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Manufacturing design and static analysis of a gear shaft

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ABSTRACT

This paper presents a gear shaft design that was constructed with the use of Solidworks, the manufacturing process of the design done by the use of the Edgecam software and also a Finite Element Analysis (FEA) which includes examining the part's displacement behavior with corresponding stress and deformation. The 3-dimensional finite element simulation and meshing of the model was done with the ANSYS Workbench. Boundary requirements including external loads were also utilized. The manufacturing design was done in two parts due to the high level of complexity associated with the gear shaft. The first part included the parametric configurations used for machining one end of the gear shaft and the second part included the parametric configurations used for machining the other end of the gear shaft. This means that when the machining process has to be done on the CNC machine, there will be two separate CNC codes to be utilized which can run successively. During the manufacturing design phase, important information was obtained, such as the overall time for machining of one or both ends of the gear shaft as well as the safety conditions that were utilized during the process.

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1. INTRODUCTION

This document gives formatting instructions for authors preparing papers for publication in the Journal of Advanced Technologies and Materials. The authors must follow the instructions given in the document for the papers to be published. You can use this document as both an instruction set and as a template into which you can type your own text. An electronic copy can be downloaded from the journal website. Manuscript must be prepared in MS Word only and should be formatted for direct printing. Figures and tables should be embedded and not supplied separately. Paper should be proof-read and have English language errors corrected before submission as we may have to return papers due to poor language usage. The features associated with a helical gear system are examined in this thesis, with a particular emphasis on contacting as well as bending stresses, utilizing the use of finite elements along with statistical analysis. To calculate the three-dimensional solid structures for stress from bending, Solidworks, a potent and contemporary solid modeling program, generates varying numbers of teeth. The study done by [1] on a pair of identical engaging cylindrical ones was done with the aim to identify the collision stresses between their connecting gears. The provided results from ANSYS are contrasted with theoretical values. ANSYS performs the numerical solution; it is a finite package for element analysis [2]. The model's parameters were determined using conceptual techniques. The strains produced and the deviations from the teeth have undergone several material analyses. The findings from the analysis of finite elements were done along with this same theory [3]. Analyses were contrasted to ensure accuracy and a decision was made regarding the material that was most effective and suitable for marine engines in light of the findings [4]. Essentially the project entails manufacturing, modeling, and design for various automotive uses with helical gearing. It was suggested that it concentrates on losing weight and achieving excellent accuracy in motors. Initially, several crucial works in gear mechanics were covered: mesh rigidity along with transmission error. A review of a new research article in gear mechanics by [5] follows the breakdown of gear dynamical designs provided in the paper. The ANSYS method for gear connection was then reviewed and accompanied by an analysis of freshly released research in the topic. It was discovered that among

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the primary causes of gear meshes, oscillation is transmission error [6]. The variation between the resultant gear's real location and its location if the matching gear tooth morphologies are exactly conjugated is known to be a transmission error. Typically, it is situated in either a straight line across the operation's path or in rotational terms [7]. This research by [8] used the finite element approach, sometimes referred to as initial-order shear distortion plate theories, to examine the vibratory behavior of composite spur gears. The composite gearing was subjected to a finite element evaluation using four and eight nodded polygonal elements, each of which has five degrees of freedoms. Matlab was used for modeling and coding the finite element concept for synthetic gears. In light of the quantitative evaluation. This was done in order to drive spur gears. With the accessible outcome, the produced Matlab code was verified, and it may be said that the current results were fairly consistent with the reference values.

2. MEASUREMENT AND DESIGN OF THE CAD MODEL

In order to guarantee that gears perform properly and meet design standards, assessing their dimensions is essential. Additionally, there are several ways of determining the size of gears; which one to choose will rely on the kind of gearing being evaluated as well as the level of precision needed [9]. Several popular techniques to determine gear dimensions are as follows:

- Calipers: Basic small tools called calipers are often utilized for determining the tooth-width, exterior diameter, as well as root diameter of a gear. Computerized and vernier calibrators are frequently employed in this exact reason.
- Micrometers: Micrometers can be used to assess essential parameters such as gear tooth width. The exterior and inner diameters are measured, accordingly, using both interior and exterior micrometers.
- Optical Profile Projector: Gear measurements can be determined by displaying a larger version of the gear upon a monitor using an optical feature projection. It makes gear contour evaluation possible without physical contact.
- Gear Measuring Wires: The tooth thicknesses along with tooth spacing length of gears are measured with gear measuring wires, sometimes referred to as gear cables or gear gauging needles. The aforementioned wires are positioned among gear teeth to measure their widths; their diameters can be determined [10].

