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# A Review research paper on: Geometry Modification of Flywheels and its Effect on Energy Storage

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**ABSTRACT:** Flywheel serves as the kinetic energy storage and retrieval device with ability to deliver high power output at high rotational speed. As being the emerging energy storage technologies available today, it is in various stages of development for spacecrafts, automobile powertrain, etc. Research efforts are being made for improving the energy storage capacity of flywheel which mostly depends upon mainly three factors- material strength, rotational speed and geometry (cross-sectional area). Material strength helps in determining the Kinetic energy level that could be produced safely coupled with rotor speed, while the geometry helps us in calculating energy density. In this research paper, study mainly focuses on the exploring effects of flywheel geometry on its energy storage/deliver capability per unit mass, defined as Specific Energy. Finite element 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.

## I. INTRODUCTION

Flywheel is a rechargeable battery which stores energy in a rotating mass. It is used to absorb electric energy from a source, store it as kinetic energy of rotation, and then deliver it to a load in the form of electrical energy that meets the load needs. Technology programs are recently focused on storing energy more efficiently using flywheel than rechargeable chemical batteries while also providing some control advantages. Since the development of high-strength materials and magnetic bearings, flywheel has gained more attention. Exploration of high-strength materials allows designers to reach high operating speeds, yielding more kinetic energy. Using magnetic bearings make it possible to reach high operating speeds providing cleaner, faster and more efficient bearing equipment at extreme temperatures. Recently designed flywheels could offer orders of magnitude increases in both performance and service life, giving advantage in the use of spacecraft, launch vehicles, aircraft power systems and power supplies. A typical flywheel system consists of, a motor/generator, and controlled electronics for connection to a larger electric power system as shown in Fig.1.

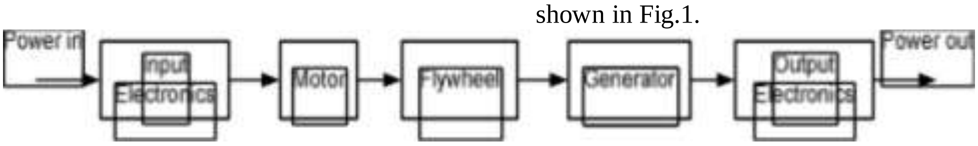


**Figure.1** Basic components of flywheel wheel energy storage system

In the development of the flywheel, current researches have focused on increasing the performance while meeting the safety considerations, i.e., material, housing and bearing failures. Investigation of energy storage and failure considerations starts with the calculation of kinetic energy. Since the input and output are typically separated in a timely manner, many approaches combine the motor and generator into a single machine, and place the input and output electronics into a single module, to reduce weight and cost.

Modern high-speed flywheels differ from their forebears in being lighter and spinning much faster. Since the energy stored in a flywheel increases only linearly with its moment of inertia but goes up as the square of its rotational speed, the tradeoff is a good one. But it does raise two issues: flywheel strength and losses caused due to air friction. To keep from flying apart, modern flywheels are complex structures based on extremely strong materials like carbon fibers.

This has given us potential advantages that flywheel energy storage system has over chemical battery.

1. No overcharge and over-discharge. The performance of the flywheel battery is not influenced when it is discharged heavily, and the overcharge can be avoided with assistance of power electronic devices.
2. Higher energy storage density. The flywheel battery whose speed exceeds 60000r/min can generate more than 20Whrs/lbm energy. But the energy storage density of the nickel- hydrogen battery is only 5-6 Whrs/lb.
3. No capacity decreases over life. The life of the flywheel battery depends mainly on the life of power electronic devices and can reach about 20 years.
4. Since mechanical energy is proportional to square of the flywheel speed; the stored energy level indicator is a simple speed measurement. In addition, the charge of the flywheel battery can be stored faster than large chemical battery

## II. PROBLEM STATEMENT

The paper deals with the finding of most efficient design and geometry for flywheel in energystorage while considering the stresses, elastic strains and deformations along various frequency modes induced in all flywheels due to different parameters like rotational velocity with fixed center of rotation of flywheel, force along with the axis of rotation of the flywheel, material of flywheel, and outer diameter of flywheel. The study performs various evaluative experiments through calculative and computative analysis of the figures like rectangle, eclipse, diamond, etc., while also including the material science behind the whole analysis which equally donates to the efficiency of the flywheel energy storage system. The analysis of the flywheel considering all the factors, was done under Ansys workbench making modelling and analysis of complex structure easier.

