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Comparative Study of Different Geometry Flywheelby Analytical and Ansys

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Abstract : *Flywheel stores the energy when supply is greater than the requirement and release energy when requirement is greater than supply. In Present work initially we design different geometry of flywheel like solid, rim, section cut and six spoke flywheel keeping constant mass.Then we calculate various functional value of flywheel like kinetic energy, specific energy stress etc. for respective flywheel. From this comparative study we conclude six spoke flywheel store more kinetic energy then other flywheel. Lastly with the help of ANSYS we calculate Von-Mises Stress & total deformation of flywheel. From ANSYS we conclude all results are valid & permissible range.*
Keywords : *Flywheel Design, Stress,Kinetic Energy, Ansys.*

I. Introduction

Flywheel is a rotating mechanical element which is store energy of rotational form[1] Flywheels used to achieve smooth operation of machine [2]. Flywheel stores the energy when supply is greater than the requirement and releases energy when requirement is greater than supply[3]. The stored kinetic energy relies on the mass moment of inertia and rotational speed [3]. The performance of a flywheel can be attributed to three factors, i.e., material strength, geometry (cross- section) and rotational speed [4]. Flywheels have become the subject of extensive research as power storage devices for uses in vehicles [4].Flywheel energy storage systems are considered to be an attractive alternative to electrochemical batteries due to higher stored energy density, higher life term, and deterministic state of charge and ecologically clean nature [4]. Flywheel is basically a rechargeable battery [4]. Present investigation deals with kinetic energy Storing capability of different geometry of flywheel, functional value and stress produced in respective flywheel with the help of analytical and ANSYS.

II. Design Of Different Geometry Flywheel

2.1. Design Of Solid Disk Flywheel

Various parameters of solid disk flywheel are given as follows.
Material used for solid disk flywheel Gray Cast Iron
Outer diameter of disk ($D_{o\ disk}$) = 500 mm   Inner diameter of disk ($D_{i\ disk}$) = 130 mm
Outer diameter of hub ($D_{o\ hub}$) = 130 mm   Inner diameter of hub ($D_{i\ hub}$) = 50mm
Width of hub (W_{hub}) =80mm   Width of disk (W_{disk}) =38mm
Density (ρ) = 7510 kg/m^3 [5]   Poisons ratio (υ) = 0.23[5]
Moment of Inertia (M.I.) of solid disk flywheel = 1.7594 kg-m^2[7]N = 750RPM [6]
Mass of solid disk flywheel = 60Kg [7]

Table: 1 Calculation of various Functional values of solid disk flywheel

Functional values	Formula	Calculation	Value
Angular velocity (ω)	2×π×N/ 60 [6]	2×π×750 / 60	78.53 rad/sec
Surface speed (v_s)	π×D×N / 60 [6]	π×0.500×750/ 60	19.63 m/s
Energy stored in flywheel (E_k)	½ × I_{total}× ω^2[6]	½ × 1.7594 ×78.53^2	5.402 KJ
Specific energy(E_k,m)	E_k/ M_{total}[6]	5.402/ 60	0.090 kJ/kg
Energy Density (E_k,v)	(E_k/ M_{total})× ρ[6]	0.090×7510	679.029 KJ/m^3

Table:2 Calculation for Stress in solid disk flywheel

Stress	Formula & Calculation	Value(Mpa)
Tangential Stress(σ_t)	$\rho\omega^2\left(\frac{3+\upsilon}{8}\right)(R_{ihub}^2+R_{odisk}^2-\frac{1+3\upsilon}{3+\upsilon}\times R^2 mean)$[6] $7510\times(78.53)^2\left(\frac{3+0.23}{8}\right)(0.025^2+0.250^2-\frac{1+3\times0.23}{3+0.23}\times0.1375^2)$	0.995
Radial Stress(σ_r)	$\rho\omega^2\left(\frac{3+\upsilon}{8}\right)(R_{ihub}^2+R_{odisk}^2-\frac{Rihub2\times Rodisk\ 2}{R2}-R^2)$[6] $7510\times(78.53)^2\left(\frac{3+0.23}{8}\right)(0.025^2+0.250^2-0.000625x0.625/0.1375^2-.1375^2)$	0.788
Resultant Stress	$\sqrt{\sigma_t^2+\sigma_r^2} = \sqrt{0.995^2+0.788^2}$[6]	1.296

