Design Optimization of Cast Iron Flywheel for Weight and Cost Reduction

A thesis submitted in partial fulfillment of the requirements for the award of the degree of

Bachelor of Engineering

in **Mechanical**

Submitted by:

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KLE TECH

MECHCANICAL ENGINEERING

KLE TECHNOLOGICAL UNIVERSITY

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JUNE 2022

In memory of

Anthony Edward "Tony" Stark

We love you 3000

BONAFIDE CERTIFICATE

This is to certify that the project titled **Optimization of Cast iron flywheel for weight and cost reduction** is a bonafide record of the work done by

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in partial fulfillment of the requirements for the award of the degree of **Bachelor of Engineering** in **Mechcanical Engineering** of the **KLE TECHNOLOGICAL UNIVERSITY, HUBBALLI**, during the year 2020-21.

PROJECT GUIDE **DEPARTMENT HOD**

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Project Viva-voce held on ___________________________

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Internal Examiner **External Examiner**

ABSTRACT

Flywheel is that component of the machine, which helps in storage of the energy when there is excess supply, and supplies the energy when there is less energy than required. In this project, we have tried to reduce the geometry of the flywheel by having trapezoidal holes in the plate. This helps in reducing the weight of the flywheel and also helps in cost reduction as there is lesser amount of material used. The objective was to reduce the weight and cost, so material and geometry of the flywheel were the main points to be kept in mind while performing the FE analysis. Based on the results we came to the conclusion of having the Flywheel with Trapezoidal cuts.

Keywords: Design Optimization of flywheel, weight reduction of flywheel, FE analysis of Flywheel.

ACKNOWLEDGEMENTS

We would like to express our deepest gratitude to the following people for guiding us through this course and without whom this project and the results achieved from it would not have reached completion.

Prof. V A Goudar, Department of Mechanical Engineering, for helping us and guiding us in the course of this project. Without his guidance, we would not have been able to successfully complete this project. His patience and genial attitude is and always will be a source of inspiration to us.

B. B. KOTURSHETTAR, the Head of the Department, Department of Mechanical Engineering, for allowing us to avail the facilities at the department.

We are also thankful to the faculty and staff members of the Department of Mechanical Engineering, our individual parents and our friends for their constant support and help.

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CHAPTER 1 INTRODUCTION

A flywheel is a mechanical device which uses the conservation of angular momentum to store rotational Energy in a form of kinetic energy proportional to the product of its moment of inertia and the square of its rotational speed. In particular, if we assume the flywheel's moment of inertia to be constant (i.e., a flywheel with fixed mass and second moment of area revolving about some fixed axis) then the stored (rotational) energy is directly associated with the square of its rotational speed.

Flywheels resist changes in their rotational speed, which helps steady the rotation of the shaft when a fluctuating torque is exerted on it by its power source such as a piston-based (reciprocating) engine, or when an intermittent load, such as a piston pump, is placed on it. Flywheels can be used to produce very high-power pulses for experiments, where drawing the power from the public network would produce unacceptable spikes. A small motor can accelerate the flywheel between the pulses. Recently, flywheels have become the subject of extensive research as power storage devices for uses in vehicles and power plants.

LITERATURE SURVEY

Paper 1: DESIGN, ANALYSIS AND OPTIMIZATION OF FLYWHEEL

Journal Link:
https://drive.google.com/file/d/18qBuYo22lE4yLGzbr8N_YC5O8kDY-DCR/view?usp=sharing

Author: Prof. Pravin B. Surwade

Objectives:

- To design and analysis of the flywheel to minimize the fluctuation in the torque.
- Reducing the cost of the flywheel by reducing the materials used, which helps to have a optimal design.
- Investigate the feasibility of materials as the main energy storage of a high speed flywheel.

Methodology:

- Designing the model using catia.
- Flywheel to be designed to a model of Maruti Suzuki Swift with maximum power of 56.67 kW.
- Analysis is done by considering its different materials, i.e., gray cast iron, Aluminum alloy, cast alloy, steel. Modelling of flywheel is done is done by using solidworks.
- FEA analysis is done for these for 4 profiles of flywheel.

Conclusion:

- Aluminum has less mass than other materials, for the triangular profile less stress are induced in aluminum alloy for same speed among all the 4 materials for all 3 profiles.
- Aluminum has less mass than other materials, for the triangular profile less stress are induced in aluminum alloy for same speed among all the 4 materials for all 3 profiles.
- Aluminum alloy is good material for this design.

Paper 2: Design of flywheel for improved energy storage using computer aided analysis.

Journal Link:
https://drive.google.com/file/d/174fgA9saziQBAkoqvfvzUrWmuJUzDsj3/view?usp=sharing

Authors: Michael Mathew

Objectives:

exploring the effects of flywheel geometry on its energy storage / delivering capability per unit mass.

This paper specifically studies the most common five different geometries (i-e straight/ concave or convex shaped 2D).

Methodology:

After the successful application of proposed procedure outlined in the previous section, all 4 steps are executed and equivalent stress distribution contours are obtained for all6 geometries.

After the optimization of all the steps, maximum allowable equivalent stresses. could be as high as sigma y=290 MPA, for AISI 1006 steel.

Minimum equivalent stresses are Calculated to be in the range of 120-200mpa. Therefore, it is considered to be within the safe stress interval.

Conclusion:

This study clearly depicts the importance of the flywheel geometry design selection & its contribution in the energy storage performance.

In this design of fly wheels, the operating conditions impose quite narrow margin of energy storing limitations, even slim amount of improvements may contribute in the overall success.

Paper 3: Design optimization of a flywheel using Solidworks Modeling and simulation capabilities.

