Product Development and Reverse Engineering by Using RPT

G. Gopinath[1], B. Chaitanaya Vamsi[2], N. Vinay[3],

[1] *Assistant Professor, Department of Mechanical Engineering, JBIET, Moinabad, Telangana.*
[2,3] *Research Scholar, Department of Mechanical Engineering, JBIET, Moinabad, Telangana.*

ABSTRACT

The automotive industry has an increasing need for the remanufacturing of spare parts through reverse engineering. In this thesis we will review the techniques used in Fused Deposition Modelling system for the reverse engineering of vintage automotive parts. The aim of this project is to develop a prototype model to optimize the design parameter of spur gear (Alloy steel) face width changing and to find the Allowable stresses to improve the life time the of spur gear, it from physical model. This physical model is scanned by using the 3D scanner machine and obtained the STL file format of manufactured component, this file is converted into CAD model and analyzed by using solid works simulation tool. After analysis, a prototype model is prepared by Fused Deposition model (FDM) method the material used to prepare prototype is poly lactic acid (PLA). In this work, five number of Face Widths are taken to observe the Allowable stresses and compare with the theoretical values. This entire process is involved in Reverse Engineering. The part geometry is first obtained with the help of scanning technology. Then with the use of different software's, the three-dimensional model of the spur gear is obtained. Once the CAD model is obtained the part is analyzed using SOLIDWORKS simulation tool. After the optimized geometry is obtained, the pattern of the part is obtained using Rapid prototyping machine. This can be used for casting of the original part.

Keyword - *FDM, PLA, and 3D Printing*

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1. INTRODUCTION

Engineering is the profession involved in designing, manufacturing, constructing, and maintaining of products, systems, and structures. At a higher level, there are two types of engineering: forward engineering and reverse engineering. Forward engineering is the traditional process of moving from high level abstractions and logical designs to the physical implementation of a system. Reverse Engineering: Engineering is the process of designing, assembling, manufacturing and maintaining products and systems. There are two types of engineering, forward engineering and reverse engineering. Forward engineering is the traditional process of moving from high-level abstractions and logical designs to the physical implementation of a system. In some situations, there may be a physical part/ product without any technical details, such as drawings, bills-of material, or without engineering data. The process of duplicating an existing part, subassembly, or product, without drawings, documentation, or a computer model is known as reverse engineering. Reverse engineering is also defined as the process of obtaining a geometric CAD model from 3-D points acquired by scanning/ digitizing existing parts/products. In some situations, there may be a physical part without any technical details, such as drawings, bills of material, or without engineering data, such as thermal and electrical properties. The process of duplicating an existing component, subassembly, or product, without the aid of drawings, documentation, or computer model is known as reverse engineering. Reverse engineering can be viewed as the process of analyzing a system to:

- Identify the system's components and their interrelationships
- Create representations of the system in another form or a higher level of abstraction
- Create the physical representation of that system

What is Reverse Engineering and how it is implemented in product manufacturing what are the advantages of Reverse Engineering in industrial manufacturing Reverse engineering is the reverse process of the design activity. It basically consists on the reconstruction of design models associated to a real product. The main goal of the reverse engineering is to go back to the results of the original design process in order to create a copy of the product, Reverse engineering has been developed as an alternative solution to define or redefine objects. Nowadays, it is widely spread in the manufacturing industry. It is used for the capitalization of information and knowledge, which haven't been collected yet. This is a critical issue for the development and evolution of products. We can list some of its applications in industry: long life products maintenance (trains, boats, aircrafts, nuclear power plants, etc.), redesign of existing products in order to improve them, competitor's product's analysis. Innovative techniques: Reverse Engineering consists of the following innovative techniques

• Digitizing.
• Segmentation of the acquired data.
• Knowledge extraction (feature recognition).
• Reconstruction of the 3D model Digitizing:
• Digitizing processes allow us to transfer real part surfaces to digital form. Basic principle of digitizing is to s can the component in space points and getting the output in CAD software.
• Main type of digitizing processes is the 3D scanning. The major system components in this process that used are the three-axes mechanical set-up, the probe head, control unit and PC.CMMs have become very powerful parts of measuring tools

