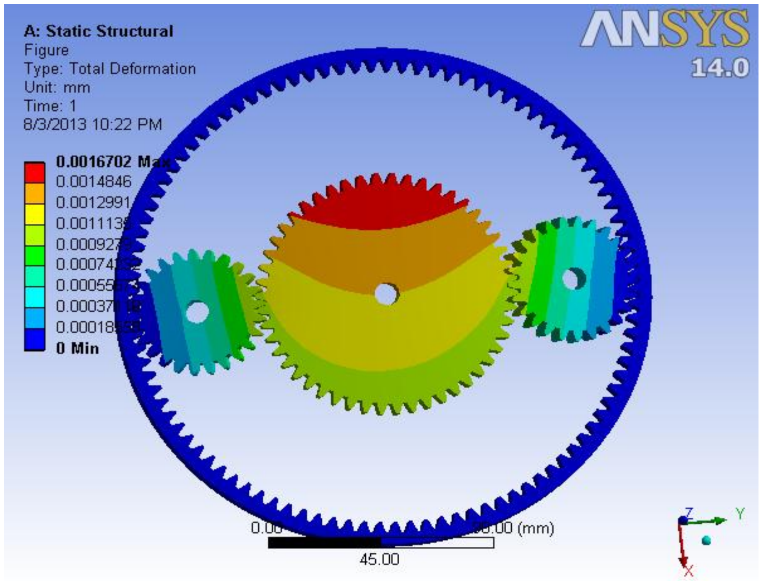


Fig. 4. Force

4.1. Total and directional deformation analysis:

In continuum mechanics, deformation involves the transformation of a body from a reference configuration to a current one, where a configuration denotes the positions of all body particles. Unlike the conventional notion of deformation, which suggests shape distortion, continuum mechanics encompasses rigid body motions without shape changes. Deformation manifests as alterations in the

metric properties of a continuous body, leading to changes in the lengths of curves from the initial to the final placement. If curves retain their lengths, a rigid body displacement is deemed to occur.
Establishing a reference configuration facilitates tracking subsequent configurations. Although the reference configuration need not correspond to an actual body state, it serves as a point of reference for all subsequent configurations. Typically, the configuration at t = 0 is designated as the reference



configuration, denoted as K0(B), while the configuration at the current time, t, represents the current state. Physical deformations are computable both within and upon a part or assembly. Fixed supports impede deformation, while locations lacking fixed support usually undergo deformation relative to their original positions. Deformations are assessed with respect to the part or assembly's world coordinate system.

Fig. 5. Total Deformation of Epicyclic gear train

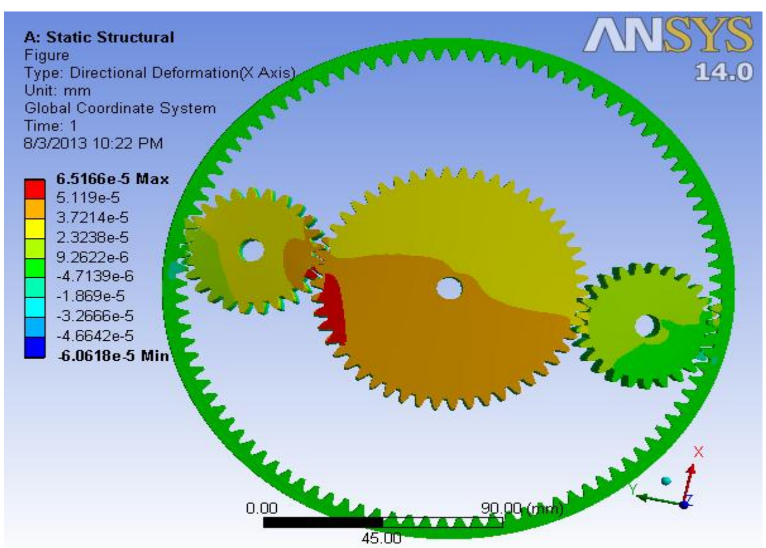


Fig. 6. Directional deformation of Epicyclic gear train

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4.2. Stress analysis:

Stress analysis involves determining the internal stress distribution within a structure, crucial for engineering tasks such as designing tunnels, dams, mechanical components, and structural frames under specified or anticipated loads. Engineers address this by solving boundary-value problems, specifying boundary conditions involving displacements and forces. Constitutive equations, such as Hooke's law for linear elastic materials, govern the stress-strain relationship in these calculations. Elastic deformation, where structures return to their original shape, is analysed using elasticity theory with infinitesimal strains under design loads. Permanent deformations invoke plasticity theory.