Journal Link: https://drive.google.com/file/d/1ndbHnDTzTaodJS9g-O1KKwEUEJ00IM/view?usp=sharing

Published date: October 2017

Authors: Ionel Chirita, Nicolae Tanase, Cristinel Ioan Ilie, Marian Popa

Objectives:

- To optimise the design of the flywheel
- Using solidworks and ansys for the design and simulation purposes.

Methodology:

- Investigation, using solidworks modeling and simulation capabilities
- Configurations of the flywheel has been created and analyzed in order to optimize the shape of the flywheel.

Conclusion:

- By changing the material usage we can optimize the design.
- By increasing the rpm we can make it as efficient as earlier.

Paper 4: Design and Analysis of Flywheel in Petrol Engine

Journal Link:
https://drive.google.com/file/d/1hkRcaQowxeCJkzxm9aX6CKiJegG7VhfL/view?usp=sharing

Authors: A.Selvakumar, S.Rajapandi, B.Santhoshkumar, R.Vaitheeswaran

Published date: January 2018

Objectives:

- Study the flywheel usage in the petrol engine.
- Considering different materials for simulation of flywheel.
- Use of different analysis tools for the study.

Methodology:

- Modelling is done using catia software.
- Solid type flywheel is taken into considerations.
- Ansys tool is used for the stress and strain deformation analysis.

Conclusion:

- Considering Aluminium, Beryllium and Carbon steel as an alternative for Cast Iron.
- The main reason for the failure is, max tensile stress and bending stress in the rim.
- Carbon steel is said to have stored more energy compared to other materials.
- But cast iron is always considered for its varied properties.

Paper 5: Analysis of flywheel used in Petrol Engine car

Journal Link:
https://drive.google.com/file/d/18CxsmJdXFAH6G_RuU_smoxE6KtKrbsbC/view?usp=sharing

Authors: Phanindra Mudragadda, T. Seshaiah

Published date: 5 May 2014

Objectives:

- Considering a flywheel of a petrol engine car.
- Perform structural and nodal stress analysis on the designed flywheel using tux materials Al alloy and cast Iron.

Methodology:

- Designing a four wheeler flywheel used in a petrol engine using theoretical calculations.
- Design 2D and 3D modelling of flywheel using relevant software.
- The flywheel of the car is modelled using a software(CAD) through reverse engineering process.
- Costly structural and nodal analysis is performed on meshed component.
- The flywheel is disassembled using hexahedral dominant elements.

Conclusion:

- For all the materials the stress values are less than their respective permissible yield stress values. So our design is safe.
- The stress value for Aluminium Alloy A360 is less than that of Cast Iron.
- So we conclude that for our design, Aluminium A360 is better material for flywheel. By using Aluminium A360 we can reduce Weight. Also it is rust free.

Paper 6: Design and Optimization of a flywheel for the 4-cylinder Diesel Engine

Journal Link: https://drive.google.com/file/d/1AsSxZToJYe42lsMwS3Whizj-WueAS0Hf/view?usp=sharing

Authors: Appala Narasimha Murthy B, P.Srinivas Reddy

Published date: May 2016

Objectives:

- To find the minimum mass of a specified material.
- To find respective values of stresses along the radius by conducting static analysis

Methodology:

- Considering the flywheel of a 4-cylinder Diesel Engine.
- Taking carbon fibre, magnesium alloy as the materials for consideration.
- 3D modelling is done using CAD tools.
- Simulation of the materials is done on different materials.

Conclusion:

- From the analysis, it is clear that, Carbon Fiber is the best material it is having low mass as compared to the other material
- The stresses and strains in the carbon fiber is also low compared to the other materials.
- Also Magnesium alloy is also the best material which is capable of withstanding stresses that are developed within the flywheel.
- by using the magnesium alloys we can reduce the stresses 77% when compared to H S steel, 75% when compared to cast iron, also by using Magnesium alloys we can reduce the mass up to 75%.

Paper 7: ANALYSIS AND OPTIMIZATION OF FLYWHEEL

Journal Link: https://drive.google.com/file/d/1plDcbAx7OWvJ4-ma1ziH02tUIBqAFN7I/view?usp=sharing

Authors: Sushama G Bawane, A P Ninawe and S K Choudhary.

Published date: July 2012

Objectives:

- Optimizing the flywheel using various parameters like, material, cost.
- By applying an approach for modification of various working parameter like efficiency, output, energy storing capacity, the results are compared with existing flywheel result.
- To minimize cost of flywheel by reducing its material.

Methodology:

- Flywheel is designed/Modelled in CATIA software similar to the assembly of MARUTHI-Omni.
- Stresses and Total deformation of the model is calculated and compared with the Ansys results.

Conclusion:

- After completion of the analysis in CAE software i.e. ANSYS 11.0 based on the values of Equivalent stresses for material loading conditions it is clearly seen that these are less than the allowable stresses for that particular material under applied conditions
- The part not going to yield and hence the design is safe.

Paper 8: FEA & Optimization of Flywheel Energy storage system.

Journal Link:
https://drive.google.com/file/d/18qBuYo22lE4yLGzbr8N_YC5O8kDY-DCR/view?usp=sharing

Authors: Akash B Rajan, Parth H Patel, Dr.Tushar M Patel.

Objective:

- To carry out a case study in finding an optimal combination of design, material designation and geometry modification of the flywheel which results in increasing the overall energy storing capacity of the flywheel.
- Choosing the different design of experiments for better selection of the flywheel.