Value Engineering Vs Reverse Engineering: Value engineering refers to the creation of an improved system or product to the one originally analysed. While there is often overlap between the methods of value engineering and reverse engineering, the goal of reverse engineering itself is the improved documentation of how the original product works by uncovering the underlying design. The working product that results from a reverse engineering effort is more like a duplicate of the original system, without necessarily adding modifications or improvements to the original design. Reason for Reverse Engineering: In some situations, designers give a shape to their ideas by using clay, plaster, wood, or foam rubber, but a CAD model is needed to enable the manufacturing of the part. As products become more organic in shape, designing in CAD may be challenging or impossible. Following are reasons for reverse engineering a part or product:

• The original manufacturer of a product no longer produces a product
• There is inadequate documentation of the original design
• The original manufacturer no longer exists, but a customer needs the product
• The original design documentation has been lost or never existed
• Some bad features of a product need to be designed out. For example, excessive wear might indicate where a product should be improved 6. To strengthen the good features of a product based on long-term usage of the product
• To analyse the good and bad features of competitors' product 8. To explore new avenues to improve product performance and features
• To gain competitive benchmarking methods to understand competitor's products and develop better products • The original CAD model is not sufficient to support modifications or current manufacturing methods
• The original supplier is unable or unwilling to provide additional parts
• The original equipment manufacturers are either unwilling or unable to supply replacement parts, or demand inflated costs for sole-source parts

Reverse engineering enables the duplication of an existing part by capturing the component's physical dimensions, features, and material properties. Before attempting reverse engineering, a well-planned life-cycle analysis and cost/benefit analysis should be conducted to justify the reverse engineering projects. Reverse engineering is typically cost effective only if the items to be reverse engineered reflect a high investment or will be reproduced in large quantities. The desired goal is always a product or component of higher efficiency or quality for a lower cost. Reverse engineering of a part may be attempted even if it is not cost effective, if the part is absolutely required and is mission critical to a system. FORWARD ENGINEERING: In current forward engineering practice informal requirements are somehow converted into a semiformal specification using domain notations without underlying precise semantics. The program then is constructed manually from the specification by programmer. Hidden in this creative construction of the program from the specification are a set of obvious as well as non-obvious design decisions about how to encode certain parts of the specification in an efficient way using available implementation mechanisms to achieve performance criteria.

Applications of Reverse Engineering: Reverse engineering is a multidisciplinary approach and virtually can be applied to industrial field universally. The prime applications of reverse engineering are either to recreate a copy of part of the original part or retrace the events of what happened. It is widely used in software and information technology industries, from software code development to Internet network security. Thousands of parts are reinvented every year using reverse engineering to satisfy the aftermarket demands that are worth billions of dollars. The invention of digital technology has fundamentally revolutionized it. Compared to the aviation and automobile industries, the applications of digitalized reverse engineering in the life science and medical device industries have faced more challenges and advanced at a more moderate pace. However, some reverse engineering applications as follows:

- In Mechanical Industry
- In Aerospace and Ship Hull Craft
- Software Industry
- In Medical Life Science

BENEFITS

- maintenance cost savings
- quality improvements
- competitive advantages
- software reuse facilitation

2. LITERATURE

Niranjan Singh [1] In today's intensely competitive global market, product enterprises are constantly seeking new ways to shorten lead times for new product developments that meet all customer expectations. Product enterprise has invested in CAD/CAM, rapid prototyping and a range of new technologies that provide business benefits. Reverse engineering is one of the technologies that provide the benefits in shortening the product development cycle. Using reverse engineering, a three-dimensional physical product can be quickly captured in the digital form, re-modelled and exported for rapid prototyping /tooling or rapid manufacturing. Reverse engineering also used to analyze "as designed" to "as manufactured", this involves importing the as designed CAD model and superimposing the scanned point cloud data set of the manufactured part. The reverse engineering software allows the user to compare the two data sets as designed to as manufactured. Damaged or broken parts are generally too expensive to replace or are no longer available. Reverse engineering involves design of a new part, copy of an existing part, recovery of a damaged or broken part, improvement of model precision and inspection of a numerical model.