2.2.Design Of Rim Flywheel

Various parameters of optimal solid disk flywheel are given as follows.
Material used for solid disk flywheel Gray Cast Iron
Outer diameter of rim ($D_{o\ rim)}$ = 500 mm Inner diameter of rim ($D_{i\ rim)}$ = 440 mm
Outer diameter of hub ($D_{o\ hub)}$ = 120 mm Inner diameter of hub ($D_{i\ hub}$) = 50mm
Width of plate (W_{plate}) =22mm Thickness of rim ($T_{rim)}$ =30mm
Density (ρ) = 7510 kg/m^3[5]Poisons ratio (υ) = 0.23[5]
Moment of Inertia(M.I.) = 2.283 kg-m^2[7]N = 750RPM[6]
Mass of rim flywheel = 60Kg[7]

Table:3Calculation of various Functional values of rim flywheel

Functional values	Formula	Calculation	Value
Angular velocity (ω)	2×π×N/ 60[6]	2×π×750 / 60	78.53 rad/sec
Surface speed (v_s)	π×D×N / 60[6]	π×0.500×750/ 60	19.63 m/s
Energy stored in flywheel (E_k)	½ × I_{total}× ω^2[6]	½ × 2.283 ×78.53^2	7.039 KJ
Specific energy(E_k,m)	E_k/ M_{total}[6]	7.039/ 60	0.1173 kJ/kg
Energy Density (E_k,v)	(E_k/ M_{total})× ρ[6]	0.1173×7510	880.92 KJ/m^3

Table: 4 Calculation for Stress in rim flywheel

Stress	Formula & Calculation	Value(Mpa)
Tangential Stress(σ_t)	$\rho\omega^2\left(\frac{3+\upsilon}{8}\right)$ (R_{ihub}^2+R_{odisk}^2- $\frac{1+3\upsilon}{3+\upsilon}$×$R^2$mean)[6] 7510×$(78.53)^2\left(\frac{3+0.23}{8}\right)$ (0.22o^2+0.250^2- $\frac{1+3\times0.23}{3+0.23}$×0.235^2)	1.533
Radial Stress(σ_r)	$\rho\omega^2\left(\frac{3+\upsilon}{8}\right)$ (R_{ihub}^2+R_{odisk}^2- $\frac{\text{Rihub 2×Rodisk 2}}{\text{R2}} - R^2$)[6] 7510×$(78.53)^2\left(\frac{3+0.23}{8}\right)$ (0.220^2+0.250^2- $\frac{0.0484\times0.0625}{0.235\text{x}0.235}$×0.235^2)	0.0168
Resultant Stress	$\sigma_t^2{}_+\sigma_r^2$ = √1.533^2+0.168^2[6]	1.533

2.3.Design Of Section Cut Flywheel

Various parameters of optimal solid disk flywheel are given as follows.
Material used for solid disk flywheel Gray Cast Iron
Outer diameter of rim ($D_{o\ rim)}$ = 500 mm Inner diameter of rim ($D_{i\ rim)}$ = 440 mm
Outer diameter of hub ($D_{o\ hub)}$ = 120 mm Inner diameter of hub ($D_{i\ hub}$) = 50mm
Width of hub (W_{hub}) =85mm Width of rim ($W_{rim)}$ =85mm
Width of plate (W_{plate}) =24mm Thickness of rim ($T_{rim)}$ =30mm
Density (ρ) = 7510 kg/m^3[5]Poisons ratio (υ) = 0.23[5]
N = 750RPM[6]
Mass of optimized solid disk flywheel = 60Kg [7]
Moment of Inertia(M.I.) of optimized solid disk flywheel = 2.337 kg-m^2[7]