## III. OBJECTIVE

Design and Analysis for obtaining highest specific energy density of Flywheel in Flywheel energy storage system using static structural force analysis, Static structural Rotational Velocity analysis and Modal analysis approach.

1. Maximum rotational velocity.
2. Optimum Flywheel design.
3. Obtaining maximum energy density.
4. Different radial stresses and hoop stresses through software analysis.

## IV. FUTURE SCOPE

1. Uninterruptible Power Supply (UPS)
2. Distributed Energy Generation
3. Aircraft power Systems
4. Spacecraft launches
5. Automobile powertrain
6. Home based energy storage system

## V. LITERATURE REVIEW: -

SudiptaSaha, Abhik Bose, G. Sai Tejesh, S.P. Srikanth (2013) 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, this study solely focuses on exploring the effects of flywheel geometry on its energy storage/deliver capability per unit mass, further defined as Specific Energy. 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. This paper specifically studies the most common five different geometries (i.e., straight/concave or convex shaped2D).

M.lavakumar, R. prasannasrinivas (2013) This paper involves the design and analysis of flywheel to minimize the fluctuation in torque, the flywheel is subjected to a constant rpm. The objective of present work is to design and optimize the flywheel for the best material. The flywheel is modeled with solid 95 (3-D element), the modeled analyses using free mesh. The FEM mesh is refined subject to convergence criteria. Preconditioned conjugate gradient method is adopted during the solution and for deflections. Von-misses stress for both materials (mild steel and mild steel alloy) are compared, the best material is suggested for manufacture of flywheel.

Choudhary (2012) By using optimization technique various parameter like material, cost for flywheel can be optimized and by applying an approach for modification of various working parameter like efficiency, output, energy storing capacity, we can compare the result with existing flywheel result. Based on the dynamic functions, specifications of the system the main features of the flywheel are initially determined; the detail design

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study of flywheel is done. Then FEA ANALYSIS for more and more designs in diverse areas of engineering is being analyzed through the software. FEA provides the ability to analyze the stresses and displacements of a part or assembly, as well as the reaction forces other elements are to impose. This thesis guides the path through flywheel design, and analysis the material selection process. The FEA model is described to achieve a better understanding of the mesh type, mesh size and boundary conditions applied to complete an effective FEA model. At last the design objective could be simply to minimize cost of flywheel by reducing material.

S. M. Dhengle, Dr. D. V. Bhope, S. D. Khamankar (2012) there is many causes of flywheel failure. Among them, maximum tensile and bending stresses induced in the rim and tensile stresses induced in the arm under the action of centrifugal forces are the main causes of flywheel failure. Hence in this work evaluation of stresses in the rim and arm are studied using finite element method and results are validated by analytical calculations. The models of flywheel having four, six and eight no. arms are developed for FE analysis. The FE analysis is carried out for different cases of loading applied on the flywheel and the maximum Von mises stresses and deflection in the rim are determined. From this analysis it is found that Maximum stresses induced are in the rim and arm junction. Due to tangential forces, maximum bending stresses occurs near the hub end of the arm. It is also observed that for low angular velocity the effect gravity on stresses and deflection of rim and arm is predominant.

Mofid Mahdi (2011) the consumption of energy is increasing drastically. The available resources of energy are limited therefore; the search of new sources is a vital issue. This has to be done with efficient energy consumption and saving. A flywheel may provide a mechanical storage of kinetic energy. A capable flywheel must have a very high rotational speed which may lead to a high stress. The stress state relies on the flywheel material properties, geometry and rotational speed. On the other hand, the stored kinetic energy relies on the mass moment of inertia and rotational speed. This paper considered three solid flywheel disk profiles that are constructed using functions of cubic splines. Using FEM, the cubic splines parameters are analyzed systematically to seek a maximum stored kinetic energy per unite mass. Subjected to maximum permissible effective stress, favorable flywheel disk profiles were achieved. All FEM computations were carried out using ANSYS.

