

Finite Element Analysis of Web Type Flywheel Made of Composite Material

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Abstract— Flywheels is device serve as kinetic energy storage and retrieval 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, i.e., space-crafts. Mainly, the performance of a flywheel can be attributed to three factors, i.e., material strength, geometry (cross-section) and rotational speed. While material strength directly determines kinetic energy level that could be produced safely combined (coupled) with rotor speed, there are many causes of flywheel failure. But maximum tensile and bending stresses induced in the web and rim under the action of centrifugal forces are the main causes of flywheel Failure.

Hence in this work evaluation of stresses induced the rim and web are studied using finite element method and results are validated by analytical calculations this study solely focuses on exploring the effects of Centrifugal stresses on web type conventional steel and composite material flywheel and comparison of theoretical and Ansys results of conventional steel with composite material flywheel

Keywords — flywheel, composite web material, FEM Analysis.

I. INTRODUCTION

A flywheel is a used as a storage device for rotational energy with a significant moment of inertia. 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. Flywheels have become the subject of extensive research as power storage devices for uses in vehicles. Flywheel energy storage systems are considered to be an good alternative to electrochemical batteries due to higher stored energy density, higher life term, and deterministic state of charge and pollution free clean nature. Flywheel is basically acting as a rechargeable battery. It is used to absorb electric energy from source and store it as kinetic energy of rotation, and then deliver it to a load at the appropriate required time, in the form that to meets the load needs.

2. Literature Review.

Sudipta Saha, Abhik Bose, G. SaiTejesh, S.P. Srikanth et al. have proposed the importance of the flywheel geometry design selection and its contribution in the energy storage performance. This contribution was demonstrated on example cross-sections using computer aided analysis and optimization procedure. Proposed Computer aided analysis and optimization procedure results show that smart design of flywheel geometry could both have a significant effect on the Specific Energy performance and reduce the operational loads exerted on the shaft/bearings due to reduced mass at high rotational speeds

Akshay P. Pundey et al. have presented the investigation of a Flywheel to counter the requirement of smoothing out the large oscillation in velocity during a cycle of an Internal Combustion Engine. A Flywheel is designed and analysed by using FEA method. They have calculated the stresses inside the Flywheel. Finally the comparison study between the design and analysis with existing Flywheel was carried out

M. Lavakumar et al. established the design and analysis of Flywheel to minimize the fluctuation in torque. The Flywheel is subjected to a constant rpm. The objective of this work was to design and optimize for the best material. Von-Misses stress for both materials (Mild steel and mild steel alloy) are compared, and the best material was suggested for manufacture of Flywheel

Phanindra Mudragadda, et al. designed a four wheeler Flywheel used in a petrol engine using theoretical calculation. They have validated the design of Flywheel on A360 & Cast iron. They observed that, for all the materials the stress values are less than their respective permissible yield stress values. By comparing the results for two materials, the stress value for aluminium alloy A360 is less than that of Cast iron.

The objectives of research work:-

- To determine stresses in conventional flywheel analytically & using Finite Element Method.

- To analyse the stresses in composite material flywheel analytically & using Finite Element Method
- To study the effect of using flywheel of composite material on fluctuation of speed

3. MODELLING OF FLYWHEEL

The major dimensions of flywheel considered for present analysis are as follows-

Table 1: Principal dimensions of flywheel

SR. NO.	DESCRIPTION	DIMENSIONS(MM)
1	Outer diameter	241
2	Mean diameter	222
3	Shaft diameter	44
4	Rim Width	38
5	Rim thickness	19

3.1 Flywheel layout:

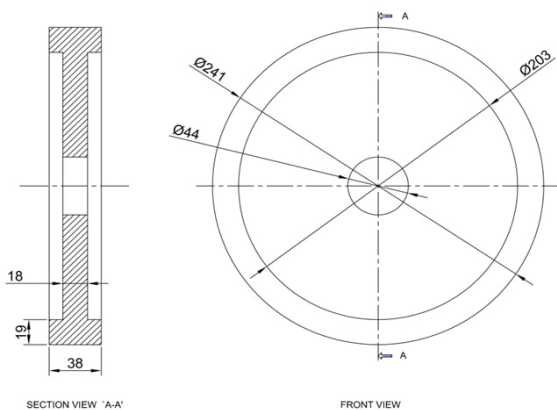


Fig.1: Flywheel layout

4. ANALYTICAL SOLUTION:

Here we determine stress analytically to compare with stresses obtained by FEA for different material flywheels theoretically.

