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 energy storage technologies available today in various stages of development, especially in advanced technological areas. There are many causes of flywheel failure among them one of is the non-linear behavior of the flywheel. Hence in this work evaluation of non-linear stresses in the flywheel for different material is done. The design of flywheel is used by solid work software. The software used for analysis and apply forces for validation of flywheel is ANSYS. The FEA of flywheel is considering centrifugal forces on its comparative non-linear analysis is done for von-mises stress, shear stress and deformation of the flywheel made of Cast iron and aluminium alloy. The paper also gives a topology optimization approach in reducing the mass of flywheel.

Key words: Finite Element Analysis, Flywheel

I. Introduction

A. *Flywheel Detail*

Several hundred years ago pure mechanical flywheels where used solely to keep machines running smoothly from cycle to cycle, thereby render possible the industrial revolution. During that time several shapes and designs where implemented but it took until the early 20th century before flywheel rotor shapes and rotational stress were thoroughly analyzed. Later in the 1970s flywheel energy storage was proposed as a primary objective for electric vehicles and stationary power backup. At the same time fibre composite rotors where built, and in the 1980s magnetic bearings started to appear. Thus the potential for using flywheels as electric energy storage has long been established by extensive research. More recent improvements in material, magnetic bearings and power electronics make flywheels a competitive choice for a number of energy storage applications.

B. *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.

C. *Objectives*

1) Detail Design Study of Flywheel as an energy storage device.
2) FEM Modeling of Flywheel
3) Perform Non-Linear Analysis
4) Consideration of flywheel model for Topology optimization.

D. *Scope*

The scope of supply regarding to flywheel material comparing to nonlinear analysis are as below-

1) Power supply for actual testing as 24 volt which is suitable for normal testing for get result.
2) Necessary equipment, tool & tackles, material both consumable and non-consumable are required for comparing different material flywheel.
3) Total setup required things like electricity, manpower, tools, safety goods etc. at the time of testing.
4) Different material flywheel which we want to get in result.
5) And most important is dynamometer, etc.

II. Computer Added Modelling & FEA

A. *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. 1: Flywheel Model

B. *Introduction to Structural analysis*

Finite element analysis process is divided into three main phase's

- Pre-processor,
- Solution,
- Postprocessor.

1) *Pre-processor*

The user constructs a model of the part to be analysed 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.

$$Kijuj = fi$$

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 coloured contours representing stress levels on the model, showing a full field picture similar to that of photo elastic or moire experimental results.

C. *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 behaviour of a continuous structure by analysing 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

III. SOFTWARE ANALYSIS OF FLYWHEEL

A. *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.

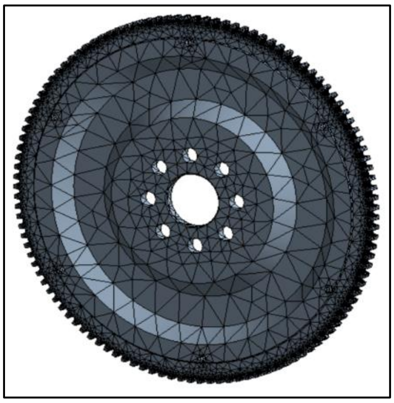


Fig. 2: Meshed Model

B. *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.

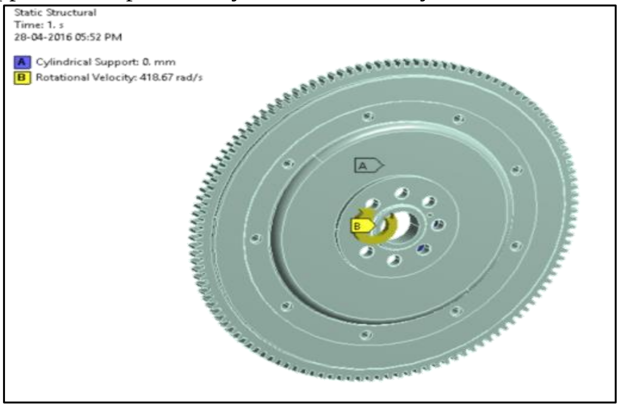


Fig. 3: Boundary Condition on Flywheel

C. FEA Analysis

1) Analysis of Flywheel as Aluminum alloy, Cast Iron, Titanium & E-glass material

a) Radial Deformation Analysis

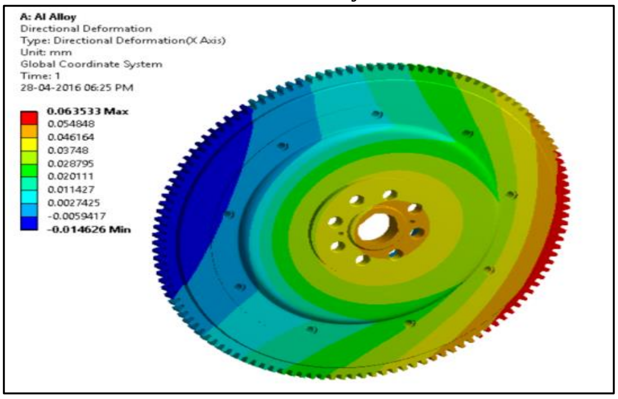


Fig. 4: Radial deformation of Al 6063 T6 flywheel.