Analysis is streamlined when physical dimensions and load distributions permit treating the structure as one- or two-dimensional. For a two-dimensional approach, plane stress or plane strain conditions are assumed. Alternatively, stresses can be experimentally determined.

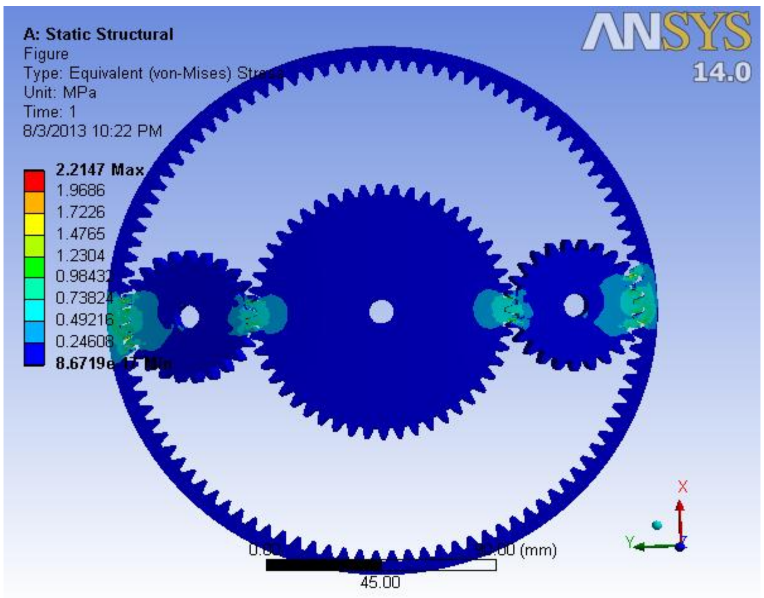


Fig. 7. Equivalent Stress of Epicyclic gear train

4.3. Equivalent elastic Strain:

Elastic strain, also known as elastic deformation, occurs temporarily when stress is applied and disappears upon stress removal. This strain results from stress-induced movement of atoms in a crystal, with all atoms displaced equally but maintaining relative geometry. Upon stress removal, atoms return to their original positions without permanent deformation.

Hooke's law governs elastic deformation, stating the relationship between applied stress (σ), material constant Young's modulus (E), and resulting strain (ε). This law applies within the elastic range, used to determine Young's modulus in tensile tests. The elastic range ends at the material's yield strength, marking the onset of plastic deformation. When sufficient load is applied to a material, it undergoes deformation, a change in shape. Elastic deformation, a reversible change, occurs at low stress levels, where the material returns to its original shape after stress removal. This deformation involves bond stretching without atomic slippage.

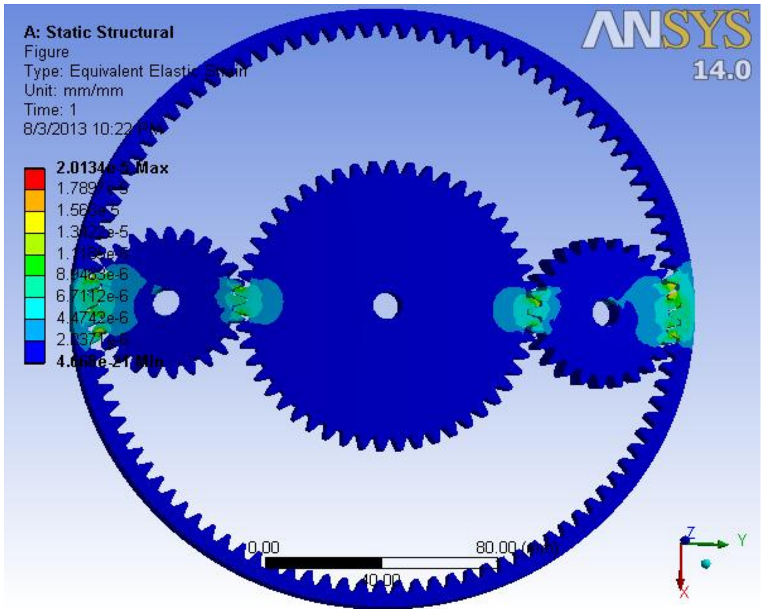


Fig. 8. Equivalent elastic Strain of Epicyclic gear train

4.4. Friction contact mechanism:

Contact mechanics involved studying the deformation of solids touching each other at one or more points. It encompassed compressive and adhesive forces perpendicular to the interface, and frictional forces tangentially. Frictional contact mechanics examined body deformation with friction, while frictionless contact mechanics assumed its absence.