Steel Flywheel:- Given: Model –1.2 Riverton engine

Power, [P] = 66 KW

Speed, N = 3250 rpm

Torque, T = 140 N-m

Now, Mean Rim Speed, $v = \frac{\pi DN}{60}$ (PSG 7.120)

Where, D = mean diameter of rim (m) = 0.222 m

N = speed (rpm)

$\therefore v = \frac{(\pi \times 0.222 \times 3250)}{60}$

$\therefore v = 37.75$ m/sec

Now, Tensile stress due to centrifugal force,

$\sigma = \frac{\gamma \times v^2}{g}$ (PSG 7.120)

Where, γ = specific weight = $\rho \times g$

g = gravitational acceleration 9.81m/sec²

$\therefore \sigma = \frac{(\rho \times g) \times v^2}{g}$

$\therefore \sigma = \rho \times v^2$

Where, ρ = density of steel = 7850 kg/m³

$\therefore \sigma = 7850 \times (37.75)^2$

$\therefore \sigma = 11.1867$ Mpa

B). Mean angular speed during the cycle

$\omega = 2\pi \times 3250 / 60 = 340$ rad / s

Since for internal combustion engine fluctuation of speed is $\pm 1.5\%$ of the mean speed, therefore total fluctuation of speed,

$N_1 - N_2 = 3\%$ of mean speed = 0.03 N

Co-efficient of fluctuation of speed,

$C_s = N_1 - N_2 / N = 0.03$

We know that maximum fluctuation of energy (ΔE)

Let m =Mass of steel rim 3.95

$\Delta E = m.R^2.\omega^2.C_s$

$\Delta E = 3.95 \times (0.111)^2 \times (340)^2 \times 0.03$

$\Delta E = 168$ N-m

Same analytical calculation done for Composite Flywheel (with Steel Rim and Carbon Fibre web)

- By ANSYS analysis, we get Max. Equivalent (Von Mises) stress induced, $\sigma = 2.0759$ MPa
- By analytical calculations, we get Max. Permissible stress, $[\sigma] = 2.021$ MPa
- Maximum fluctuation of energy carbon fiber flywheel (ΔE),

$\Delta E = 168$ N-m

5. MODELLING:-

Modelling plays very important role in design and it's a first step to move to the analysis. Model of a flywheel is created based on geometry assigned and it is shown below.

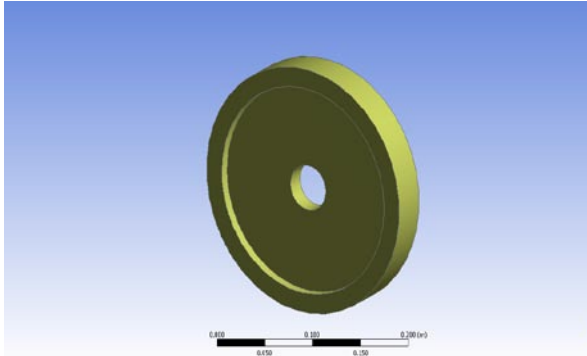


Fig 2: Steel Flywheel model in CATIA V5

6. FLYWHEEL ANALYSIS

6.1. Material Properties:-The material properties are as follows

Table 2: Material properties

SR. NO.	MATERIAL PROPERTIES	UNIT	STEEL	CARBON FIBER
1	Density	kg/m ³	7850	1800
2	Poisson's ratio	-	0.3	0.23
3	Young's Modulus	MPa	2×10 ⁵	2×10 ⁵
4	Tensile Yield stress	MPa	1300	1950
5	Tensile Ultimate stress	MPa	1550	1500

6.2. Element Type

Hexahedral element presents other advantages in FEA model building. Meshes comprised of hexahedrons are easier to visualize than meshes comprised of tetrahedrons. In addition, the reaction of hexahedral elements to the application of body loads more precisely corresponds to loads under real world conditions. The eight-node hexahedral elements are therefore superior to tetrahedral elements for finite element analysis. It is pertaining to the element solid 72, a 3dimension 8-noded Hex-Dominant structural solid with rotation is used for meshing

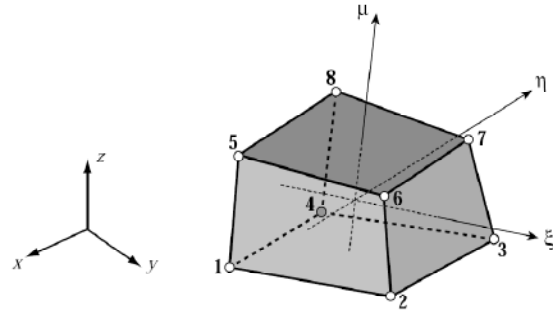


Fig.3: Hexahedral of elements

6.3. Meshing Method:-Mesh generation is the practice of generating a polygonal or polyhedral mesh that approximates a geometric domain. For structural analysis quad and hex are preferred over tetras, Penta's. The meshing related diagrams are given below as per the nodes and elements chosen. By using the Hex-Dominant Method, we get Nodes 18350 and Elements 4310 with fine meshing.