D. K. Pal, Dr. B. Ravi, L. S. Bhargava [2] Reverse engineering is widely used in numerous applications such as manufacturing, industrial design and jewelry design and reproduction, dental surgery. For example new car is launched in the market; competing manufactures may buy one and disassemble it to learn how it was built and how it works. In some situations, such as automotive styling, designers give shape to their ideas by using clay, plaster, wood or foam rubber but a CAD model is needed to manufacture the part. As products become more organic in shape, designing in CAD becomes more challenging and there is no guarantee that the CAD representation will replicate the sculpted model exactly. Reverse engineering provides a solution to this problem because the physical model is the source of information for the CAD model. This is also referred to as the physical-to-digital process depicted in another reason for reverse engineering is to compress product development cycle times. Need of intensely competitive global market, manufacturers are constantly seeking new ways to shorten lead times to market a new product. Rapid product development refers to recently developed technologies and techniques that assist manufacturers and designers in meeting the demands of shortened product development time

M. Lehman [3] Reverse engineering is also defined as the process of obtaining a geometric CAD model from 3D points acquired by scanning/ digitizing the existing products. Reverse Engineering originally emerged as the answer to provide spares for replacing broken or worn out parts for which no technical data was available. This can be the case if the part was originally imported (without drawings) or the drawings being misplaced or lost. Reverse Engineering has been defined as a process for obtaining the technical data of a critical spare component. Computer-aided reverse engineering relieson the use of computer-aided tools for obtaining the part geometry, identifying its material, improving the design, tooling fabrication, manufacturing planning and physical realization. A solid model of the part is the back bone for computer-aided reverse engineering. The model data can be exported from or imported into CAD/CAE/CAM systems using standard formats such as IGES, STL, VDA and STEP

R. Kazman and S. Carrie [4] Rapid prototyping is a procedure of producing models. There are various methods of rapid prototyping. The main advantage of rapid prototyping lies in the speed of producing physical prototypes as well as almost unlimited complexity of geometry. RP procedures do not require planning during process, specific equipments for work with materials, transport between work places etc. however, compared with CNC processing, the main drawback of these processes is that they are currently limited to fewer materials. Therefore CNC process is used for majority of materials including metals. Furthermore physical object made by rapid prototyping is mainly used as models or prototypes for other production procedures. The objective of work is to optimize the parameters of rapid prototype product

Dr. D. Chandra Mohan [5] Engineering practice tends to focus on the design and implementation of a product without considering its lifetime. The notion of computers automatically finding useful information is an exciting and promising aspect of just about any application intended to be of practical use However, the major effort in software engineering organizations is spent after development on maintaining the systems to remove existing errors and to adapt them to changed requirements. Unfortunately, mature systems often have incomplete, incorrect or even nonexistent design documentation. This makes it difficult to understand what the system is doing, why it is doing it, how the work is performed, and why it is coded that way. Consequently, mature systems are hard to modify and the modifications are difficult to validate

3. METHODOLOGY

A case study of Gear is done for the purpose of obtaining point cloud data which was exported into associate nursing .stl format of the CAD program. The best method to approximate a 3D geometrical model is by approximating it with lots of triangular aspects.

REVERSE ENGINEERING USING TECHNIQUES: Techniques used to aid program understanding can be grouped into three categories: unaided browsing, leveraging corporate knowledge and experience, and computer-aided techniques like reverse engineering Unaided browsing is essentially “human ware”: the engineer manually flips through source code in printed form or browses it online, perhaps using the file system as a navigation aid. This approach has inherent limitations based on the amount of information that an engineer may be able to keep track. Leveraging corporate knowledge and experience can be accomplished through mentoring or by conducting informal interviews with personnel knowledgeable about the subject system. This approach can be very valuable if there are people available who have been associated with the system as it has evolved over time. They carry important information in their heads about design decisions, major changes over time, and troublesome subsystems. However, leveraging corporate knowledge and experience is not always possible. The original designers may have left the company. The software system may have been acquired from another company. Or the system may have had its maintenance out-sourced. In these situations, computer-aided reverse engineering is necessary. A reverse-engineering environment can manage the complexities of program understanding by helping the engineer extract high-level information from low-level artifacts, such as source code. This frees engineers from tedious, manual, and error-prone tasks such as code reading, searching, and pattern matching by inspection Reverse Engineering Process: Generally speaking, reverse engineering is a series of four independent stages, each stage building on the findings of the previous stage preceded by a prescreening process. The whole process progresses linearly with time as shown in Figure It is charted on the flow diagrams which visually illustrate each step of each stage.

