IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 4 Ver. VII (Jul. - Aug. 2015), PP 32-37
www.iosrjournals.org

Mass Optimization of Solid Disk Flywheel Used In Thresher Machines

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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. Present work deal with weight optimization of solid disk flywheel, keeping same moment of inertia. Initially we calculate kinetic energy & stress produced in existing flywheel (60kg solid flywheel) by analytical method then further process to mass optimization of solid disk flywheel by using graphical method; with the help of optimized mass (52kg solid flywheel) we find kinetic energy, stresses & deflection. Lastly with the help of ANSYS we calculate Von-Mises Stress & total deformation of existing & optimized solid flywheel. From ANSYS we conclude all results are valid & permissible range. The result shows that kinetic energy, stresses, deflections of optimized solid flywheel are nearly equal as compare to existing flywheel. From this process we success to save 12% material.*

Keywords:*Solid Flywheel, Kinetic Energy, optimization, Ansys.*

I. Introduction

Flywheels have been used to achieve smooth operation of machine [1].As stated in [2], a flywheel is a rotating mechanical element which is used to store energy of rotational form.Flywheel stores the energy when supply is greater than the requirement and releases energy when requirement is greater than supply[3]. Solid disk flywheel used in the Single flywheel thresher is made up of cast iron. Solid disk flywheel is provided with hub and disk. In design calculation of solid disk flywheel various parameters are used as inputs such as dimensions of solid disk flywheel and resulting functional values are calculated. The stresses produced into the solid disk flywheel are also calculated.

The mass of flywheel is optimized subject to constrain of required moment of inertia and admissible stresses [4]. Design optimization can be defined as the process of finding the maximum or minimum of some parameters which may call the objective function and it must also satisfy a certain set of specified requirements called constraints [5]. Many methods have been developed and are in use for design optimization [5]. The objectives in a design problem and the associated design parameters vary from product to product [5]. Different techniques are to be used in different problems. The purpose is to create optimal design problem, which then can be solved using an optimization technique [5].

In the previous studies,Mouleeswaran S Kumar [2] concludes cast iron flywheels are having higher mass & less angular speed. Aluminium alloy, mar aging steel & E-glass composites lies almost in same category in between cast iron & carbon fibre composites can be used in flywheel to store energy with less mass.

S.M.Choudhary [3] studied various profile of flywheel & stored kinetic energy is calculated for respective flywheel.A.P.Ninawe [6] study useful for what parameter should have been taken into account while defining the flywheel.SudiptaSaha[7]study depicts the importance of the flywheel geometry design selection & its contribution in the energy storage performance.

Present work deal with weight optimization of solid disk flywheel, keeping same moment of inertia. Initially we calculate kinetic energy & stress produced in existing flywheel by analytical method, then further process to mass optimization of solid disk flywheel by using graphical method; with the help of optimized mass we find kinetic energy, stresses & deflection. Lastly with the help of ANSYS we calculate Von-Mises Stress & total deformation of existing & optimized solid flywheel.

II. Design Of 60kg 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 [6] Poisons ratio (υ) = 0.23[6]
Moment of Inertia (M.I.) of solid disk flywheel = 1.7594 kg-m^{2}N = 750RPM [3]

Mass of solid disk flywheel = 60Kg

Table: 1 Calculation for Stress in rotating solid disk flywheel

Stress	Formula & Calculation	Value(Mpa)
Tangential Stress(σ_t)	$\rho\omega^2\left(\frac{3+\upsilon}{8}\right)$ ($R_{ihub}{}^2$+$R_{odisk}{}^2$- $\frac{1+3\upsilon}{3+\upsilon}$ ×R^2mean)[7] $7510\times(78.53)^2\left(\frac{3+0.23}{8}\right)(0.025^2+0.250^2-\frac{1+3\times0.23}{3+0.23}\times0.1375^2)$	0.995
Radial Stress(σ_r)	$\rho\omega^2\left(\frac{3+\upsilon}{8}\right)$ ($R_{ihub}{}^2$+$R_{odisk}{}^2$- $\frac{\text{Rihub 2}\times\text{Rodisk 2}}{\text{R2}}$ $-R^2$)[7] $7510\times(78.53)^2\left(\frac{3+0.23}{8}\right)(0.025^2+0.250^2$-0.000625x0.625/$0.1375^2$-.$1375^2$)	0.788
Resultant Stress	$\sqrt{\sigma_t{}^2{}_+\sigma_r{}^2}$ $=\sqrt{0.995^2+0.788^2}$	1.296