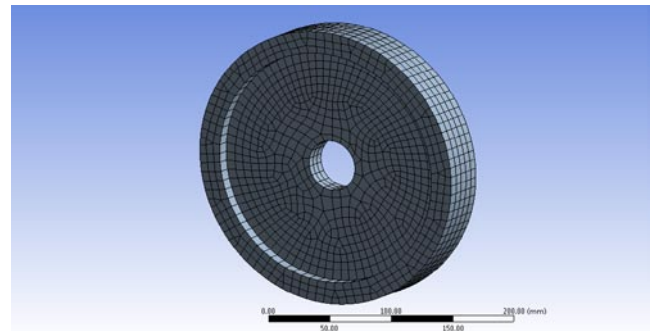


Fig.4: Fine Meshing with Hex-Dominant method.

6.4. Boundary Conditions and Loads

In boundary condition all the six degrees of freedom are taken into account as region of a part selected is shaft hole based on angle and boundary condition type is displacement/rotation. All degrees of freedom of nodes on inner surface of hole are restricted.

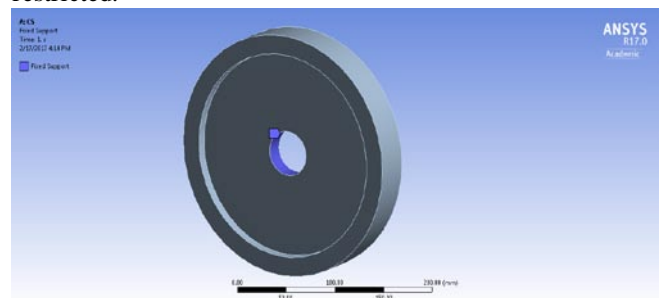


Fig 5: Boundary condition applied at shaft hole

As per the load consideration here rotational body force is selected with rotational velocity mean velocity 3250 rpm.

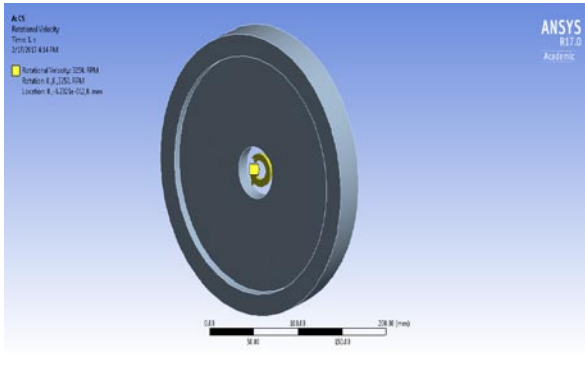


Fig 6: Location of Moment application

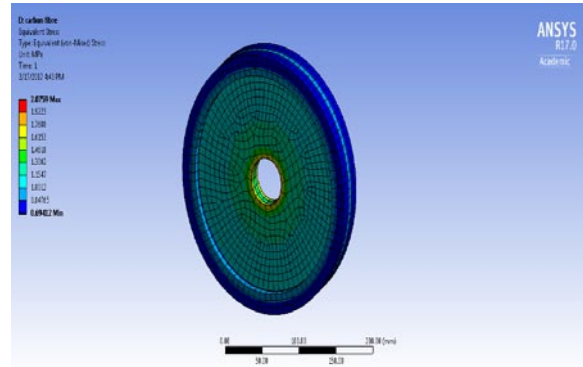


Fig.9: Stress in steel rim and Carbon fibre

7. FE ANALYSIS

Case 1: Fully Steel Flywheel: -Max. Equivalent (Von Mises) stress induced in the steel flywheel is 11.548 MPa. Max. Total deformation in the flywheel is 0.0016943mm&mass of flywheel is 8.3kg.

