Non Linear Analysis And Optimization Of Flywheel

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Abstract *- Flywheels serve as kinetic energy storage and retrieval devices with the ability to deliver high output power at high rotational speeds as being one of the emerging storage energy technologies is available today in various stages of development feild, especially in advanced technological areas. Many causes are there of flywheel failure among them and one of is the non-linear behavior of the flywheel. Hence this work evaluation is done of non-linear stresses in the flywheel for different material . The solid work software used fordesign of flywheel. The ANSYS software is used for analysis and apply forces for validation of flywheel is. The FEA of flywheel is considering centrifugal forces on its comparative non-linear analysis von-mises stress is done, shear stress and deformation of the flywheel made of Cast iron and aluminum alloy. The paper gives too topology optimization approach in the mass of flywheel reducing.*

1. INTRODUCTION

1.1 Flywheel Detail

The word 'flywheel' appeared first during the start of industrial revolution. There were two important developments during this period, one is the use of flywheels in steam engine and other is widespread use of iron. Iron material has high integrity that flywheels made up of wood, stone or clay.
Flywheel is a device (mechanical) which is used as a storage device for rotational energy due to its significantly high moment of inertia. Flywheels are required where there is a fluctuation in input power and output load is constant or there where is a fluctuation in output load and the input power remains constant Flywheel is like as a reservoir to store energy when supply is more than requirement and to release the energy when requirement is more than supply. Flywheel provides an effective way to smooth out the fluctuation of speed.

1.2 Problem Statement

The flywheel is dynamic part hence the non-linear static analysis does not gives the exact value of stresses developed in flywheel. It is difficult to find out such type of stresses with the help of numerical analysis to overcome these problems. Modern technologies are used such as FEA software. The paper deals with the study of stresses induced in a flywheel made of different material by using non-linear analysis.

1.3 Objectives

1. To study the stress induced in Subaru EJ25D gasoline engine flywheel..
2. FEM Modeling of Flywheel
3. Perform Non-Linear Analysis using ANSYS.
4. Consideration of flywheel model for shape optimization.
5. Experimental Validation.

1.4 Scope

Considering the overall importance of Flywheel as an energy storage device, we focus on nonlinear analysis by using step loading apply & shape optimization of flywheel. Hence the main concentration will be:

1. To use FEA/FEM as method and software to find the stresses in the flywheel.
2. Optimize the flywheel for reduction in cost & high fuel efficiency.
3. Perform non linear analysis to find the best suitable material for flywheel manufacturing.
4. And most important is dynamometer test perform on flywheel, etc.

2. COMPUTER ADDED MODELLING & FEA

2.1 Introduction to Solid works

Solid works is based on a single database, parametric, and modular process-oriented PLM system. Today all over the world as businesses, small, SMEs and large industrial companies from all sectors to all types of design processes and product development,
production machinery, moulds, household appliances, automotive, agricultural machinery ,shipbuilding, electrical / electronics, medical products, telecommunications, household appliances, metal products, heating and cooling and the manufacturing sectors such as defence and aerospace design and product development processes of all types of co lateral industries, universities , institutes of technical education institutions and R&D is the software used. This is the result of the different sectors to respond to the modular structure.

Fig. Fig 01- Flywheel Model

2.2 Introduction to Structural analysis

Finite element analysis process is divided into three main phase's
a) Pre-processor,
b) Solution,
c) Postprocessor.

1. Pre-processor

The user constructs a model of the part to be analyzed in which the geometry is divided into a number of discrete sub regions or elements," connected at discrete points called nodes." Certain of these nodes will have fixed displacements, and others will have prescribed loads. These models can be extremely time consuming to prepare, and commercial codes with one another to have the most user- friendly graphical pre-processor" to assist in this rather tedious chore. Some of these pre-processors can overlay a mesh on a pre-existing CAD file, so that finite element analysis can be done conveniently as part of the computerized drafting-and-design process. The pre-processor is a program that processes the input data to produce the output that is used as input to the subsequent phase (solution). Following are the input data that needs to be given to the pre-processor:

2. Solution

Solution phase is completely automatic. The FEA software generates the element matrices, computes nodal values and derivatives, and stores the result data in files. These files are further used by the subsequent phase (postprocessor) to review and analyze the results through the graphic display and tabular listings. The dataset prepared by the pre-processor is used as input to the finite element code itself, which constructs and solves a system of linear or nonlinear algebraic equations.

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3. Post-processor

In the earlier days of finite element analysis, the user would pass through of numbers generated by the code, listing displacements and stresses at discrete positions within the model. It is easy to miss important trends and hot spots this way and modern codes use graphical displays to assist in visualizing the results. Typical postprocessor display overlays colored contours representing stress levels on the model, showing a full field picture similar to that of photo elastic or moire experimental results.