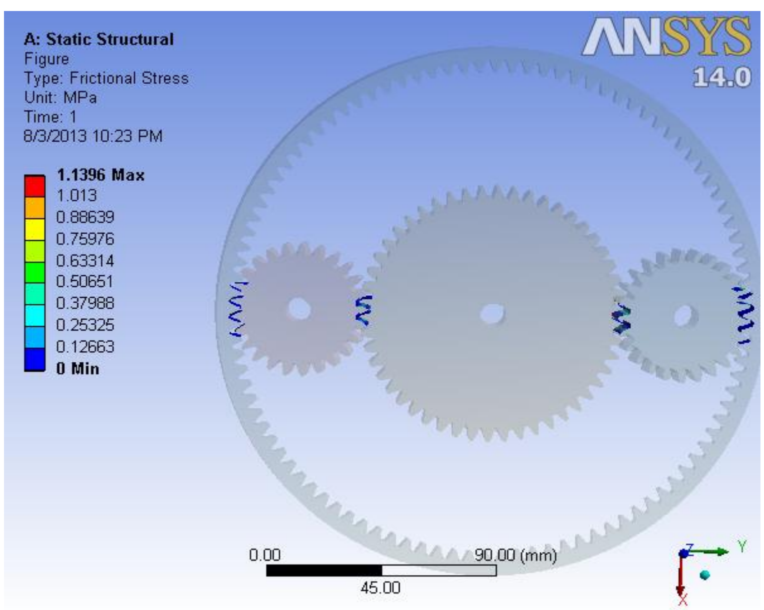


Fig. 9. Frictional Stress of Epicyclic gear train

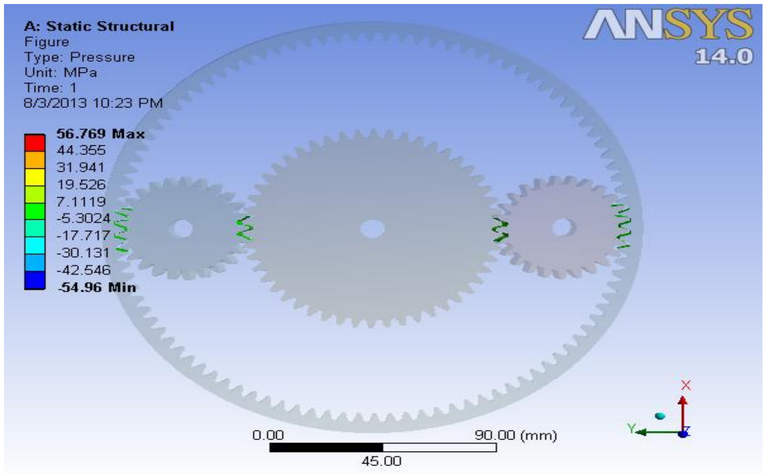


Fig. 10. Contact Pressure of Epicyclic gear train

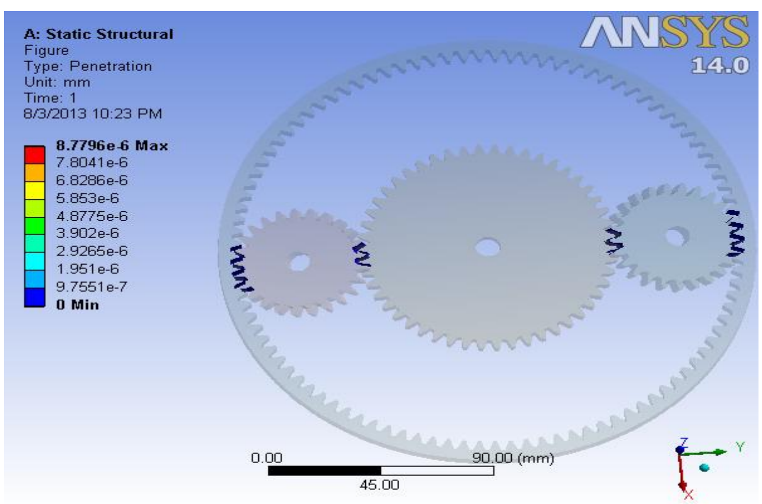
4.5. Contact Pressure:

Pressure is defined as the ratio of force to the area over which it is distributed. It is the force per unit area applied perpendicular to an object's surface. Gauge pressure, relative to local atmospheric or ambient pressure, is commonly used. Pressure is measured in units of force divided by area. The SI unit for pressure is the pascal (Pa), named after Blaise Pascal. One pascal (Pa) is relatively small, approximately the pressure exerted by a dollar bill resting flat on a table. Kilopascals (kPa) are often used for everyday pressure measurements (1 kPa = 1000 Pa).

