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Design and Analysis of Gear System for Turboshaft Aero Engine Reduction Gearbox

Ritu Jacob Boby and E. Raj Kumar

School of Mechanical Engineering (SMEC), Department of Design and Automation, VIT University, Vellore, Tamil Nadu, India; ritujacob.boby2014@vit.ac.in, rajkumar.e@vit.ac.in

Abstract

Background/Objective: This paper focuses on the designing and analysis of a gear system for a turboshaft aero engine reduction gearbox considering various operational, safety and economic parameters involved. **Methods/Statistical Analysis:** Design for the gear system is made in conformance to International Standards. Various design parameters including stresses developed in the system is determined theoretically and experimentally. Gear blank is later optimised and results validated through finite element analysis. **Findings:** Contact and bending stresses obtained through finite element method for altered gear blank is found to be in acceptance with theoretical value calculated in accordance with standards for high speed gear systems. Influence of pinball region of contact is also determined. This specifically aids in validation of finite element results with that obtained through theoretical calculations for gear blank related optimisation requirements. **Application/Improvements:** Instead of concentrating on one or two specific stages of design, the process of designing case specific gearing can be improvised by utilising finite element methods at more design stages.

Keywords: FEA, Gear Design, Gear Optimization, High Speed Gears, Solid Modelling

1. Introduction

There is considerable variation in power requirements from engine during various flight modes of the helicopter. This results in the considerable amount of varying loads or in other words, dynamic loads, acting on different components present in the drive train. This paper intends to outline the design and analysis of a gear system present in this drive train. Failure of any one component inside gearbox can lead to loss of power supplied to the main rotor, which is the only component keeping the aircraft airborne. This can lead to hefty and unpredictable losses. Hence all the design stages are in conjunction with International Standards and each parameter involved in the design are taken seriously.

Based on the requirements, a program is made to calculate gear parameters in conformance with International Standards. Gear system based on the parameters is then modelled using NX9 software. Gear blank in the system has to be optimized to reduce material mass as well as cost. Main objective of this paper is to validate the process of removal of material from blank, without affecting structural integrity of the gear system. Solid model of the gear blank is generated and subjected to finite element analysis using ANSYS APDL software. Based on the results a refined 3D solid model of gear is generated using Solidworks 2013 software and subjected to static analysis in ANSYS Workbench. Results obtained through static analysis and theoretical calculations according to standards are later compared.

In[1] mentions about the operational characteristics of helicopter. Lift required for the flight of helicopter is generated with the help of main rotor. Rotor blades have an aerofoil profile, the angle of attack of which can be altered by the pilot. Lift generated varies with changing angle of attack. Changing angle of attack of all the main rotor blades collectively is referred to as the changing of collective pitch. Speed of the main rotor should remain within a limit irrespective of the operational conditions. Apart from varying thrust of rotor independently of the

** Author for correspondence*

rotor speed, changes in collective pitch are required to compensate for the changes in air density with altitude and also to compensate for the changes in angle of attack due to variations in axial flow in translational flight. Lift is gained by imparting a downward momentum to particles of air and the flow of air above rotor would vary considerably along the span.

Different types of missions in which a helicopter operate include search and rescue, medical evacuation, transport, attack and observation helicopters. Based on the missions, it's power requirements will vary considerably. Based on this varying power requirement, components have to be designed.

In[2] discusses based on the fundamental requirements governing the shapes that any pair of conjugate tooth profiles have, which are summarized in the Willis fundamental law of gearing, for parallel axis gearing. It states that the normal to the profile of mating teeth must, at all points of contact, pass through a fixed point located on the line of centre. This ensures a constant angular velocity ratio when one gear teeth is made to move the other by sliding contact. In[3] shows the influence of stress concentration on various failure methods in gears like rupture, fatigue, scoring and pitting.

In[4] mentions about the approach to be followed for determining the contact and bending stresses in helical gear systems. Finite Element Method (FEM) analysis results are discussed for a moderately loaded gear, which arerequired for the validation of theoretical results based on standards. But variations are obvious in highly loaded cases. FEM analysis in the determination and validation of results obtained through International Standards is of vital importance and is discussed[5,6] mentions about nontraditional optimization methods which can be used in conjunction with requirements for assembly and mass reduction.

2. Experimental Procedure

Proper design criterion for gears requires that the input speed, transmission ratio, design torque/torque-time characteristics, design life and reliability be pre-established.

2.1 Design Parameters

Depending on the mission requirements of the helicopter, a torque time characteristic is generated which is later utilised for the determination of design torque by Miner's rule. Input speed is necessarily the engine rotational speed whereas the output speed is based on the main rotor rotational speed. These data were utilised to determine gear ratio for the drive. Design life is based on the overhauling frequency of the helicopter. Utilizing these data as input, a program is made to determine the required gear parameters in conformance with International Standards[7].