Table: 2 Calculation of various Functional values of solid disk flywheel

Functional values	Formula	Calculation	Value
Angular velocity (ω)	2×π×N/ 60	2×π×750 / 60	78.53 rad/sec
Surface speed (v_s)	π×D×N / 60	π×0.500×750/ 60	19.63 m/s
Energy stored in flywheel (E_k)	½ × I_{total}× ω^2[7]	½ × 1.7594 ×78.53^2	5.402 KJ
Specific energy(E_k,m)	E_k/ M_{total}[7]	5.402/ 60	0.090 kJ/kg
Energy Density (E_k,v)	(E_k/ M_{total})× ρ[7]	0.090×7510	679.029 KJ/m^3

III. Optimization Of 60 Kg Solid Flywheels Using Graphical Method

Problem formulation is

Minimize: Z = f (x) = 23593.36 $x_1{}^2x_2$

Subject to: $g_1(x)$ = 23593.36 $x_1{}^4$ x_2 -3.5188 ≤ 0

$g_2(x)$ = 36.374 ×10^6 $X_1{}^4$ x_2 - 5402≤ 0

Side constraints: 0.25 < x1$_<$ 0.32

0.025 < x2 < 0.035

X_1 = R (Radius of solid disk flywheel)

X_2 = H (Thickness of solid flywheel disk)

SOLUTION:

Table: 3 Moment Of Inertia (I) x_2 = 3.5188 / 23593.36 $x_1{}^4$

X_1	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32
X_2	0.0381	0.0326	0.0224	0.0242	0.0210	0.0184	0.0161	0.0142

Table: 4 Kinetic Energy Stored (ΔE) X_2 = 1.480 × 10^{-4} / $x_1{}^4$

X_1	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32
X_2	0.0378	0.0323	0.0278	0.0240	0.0209	0.0182	0.0160	0.0141

Considering various values for objective function

M = 23593.36 $x_1{}^2x_2$

Table: 5 For M = 55 Kg 23593.36 $x_1{}^2x_2$ = 55

X_2	0.025	0.026	0.027	0.028	0.029	0.030	0.031	0.032
X_1	0.305	0.299	0.293	0.288	0.283	0.278	0.274	0.269

Table: 6For M = 50 Kg 23593.36 $x_1{}^2x_2$ = 50

X_2	0.025	0.026	0.027	0.028	0.029	0.030	0.031	0.032
X_1	0.291	0.285	0.280	0.275	0.270	0.265	0.261	0.257

Table:7 For M = 52 Kg 23593.36 $x_1{}^2x_2$ = 52

X_2	0.025	0.026	0.027	0.028	0.029	0.030	0.031	0.032
X_1	0.296	0.291	0.285	0.280	0.275	0.271	0.266	0.262

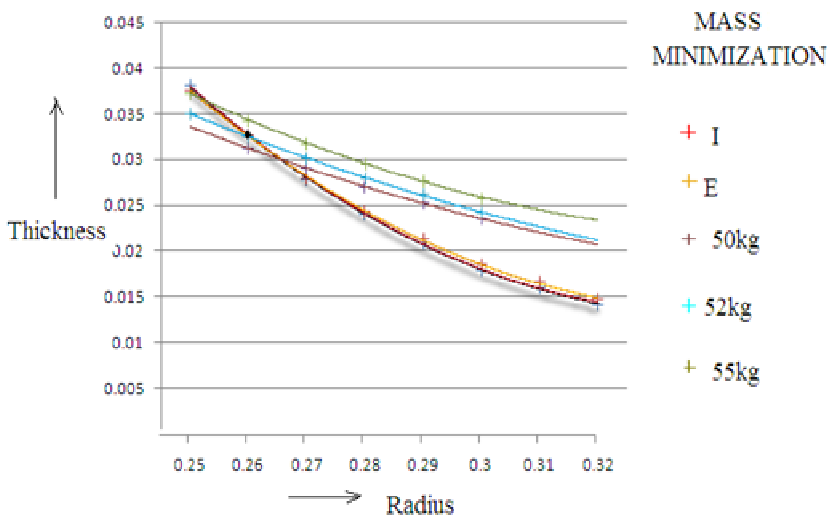


Fig.1. Graphical Representation of Mass Minimization of Solid Disk Flywheel

The graphical representation of mass minimization of solid disk flywheel shows that the moment of inertia curve and energy curve crosses each other at a point called as optimal point . The optimal point shows that both the constraints equation for moment of inertia and energy are satisfied. Various curves for the objective function having different masses are drawn for the mass minimization of solid flywheel. The curve for objective function having 52 kg mass passes through the optimal point and satisfies both the constraints equation for moment of inertia and energy of flywheel. To obtain constraints moment of inertia and energy of flywheel with 52 kg mass, the optimal radius and thickness found to be 0.2604 m and 0.0325 m.