Table:5Calculation of various Functional values of section cut flywheel

Functional values	Formula	Calculation	Value
Angular velocity (ω)	2×π×N/ 60 [6]	2×π×750 / 60	78.53 rad/sec
Surface speed (v_s)	π×D×N / 60 [6]	π×0.500×750/ 60	19.63 m/s
Energy stored in flywheel (E_k)	½ × I_{total}× ω^2[6]	½ × 2.337 ×78.53^2	7.206 KJ
Specific energy(E_k,m)	E_k/ M_{total}[6]	7.206/ 60	0.1201 kJ/kg
Energy Density (E_k,v)	(E_k/ M_{total})× ρ[6]	0.1201×7510	901.951 KJ/m^3

Table:6Calculation for Stress in section cut flywheel

Stress	Formula & Calculation	Value(Mpa)
Tangential Stress(σ_t)	ρVs^2 7510×$(19.63)^2$	2.893
Bending Stress(σ_b)	$\Pi^2 Vs^2\ D_{o\ rim}\rho/i^2 T_{rim}$ Π^2x19.63^2x0.500x7510/4^2x0.030	29.75
Total Stress	¾ σ_{t+}¼σ_b ¾ x 2.893$_+$¼ x 29.75	9.60

2.4.Design Of Six Spoke Flywheel

Various parameters of optimal solid disk flywheel are given as follows.
Material used for solid disk flywheel Gray Cast Iron
Outer diameter of rim ($D_{o\ rim}$) = 500 mm Inner diameter of rim ($D_{i\ rim}$) = 410 mm
Outer diameter of hub ($D_{o\ hub}$) = 130 mm Inner diameter of hub ($D_{i\ hub}$) = 50mm
Width of hub (W_{hub}) =90mm Width of rim (W_{rim}) =90 mm
Density (ρ) = 7510 kg/m^3[5]Poisons ratio (υ) = 0.23 [5]
Thickness of rim (T_{rim}) =45mm
N = 750RPM [6]
Mass of optimized solid disk flywheel = 60Kg [7]
Moment of Inertia(M.I.) of optimized solid disk flywheel = 2.603 kg-m^2[7]

Table:7Calculation of various Functional values of six spoke flywheel

Functional values	Formula	Calculation	Value
Angular velocity (ω)	2×π×N/ 60 [6]	2×π×750 / 60	78.53 rad/sec
Surface speed (v_s)	π×D×N / 60 [6]	π×0.500×750/ 60	19.63 m/s
Energy stored in flywheel (E_k)	½ × I_{total}× ω^2[6]	½ × 2.6038 ×78.53^2	8.026 KJ
Specific energy(E_k,m)	E_k/ M_{total}[6]	8.026/ 60	0.1337 kJ/kg
Energy Density (E_k,v)	(E_k/ M_{total})× ρ[6]	0.1337×7510	1004.087 KJ/m^3

Table:8Calculation for Stress in six spoke flywheel

Stress	Formula & Calculation	Value(Mpa)
Tangential Stress(σ_t)	ρVs^2 7510×$(19.63)^2$	2.893
Bending Stress(σ_r)	$\Pi^2 Vs^2\ D_{o\ rim}\rho/i^2 T_{rim}$ Π^2x19.63^2x0.500x7510/6^2x0.030	8.815
Total Stress	¾ σ_t+¼σ_b ¾ x 2.893+¼ x 8.815	4.373