2.1 Design Process of the Gear Shaft

The chosen computer-aided software to be used for the model design was SOLIDWORKS due to the freedom that this gives to an engineer to switch between the 2-D work space and the 3-D workspace and the very much friendly user interface to perform various *design* operations. The design of the gear shaft was broken down into stages to make the development of the final model much easier and more possible. With the aid of the chosen CAD model, the main part of the gear shaft was created, from which other parts can be generated from and the best operation that seemed suitable to create this main part was the revolve operation. The outline for the revolve action to be done was designed in the 2-D space and the dimensions and shape was derived from the measured sketch that was done from the actual gear shaft. To ensure that this part is fully defined, additional dimensions had to be included at specific sections in the sketch. The revolve operation will not be possible in the 2-D sketch based on two important conditions which are:

- The sketch must always be fully defined
- The sketch must be a completely closed sketch

This means that all lines on the sketch must have no opening or separation from each other. Based on these specific conditions, the 2-D sketch was fully defined and closed to confirm if the revolve operation was successful. Circular patterns were used to create the helical gear and the spur gear on opposite ends of the CAD model.

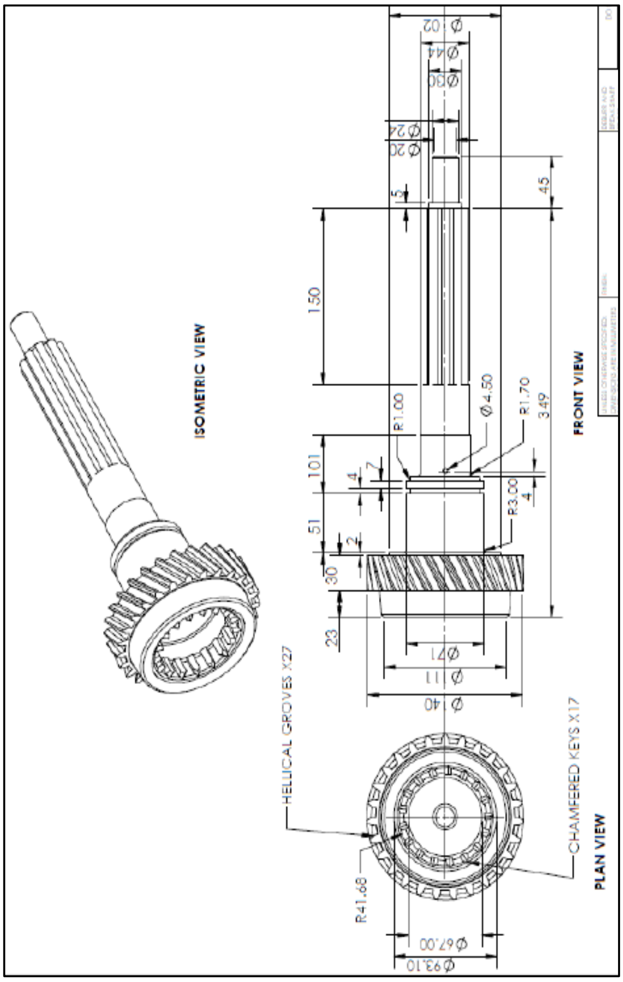

Fig. 1 *The CAD model in Solidworks*

2.2 Material Selection for the CAD model

The chosen material for the gear shaft after much research had been done online was Alloy Steel and this was the dedicated material for all portions of the CAD model created in the software. Although different materials have been used to create a gear shaft depending on the

automobile that is being developed, the alloy steel seemed much generalized to use as it covers the combination of multiple material properties to create a hybrid material.
Based on the selected material suitable for the CAD model, the Mass properties was evaluated by a feature in the CAD software. These parameters include the mass, volume, surface area and center of mass as the important parameters to be noted. The table below shows the resulting evaluation of the mass properties of the CAD model.