4.6. Contact Penetration:

Considerations for adjusting contact penetration include:

i. Cotter pins might require breaking for adjustments.
ii. The target contact penetration is 7/8 of an inch, with a tolerance of plus or minus 1/8 (or 3/4 + 1/16 for 2500 MVA).
iii. Penetration should not be confused with surface contact.
iv. Excessive penetration could heighten the risk of the pull rod hitting the blast tube.
v. Removal of arc chutes may be necessary



vi. .Fig. 11. Penetration of Epicyclic gear train

FUTURE SCOPE OF THE STUDY

The findings of this research can serve as a foundation for further exploration and advancement in the field of epicyclic gear trains and FEA analysis. Future research endeavours may include:

1. Investigating the dynamic behaviour of epicyclic gear trains, considering factors such as vibration and noise.
2. Exploring the influence of different lubrication regimes on the performance and longevity of gear systems.
3. Integrating advanced optimization techniques to further enhance the design and efficiency of epicyclic gear trains.
4. Extending the analysis to encompass multi-stage gear trains and complex gear arrangements.
5. Exploring the application of FEA tools in the design and analysis of other mechanical systems with similar structural complexities.
6. Overall, this research sets the stage for ongoing exploration and innovation in the realm of epicyclic gear trains, offering valuable insights for improving the performance and reliability of these essential mechanical components.

ADVANTAGES OF THE STUDY

Analysing an epicyclic gear train using ANSYS, a Finite Element Analysis (FEA) tool, offers a multitude of advantages:

1. Accurate Simulation: ANSYS provides highly accurate simulations of the structural behaviour of epicyclic gear trains. Its advanced algorithms enable precise prediction of stress distribution, deformation, and contact pressures within the gear system, aiding in robust design decisions.
2. Cost Savings: By conducting virtual simulations, ANSYS reduces the need for expensive physical prototypes and testing. This cost-effective approach allows engineers to identify design flaws early in the development process, minimizing costly iterations and speeding up time-to-market.
3. Optimization Opportunities: ANSYS facilitates optimization of epicyclic gear train designs. Engineers can iteratively refine the design to improve performance, efficiency, and reliability. ANSYS's parametric capabilities enable rapid exploration of design variations to achieve optimal outcomes.
4. Comprehensive Analysis: With ANSYS, engineers can conduct comprehensive analyses, including structural, thermal, and dynamic simulations. This holistic approach enables the assessment of various performance aspects, ensuring the gear train meets all functional requirements.
5. Understanding Complex Interactions: Epicyclic gear trains involve intricate interactions between gears, shafts, bearings, and housings. ANSYS allows engineers to visualize and understand these complex interactions, providing insights into the system's behaviour under different operating conditions.
6. Flexibility and Versatility: ANSYS offers a wide range of features and capabilities suitable for analysing diverse mechanical systems. Its flexibility allows engineers to adapt analyses to specific needs and requirements, making it suitable for a variety of applications beyond epicyclic gear trains.
7. Validation and Verification: ANSYS enables engineers to validate and verify designs through comparison with experimental data or analytical calculations. This validation process ensures the accuracy and reliability of the simulation results, instilling confidence in the design's performance.
8. Optimized Material Selection: ANSYS facilitates material selection by simulating the behaviour of different materials under various loading conditions. Engineers can evaluate factors such as strength, stiffness, and thermal properties to choose the most suitable materials for the gear train components.

In summary, leveraging ANSYS for analysing epicyclic gear trains offers numerous advantages, ranging from accurate simulation and cost savings to optimization opportunities and comprehensive analysis capabilities. These advantages empower engineers to develop robust and efficient gear systems essential for various industrial applications.

CONCLUSION

The planetary gear train underwent testing for stress, strain, deformation, and contact analysis using ANSYS 14.0, and the results were deemed satisfactory. Copper alloy was chosen for the analysis due to its lightweight nature and frequent use in gear train manufacturing. The gear train rotated at a low speed of 20 rad/sec for the analysis, with a force of 35 Newton applied to the impeller blades. Results drawn from the analysis aligned with material properties. The results depicted maximum deformation and stresses occurring at the teeth of the gears. Contact analysis confirmed satisfactory meshing and penetration based on the applied parameters.

Also, the analysis of the epicyclic gear train using ANSYS, a Finite Element Analysis tool, has provided valuable insights into its structural integrity and performance characteristics. The results obtained from the analysis have shed light on the distribution of stresses, vibration behaviour, and noise generation within the gear system. This comprehensive understanding can serve as a foundation for further optimizations aimed at enhancing the gear train's efficiency, durability, and overall performance. Additionally, the utilization of ANSYS has demonstrated its effectiveness as a powerful tool for simulating and evaluating complex mechanical systems, offering engineers and designers a reliable means of assessing and improving gear train designs.

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