Different stages of the program include establishment of design torque based on load spectrum input, identification of permissible stresses for the material, rough sizing of the gear, establishment of dynamic load factor in conformance with DIN3991, Gear stress analysis and design refinement. The output is utilised to make design parameters represented in Table 1.

Table 1. Gear design parameters

	Pinion	Gear
No. of Teeth	33.00	132.00
Face width ratio	0.45	0.45
Module	2.00	2.00
Pressure Angle	20.00	20.00
Helix Angle	15.00	15.00
Pitch Diameter	68.33	273.31
Face width	30.42	
Center Distance	170.82	
Base circle diameter	64.21	256.83
Circular Pitch	6.28	6.28
Tooth Thickness	3.14	3.14
Addendum	2.00	2.00
Dedendum	2.40	2.40
Addendum Radius	36.16	138.66
Dedendum Radius	31.66	134.16
Contact Stress	1098.7	
Bending Stress	491.46	
Dynamic Factor	1.13	

2.2 3D Model Development

Catia software is utilised to model the rough sized gear for determining the approximate mass per facewidth mentioned in DIN3991. The data made in this manner is utilised in the calculation of dynamic load factor. Rough sized model with properties is represented in Figure 1 and 2.

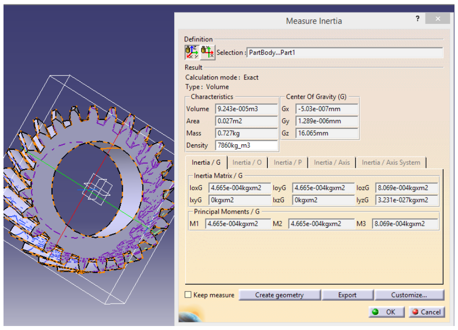

Figure 1. Rough sizing of pinion.

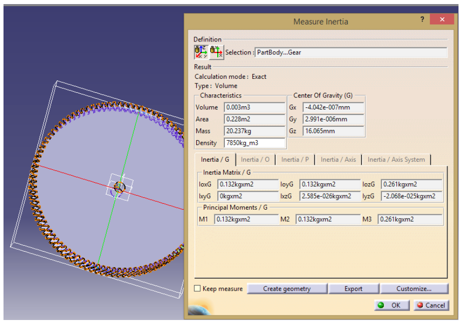

Figure 2. Rough sizing of gear.

After establishing the final design specification through design refinement stage, working 3D model of the gear system was made using NX 9 software. These models are utilised for conformance of gear mesh as well as optimisation of the gear blank design through finite element analysis. The generated models are represented in Figure 3.

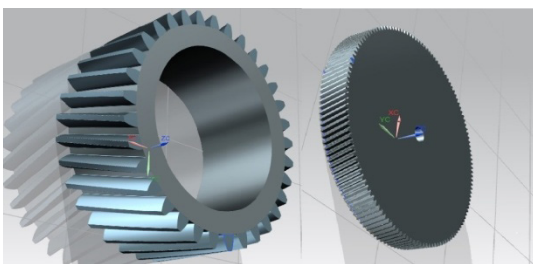

Figure 3. 3D model of gear system.

2.3 Gear Blank Selection

Selection of gear blank is carried out with priority for reducing mass of the gear system. Reduction of weight is a major factor of consideration for the design of aircraft components. This task was accomplished by analyzing multiple configurations using ANSYS to find out the variation in deflection and stress distribution for each configuration. Configurations used are shown in Figure 4 and 5.

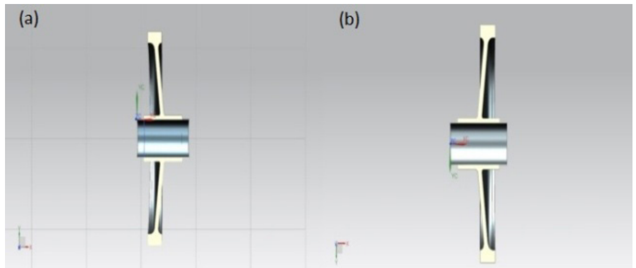

Figure 4. Configuration 1(a) and Configuration 2(b).

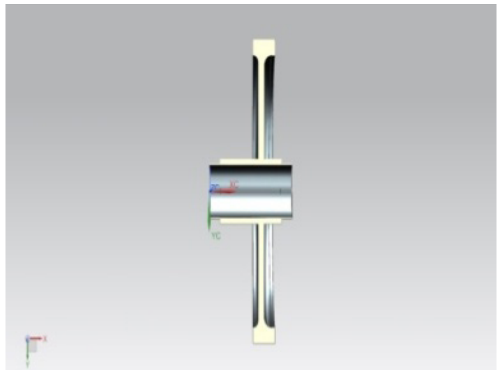

Figure 5. Configuration 3.