Table 1 - *Material Properties of the CAD model*

Property	Value	Units
Elastic Modulus	2.10E-11	N/m^2
Shear Modulus	7.90E-10	N/m^2
Mass Density	7700	kg/m^3
Poisson's Ratio	0.28	N/A
Mass	7.93	kg
Volume	1029464.74	cm^3
Surface Area	135064.95	cm^2

3. MANUFACTURING PROCESS OF THE GEAR SHAFT

From the successfully development of the CAD model in the previous chapter, the next process can be carried out. Due to the complexities of the intricate parts and sections on the gear shaft model, various operations had to be considered and multiple actions had to be carried out within each of the various operations with design parameters to be considered along the way. This chapter will attempt to breakdown the various procedures done to manufacture both sections of the gear shaft. From previous papers by scholars [2,3,6], there have been so many engineers in the past that have done similar works, which have been mentioned in chapter 1. They have used all types of Computer Aided Manufacturing software that is in existence ranging from Mastercam, Edgecam, Solidcam, Worknc, Inventor, etc. They all mentioned the options that the software provided and the probability that an engineer will understand the software when they are using this for the first time. This made the conclusion that the most preferred software for the gear shaft is the Edgecam software mainly because of the easy-to-understand user-interface that it offers. Before anything can be done on the Edgecam software, the machining environment had to be set. These machining environments can be either Milling operation or Turning operation. The selection of the turning environment was selected which will now lead us to the next step to be done. The gear shaft model that was created in solidworks was exported as a (.sldprt) part and was loaded into the Edgecam model, figure 2.

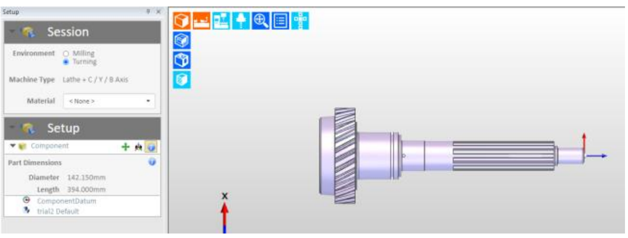

Fig. 2. *The CAD model loaded in Edgecam*

The stock dialog box offers the option to add an offset from the surface of the CAD model so that an engineer can smoothen the surfaces in case the surface may encounter damages of some sort. The parameters that were considered during the creation of the stock were the Front face offset and the Back face offset. The dimensions for both of these parameters were 10mm offset distance.

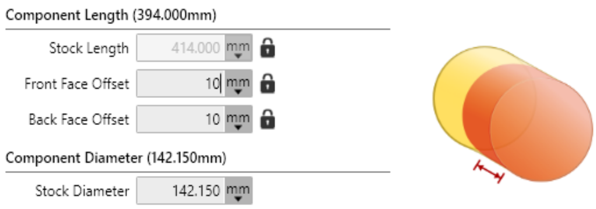

Fig. 3. *Adding stock and offset distance to the model*

The database of the clamping devices (also known as fixtures) was separated into three sections by Edgecam which are Chuck with jaws, Chuck collet and Vices. The most efficient clamping device for the model seemed to be under the Chuck with jaws section must be embedded into the text and not supplied separately. The selected fixture or clamping device that was chosen for the CAD model was the 6inch 3 Jaw Biston Scroll Chuck – Reverse Jaws and the dimensions for the fixture can be seen in the figure below. The fixture was set to grip the stock with no offset at the point of contact between the fixture and the stock so that there will be no redundancies when operating on the stock model.

3.1 Creating the machining sequence for one end of the gear shaft

The next step was selecting the machine for the operations to be performed on the stock. The turning sequence was selected and a list of various lathe machines appeared in a dialog box. This machines, like the fixture database, have already been installed in the Edgecam software, figure 4.