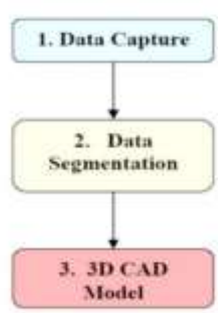


Figure: Flowchart showing basic transformation phases of reverse engineering

In order to reverse engineer a product or component of a system, engineers and researchers generally follow the following four-stage process:
Stage 1: Evaluation and Verification
Stage 2: Technical Data Generation
Stage 3: Design Verification 11
Stage 4: Project Implementation

Stage 1: Evaluation and Verification The primary steps in Stage 1 are as follows:
- Visual and dimensional inspection
- Discrepancy review versus available data
- Failure analysis
- Quality evaluation report
- Stage 1 report
- Go/no-go decision in the first stage in the process, sometimes called "prescreening," reverse engineers determine the candidate product for their project. Potential candidates for such a project include singular items, parts, components, units, subassemblies, some of which may contain many smaller parts sold as a single entity the visual and dimensional inspections constitute the first task conducted in stage 1. The visual inspection is simply a review of the overall condition of the part in terms of reproducibility, quality, and its present state of deterioration or wear. The available data is reviewed for completeness while the data adequacy is detailed. The stage 1 report contains the data necessary for project leader to recommend a decision to go onto stage 2 or to justify the decision to stop the project at the conclusion of stage 1 on the basis of information collected and reviewed to this point.

Stage 2: Technical Data Generation The second stage, disassembly or decompilation of the original product, is the most time-consuming aspect of the project. In this stage, reverse engineers attempt to construct a characterization of the system by accumulating all of the technical data and instructions of how the product works. The objective is to develop a complete and unrestricted technical data package which will be sufficient for both fabrication and procurement of the part in the future. The engineering drawing defines the configuration of the component, and the technical package contains all additional inspection and quality assurance requirements to manufacture the part.

Stage 3: Design Verification In the third stage of reverse engineering, reverse engineers try to verify that the data generated by disassembly or decompilation is an accurate reconstruction the original system. The design generated in stage 2 is verified by testing of a preliminary technical data package (PTDP) on one or many levels. The verification method requires two separate operations to be conducted, yet the outcome is dependent on the completeness of the data to achieve success in both areas. The two operations are prototype fabrication and prototype testing. Engineers verify the accuracy and validity of their designs by testing the system, creating prototypes, and experimenting with the results.

Stage 4: Project Implementation The final stage of the reverse engineering process is the introduction of a new product into the marketplace. With the inclusion of all test, inspection and quality assurance reports, the data have completely become the complete technical data package 13 (CTDP). The delivery of prototypes, the engineering and the economic summary, and the CTDP with procurement requirements form the final TDP. These new products are often innovations of the original product with competitive designs, features, or capabilities. These products may also be adaptations of the original product for use with other integrated systems, such as different platforms of computer operating systems. Often different groups of engineers perform each step separately, using only documents to exchange the information learned at each step. This is to prevent duplication of the original technology, which may violate copyright. By contrast, reverse engineering creates a different implementation with the same functionality.

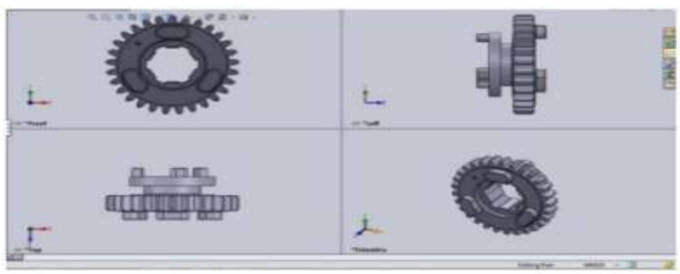
THE TYPICAL REVERSE ENGINEERING PROCESS CAN BE SUMMARIZED IN FOLLOWING STEPS:
1. Physical model which needs to be redesigned or to be used as the base for new product.
2. Scanning the physical model to get the point cloud. The scanning can be done using various scanners available in the market.
3. Processing the points cloud includes merging of points cloud if the part is scanned in several settings. The outlines and noise is eliminated. If too many points are collected then sampling of the points should be possible.
4. To create the polygon model and prepare .stl files for rapid prototyping.
5. To prepare the surface model to be sent to CAD/CAM packages for analysis.