2.3 Finite Element Analysis (FEA) Software –

Finite Element Analysis is one of several numerical methods that can be used to solve complex problems and is the dominant method used today. As the name implies, it takes a complex problem and breaks it down into a finite number of simple problems. A continuous structure theoretically has an infinite number of simple problems, but finite element analysis approximates the behavior of a continuous structure by analyzing a finite number of simple problems. Each element in a finite element analysis is one of these simple problems. Each element in a finite element model will have a fixed number of nodes that define the element boundaries to which loads and boundary conditions can be applied. The finer the mesh, the closer we can approximate the geometry of the structure, the load application, as well as the stress and strain gradients. However, there is a trade-off: the finer the mesh, the more computational power is needed to solve the complex problem. The strategy of optimizing the mesh size can greatly reduce an analyst's t ime without compromising on the quality of analysis results

3. SOFTWARE ANALYSIS OF FLYWHEEL

3.1 Meshing Method

The element is defined by 4-nodes with 6 DOFs at each node and well suitable to create irregular meshes. It also has stress stiffening capability. Free mesh with smart element sizing is adopted to automatically and flexibly mesh the model. Compared to mapped mesh, which is restricted to only quadrilateral (area) or only hexahedron (volume) elements; free mesh has no restrictions in terms of element shapes. Smart sizing gives the meshes a greater opportunity to create reasonably shaped element during automatic element generation.

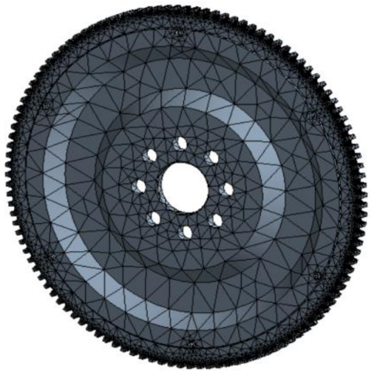


Fig. 02- Meshed Model

3.2 Boundary Conditions and Load

A Cylindrical support is given at the shaft and flywheel contact, that is, the shaft-hole of the flywheel. The flywheel is radially and axially made fixed while it is free to rotate tangentially. The flywheel is rotated by 418.67 radians/s with the axis of rotation being the perpendicular line passing through the centre of the flywheel, outwards of the plane of flywheel. The rotational velocity of 418.67 radians/s is applied in steps of every 1 second linearly.

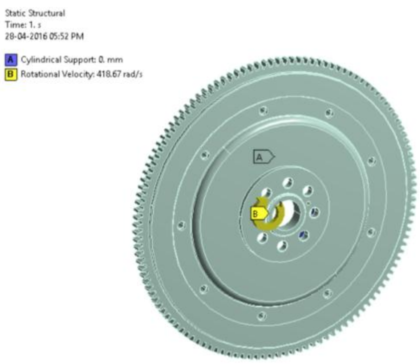


Fig. 03- Boundary Condition on Flywheel

3.3 FEA Analysis

1. Analysis of FLYWHEEL as Aluminum alloy, Cast Iron, Titanium & E-glass material

a) Radial Deformation Analysis

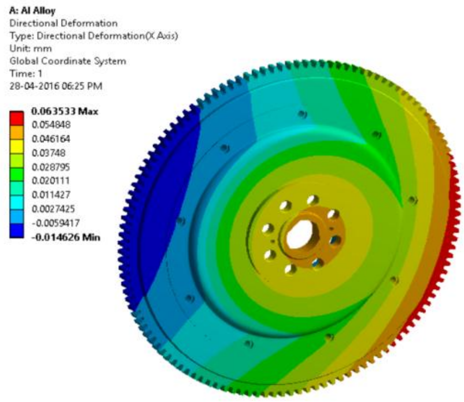


Fig. 04- Radial deformation of Al 6063 T6 flywheel.