Methodology:

- The materials considered for the computation of flywheel energy are cast iron, carbon steel & aluminium alloy
- Performing analysis on the various sets of variable at disposal.
- Stastistical analysis & interpretation of experimental results.
- Final combination of finite analysis & theoretical data for validation.

Results and Conclusions:

- In a modelling software after designing all 3 forms of design of flywheel & assigning materials to them. It’s found out that the arm type flywheel assigned with carbon steel has lowest weight, while solid flywheel with some material has highest weight.
- Optimization of the flywheel is of extreme importance as it is an energy storage system with efficiency higher than any other system with broad scope of application.
- The data obtained from analysis and theoretical data, the better design of the flywheel is selected which has energy storing capacity 0.95% more than that of the original design.

Paper 9: Analysis of Flywheel.

Journal Link:
https://drive.google.com/file/d/174fgA9saziQBAkoqvfvzUrWmuJUzDsj3/view?usp=sharing

Authors: Akshay P.Punde,G.K.Gattani

Objective:

- To counter the requirement of smoothing out the large oscillations in velocity during cycles of a IC Engines, a flywheel is designed and analysed.
- Using FEA to calculate the stress inside the flywheel,results of design and analysis can be compared with existing flywheel.

Methodology:

- A Maruti 800 flywheel is modelled in Catia
- Analysis is conducted in Ansys
- Two materials are used, Cast iron , S-glass e-poxy.
- Based on considerations in the flywheel, the element solid 72,3D-4-node tetrahedral structural solid with rotators is used to model meshes.

Conclusion:

- *Cast iron flywheels are having higher stress and deformation.
- *E Glass-epoxy can be used in flywheels to store energy with less mass, also used in high speed applications.

Paper 10 - Design & FEA Analysis of surface mounted permanent magnet motor generator for high-speed modular flywheel energy storagae systems

Journal Link: https://drive.google.com/file/d/1ndbHnDTzTaodJS9g-O1KKwEUEJ00IM/view?usp=sharing

Authors: Parag Upadhyay, Ned Mohan

Objective:

- To design a ceramic based surface-mounted Permanent-magnet(PM) motor/generator for the modular flywheel storage units.
- Design & analysis of a 2.5kw,2400 rpm, Surface-mounted PM motor suitable for a 10-kwh storage system.

Methodology:

- A 2.5 kw,2400 rpm,3 phase,240v surface mounted PM motor with ceramic magnets is designed in CAD.
- The current density between 4 to 10 A/mm^2 is generally recommended for PM motor windings
- The design obtained from the CAD program is modelled in Ansoft - Maxwell 2D to verify the results.
- Using FEM, the variation of rotor flux density is observed through the parametric analysis for the dynamic conditions at full load.
- Using parametric FEA analysis, the constant rotor flux density is achieved to reduce the rotor losses.

Results and Conclusions:

- Choice of ceramic magnet with larger length & larger air gap is better option for the machine.
- The low value of lower retentivity results in lower airgap flux density and hence lower stator teeth & core flux densities.

CHAPTER 3

Problem Definitions

1. Construction of a flywheel for uniform distribution of power in the crankshaft along all 4 strokes with minimum cost consumption.
2. Flywheel is a device that can help in storing energy, we need to reduce the space utilized by the flywheel and optimize the cost which does not affect the efficiency and working of the flywheel.
3. Performing Design analysis on the Flywheel to get an optimal Design which helps in reduction of the materials used and also help in reduction of the cost.
4. Using various CAE tools to build an optimized Flywheel model, with low cost and better efficiency for the storage of energy in 4 Stroke Engines with reduced mass.

Scope of work

- Reducing the cost of the Flywheel with reduction in material usage with the help of various CAE tools for analysis.
- Reverse Engineering of a particular Flywheel, to get accurate dimensions and get better results.
- The modelling of parts is done using the dimensions we get from reverse engineering.
- Using various CAD softwares for modeling.
- The FEA model for stress and deformation analysis is done using FE analysis softwares.

Redefined Problem Statement

To build 3D model of Flywheel using modelling softwares. Using this model, Stress and deformation analysis of Flywheel need to be performed using simulation tools. The same has to be carried out for different materials and results have to be compared. The optimum material for the Flywheel with reduced weight and without affecting the functionality of Flywheel need to be selected on the basis of the analysis.

CHAPTER 4

Design Calculations

Fluctuation of Energy:

$\Delta E_f = \frac{C_e * 1000 * P}{N/60}$

Engine Specs.

Power $P = 48.171kW$ @4000RPM

Torque $T = 115Nm\ @4000RPM$

Theoretical weight 6kg=W

$$\Delta E = \frac{0.17 * (1000 * 48.171)}{(4000/60)}$$

ΔE= $\mathbf{144.513}$ Nm

For Grey Cast Iron Flywheel Limiting speed v=50m/s

Mean Rim Dia. =(60*v)/(π*N)

= (60*50)/(π*4000)

= 0.2387m = **238mm**

Practically Mean rim dia. = (224+264)/2

= 244mm.

