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# Stress Analysis on Flywheel

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**Abstract**
*This paper deals with a stress analysis scenario of flywheel to study the change in stress values due to change in different parameters. A total of five parameters are considered such as speed, outer diameter of the flywheel, number of spokes, diameter of spoke and material to study the change in stress behavior. The general problem faced in such an analysis is that it is difficult in a numerical background. Overcoming this problem in modern world was easy with the help of FE platform. The results were obtained which paved the way to study the stress behavior on flywheel in different parameters.*

**Keywords**
*Von mises stress, FEA, Flywheel*

## I. Introduction
Flywheel is a heavy rotating body which serves as an energy reservoir. The flywheel stores the energy in the form of kinetic energy during the period when the supply of energy from the prime mover is more than the requirement of energy by the machine, and releases it during the period when the requirement of energy by the machine is more than the supply of energy by the prime mover. In this work stress induced in a flywheel was studied and considered different parameters such as speed, material, outer diameter of flywheel, diameter of spoke and number of spoke.

### A. Problem Definition
The paper deals with the study of stresses induced in a flywheel due to different parameters like speed, material of flywheel, number of spokes, diameter of spokes and outer diameter of flywheel. Through this study it is possible to find out the factors that contribute to increase in stresses on a flywheel. The main problem faced in such a study is that it is tedious to be done in a numerical background. To overcome this problem, modern technology was used. Using modern software like creo 1.0 and ansys workbench, modeling and analysis were made easier and more accurate.

### B. Methodology
The modeling of the flywheel was done on the design software tool Creo 1.0 created by PTC Inc. A total of 27 models were created in .prt format and were converted to .igs using the format converter provided by Creo itself. All the models are created with varying dimensions.
A total of 243 analyses were done using the FE platform provided by Ansys Inc. The materials considered for this work were Gray cast iron (Density=7200 kg/m³), Structural steel (Density=7850 kg/m³) and Copper alloy (Density=8300 kg/m³). Each material carry 81 analysis varying all the parameters and incorporating them in order to obtain a complete review on the equivalent von mises stress induced in the flywheel. The values were compared to perform overall study of stresses induced in flywheel at different parameter variations

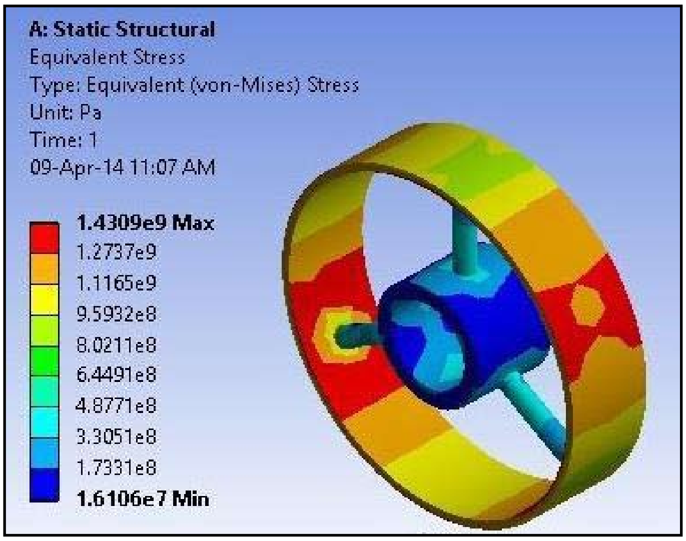


Figure 1: Representation of stress distribution on a flywheel using Ansys Workbench

The above figure is the representation of stress distributed over a flywheel obtained using the analysis software Ansys workbench.

### C. Geometric Description
The parameters considered in the study were outer diameter ($D_o$), speed (s), density (ρ), diameter of spoke (d) and number of spokes (N). The flywheel considered for this work was part of a speed retardation test apparatus. The main changes done to the basic design of the model was varying the outer diameter values, the number of spokes, material, diameter of spoke and speed to obtain different values for equivalent stress using the FE platform designed by Ansys Inc. Ansys Workbench 14.5 is a well-designed software tool made to perform analysis on different conditions such as fluid flow, electromagnetic, structural mechanics etc.