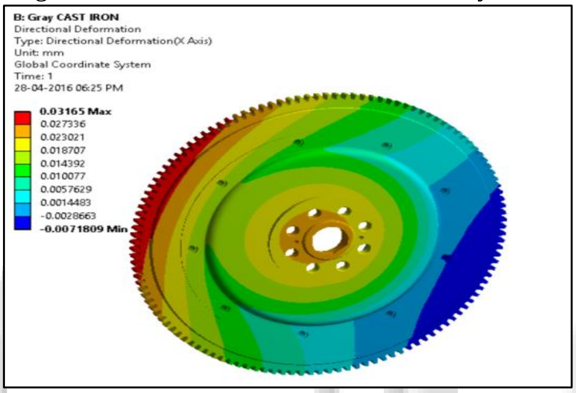


Fig. 5: Radial deformation of cast alloy steel flywheel.

b) Radial Stresses Analysis

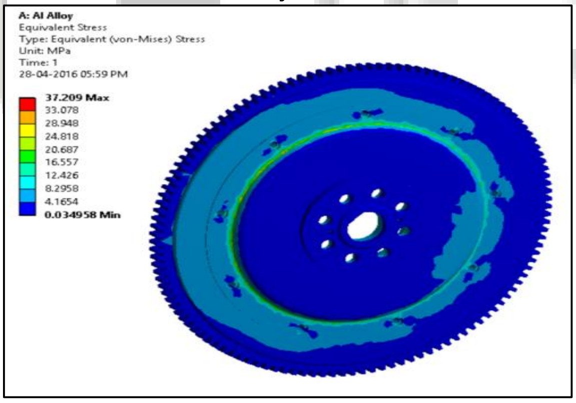


Fig. 6: Radial stress developed in Al 6063 T6 flywheel

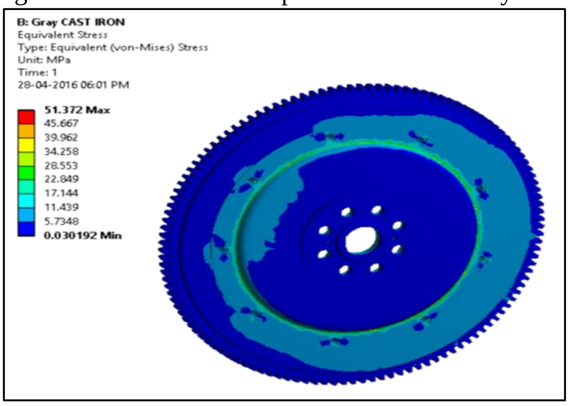


Fig. 7: Radial stress developed in cast alloy flywheel.

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.

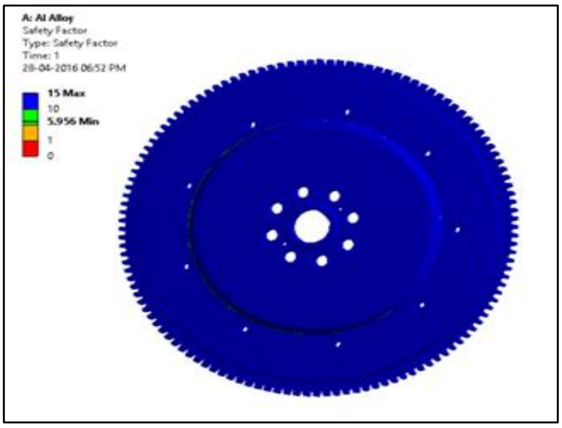


Fig. 8: Factor of safety of Al 6063 T6 flywheel.