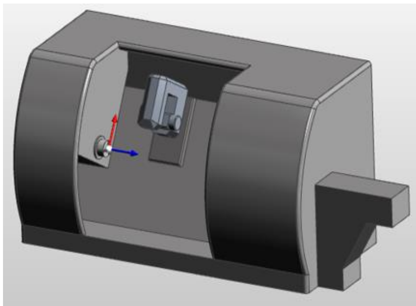

Fig. 4. *Desired machine loaded in the machining environment*

These machines offered the opportunity to carry out a trial and error on the basis of understanding each of the machines and knowing which is the best machine to be used for the manufacturing simulation. The chosen lathe machine was the Sample Lathe 2 CYB mm machine due to the degrees of freedom that is included. The workflow was loaded as well and the machine was added to the work environment.

The certain features that were discovered by the action of the Feature Finder in the Edgecam software can be seen in the figure 4. With these features in mind, we can begin the machine procedure with an idea for an engineering process on which tool parameters will best carry out each task with maximum efficiency. The figure 5 shows the planning board which contains a list of the actions that will be carried out for the manufacturing of the gear shaft.

Fig. 5. *Planning Board for the manufacturing process*

The selected tools were used for the manufacturing of the desired part on the face and body of the stock model and a visual representation was displayed on the machining environment for the engineer to be aware of the action that will be done. The figure 6. shows the visuals of the action that was done for the facing and turning action.

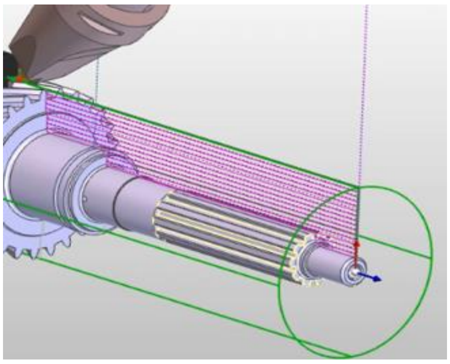
Fig. 6. *Facing and Turning operations*

Justifying the various values decided to be used for the parameters on every tab for the profile milling dialog box, the dialog box was saved and we proceeded to regenerate the machining sequence to load the action into the machining environment. The action was successful and the visual was also displayed on the machining environment.

The figure 7. shows the visual representation of the milling operation for the longitudinal groove that was carried out on the body of the shaft.

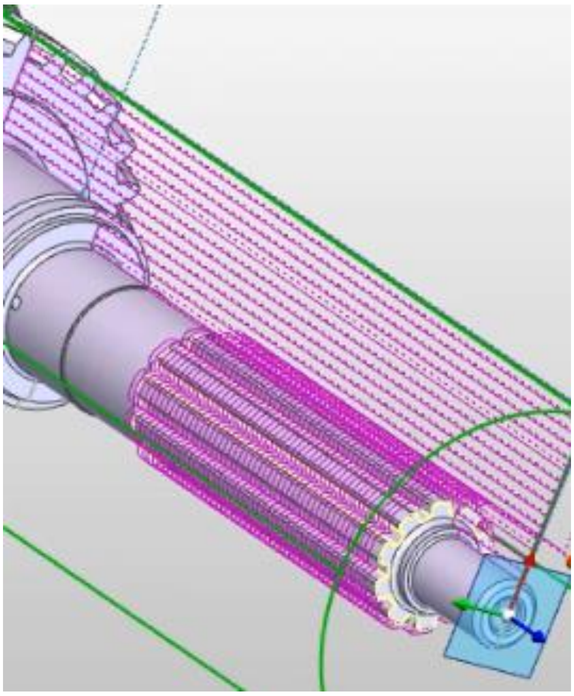
Fig. 7. *Milling operation for the machining sequence*

3.2 Creating the machining sequence for the other end of the gear shaft

Further to the successful completion of the machining sequence of the first end, the final step was the manufacturing process for the other end which involved the countersunk hole and helical gears. This step required much focus and attention to detail as well as gaining a higher level of understanding of the Edgecam software. The chosen machining action for the creation of the helical gears was the profile milling (Edgecam also calls this profiling), because it was the suitable operation that could carry out the desired task. The same cutting tool which was used for the manufacturing of the countersunk hole and internal groove was used for the creation of the helical gears. There were certain parameters that had to be brought into consideration under the profile milling dialog box and these parameters had a specific value assigned to them in order to produce the desired result.