Mass of Flywheel

$$M = \frac{\Delta E}{v\mathbf{2} * Cs}$$

$M = \frac{144.51}{50*50*0.01}$

M = 5.2024 kg

For Design Alternative 1

$\Delta E \quad = M * v^2 * C_s$

$M \quad = 5.070$ kg, $v = 50$m/s, $C_s = 0.01$

$\Delta E \quad = 5.070 * 50^2 * 0.01$

$\mathbf{\Delta E \quad = 126.75\ Nm}$

For Design Alternative 2

$\Delta E \quad = M * v^2 * C_s$

$M \quad = 4.675$ kg, $v = 50$m/s, $C_s = 0.01$

$\Delta E \quad = 4.675 * 50^2 * 0.01$

$\mathbf{\Delta E \quad = 116.87\ Nm}$

For Design Alternative 3

$\Delta E \quad = M * v^2 * C_s$

$M \quad = 4.762$ kg, $v = 50$m/s, $C_s = 0.01$

$\Delta E \quad = 4.762 * 50^2 * 0.01$

$\mathbf{\Delta E \quad = 119.05\ Nm}$

Stresses in Rim:

$\boldsymbol{\sigma = \rho\upsilon^2}$

$\sigma = 7200*50^{2*}10^{-6}$

$\boldsymbol{\sigma = 18}$ **MPa**

Calculated Stress in Ansys

$\boldsymbol{\sigma = 26}$ **MPa**

Factor of Safety

$$FOS = \frac{\text{Ultimate Strength}}{Calculated\ Stress}$$

$$FOS = \frac{\text{200 MPa}}{26\ MPa}$$

FOS= 7.6

Design is Safe

Percentage Weight Reduction

Original weight = 5.2024 kg

New Weight = 4.762 kg

Reduced Weight = 5.2024 – 4.762

Reduced Weight = 0.440 kg

$$\% \boldsymbol{Weight\ reduction} = \frac{\text{Original} - \text{New}}{Original} x\ 100$$

$$= \frac{5.2024 - 4.762}{5.2024}\ x\ 100$$

$$= \mathbf{8.465\%}$$

Percentage Cost Reduction

Cost of Grey cast iron = Rs. 65/kg

Original Cost = 65*5.2024

= Rs. 338.15

New Cost = 65*4.762

= Rs. 309.53

Reduced Cost = 338.15 - 309.53

Reduced Cost = Rs. 28.62

$$\% \boldsymbol{Cost\ reduction} = \frac{\text{Original} - \text{New}}{Original} x\ 100$$