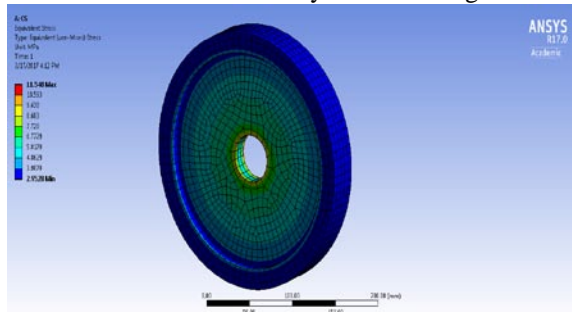


Fig.7: Equivalent Stress in Fully Steel Flywheel

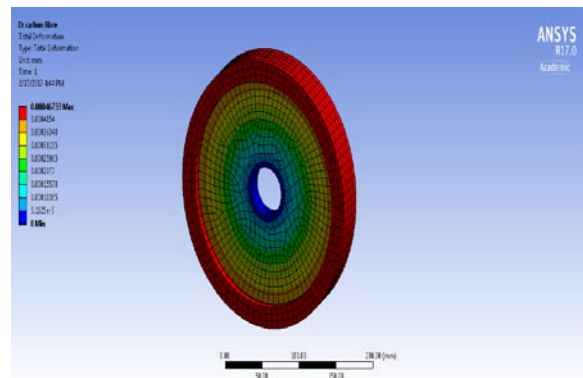


Fig.10: Total deformation in steel rim and Carbon fibre

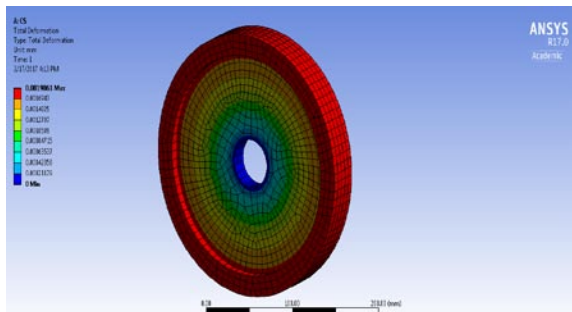


Fig.8: Total deformation in full steel flywheel

Case 2: Composite Flywheel (with Steel Rim and Carbon Fibre web):-

Max. Equivalent (Von Mises) stress induced in the flywheel is 2.0759MPa.Total max Deformation in the flywheel is 0.00046733mm.And total massofflywheelis5.13kg.

8. RESULTS AND DISCUSSION:-

- For steel flywheel by analytical calculations and, By ANSYS analysis we get Max. Centrifugal stress are, $[\sigma] = 11.186 \text{ MPa}$ $\sigma = 11.548 \text{ MPa}$ respectively and max deformation is 0.0032132mm
- For composite flywheel (steel rim and carbon fibre web) by analytical calculations Max. centrifugal stress (2.0759MPa) and, By Ansys (2.021MPa)
- Also, the mass of flywheel obtained is 5.13 kg and deformation is 0.00046733mm
- From total mass of steel flywheel mass of composite material web is subtracted. This will give increased mass of rim. i.e. m_{modified}
Let $m_{\text{modified}} = \text{Mass of steel rim}$ is 7.1 kg
 $\Delta E = m \cdot R^2 \cdot \omega^2 \cdot C_s$
 $168 = 7.1 (0.111)^2 \times (340)^2 \times C_s$
Fluctuation of speed $C_s = 0.0166$
- By using composite material web we will increase the weight of the rim and reduce the fluctuation of speed.

9. RESULTS IN TABULAR FORM:-

9.1 Equivalent stress, percentage error and deformation in flywheel:-

MATERIAL	EQUIVALENT STRESS(ANALYTICAL)	EQUIVALENT STRESS(ANSYS)	% ERROR	TOTAL MAX DEFORMATION(MM)
Carbon Steel	11.186	11.548	-3.236	0.0032132
Carbon Fiber web	2.021	2.075	-2.671	0.0004673

9.2 Total mass of flywheel and co-efficient of fluctuation of speed

MATERIAL	TOTAL MASS [KG]	MASS OF WEB	MASS OF RIM	CO-EFF. OF FLUCTUATION OF SPEED
Carbon Steel	8.3	4.35	3.95	0.03
Carbon Fiber web	8.3	1.2	7.1	0.016

10. CONCLUSIONS:-

- Stresses in flywheels obtained using Finite Element method are nearly equal to the stresses determined using analytical equations.
- Deformation in steel flywheel is slightly more than that of carbon fibre web & steel rim flywheel.
- Using carbon fibre web & keeping the same total weight of flywheel by increasing the weight of rim, coefficient of fluctuation of speed can be reduced to a large extent.

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