6. Tool path generation with CAM package for suitable CNC machine manufacturing of final part on the CNC machine.

Figure: Front view of Gear which has to be produced

Figure: Isometric view of Gear which has to be produced

Figure: STL Image File of Scanned Component



THE DATA OBTAINED FROM THE SCANNING 3D-MODEL

symbol	parameter	Gear
m	module	1.655mm
b	Face width	8.5 to 16.5mm
T	No of teeth	29
D	Pitch diameter	48mm
	profile	20^0 full depth involute
y	Lewis form factor	0.1225
C_v	Velocity factor	0.229
V	Velocity of gear	20.10m/sec

STRUCTURAL ANALYSIS OF GEAR USING SOLIDWORKS SIMULATION:

TOOL Apparatus investigation can be performed utilizing diagnostic techniques which required various supposition and rearrangements which go for getting the most extreme pressure esteems just however rigging examinations are multidisciplinary including computations identified with the tooth worries .

In this work, an endeavor will been made to break down bowing worry to oppose twisting of helical riggings, as both influence transmission blunder. Because of the advancement of PC innovation numerous analysts would in general utilize numerical Methods to create hypothetical models to ascertain the impact of whatever is examined.

THEORITICAL ANALYSIS OF SPUR GEAR: ¬

This design is based on "LEWIS EQUATION" or "BEAM STRENGTH".

σW = WT/b.π.m.y.Cv

Where, σw = Working stress

b = Face width

Cv = Velocity factor

m = Module in mm

wT = tangential tooth load Factor of safety

(FOS) = σultimate stress/σ working stress [For steels]

FOS = ultimate stress/working stress

FOS = σulti/σw

To calculate ultimate stress,

σ0 = σulti/3

σulti = σ0 * 3

σulti = 350*3

σulti = 1050 mpa

The Tangential tooth load in taken as

WT = 500N

IF Face width b =8.5 mm

σw = WT/b.π.y.m.Cv

σw = 500/8.5*π*0.12*0.22*1.65 = 429.84 mpa

σw = 429.84 mpa

FOS1 = σulti/σw

FOS1 = 1050/429.84

FOS1 = 2.44

IF Face width b = 10.5 mm

σw = WT/b.π.y.m.Cv

σw = 500/10.5*π*0.12*0.22*1.65

σw = 347.97 mpa

FOS2 = σulti/σw

FOS2 = 1050/347.97

FOS2 = 3.01

IF Face width

b = 12.5 mm

σw = WT/b.π.y.m.Cv

σw = 500/12.5*π*0.12*0.22*1.65

σw = 292.29 mpa

FOS3 = σulti/σw

FOS3 = 1050/292.29

FOS3 = 3.59

IF Face width

b = 14.5 mm

σw = WT/b.π.y.m.Cv

σw = 500/14.5*π*0.12*0.22*1.65

σw = 251.97 mpa

FOS4 = σulti/σw

FOS4 = 1050/251.97

FOS4 = 4.167

4. RESULTS AND DISCUSSIONS

Solid modelling is done using specialised reverse engineering software like Geomagic design X, Transmagic and Polyworks etc. It involves extraction of surfaces and then making a 3D model of it. The process includes extracting 2D sketches at various cross-sections of the model. From these sketches surfaces are formed and from these surfaces a solid body is created. The accuracy or deviation between the actual model and the model made can be checked at any stage within the software. The solid models made can then be transferred to main stream CAD software's for further analysis. The results can be transferred in standard conventional files like .STEP or .STP or directly transferred from some reverse engineering software's like Geomagic etc to main stream CAD software's without the loss of parametric data Structural analysis procedure: -

The Structural analysis involves the following procedure:

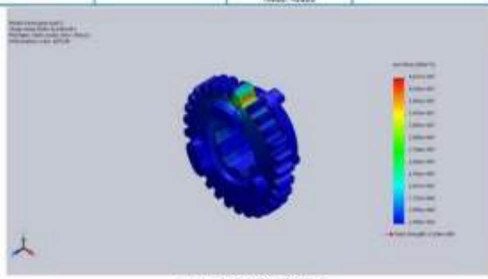
- Pre-Processing: It include the description of the geometry or model, the physical characteristics of the model. Definition of type of analysis, material properties, Loads and boundary conditions
- Solution: it involves the application of the finite element analysis _ Run analysis to obtain solution (stresses).
- Post-Processing: It includes the visualization and interpretation of the results of the solution.