## VI. METHODOLOGY

Flywheel design and analysis requires a number of steps to be followed sequentially to reach the objectives defined. This includes all the necessary stages of flywheel design and its dynamic study using finite element method. The methodology to be followed to design flywheel using different geometries as well as different material is listed below:

1. Selection and dimensions of Flywheel: The first step to be taken is to get the dimensions of the existing flywheel.
2. 3D Modelling of Flywheel Using CATIA: After getting the dimensions of the flywheel, a 3D Model of these manifolds was created on CATIA workbench.
3. Theoretical Calculations: On the basis of the thorough research done during the literature survey, the boundary conditions on the system are defined. Accordingly, theoretical calculations to find energy density of the solid flywheel were carried out.
4. Simulation Using FEA: Simulation of the design was done for the geometry shortlisted using Finite Element Analysis software ANSYS WORKBENCH.
5. Results Calibration and Conclusion: The simulation results are compared with theoretical values on the basis of various factors and the best design was finalized based on results.

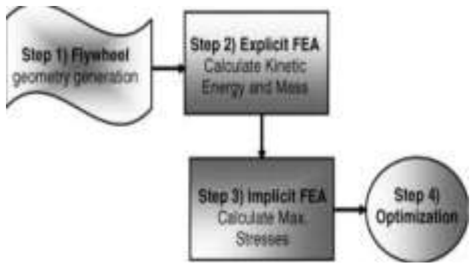


**Figure.2** Finite element procedure flowchart

**Design Procedure –**

Nomenclature

c1, c2: Constants of integration
E: Energy
EY: Elastic modulus
em: Energy per unit mass, specific energy
ev: Energy per unit volume, specific energy
h: Constant of disk profile
J: Polar moment of inertia
K: Shape factor
m: Mass m1,
m2: Constants
r: Radius of disk
ra : Inner radius of disk from axis of rotation
rb: Outer radius of disk from axis of rotation

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s: Exponential constant of disk profile
t(r): Thickness at radius, r
ta: Thickness at ra
tb: Thickness at rb
V: Volume Greek Symbols
r: Radial stress
*σ r: ANSYS generated radial stress

tθ: Hoop stress
*σθ : ANSYS generated hoop stress
ω@ 1 K σ = : Hoop stress at ω@ K = 1
ω: Rotational velocity ω@ K = 1: Rotational velocity at K=1
ωmax: Maximum rotational velocity for a specific shape and material

This paper analyzes flywheel profiles based on the shapes shown in Figs. 3 and 4. Figure 3 was chosen based on a common flywheel shape: the thick rimmed flywheel. The profile in Fig. 3 has most of its mass concentrated on the outer radius. Figure 4 is essentially the reversed or flipped cross sectional profile of Fig. 3.

Equation (1) is the mathematical representation of the thickness profile for both Figs. 3 and 4 (Ugural and Fenster, 2011). In developing a set of stress equations to solve for flywheels with the shapes given in Figs. 3 and 4, Ugural and Fenster (2011) used the shape shown in Fig. 3 as a template to set up the stress equations. Equation (1) can be manipulated and used to describe the profile in Fig. 3 in order to be used with the same stress equations. The value of 's' becomes positive with Profile #1 and negative with Profile #2. Equations (2) and (3), which are dependent on the shape of the profile, are derived from Ugural and Fenster (2011):