### D. Stresses In Rimmed Flywheel
A rimmed flywheel consists of a rim at which the major portion of the mass of flywheel is concentrated, a hub for mounting the flywheel on the shaft and a number of arms for supporting the rim on the hub. The maximum stress value obtained on a flywheel is found to be on its rim. The following equation was obtained from

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design data book [1]

$$\sigma_{rim} = \rho v^2 \left[0.75 + \frac{0.25\pi^2 D}{n^2 t}\right] \qquad \text{Eqn 1}$$

ρ = mass density of the flywheel, kg/m$^3$
v = linear rim speed at mean radius, m/s = $R_m\,\omega$
ω= angular speed of the flywheel, rad/s
$R_m$ = mean radius of the rim, m
n = number of arms
t = thickness of the rim, m
D =Outer diameter, m

### E. Finite Element Analysis (FEA)

Finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for differential equations. It uses variational methods (the calculus of variations) to minimize an error function and produce a stable solution. Analogous to the idea that connecting many tiny straight lines can approximate a larger circle, FEM encompasses all the methods for connecting many simple element equations over many small subdomains, named finite elements, to approximate a more complex equation over a larger domain.

The subdivision of a whole domain into simpler parts has several advantages such as accurate representation of complex geometry, inclusion of dissimilar material properties, easy representation of the total solution and capture of local effects

A typical work out of the method involves dividing the domain of the problem into a collection of subdomains, with each subdomain represented by a set of element equations to the original problem, followed by systematically recombining all sets of element equations into a global system of equations for the final calculation. The global system of equations has known solution techniques, and can be calculated from the initial values of the original problem to obtain a numerical answer.

### F. Von-Mises Stress

In an elastic body that is subject to a system of loads in 3 dimensions, a complex 3 dimensional system of stresses is developed. That is, at any point within the body there are stresses acting in different directions, and the direction and magnitude of stresses changes from point to point. The Von Mises criterion is a formula for calculating whether the stress combination at a given point will cause failure. There are three "Principal Stresses" that can be calculated at any point, acting in the x, y, and z directions.

Von Mises found that, even though none of the principal stresses exceeds the yield stress of the material, it is possible for yielding to result from the combination of stresses. The Von Mises criterion is a formula for combining these 3 stresses into an equivalent stress, which is then compared to the yield stress of the material. The yield stress is a known property of the material, and is usually considered to be the failure stress.

The equivalent stress is often called the "Von Mises Stress" as a shorthand description. It is not really a stress, but a number that is used as an index. If the "Von Mises Stress" exceeds the yield stress, then the material is considered to be at the failure condition.

## II. Benchmark Problem

A benchmark problem was done to check the error percentage between the value obtained using Ansys workbench software and with a standard equation.

Consider a flywheel of

**Table 1**: Flywheel parameter values taken

| | |
|---|---|
| Outer Diameter | 200mm |
| Speed | 600rpm |
| Number of spokes | 3 |
| Material | Structural steel (Density=7850 kg/m$^3$) |
| Diameter of spoke | 37.5mm |

The above table values were used in solving principal stress value for both the equation and the analysis software.

Principal stress value obtained for the above details using FEA analysis on Ansys workbench

Principal stress=2.98e8 Pa

Principal stress value obtained for the above details using Eqn.1 [1]

Principal stress=3.004e8 Pa

The error was found to be around 1% and is negligible.

## III. Result And Discussion

This method considers two variables varying keeping all the other three variables constant. This helps in understanding the effect of a variable with respect to another variable on stress induced. A total of 20 graphs were plotted using the five parameters. Some important results are discussed below.