III. Modelling Of Flywheel

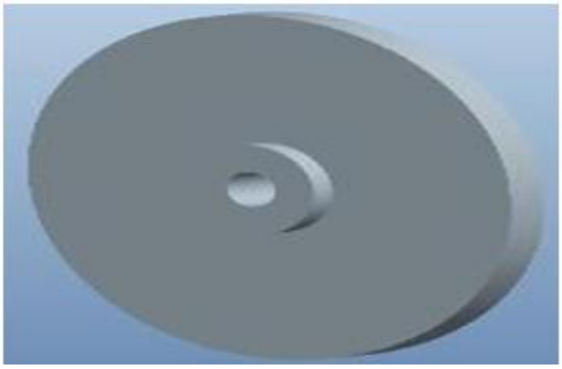

Fig.1 Solid Disk Flywheel

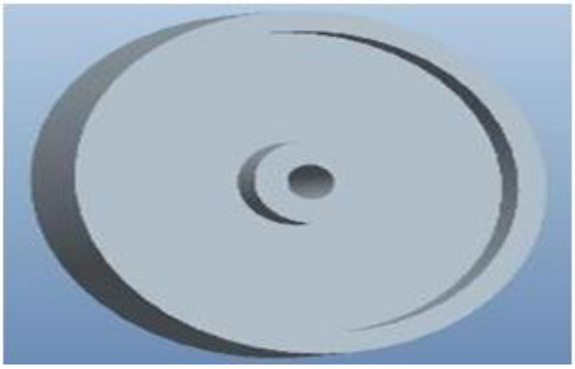

Fig.2 Rim Flywheel

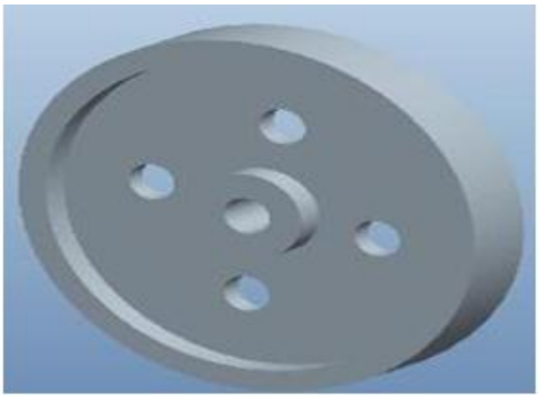

Fig.3 Section Cut Flywheel

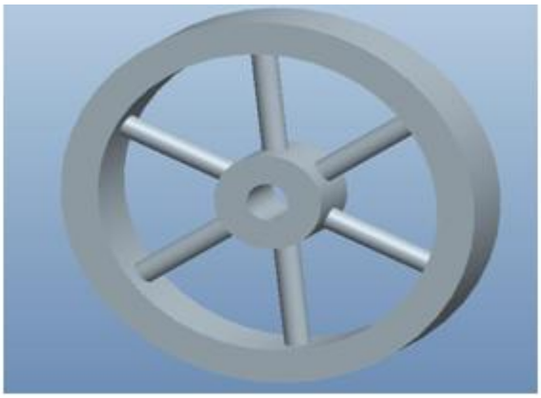

Fig.4 Six Spoke Flywheel

IV. Analysis Of Flywheel Using Ansys

4.1. Analysis Of Soild Flywheel

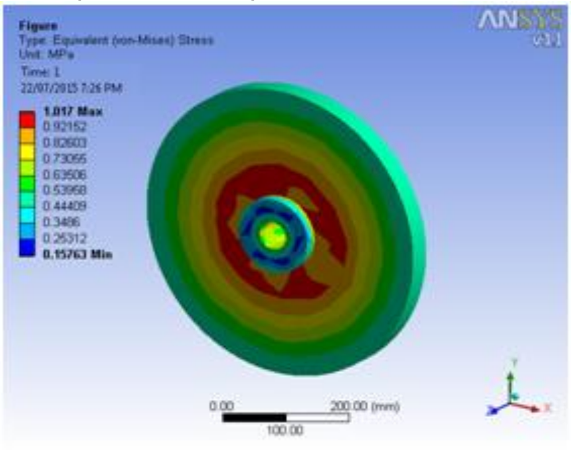

Fig.5. EquiVon Mises In Solid Flywheel

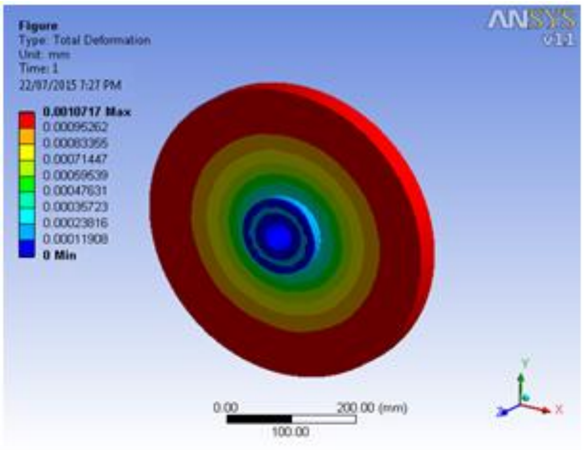

Fig.6. Deflection in Solid Flywheel

4.1. Analysis Of Rim Flywheel

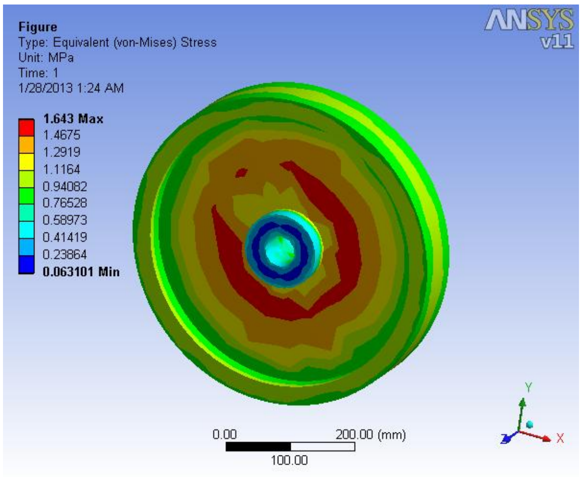

Fig.7. EquiVon Mises In rim Flywheel

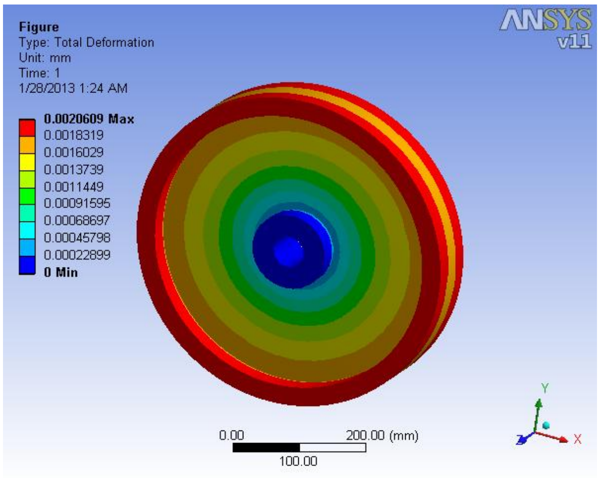

Fig.8. Deflection in rim Flywheel

4.3. Analysis of Section Cut Flywheel

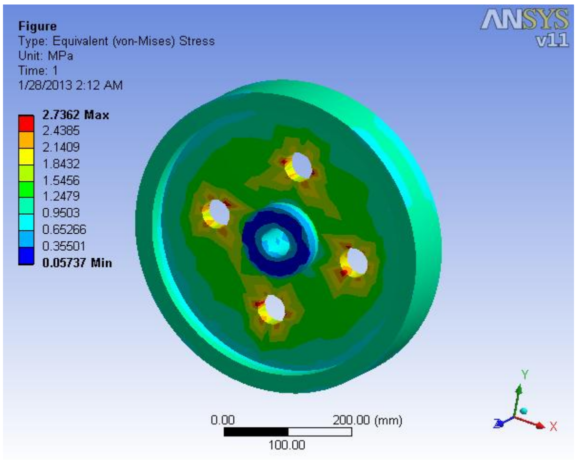

Fig.9. EquiVon Mises In Section cut Flywheel

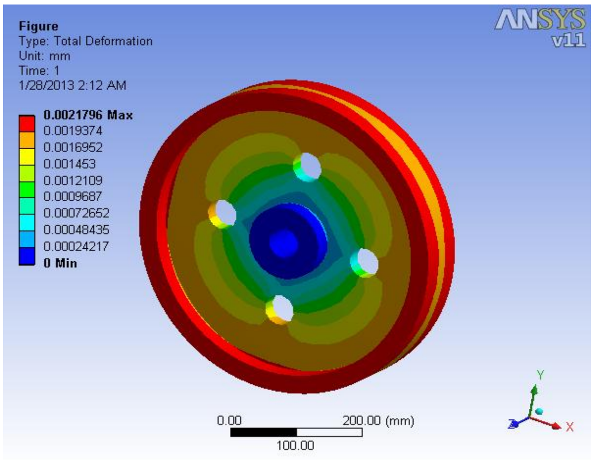

Fig.10. Deflection in Section cut Flywheel

4.4. Analysis Of Six Spoke Flywheel

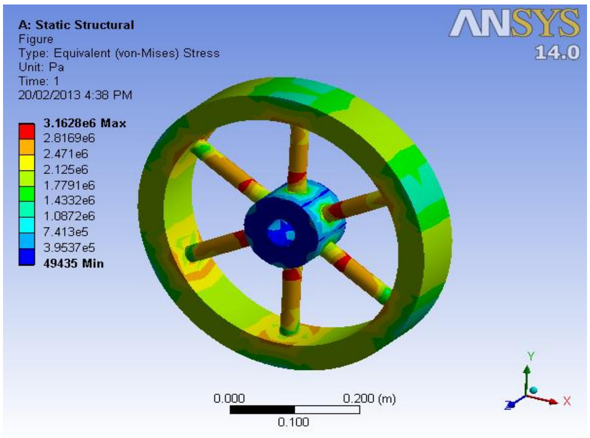