$$= \frac{338.15 - 309.53}{338.15}\ x\ 100$$

= 8.463 %

CHAPTER 5

Cad Modeling

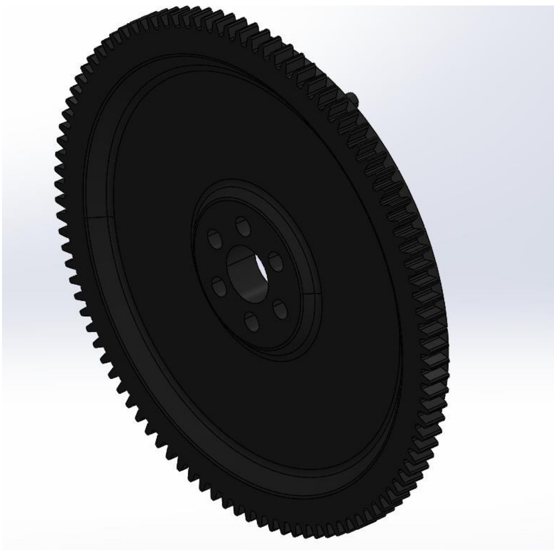


Fig 1

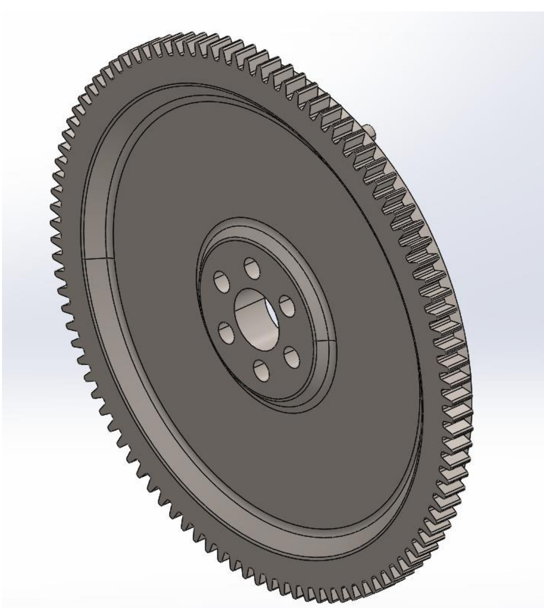


Fig 2

Fig 3

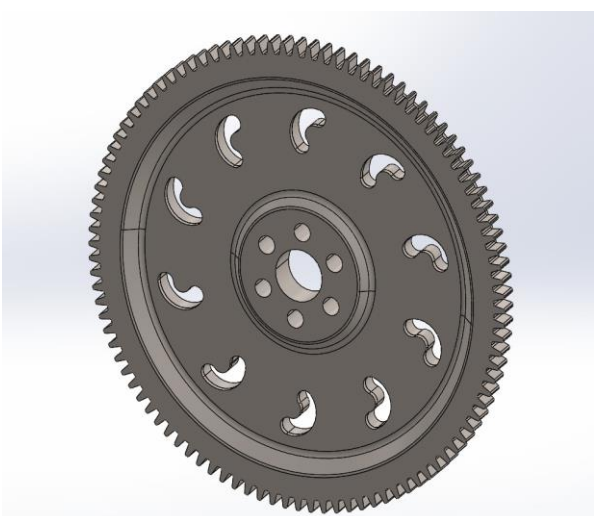


Fig 4

Fig 5

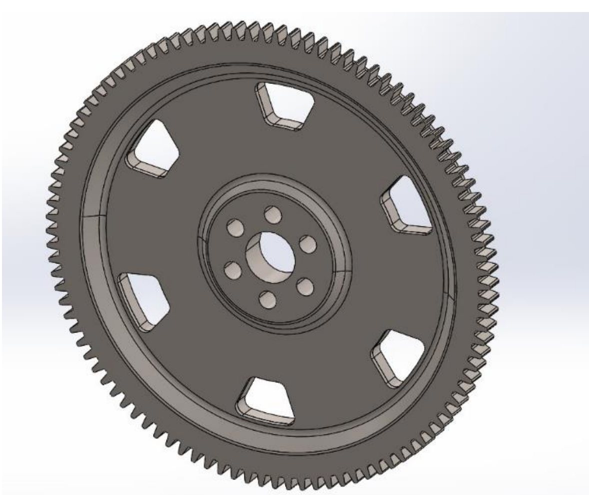


Fig 6

CHAPTER 6