$$t(r) = h \cdot r^{-s} \tag{1}$$

Where

$$s = \frac{\ln \frac{t_b}{t_a}}{\ln \frac{r_b}{r_a}} \tag{2}$$

$$h = \frac{t_b}{r_b^{-s}} \tag{3}$$

Equations (2) and (3) are mathematical definitions of the constants identified in Equation (1). Tables 1 and 2 list the different combinations of ta , tb, ra and rb used for this analysis. Although all of the numbers look arbitrary, the numbers were picked based on different ratios of ta /tb, rb/ta and rb/ta. Two ta /tb ratios, 0.10 and 0.83 were selected because they fall between 0 and 1. Zero being an infinitely small ta , to 1 being a flat disk profile. Different values of rb/tb were chosen due to the uncertainty of plane stress being applicable to certain profiles. Ratios of 8 to 1, 6 to 1, 4 to 1 and 2 to 1 were chosen to determine which range of ratios would be applicable to the set of stress equations in the next section. ra = 0.05 m and rb = 0.5 m are the inner and outer radius, respectively, for all of the evaluated sections. The values for h and s were solved based on the combinations of ta , tb, ra and rb. Setting up an array of profiles in this manner will provide a quasi-parametric analysis that can be used for a variety of different thicknesses and radii.

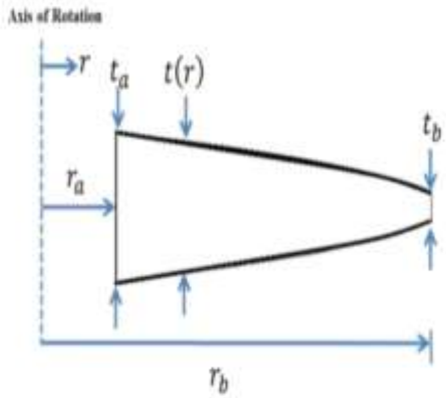


**Figure.3:** Profile number #1

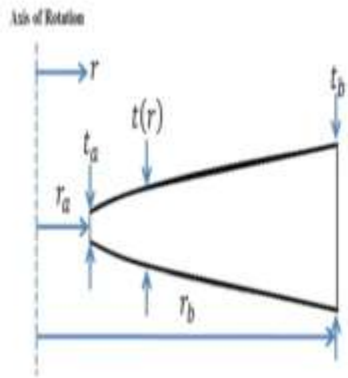


**Figure.4**: Profile number #2

Hoop and Radial Stress Equations:

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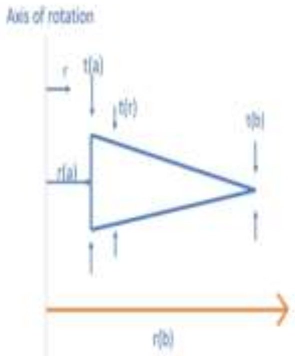


**Figure.5:** Profile number #3

$$\frac{d}{dr}\left[t(r)r\sigma_r\right]-t(r)\sigma_\theta+t(r)\rho\omega^2r^2=0 \qquad (4)$$

Equation (4) is the governing equation for the stress distribution in a disk of variable thickness (Ugural and Fenster, 2011). The final solution for radial and hoop stress are expressed in Equations (5) and (6). Equation (6), hoop stress, is the highest stress generated in a spinning disk; therefore it is the stress that will ultimately determine how fast the flywheel can operate before failure.

**Table 1.** Parameters for flywheel profile #1

| CASE | tam | tbm | ta/tb | rb/ta | s | h |
|---|---|---|---|---|---|---|
| 1. | 0.06250 | 0.051875 | 1.2 | 8 | 0.06 | 2.50 |
| 2. | 0.06250 | 0.006250 | 10.0 | 8 | 0.77 | 2.50 |
| 3. | 0.08325 | 0.069098 | 1.2 | 6 | 0.06 | 3.33 |
| 4. | 0.08325 | 0.008325 | 10.0 | 6 | 0.77 | 3.33 |
| 5. | 0.12500 | 0.103750 | 1.2 | 4 | 0.06 | 5.0 |
| 6. | 0.12500 | 0.012500 | 10.0 | 4 | 0.77 | 5.0 |

DIFFERENT CASES FOR PROFILE1 –
Exponential disk profile,Using equation 2 and 3

$$\sigma_r=\frac{c_1}{h}r^{m_1+s-1}+\frac{c_2}{h}r^{m_2+s-1}-\frac{3+\nu}{8-(3+\nu)s}\rho\omega^2r^2 \qquad (5)$$

$$\sigma_\theta=\frac{c_1m_1}{h}r^{m_1+s-1}+\frac{c_2m_2}{h}r^{m_2+s-1}-\frac{1+3\nu}{8-(3+\nu)s}\rho\omega^2r^2 \qquad (6)$$