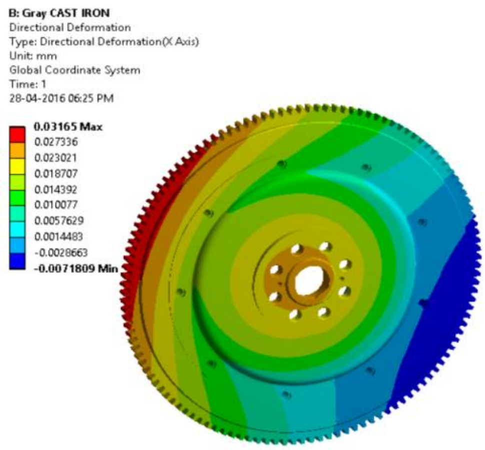


Fig. 05- Radial deformation of cast alloy steel flywheel.

b) Radial Stresses Analysis

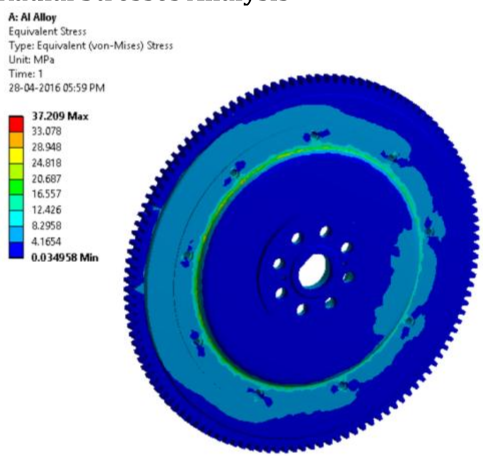


Fig. 06- Radial stress developed in Al 6063 T6 flywheel

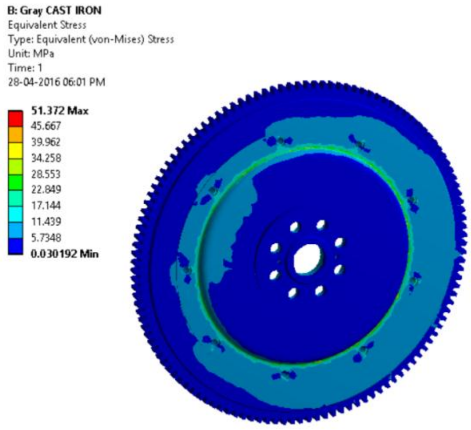


Fig. 07- Radial stress developed in cast alloy flywheel.

c) Factor of Safety Analysis

The factor of safety for the different materials of the flywheel are found to be within safe limits, which depicts that the flywheel designs are feasible and their manufacturing can be carried out for real time simulation.

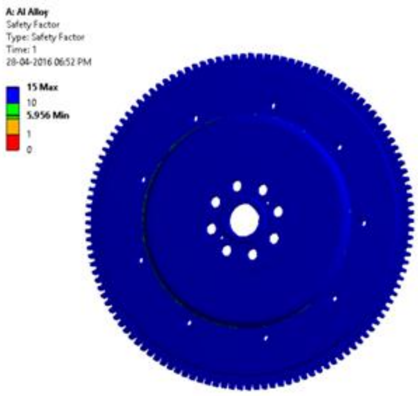


Fig. 08- Factor of safety of Al 6063 T6 flywheel.

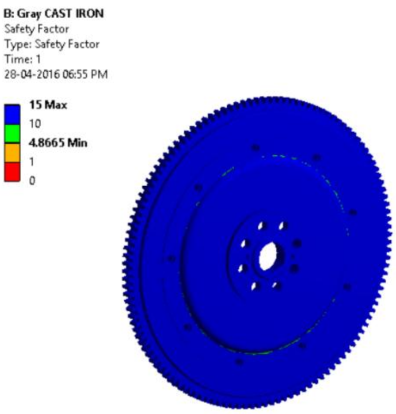


Fig. 09- Factor of safety of cast alloy flywheel.

d) Step loading Chart

Table 01: Step loading Chart

Time	Rotational Velocity
0.	**0.**
1.	**100.**
2.	**200.**
3.	**300.**
4.	**418.67.**

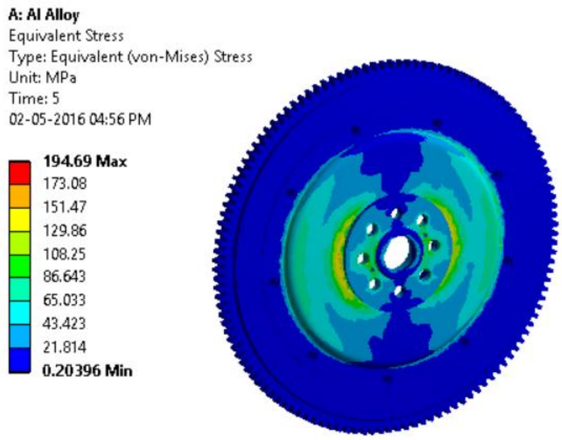


Fig. 10- Non-Linear Radial stress developed in Al 6063 flywheel.