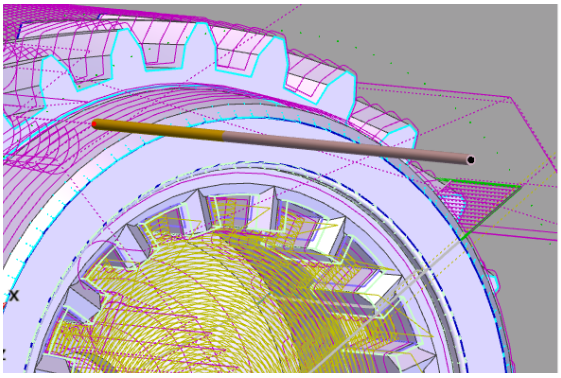
Fig. 8. *Profile milling and hole operations for the machining sequence*

3.3 Generating the g-code for the machining sequence

Since the machining sequence for both ends of the gear shaft were successfully created, the G-code for the entire machining sequence was successfully generated and this code can be inputted into the CNC machine to carry out the manufacturing design for this paper.

Table 2 - *Some CNC programming codes [8]*

G-code	Description
G00	Rapid Positioning
G01	Linear Interpolation
G02	Circular or Helical Interpolation CW
G03	Circular or Helical Interpolation CCW
G04	Dwell
G09	Exact Stop
G10	Parameter Setting
G17	Circular Interpolation Plane Selection XY
G18	Circular Interpolation Plane Selection ZX
G19	Circular Interpolation Plane Selection YZ

4. STATIC STRUCTURAL ANALYSIS FOR THE GEAR SHAFT

The final task for my thesis was to perform a FEA (Finite Element Analysis) on the gear shaft model that was created. This was going to be done my converting the model from a (.SLDPRT) into a (.STEP) file to be exported to be utilized in Ansys. For the analysis to be done, another gear was created to be used in relation to the gear shaft. These two models will have to be assembled to be a gear system and then apply loads and other constraints to the gear system to run the FEA.

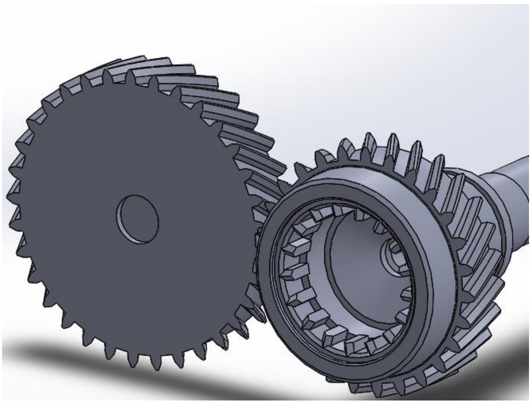

Fig. 9. *Creation of the assembly of both models for a gear system*

4.1 Adding Load and Boundary conditions

The next phase was to apply meshing to the gear system before carrying out the FEA. The mesh was generated to having 56507 total number of nodes and 31193 total number of elements. The figure 10. shows the meshing generated for the gear system.

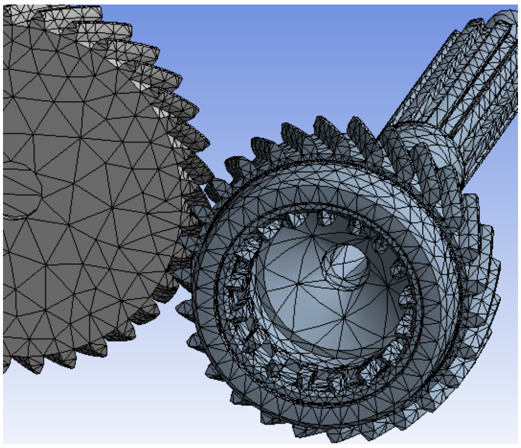

Fig. 10. *Generated mesh for the gear system*

The frictional support was applied to the cylindrical portion below the internal grooves. The force of 50N was applied to one of the teeth of the gear shaft (driving gear) acting in a direction that causes the gear system to be rotated in the counter-clockwise direction. The fixed support was applied to two regions, the internal cylindrical portion towards the bottom of the countersunk hole for the gear shaft and the internal cylindrical portion of the driven gear. The figure below shows the loads and constraints applied to the gear system.