### A. Effect of Speed with Varying Material

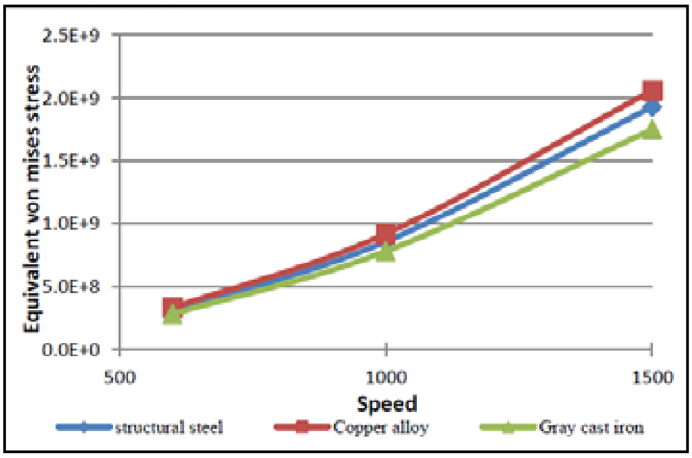


Figure 2: Effect of Speed with Varying Material

The effect of speed with all other parameters constant shows that the equivalent stress value increases as the speed increases from 600rpm to 1500rpm. The drastic increase in the stress due to increase in speed shows that the effect of speed on the stress induced is high. This increase is shown in figure 2. Considering the change in material, the material with the lowest density has the lowest curve compared to the other materials. This shows that as the material property such as density changes, stress induced also changes. As the density increases the stress induced also increases.

### B. Effect of Material With Varying Speed

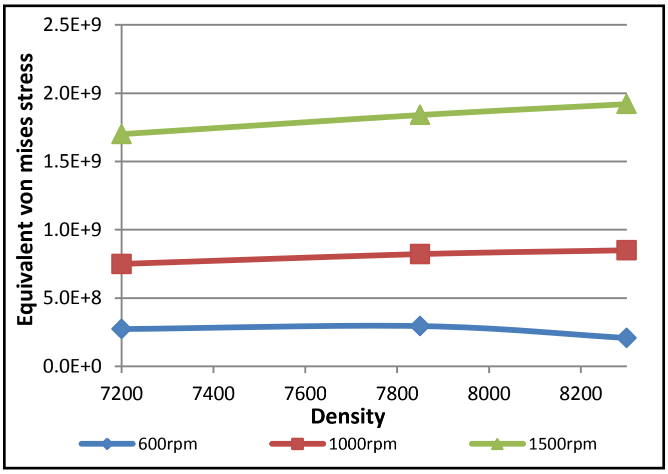


Figure 3: Effect of Material with Varying Speed

Figure 3 considers the effect of material while varying speed taking all other parameters constant. The materials considered for this work were Gray cast iron (Density=7200 $kg/m^3$), Structural steel (Density=7850 $kg/m^3$) and Copper alloy (Density=8300 $kg/m^3$). Considering the effect of material with all other parameters constant shows that the stress induced is directly increasing the stress induced value. Even though the stress increase is considerably small, other material properties also may be the reason for this phenomenon. Considering different curves for varying values of speed, the curve with 600 rpm shows an increase then a decrease towards the increase in density of the material. This leads to the possibility of a critical speed at which the effect of change in density of a material is not affected. Finding such a critical speed and applying them will lead to better protection of flywheel against failures due to stresses.

### C. Effect of Number of Spokes with Varying Speed

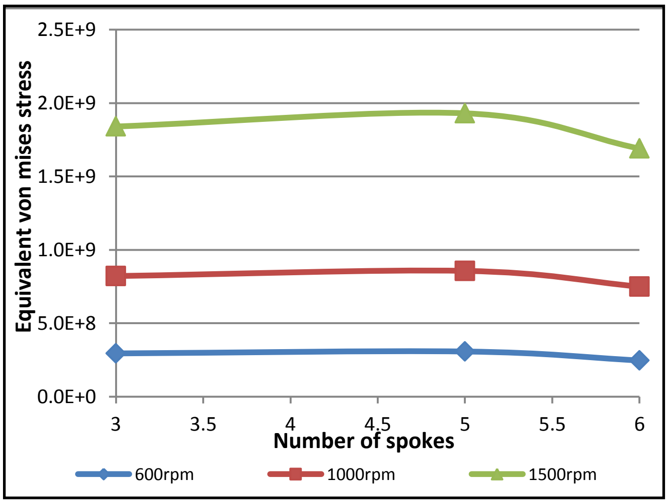


Figure 4: Effect of Number of Spokes with Varying Speed

By categorizing the number of spokes into balanced and unbalanced, it may be observed that the stress induced shows an increase for unbalanced type of flywheel whereas a slight decrease is observed in the case of balanced flywheels. This provides an information that the stress value induced in an arm type flywheel decreases as the number of spokes of the flywheel becomes balanced.