Fig11. EquiVon Mises In Six spoke Flywheel

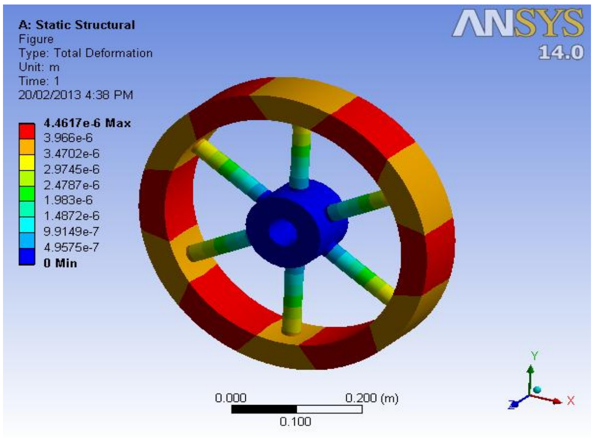

Fig.12. Deflection in Six spoke Flywheel

V. Result And Discussion

The results obtained for the flywheel on the basis of their functional values and equivalent max. Von-mises stresses and total deformation available into the flywheel. From comparison it is found that energy stored into the flywheel is increasing from solid toSix spoke type flywheel. Equivalent max. Von- mises stresses and total deformation available into the flywheel goes on increasing from solid to spoke type flywheel but it is under permissible limit.

Table:9 Various functional value introduced in different flywheel

Functional values	Solid Flywheel	Rim Flywheel	Section Cut Flywheel	Six spoke Flywheel
Moment of inertia(I) Kg-m^2	1.7594	2.283	2.337	2.603
Kinetic energy(ΔE) stored KJ	5.402	7.039	7.206	8.026
Spe. Energy KJ/kg	0.090	0.1173	0.1201	0.133
Spe. Density KJ/m^3	679.029	880.92	901.95	1004.087

Table:10 Stress introduced in different flywheel

Stress(Mpa)	Solid Flywheel	Rim Flywheel	Section Cut Flywheel	Six spoke Flywheel
TangentialStress(σ_t)	0.995	1.533	2.893	2.893
RadialStress(σ_r)	0.788	0.0168	29.75	8.815
ResultantStress	1.296	1.533	9.60	4.373

Table:11 Analysisof different flywheel

Type of Flywheel	Load	Equi.Vonmises stresses(Mpa)	Total Deformation (mm)
Solid Flywheel	ω=78.53 rad/sec	1.017	0.00107
Rim Flywheel	ω=78.53 rad/sec	1.643	0.00206
Section cut Flywheel	ω=78.53 rad/sec	2.736	0.00217
Six Spoke Flywheel	ω=78.53 rad/sec	3.162	0.00446

VI. Conclusion

- Amount of kinetic energy stored in six spoke flywheel is always greater than solid flywheel, rim flywheel, section cut flywheel for constant weight of flywheel.
- Resultant stress introduced in six spoke flywheel is more as comparative to solid disk flywheel but these stress are in permissible range
- Flywheel geometry play very important role in storing kinetic energy.

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