2.4 Analysis of Configurations

Each of the configuration shown in Figure 4 and Figure 5, have similar geometry as the gears excluding teeth, for ease of computation. Loads are applied at the middle point of facewidth, at pitch circle diametrical distance. All degrees of freedom at the points of contact of shaft is arrested for aiding static analysis. Each configuration was meshed with 10 node 187 element. Meshes generated are shown in Figure 6.

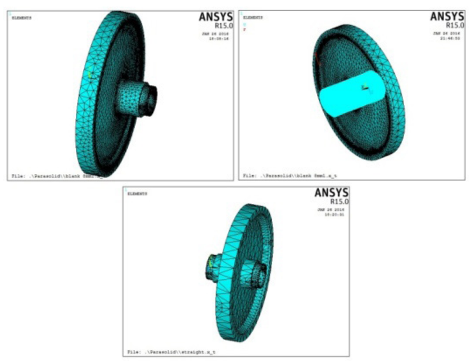

Figure 6. Meshing of all blank configurations.

Table 2. Analysis parameters

Parameter	Input
Analysis type	Static
Element type	Solid 10 node 187
Material	Steel
Young's modulus	200000N/mm^2
Density	7850 kg/m^3
Axial load	4119.536 N
Radial load	5793.193 N
Tangential load	15374.32 N

Analysis parameters are represented in Table 2. Results obtained through analysis are shown in Figure 7 to 9. It can clearly be concluded based on the stresses and deflection values that curved configuration 1 is the most suitable arrangement in this gear setup. Though the stress values are lower in straight configuration, deflection of the gear seems to be significantly higher.

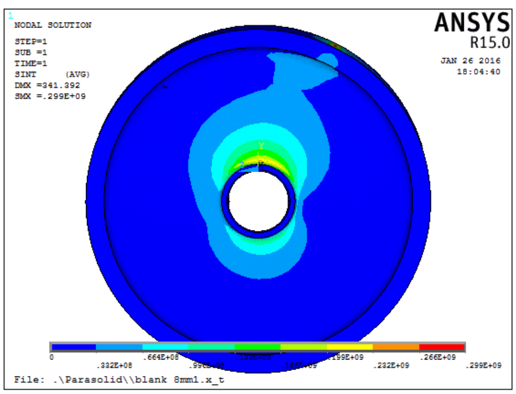

Figure 7. Stress on curved configuration 1.

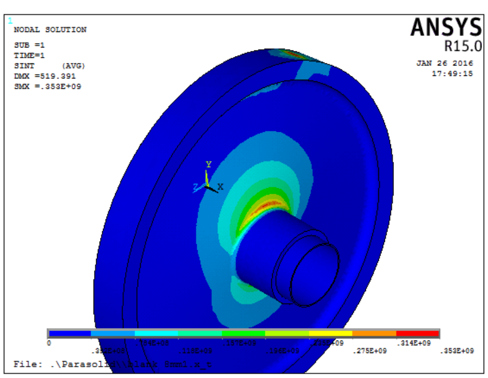

Figure 8. Stress on curved configuration 2.

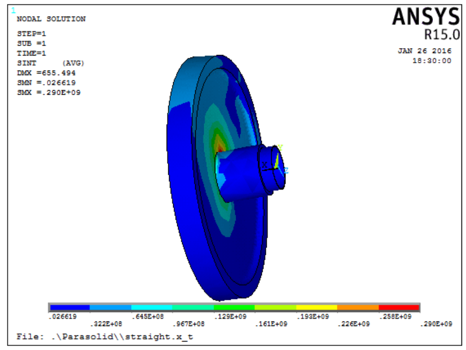

Figure 9. Stress on straight configuration.

2.5 Design Refinement and Analysis

Based on the configuration of blank obtained, a 3D model of gear is generated in Solidworks 2013 software. The design is made by modifying the blank according to the bearing seat requirement and load transmission through the system. 3D Model of the gear is represented in Figure 10.

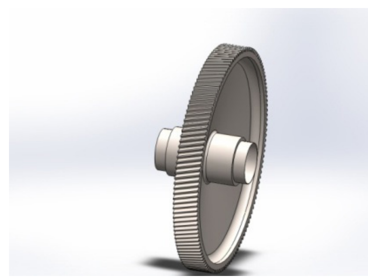

Figure 10. Refined gear design.

Constraints necessary for gear assembly include the centre to centre distance between gear and pinion, coincidence of parallel surfaces and mechanical constraint for rotation of gears based on gear ratio. These constraints are applied and the assembly generated as shown in Figure 11.