Composition of steel alloy:

Aluminum	0.95-1.30%
Boron	0.001-0.003%
Chromium	0.5-18%
Copper	0.1-0.4%
Manganese	0.25-13%
Nickel	2-20%

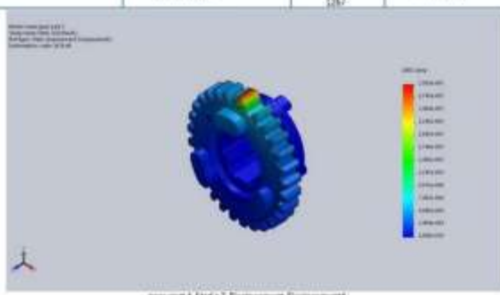
Study Results for face width 8.5 mm

Name	Type	Min	Max
Stress1	VON: von Mises Stress	24.5754 N/m^2 Node: 43135	4.62707e+007 N/m^2 Node: 60996



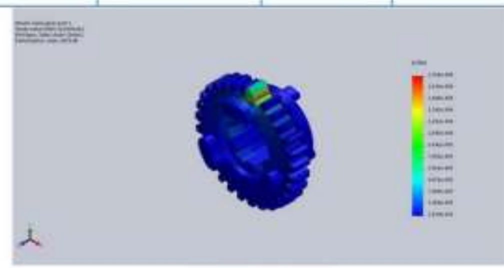
gear part 1-Static 3-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1267	0.00299278 mm Node: 5314



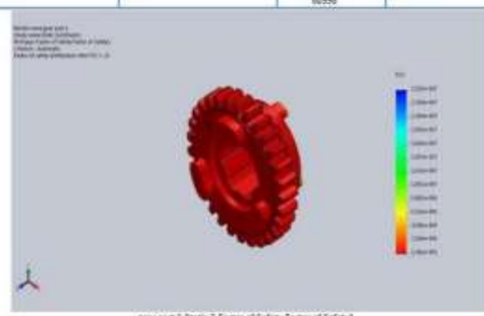
gear part 1-Static 3-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.03357e-010 Element: 9895	0.000178822 Element: 38078



gear part 1-Static 3-Strain-Strain1

Name	Type	Min	Max
Factor of Safety1	Automatic	13.4085 Node: 60996	2.52456e+007 Node: 43135



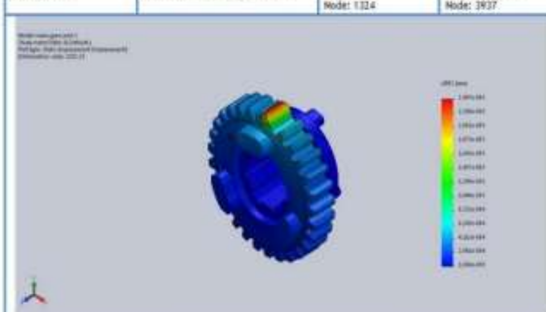
gear part 1-Static 3-Factor of Safety-Factor of Safety1

Study Results for face width 10.5 mm:

Name	Type	Min	Max
Stress1	VON: von Mises Stress	14.6992 N/m^2 Node: 62238	4.4295e+007 N/m^2 Node: 86415

gare part 2-Static 4-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1324	0.00249704 mm Node: 3937

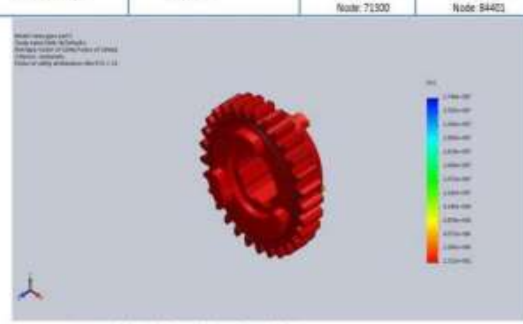


gare part 2-Static 6-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	9.53713e-011 Element: 13336	0.000163859 Element: 34142

gare part 2-Static 6-Strain-Strain1

Name	Type	Min	Max
Factor of Safety1	Automatic	13.3186 Node: 71300	2.74357e+007 Node: 84401



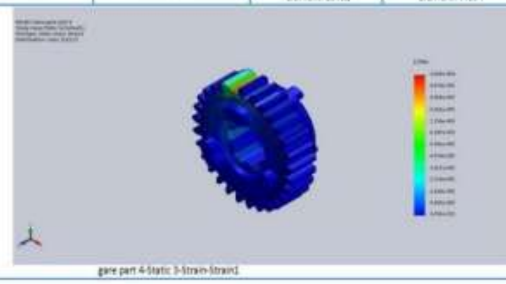
gare part 2-Static 4-Factor of Safety-Factor of Safety1

Study Results for face width 12.5 mm:

Name	Type	Min	Max
Stress1	VON: von Misses Stress	11.5117 N/m^2 Node: 52400	3.47243e+007 N/m^2 Node: 39683

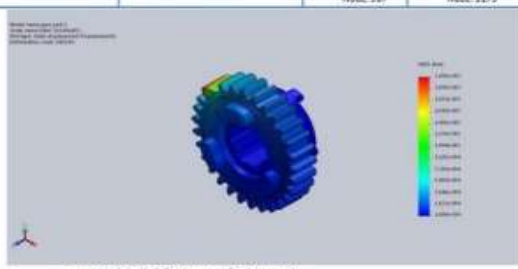
gare part 3-Static 3-Stress-Stress1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	4.78567e-011 Element: 10411	0.000108811 Element: 44994



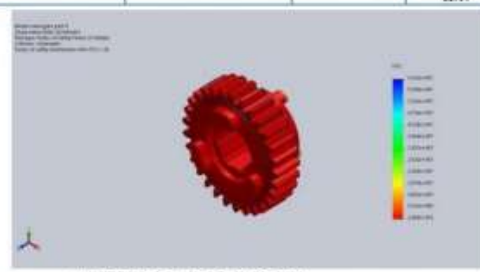
gare part 4-Static 3-Strain-Strain1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 967	0.00218751 mm Node: 3179



gare part 3-Static 3-Displacement-Displacement1

Name	Type	Min	Max
Factor of Safety1	Automatic	19.8774 Node: 2547	6.31476e+007 Node: 81794



gare part 4-Static 3-Factor of Safety-Factor of Safety1

Study Results for Face Width 14.5mm:

Name	Type	Min	Max
Stress1	VON: von Mises Stress	14.9038 N/m^2 Node: 24243	2.57757e+007 N/m^2 Node: 14953

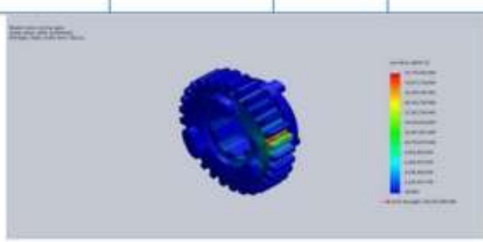


Figure: Stress

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	3.18208e-011 Element: 5186	9.05585e-005 Element: 12900

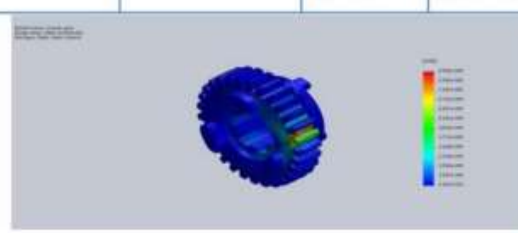


Figure: Strain

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 643	0.00206972 mm Node: 1548

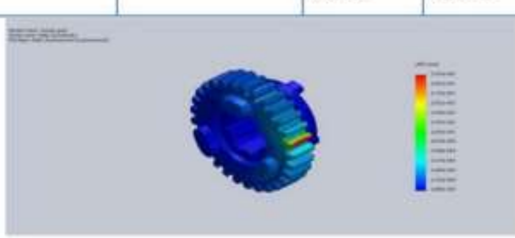


Figure: deformation

Name	Type	Min	Max
Factor of Safety1	Automatic	24.07 Node: 14953	4.16285e+007 Node: 24243

Figure: factor of safety

COMPARISON OF THEORITICAL STRESS VALUES AND SOLID WORKS VALUES

Face width (mm)	Allowable stresses (Mpa) (Lewis equation)	Allowable stresses (Mpa) (static analysis)
8.5	429.82	462.70
10.5	347.97	443.95
12.5	297.29	347.24
14.5	251.97	312.12

5. CONCLUSIONS

In theory of Gear, we are considering that the load is acting at one point and the stress is calculated. The calculation of maximum stresses in a gear at tooth root is three dimensional problems. The accurate evaluation of stress state is complex task. The contribution of this thesis work can be summarized as follows:

- The strength of gear tooth is a crucial parameter to prevent failure. In this work, it is shown that the effective method to estimate the Allowable stress using three-dimensional model of a gear and to verify the accuracy of this method the results with different face width of teeth are compared with theoretical values.
- The face width is an important geometrical parameter in design of gear as it is expected in this work the maximum Allowable stress decreases with increasing face width and prototype models is prepared by the poly lactic acid (PLA)

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