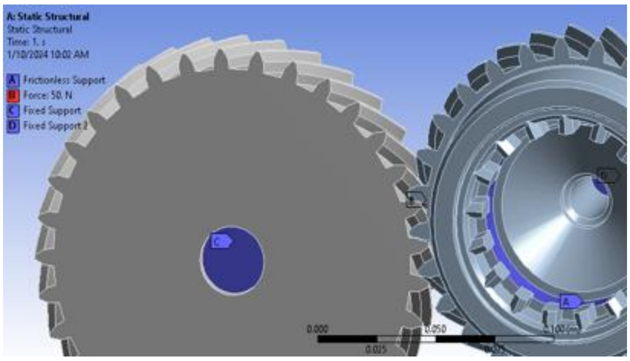

Fig. 11. *Load and constraints applied to the gear system*

The figures below show the resulting simulation of the equivalent stress and total deformation for the gear system.

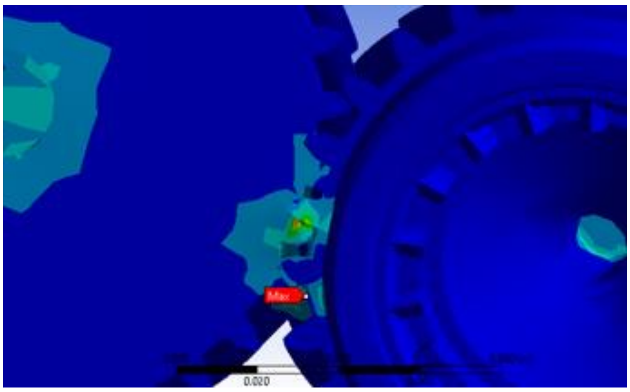

Fig. 12. *Equivalent (Von-Mises) stress for the gear system*

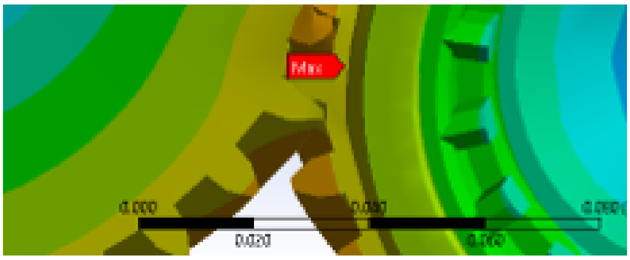

Fig. 13. *Total deformation for the gear system*

5. Conclusion

In conclusion, the machining sequences developed in Chapters Three and Four were successfully implemented, with precise values assigned to the parametric dialog boxes for both ends of the model. This meticulous approach ensured the accurate generation of the G-code for the entire machining process. The successful completion of the preceding operations facilitated the smooth creation of the final G-code, validating the effectiveness of the defined machining sequences.

Furthermore, the analysis of the mechanical properties revealed that the equivalent Von Mises stress ranged from 9.0286e-6 Pa to 1.4205e6 Pa, demonstrating the model's ability to withstand significant stress variations. Similarly, the total deformation analysis indicated a range from 0 meters to 2.3723e-7 meters, highlighting the model's structural integrity under the applied loading conditions.

Overall, this study underscores the importance of precise parameter assignment in the successful execution of machining sequences and the generation of accurate G-codes. The findings from the stress and deformation analyses provide valuable insights into the model's performance, paving the way for further optimization and application in practical machining scenarios. Future work could focus on refining the parameter values and exploring additional machining strategies to enhance the efficiency and accuracy of the process.

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