Where:

$$m_1,m_2=-\frac{s}{2}\pm\sqrt{\left(\frac{s}{2}\right)^2+(1+\nu s)} \qquad (7)$$

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S1 = 0.06
S2 = = 0.77
S3 = = 0.06
S4 = ln(0.008325/0.08325)/ln(0.5/0.05) = 0.77
S5 = ln(0.103750/0.12500)/ln(0.5/0.05) = 0.06
S6 = ln(0.012500/0.12500)/ln(0.5/0.05) = 0.77
Disk profile,

H1 = = 2.50
H2 = = 2.50
H3 = 3.33
H4 = 0.008325/0.5^-0.77 = 3.33
H5 = 0.103750/0.05^-0.06 = 5.0
H6 = 0.012500/0.05^-0.77 = 5.0

**Table 2**. Parameters for flywheel profile #2

| CASE | tam | tbm | ta/tb | rb/ta | s | h |
|---|---|---|---|---|---|---|
| 1. | 0.051875 | 0.06250 | 0.83 | 8 | -0.06 | 2.08 |
| 2. | 0.006250 | 0.06250 | 0.10 | 8 | -0.77 | 0.25 |
| 3. | 0.069098 | 0.08325 | 0.83 | 6 | -0.06 | 2.76 |
| 4. | 0.008250 | 0.08325 | 0.10 | 6 | -0.77 | 0.33 |
| 5. | 0.103750 | 0.12500 | 0.83 | 4 | -0.06 | 4.15 |
| 6. | 0.012500 | 0.12500 | 0.10 | 4 | -0.77 | 0.50 |

Similar calculations as earlier.
The s(constant) is negative because it is the exact opposite shape of the earlier profile we experimented on.

DIFFERENT CASES FOR PROFILE2 -
Exponential disk profile,
S1 = ln(0.06250/0.051875)/ln(0.5/0.05) = -0.06
S2 = ln(0.06250/0.006250)/ln(0.5/0.05) = -0.77
S3 = ln(0.08325/0.069098)/ln(0.5/0.05) = -0.06
S4 = ln(0.08325/0.008250)/ln(0.5/0.05) = -0.77
S5 = ln(0.12500/0.103750)/ln(0.5/0.05) = -0.06
S6 = ln(0.12500/0.012500)/ln(0.5/0.05) = -0.77

Disk profile,
H1 = 0.06250/0.5^-(-0.06) = 2.08
H2 = 0.06250/0.5^-(-0.77) = 0.25
H3 = 0.08325/0.5^-(-0.06) = 2.76
H4 = 0.08325/0.5^-(-0.77) = 0.33
H5 = 0.12500/0.5^-(-0.06) = 4.15
H6 = 0.12500/0.5^-(-0.77) = 0.50

**Table 3**. Parameters for flywheel profile #3:

| CASE | tam | tbm | ta/tb | rb/ta | s | h |
|---|---|---|---|---|---|---|
| 1. | 0.06250 | 0.006250 | 10.0 | 8 | 0.77 | 2.50 |
| 2. | 0.04150 | 0.004150 | 10.0 | 10 | 0.77 | 2.10 |
| 3. | 0.08350 | 0.008325 | 10.0 | 6 | 0.77 | 3.33 |

CALCULATIONS:
S1 = ln(0.006250/0.06250)/ln(0.5/0.05) = 0.77
S2 = ln(0.004150/0.04150)/ln(0.5/0.05) = 0.77
S3 = ln(0.008325/0.08350)/ln(0.5/0.05) = 0.77
Disk profile,
H1 = 0.006250/0.5^0.77 = 2.50
H2 = 0.004150/0.5^0.77 = 2.10
H3 = 0.008325/0.5^0.77 = 3.33

Energy and Shape Factor Equations Equation

Equation (10) is derived from both the definition of polar moment of inertia and the cylindrical shell method for calculating volume.
Shape factor, K, is only dependent on the polar moment of inertia. The shape factor, usually, ranges between 0.3 and 1.0.