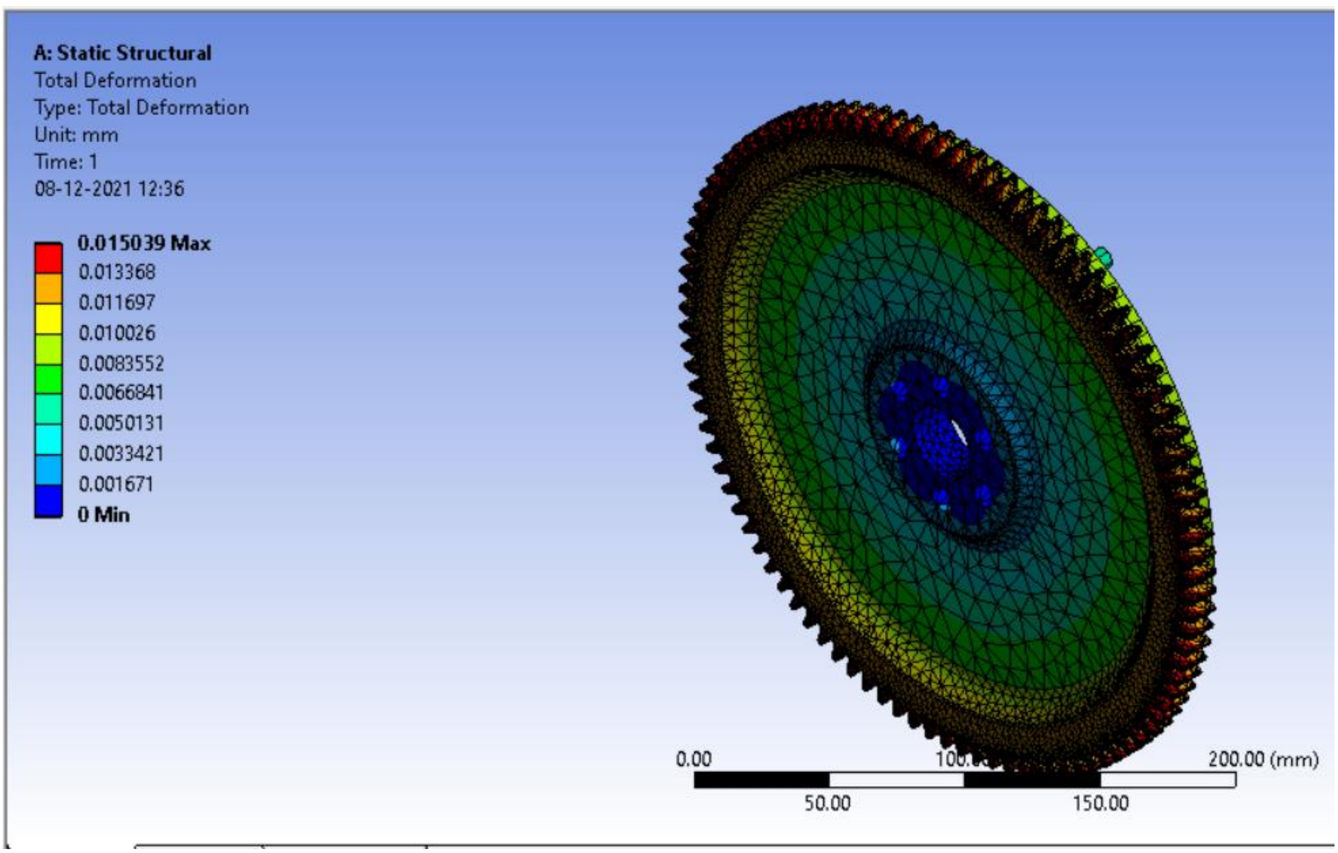
FE Analysis

Mesh type: Tetrahedral Mesh

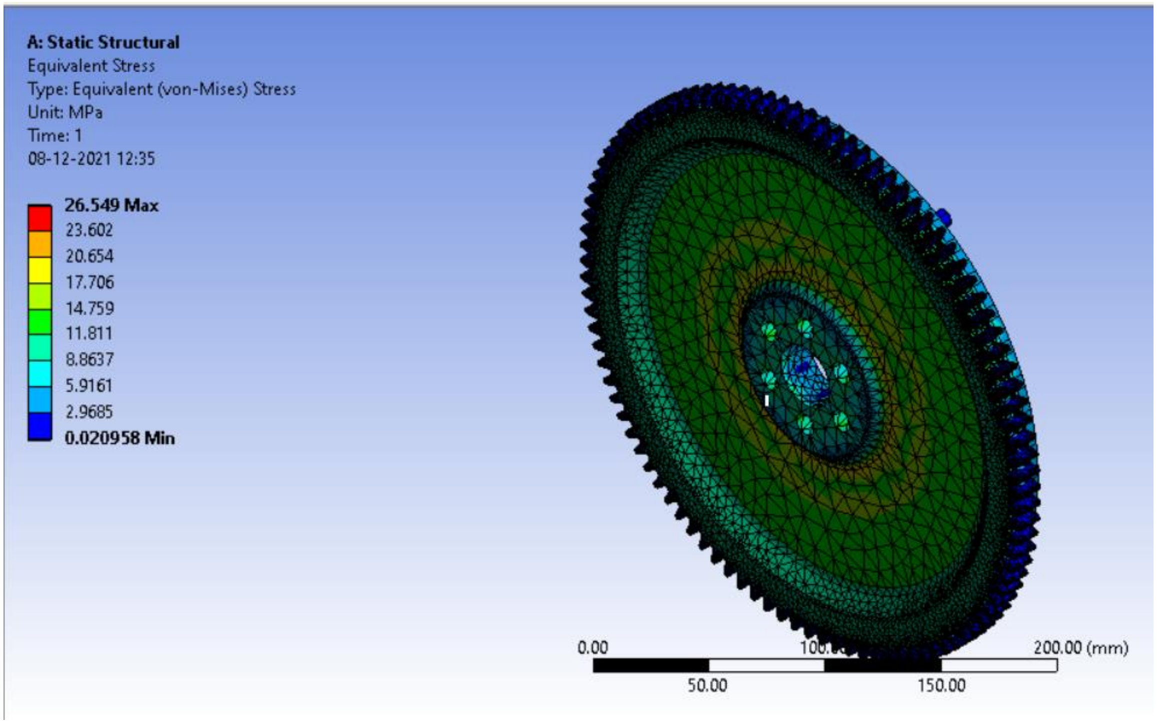
Element size: 3mm

Grey Cast Iron Design Alternative 1

Stress Analysis

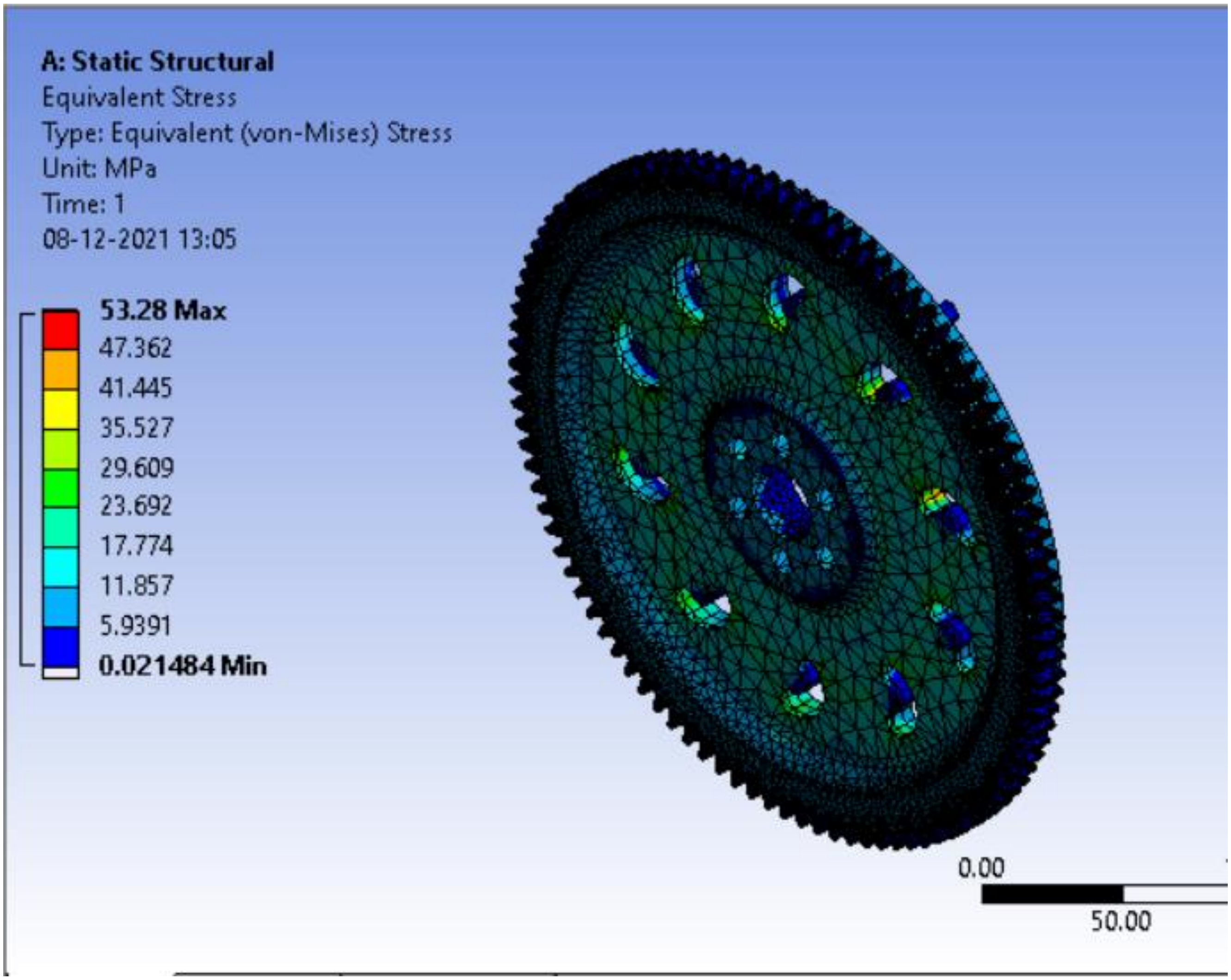


Total Deformation

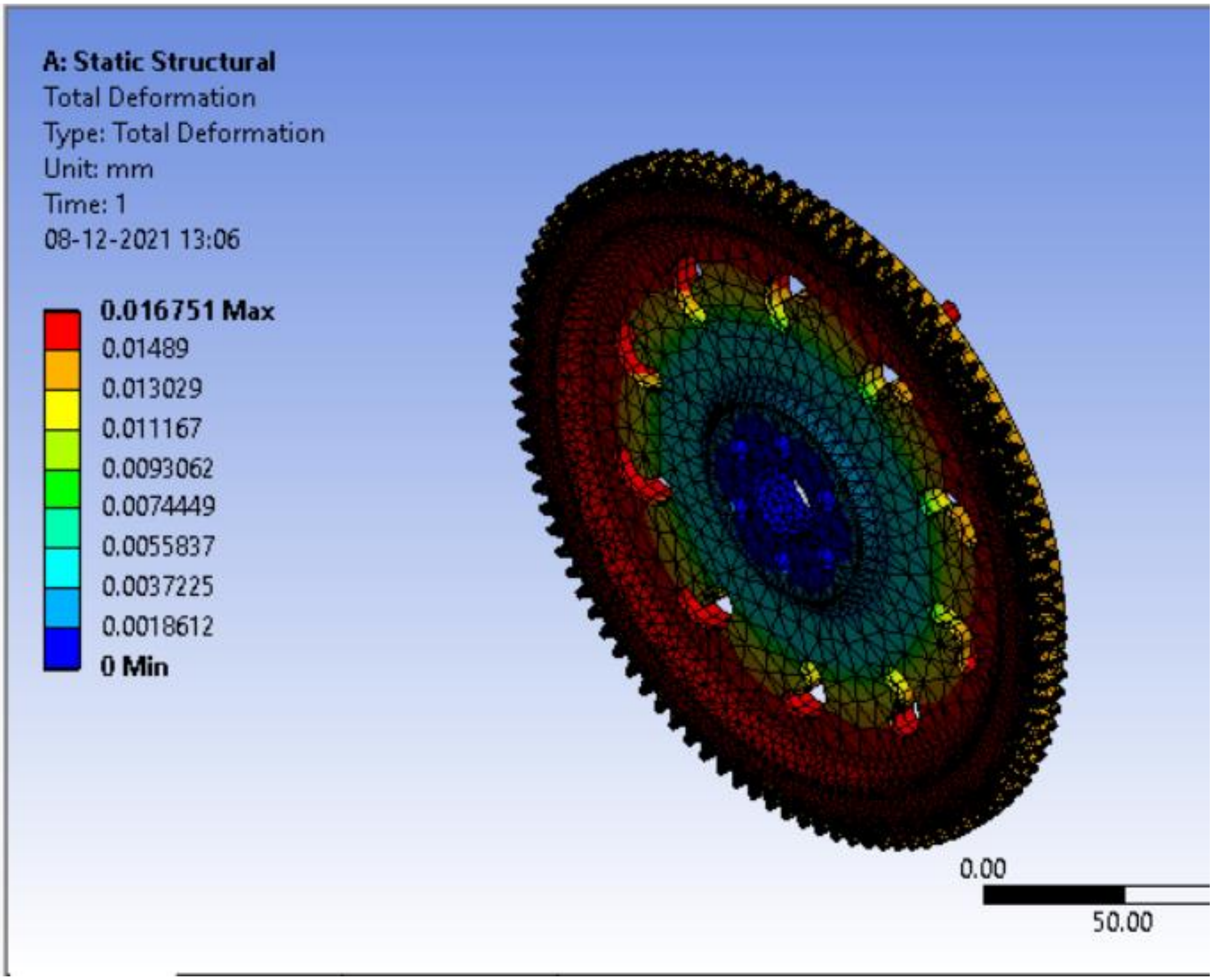


Design Alternative 2

Stress Analysis