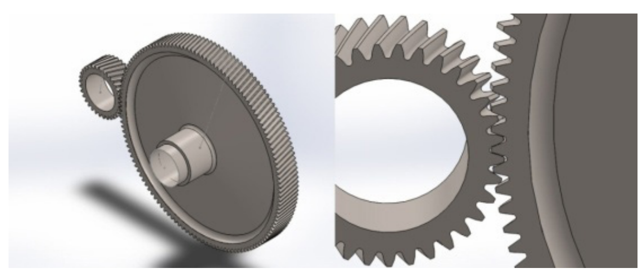

Figure 11. Gear system assembly.

The generated assembly is then converted into Initial Graphics Exchange Specification (IGES) file format and exported to ANSYS Workbench. Static analysis is carried out in multiple stages. Initially the system is defined as a complete solid utilising solid modeller. It is then subjected to various boundary conditions as represented in Table 3. Meshing is done followed by application of moment and angular velocities. Meshes are refined along the teeth in order to determine proper stress values on contact. Equivalent contact as well as bending stresses developed near root radius of mating gear is considered for validation of theoretical results.

Table 3. Boundary Conditions

Condition	Value
Gear Rotational Velocity	523 rad/s in clockwise direction
Pinion Rotational Velocity	2094 rad/s in anticlockwise direction
Torque applied through pinion	553Nm in anticlockwise direction
Pinion support	Frictionless
Gear support	Cylindrical

A stress probe is placed near to the root diameter in order to determine stress concentration for bending. Meshing was then carried out as represented in the Figure 12.

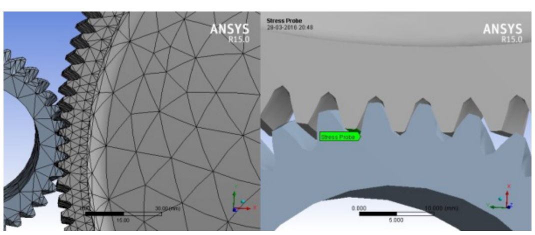

Figure 12 Mesh pattern and location of stress probe.

3. Results

Theoretical calculations for contact and bending stresses are shown in Table 3. The values of contact and bending stresses are found out to be 1098MPa and 491MPa respectively. Results from ANSYS are represented in Figure 13 and Figure 14. Maximum contact stress is found out to be 947.43MPa which is within a close tolerance of 15% from the theoretical value.

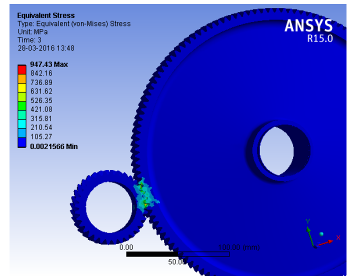

Figure 13 Stress Concentration in the system.

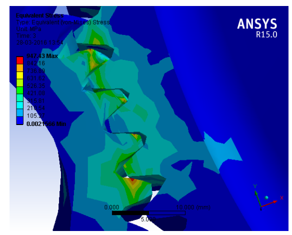

Figure 14 Stress Concentration around mating teeth.

The result for bending stresses is found out to be slightly higher, with a 20% variation from theoretical value. The variation in results is mainly due to the variation in pinball region in contacts assigned.

4. Conclusion

The design modification is acceptable because of the conformance of theoretical and analysis values. Finite Element Analysis (FEA) is a vital tool for designing applications. In case of high speed gears, it is capable of obtaining results with all valid operating boundary conditions like very high moment and angular velocity. However specifying the exact point of contact, which is highly influenced by pinball region of contact, is a difficult process. Gear design, being a mature area, has large opportunities for validation of results with respect to region of contact, which is already established without FEA.

5. References

1. John Fay. The Helicopter: History, Piloting and how it flies. 4th editionn. David & Charles Publication, 1990.
2. Stephen P Radzevich. Theory of Gearing: Kinematics, Geometry, and Synthesis. CRC Press, 2012 Jul.

3. Lester E Alban. Systematic Analysis of Gear Failures. 2nd edition. ASM International, 1986, p. 586–601.
4. Jyothirmayi S, Ramesh R, Swarnalatha T, Renuka D. A finite element approach to bending, contact, and fatigue stress distribution in helical gear systems. Procedia Materials Science. 2014 Sep; 6:907–918.
5. Govind T Sarkar, Yogesh L Yenarkar, Dipak V Bhope. Stress analysis of helical gear by finite element method. International Journal of Mechanical Engineering and Robotics Research. 2013 Oct; 2(4):1-8.
6. Raj Kumar E, Annamalai K. Recent nontraditional optimization techniques for Assembly sequence planning. International journal of pure and applied mathematics, 2015 Mar; 101(5):707-715.
7. ISO 6336-2006. Calculation of load capacity of spur and helical gears.