The shape factor can be associated with the efficiency of the system due to the fact that when

100% specific energy from the material can be converted to specific energy from the shape and mass, K is equal to 1. In order to find K for each profile case, the equation to determine specific energy, equation (11) or (12) I used.

$$E = \frac{1}{2} J\omega^2 \tag{8}$$

Where:

$$J = \int r^2 dm \tag{9}$$

Or:

$$J = \int_{r_i}^{r_o} 2\pi\rho r^3 t(r) dr \tag{10}$$

Where:

$$dm = \rho dV \text{ and } dV = 2\pi r t(r) dr$$

$$e_V = \frac{E}{V} = K\sigma_{ult} \tag{11}$$

Or:

$$e_m = \frac{E}{m} = K\frac{\sigma_{ult}}{\rho} \tag{12}$$

To solve for the maximum operating speed, ωmax, for each disk shape and material, Equations (13) through (16) are used.
For
K = 1
This value is used as an input to Equations (5) and (6) to solve for σθ which is the dominating stress in determining the ultimate speed at which the flywheel can operate. To solve for actual value of K:
K = σult / σk=1
To solve for the true maximum operating speed of the flywheel, ωmax, Equation (16) is used:
W = (K^1/2)*wk=1

## VII. RESULTS

All of the ANSYS results shown below were analyzed using 5000 rpm and structural steel ( v= 0.3, EY = 200 GPa, rho(ṗ) = 8027.20 kg/m3 ) as a basis to compare with the analytical results from Equations (5) and (6). A default constraint, placed on the inner face of the central hole, was used instead of a fixed or frictionless support. When ANSYS detects a rigid body displacement during the analysis, weak springs placed where it would prevent a rigid body movement due to the applied force. In Tables 4 and 5, results from ANSYS are compared with results from Equations (5) and (6). All results use structural steel rotated at 5000 rpm. Although the results surpass the ultimate strength of structural steel, 460.01 MPa, these values are only meant to calculate the percent difference between ANSYS values and values obtained from Equations (5) and (6). Negative percent differences mean ANSYS values were more conservative and positive values mean

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$$E/m = \sigma_{ult} / \rho$$

$$\frac{E}{m} = \frac{\sigma_{ult}}{\rho} \quad (13)$$

Solving for ω:

$$\omega_{@K=1} = \sqrt{\frac{2\sigma_{ult}}{\rho J}} \quad (14)$$

Equations (5) and/or (6) are more conservative. Stress values with an asterisk are values obtained from ANSYS.

**Factor of Safety** for structural steel flywheel:
Ultimate strength (Sut) = 460.01 MPa

Max. Tensile stress inside the flywheel = Max. Radial stress = 203.96 MPa
FOS = 460.01/203.96 = 2.25539
Therefore, design FOS for structural steel flywheel in flywheel energy storage system 2 → 3.

**Table 4**. Percent difference between analytical and ANSYS results for profile #1

| CASE | tam | tbm | ta/tb | σr MPa | σr* MPa | % difference | σθ MPa | *σθ MPa | % difference |
|---|---|---|---|---|---|---|---|---|---|
| 1. | 0.0620 | 0.05185 | 1.2 | 203.96 | 198.77 | 2.55 % | 429.66 | 435.60 | -1.38 |
| 2. | 0.0620 | 0.006250 | 10.0 | 149.60 | 121.28 | 18.93 | 149.53 | 257.89 | -72.46 |
| 3. | 0.08325 | 0.069098 | 1.2 | 203.96 | 201.19 | 1.36 | 149.53 | 425.95 | 0.86 |
| 4. | 0.0832 | 0.008325 | 10.0 | 149.60 | 120.83 | 19.23 | 429.66 | 252.33 | -68.74 |
| 5. | 0.1250 | 0.103750 | 1.2 | 203.96 | 221.65 | 1.28 | 510.84 | 544.69 | 2.63 |
| 6. | 0.1250 | 0.012500 | 10.0 | 149.60 | 404.09 | 19.10 | 1226.47 | 251.13 | -67.95 |