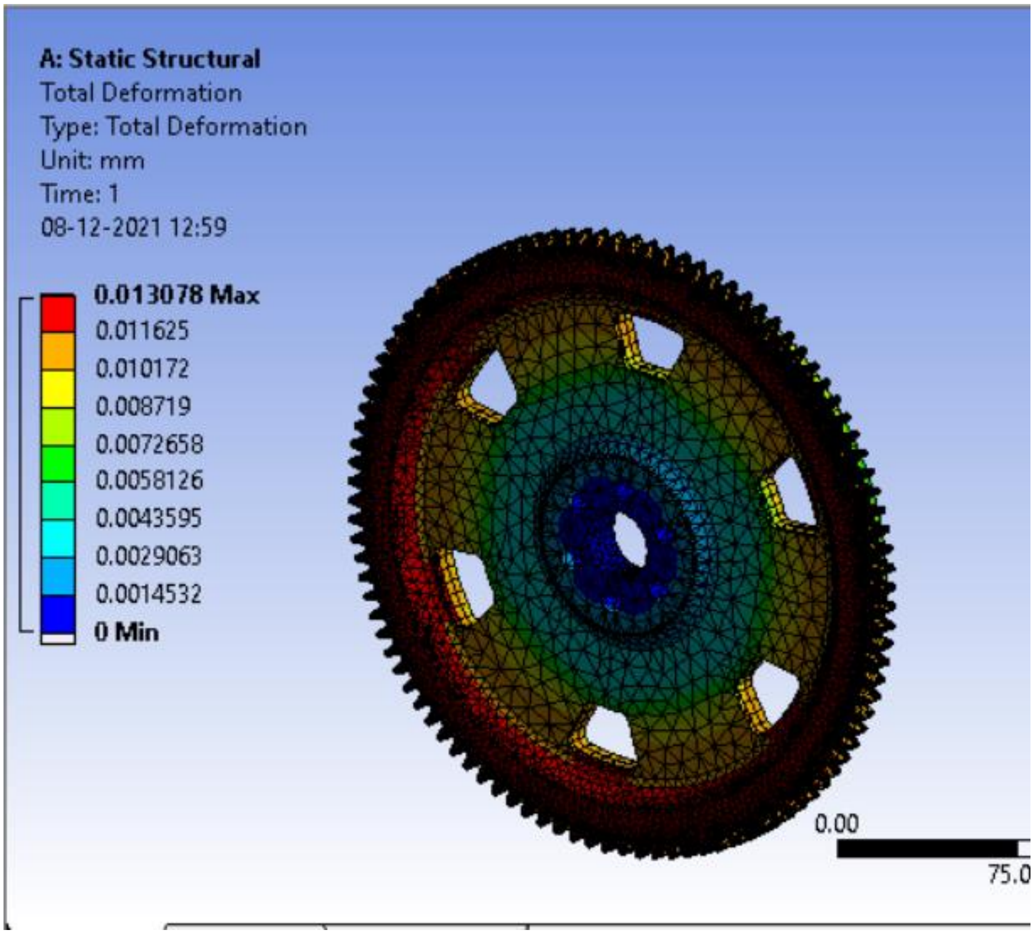


Total Deformation

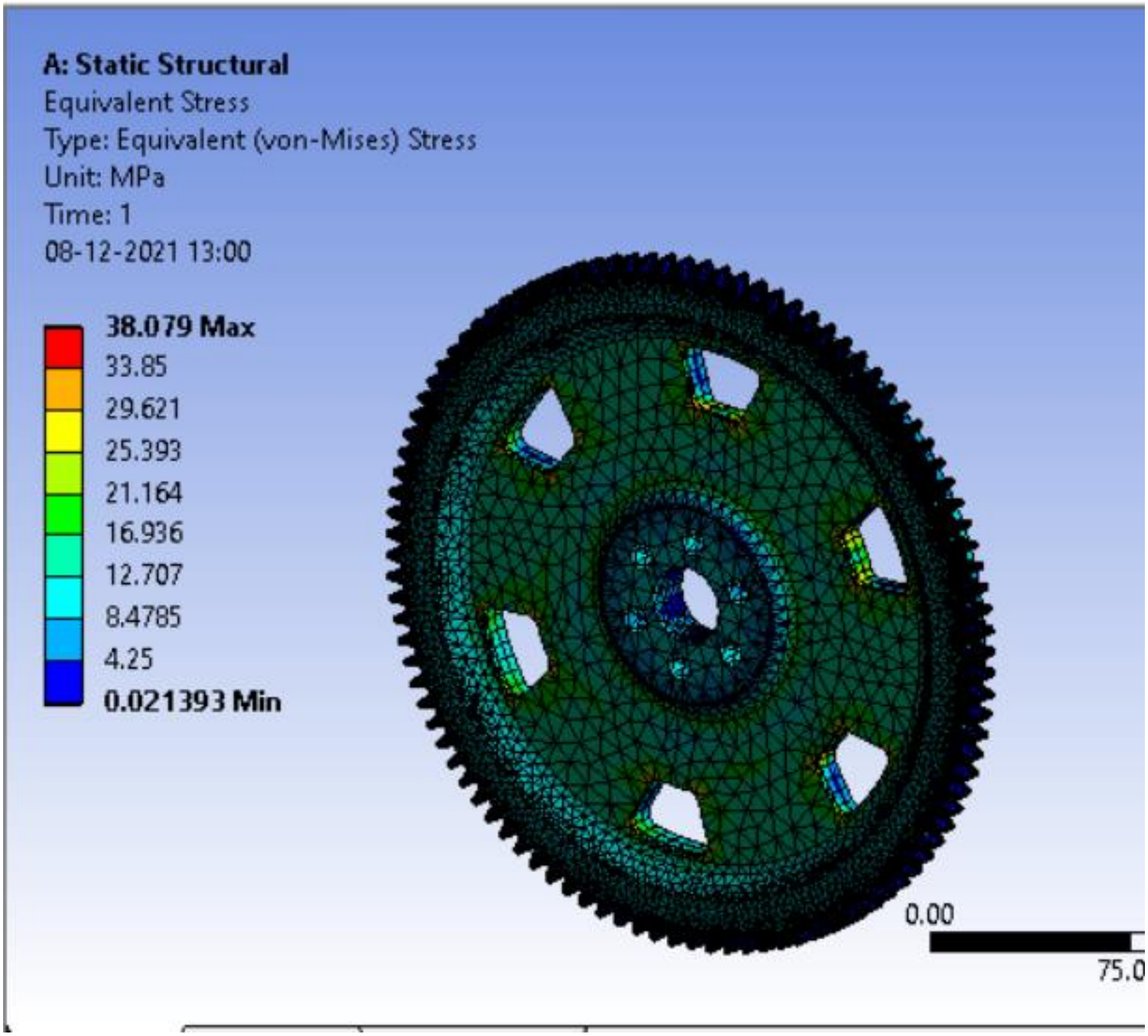


Design Alternative 3

Stress Analysis



Total Deformation



Conclusion:

- We calculated the dimension of the flywheel using reverse engineering technique.
- We designed the 3D model using solidworks software and made the FE analysis using ANSYS.
- Then we designed 2 different types of models using 2 materials; i.e., Grey Cast Iron & Stainless Steel, thus having 6 different models of flywheel for the analysis.
- After the calculation we came to a conclusion of considering the design having trapezoidal hole, made up of grey cast iron.