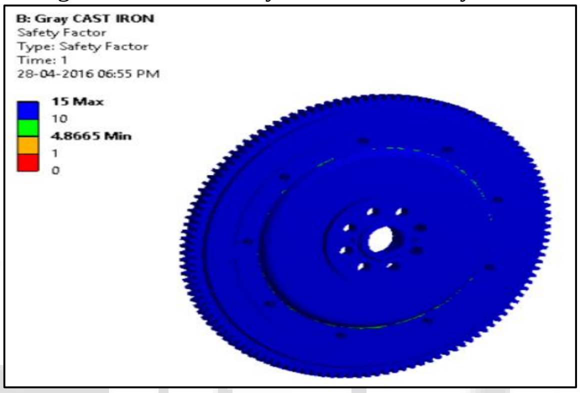


Fig. 9: Factor of safety of cast alloy flywheel.

d) Step loading Chart

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

Table 1: Step loading Chart

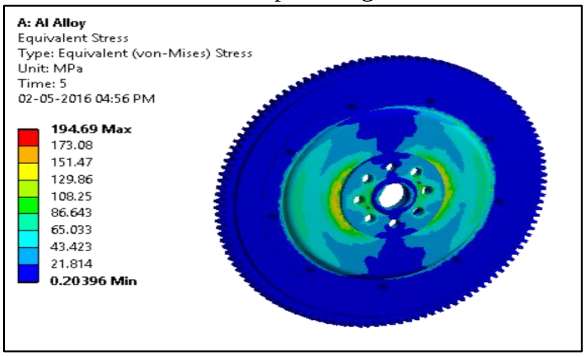


Fig. 10: Non-Linear Radial stress developed in Al 6063 flywheel.

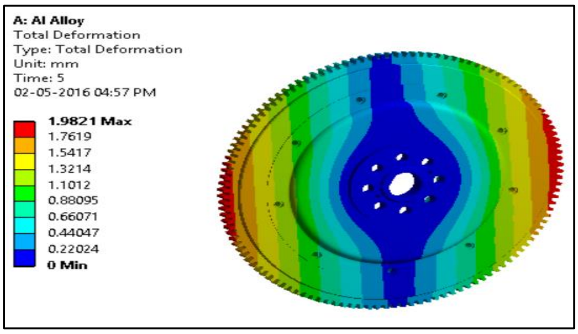


Fig. 11: Total Deformation developed in Al 6063 flywheel.

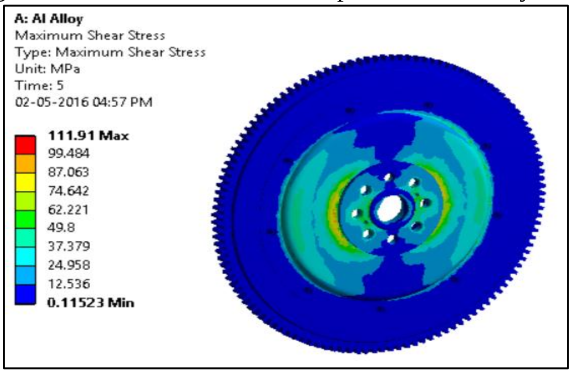


Fig. 12: Shear stress developed in Al 6063 flywheel.

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.

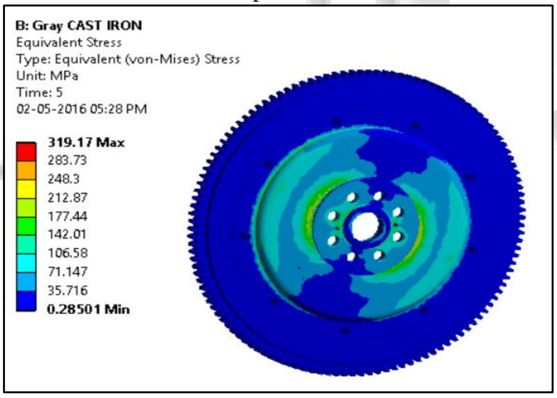


Fig. 13: Non-Linear Radial stress developed in Gray CI flywheel.

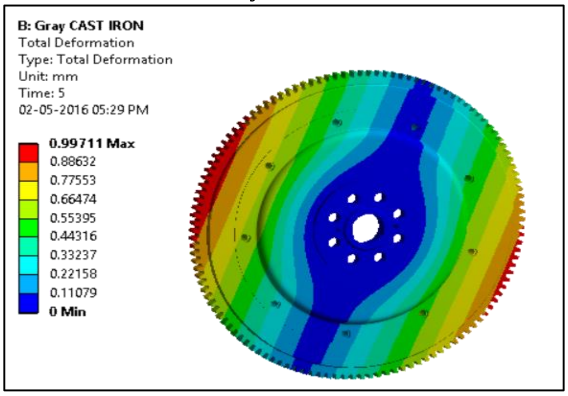


Fig. 14: Non-Linear Radial stress developed in Gray CI flywheel.