θ

**Table 5.** Energy and shape factor for profiles #1 -structural steel:

| CASE | tam | tbm | ta/tb | ω (k=1) | Mass (kG) | σult | J, kg.m2 | E, N.m |
|---|---|---|---|---|---|---|---|---|
| 1. | 0.06250 | 0.051875 | 1.2 | 9091.92 | 353.26 | 460.01 | 44.95 | 13,193,543.89 |
| 2. | 0.06250 | 0.006250 | 10.0 | 10217.65 | 65.50 | 460.01 | 6.60 | 1,613,534.13 |
| 3. | 0.08325 | 0.069098 | 1.2 | 9091.92 | 470.54 | 460.01 | 59.87 | 8,786,900.23 |
| 4. | 0.08325 | 0.008325 | 10.0 | 10217.64 | 470.54 | 460.01 | 8.79 | 8,786,900.23 |
| 5. | 0.12500 | 0.103750 | 1.2 | 9091.92 | 706.52 | 460.01 | 89.90 | 13,193,543.89 |
| 6. | 0.12500 | 0.012500 | 10.0 | 10217.65 | 131.00 | 460.01 | 13.20 | 3,314,054.15 |

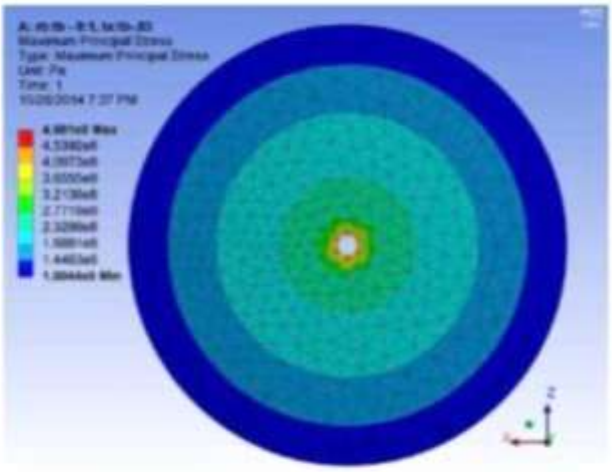
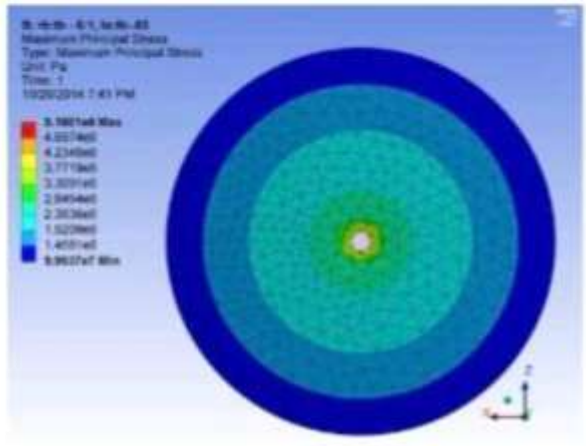