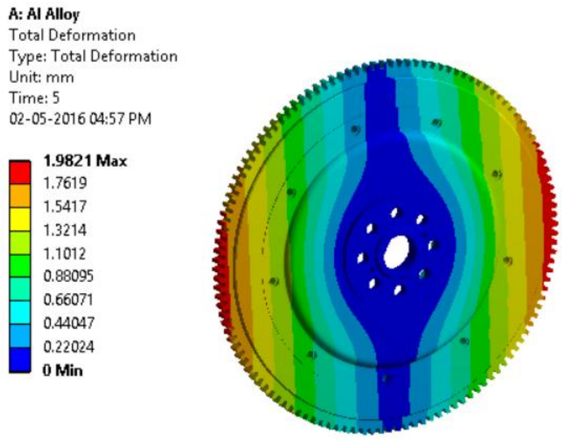


Fig. 11- Total Deformation developed in Al 6063 flywheel.

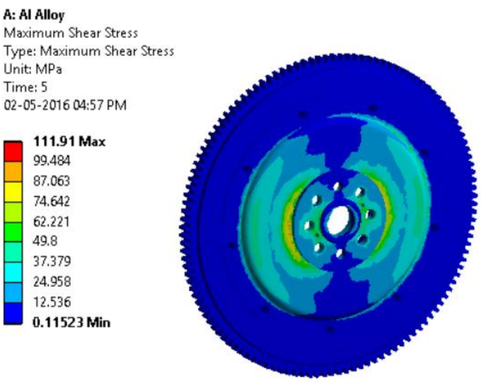


Fig. 12- Shear stress developed in Al 6063 flywheel.

As with step loading formulation, the actual stress and deformation were plotted for Al Alloy and Gray CI.
It is seen that the difference the stress and deformation is very large and we could say that with linear analysis the results plotted are following the linear stress – strain relation, but in actual practice the relation is not linear.

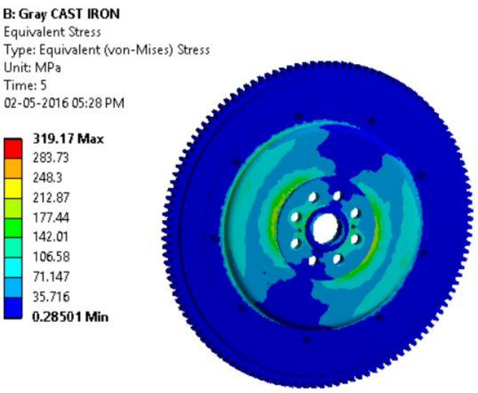


Fig. 13- Non-Linear Radial stress developed in Gray CI flywheel.

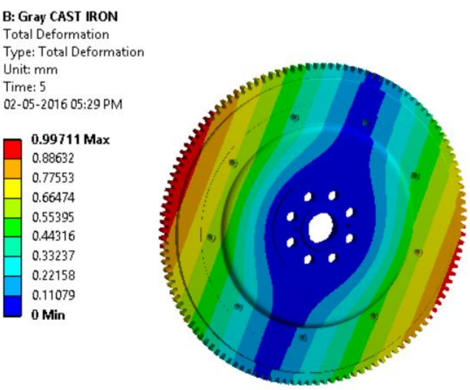


Fig. 14- Non-Linear Radial stress developed in Gray CI flywheel.

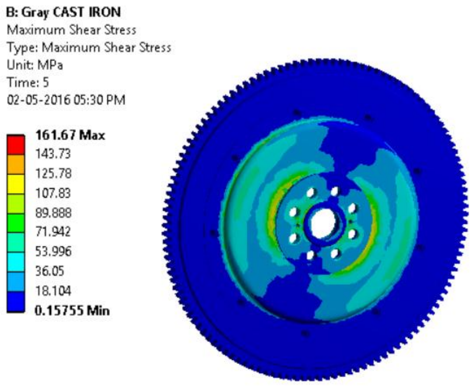


Fig. 15- Shear stress developed in Gray CI flywheel.

2. Shape Optimization of flywheel

At last through the software for reduction of 20%weight of material can be removed from the periphery of the flywheel. In optimization process a comparative study was made and cost wise efficient material is considered as Al alloy.

Table 02: Structural Optimization

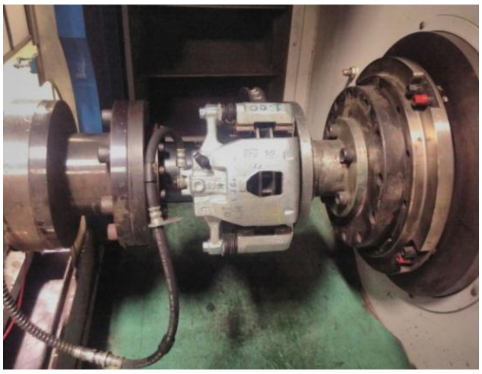
Scope	
Geometry	All1 Bodies
Definition	
Target Reduction	20%
Result	
Original Mass	5.5006 kg
Optimized Mass	4.4004 kg
Marginal Mass	0.0000 kg

Fig. 16- Optimization result for Al Alloy Flywheel.