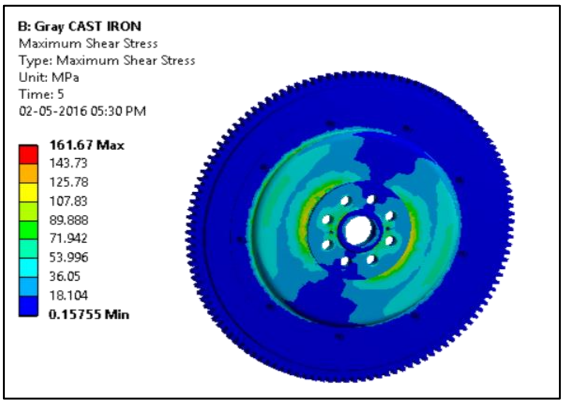


Fig. 15: Shear stress developed in Gray CI flywheel.

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.

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

Table 2: Structural Optimization

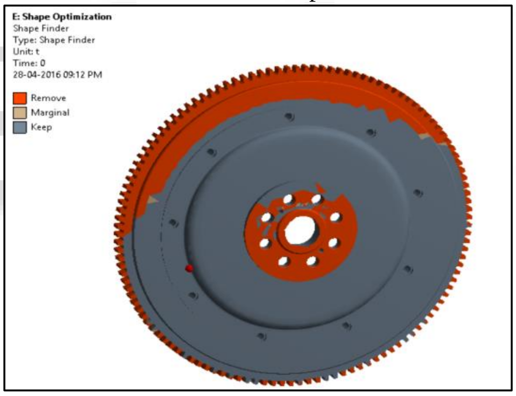
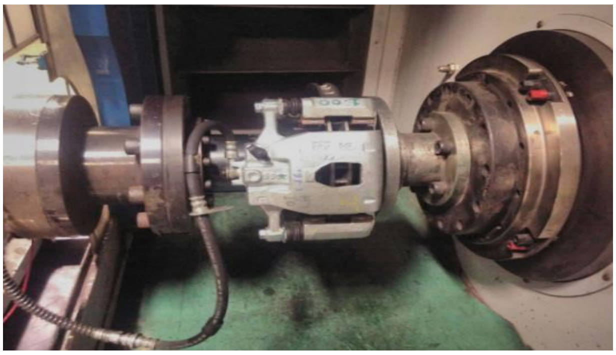


Fig. 16: Optimization result for Al Alloy Flywheel.

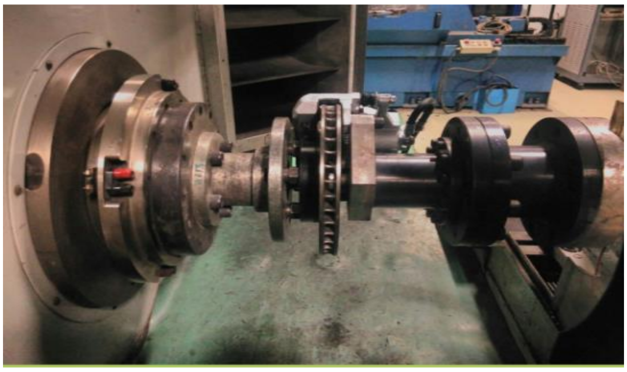
IV. Experimental Validation

A. 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.

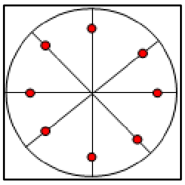


Fig. 18: Flywheel

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

Table 3: Defection Reading For Al Alloy & Cast Iron

1) *Final length For Aluminum 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

B. *Experimental Deflection Calculation*

1) *Deflection for Aluminum 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

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

Table 4: Defection Results for Al Alloy & Cast Iron

V. 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:

Cast iron, Al 6063-T6, Titanium alloy and E-glass. The structural analysis of the original flywheel made of cast iron was carried out and the deformation, radial stress and the Factor of Safety (FOS) was reported. The material of the flywheel was changed to Al 6063-T6, Titanium alloy and E-glass in succession, and the structural analysis on ANSYS workbench was reported for each of the materials. The results of the deformation and stress analysis were found to be within safe limits. The manual calculations are also found to agree with the results obtained from the analysis. However, the deformation and stress developed for aluminum 6063-T6 flywheel was found to be the least among the four materials under consideration.

The nonlinear analysis of Al Alloy and Gray CI shows that the stress developed with Al Alloy is quite less than that of Gray CI. Al alloy also has an added advantage of higher strength-to-weight ratio compared to the other materials. Thus, Al was found to be the best suited material for constructing the flywheel. Thus by using Al alloy flywheel, the weight can be reduced as compared to cast iron flywheel which can help in reducing the weight of the vehicle and increase the fuel economy. However, the life of the flywheel will also get affected.

This project also highlights the importance of composites as an alternative for constructing the flywheel due to its high specific tensile strength. This is one reason why E-glass is a material of interest. Using E-glass will result in a weight saving as compared to the cast iron flywheel.

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