**Fig. 7:** Case #1-hoop stress



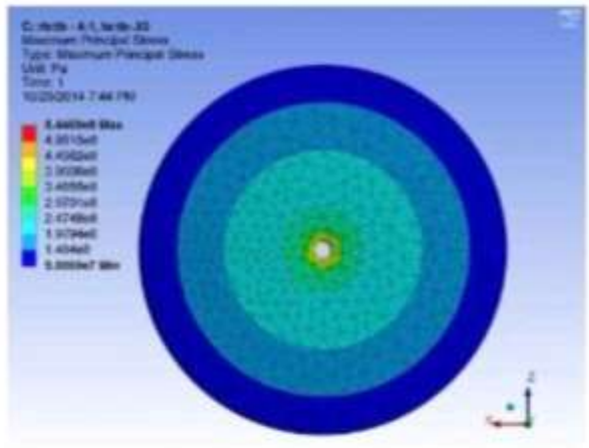


**Fig. 8:** Case #2-hoop stress
**Fig. 9:** Case #3-hoop stress

## VIII. CONCLUSION

The results of this research work showed that the flywheel with diamond-shaped cross-sectional geometry stores maximum kinetic energy per unit mass compared to all other combination of geometry. It is observed that the mass goes on decreasing from present geometry to modified geometries, thus increasing flywheels maximum rotational speed, and hence maximum kinetic energy to corresponding rotational speed. This new design of flywheel saves weight by 88% as compared to existing flywheel design which is significant. In the design of flywheel, there is still room for research, especially when the performance is primary objective. The operating conditions impose quite narrow margin of energy storing limitations, even slim amount of improvements may contribute in overall weight reduction. Till time, the use of flywheel was restricted to low speed application due to inability of existing flywheel material to withstand high rotational speed. This study clearly depicts the importance of flywheel geometry design selection and its contribution in the energy storage performance. Problem and objective are formulated in terms of kinetic energy per unit mass and its maximization through the selection of best geometry among the three predetermined cross sections. With the use of composite material, it is possible to develop a flywheel which can give maximum kinetic energy at very high rotational speeds

## REFERENCES

[1]. Akshay P. Punde, G.K.Gattani , Analysis of Flywheel, International Journal of Modern Engineering Research (IJMER) , Vol.3, Issue.2, March-April. 2013 pp-1097-1099

[2]. M.lavakumar, R.prasannasrinivas, Design and analysis of light weight motor vehicle flywheel, International Journal of Computer Trends and Technology (IJCTT) – volume 4 Issue -7July 2013

International Journal of Advances in Engineering and Management (IJAEM)
Volume 2, Issue 10, pp: 407-417 www.ijaem.net ISSN: 2395-5252

[3]. Bjorn Bolund, Hans Bernhoff, Mats Leijon, Flywheel energy and power storage systems,international journal of Renewable and Sustainable Energy Reviews 11 (2007) 235–258
[4]. Sushama G Bawane, A P Ninawe and S K Choudhary, Analysis and optimization of flywheel, International Journal of mechanical engineering and robotics Vol. 1, No. 2, July 2012
[5]. S. M. Dhengle, Dr. D. V. Bhope, S. D. Khamankar ,sInvestigation of stresses in arm type rotating flywheel, International Journal of Engineering Science and Technology (IJEST), Vol. 4 No.02 February 2012.
[6]. D.Y. Shahare, S. M. Choudhary, Design Optimization of Flywheel of Thresher usingFEM, Advanced Materials Manufacturing & Characterization Vol3 Issue 1(2013)
[7]. SudiptaSaha, Abhik Bose, G. Sai Tejesh, S.P. Srikanth, computer aided design & analysis on flywheel for greater efficiency, International Journal of Advanced Engineering Research and Studies, IJAERS/Vol. I/ Issue II/January-March, 2012/299-301
[8]. Arlan, J.G.,1998. Flywheel technilogy: Past present and 21st century projections. IEEE AE Syst. Magazine,13:13-16 .DOI: 10.1109/62.707557
[9]. Genta. G., 1985. Kinetic energy storage: Theory and practice of advance flywheel system.1st edition, Buttersworth, London, ISBN-10, Syst. Magzine,1:13-16. DOI: 10.11/09/62.707577
[10]. Kouhou .T, P.Brul, A. Jamil,El Rafiki and Y.zeraouli, 2014. Energy storage and challenges. Solar Energy matter. Solar cells, 120: 59-80. DOI:10.1016/j.solmat2013.08.15
[11]. Ashley. S. Flwheel put a new spin on Eletric vehicles. Mech Engg. 1993:44-51
[12]. Christopher DA, Bench R. Flwheel technology development program for erospace applications. IEEE AES Syst. Magzine 1998; 13(6)9:14
[13]. Pena-Alzola, R.R Sebastian, J.Quesda and A columnar, 2011. Review of flywheel based energy storage system. Proceeding on international conference on power engineering. May11-13, IEEE explore press, Malaga, pp:1-6. DOI:10.11/09/Power Eng.2011.6036455
[14]. ANSYS and ANSYS/LS-DYNA Inc. Available from <http://www.ansys.com>