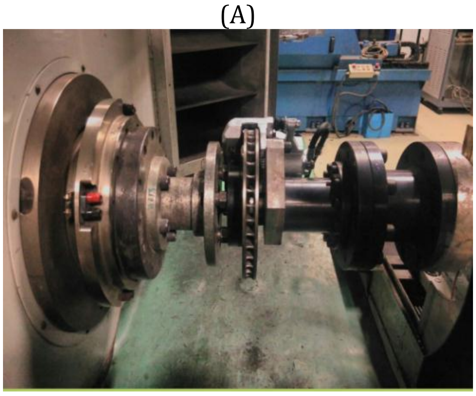
4. EXPERIMENTAL VALIDATION

4.1 Experimental Setup –

As shown in below fig. The setup of flywheel testing. In this set up we are going to check deflection at different point. The point where we get deflection value can show in Fig. As below.



(A)



(B)

Fig. 17- Experimental setup of flywheel

Deflection reading of flywheel is taken at 8 different Points. This 8 different reading is as below. The original thickness of flywheel is 29 mm.

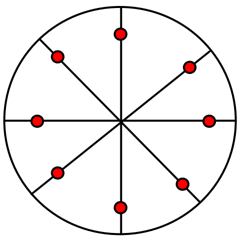


Table 03: Defection Reading For Al Alloy & Cast Iron

Sr. no	Defection Reading For Al Alloy	Defection Reading For Cast Iron
1	29.14 mm	29.175 mm
2	28.97 mm	29.112 mm
3	29.097 mm	29.159 mm
4	28.972 mm	29.070 mm
5	29.196 mm	28.995 mm
6	29.134 mm	28.998 mm
7	29.19 mm	29.099 mm
8	28.984 mm	29.160 mm

1) Final length For Aluminium Alloy:

$$\text{Final length} = \frac{29.14+28.97+29.097+28.972+29.196+29.134+29.19+28.984}{8}$$

Final length = 29.085mm

2) Final length For Cast Iron:

$$\text{Final length} = \frac{29.175+29.112+29.159+29.070+28.995+28.998+29.099+29.160}{8}$$

Final length = 29.096mm

Deflection Calculation:

1) Deflection For Aluminium Alloy:

Deflection = Final length − Original length
Deflection = 29.085 − 29
Deflection = 0.085 mm

2) Deflection For Cast Iron:

Deflection = Final length − Original length
Deflection = 29.096 − 29
Deflection = 0.096 mms

Table 4.2: Defection Results For Al Alloy & Cast Iron

Sr. no	Material	Experimental Deflections
1.	Al Alloy	0.085mm
2.	Cast Iron	0.096mm

Experimental Stress Calculation:
1) stress For Aluminium Alloy:

$$\sigma_E = E \times \varepsilon$$
$$\sigma_E = E \times \frac{\delta l_E}{L}$$
$$\sigma_E = 69 \times 10^3 \times \frac{0.085}{29}$$
$$\sigma_E = 202.24 \text{ Mpa.}$$

2) Stress For Cast Iron:

$$\sigma_E = E \times \varepsilon$$
$$\sigma_E = E \times \frac{\delta l_E}{L}$$
$$\sigma_E = 100 \times 10^3 \times \frac{0.096}{29}$$
$$\sigma_E = 331.034 \text{ Mpa.}$$

5. CONCLUSION

The modelling of the flywheel was performed using Solid works 2013. The Finite Element Analysis (FEA) was carried out using ANSYS workbench 16.0 for the four materials:

The linear analysis was carried out on Aluminium alloy, Cast Iron, Titanium & E-glass materials that's shows the less stress developed in cast Iron & Al alloy, so that non-linear analysis is carried on the same materials.

The Finite Element Analysis (FEA) for non- linear was carried out using ANSYS workbench 16.0 for the two materials: Cast iron, Al 6063-T6,

The nonlinear analysis of Al Alloy and Gray CI shows that the stress developed with Al Alloy is less than that of Gray CI. Experimental validation conducted on both materials and results are compared with FEA analysis and percentage error lies between 3-4%. Thus, Al was found to be the best suited material for constructing the flywheel due to minimum stress and low weight as compared to cast iron.

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