### D. Effect of Outer Diameter with Varying Speed

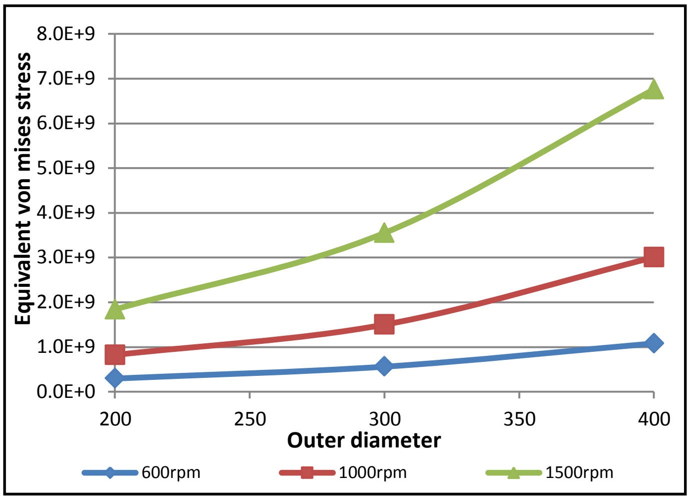


Figure 5: Effect of Outer Diameter with Varying Speed

As the outer diameter increases the stress value also increases. This characteristic is shown in a single curve in the above curve. Therefore outer diameter of flywheel has a high effect on the stress induced. Comparing every single curve it can be found that as the speed increases the slope of the curve also increases. This shows that the speed also has a relation with the stress induced in the diameter varying flywheel. The flywheel with 400mm outer diameter rotating at 1500rpm has the maximum stress induced value while the flywheel with 200mm outer diameter and 600rpm rotational speed has the lowest value of stress induced.

### E. Effect of Diameter of Spoke with Varying Number of Spoke

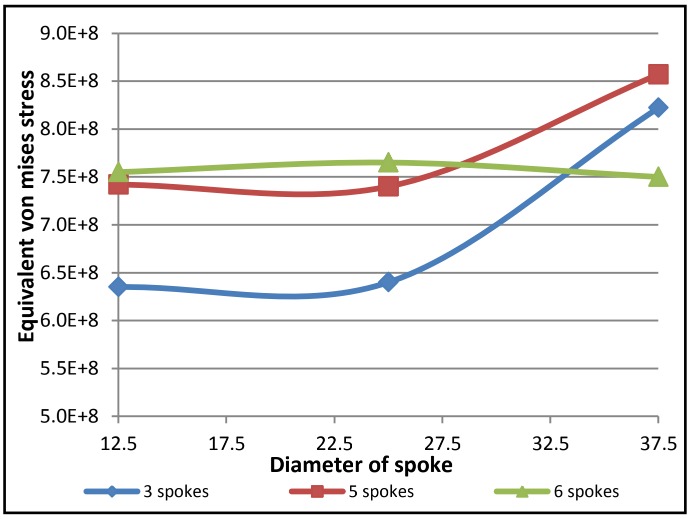


Figure 6: Effect of Diameter of Spoke with Varying Number of Spoke

Diameter of spoke has a negligible effect on the stress induced while in the case of 37.5mm diametric spoke flywheel, the stress seems to drastically increase. This may be explained as the overlapping of spokes at the hub. While this phenomenon exists, the curve for 6 number of spoke flywheel seems to differ. The drastic increase in stress value for 37.5mm diametric spoke flywheel was minimized by the balancing nature of the flywheel. This shows that the extra stress induced because of overlapping of spokes can be overcome by making the flywheel balanced.

## IV. Conclusion

The following conclusions were obtained from the experiment.

- The stress value gets affected by the speed of rotation of the flywheel drastically. As the speed increases the stress value also increases.
- The relation between the number of spokes and the stress induced on a flywheel largely depends upon whether the flywheel is balanced or not. Balanced number of flywheel number of spokes shows lower stress induced.
- The material effect over stress values is low considering the density of the material. Other properties may largely promote high stress induction on the flywheel.
- There is a possible presence of a critical speed value below which the effect of density of material gets negligibly low.
- Increase in diameter of spoke tends to promote more stress induction but this effect gets nullified when the number of spokes makes the flywheel balanced.
- Outer diameter of flywheel and speed of rotation together facilitates the drastic increase in stress values. Flywheel with higher outer diameter and higher speed has more stress induced. Keeping any one of them ensures more protection against failures.

## V. Acknowledgement

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