IV. Design Of Optimal Solid Disk Flywheel

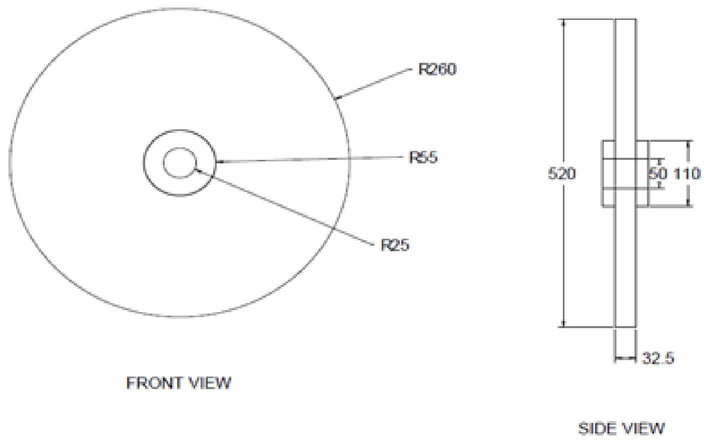


Fig.2. Optimal Solid Flywheel

Various parameters of optimal solid disk flywheel are given as follows.
Material used for solid disk flywheel Gray Cast Iron
Outer diameter of disk ($D_{o\ disk)}$ = 520 mm Inner diameter of disk ($D_{i\ disk)}$ = 110 mm
Outer diameter of hub ($D_{o\ hub)}$ = 110 mm Inner diameter of hub ($D_{i\ hub}$) = 50mm
Width of hub (W_{hub}) =70mm Width of disk ($W_{disk)}$ =32.5mm
Density (ρ) = 7510 kg/m^3Poisons ratio (υ) = 0.23
N = 750RPM
Mass of optimized solid disk flywheel = 52Kg
Moment of Inertia(M.I.) of optimized solid disk flywheel = 1.7528 kg-m^2

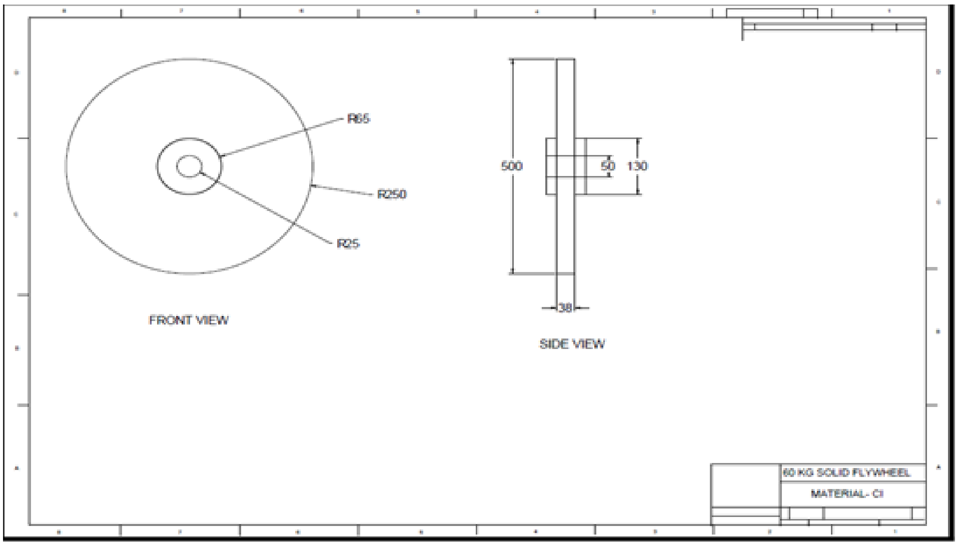
Table:8 Calculation for Stress Produced in rotating solid disk flywheel

Stress	Formula & Calculation	Value(Mpa)
Tangential Stress(σ_t)	$\rho\omega^2\left(\frac{3+\upsilon}{8}\right)(R_{ihub}{}^2+R_{odisk}{}^2-\frac{1+3\upsilon}{3+\upsilon}\times R^2mean)$[7] $7510\times(78.53)^2\left(\frac{3+0.23}{8}\right)(0.025^2+0.260^2-\frac{1+3\times0.23}{3+0.23}\times0.1425^2)$	1.077
Radial Stress(σ_r)	$\rho\omega^2\left(\frac{3+\upsilon}{8}\right)(R_{ihub}{}^2+R_{odisk}{}^2-\frac{Rihub\,2\times Rodisk\,2}{R2}-R^2)$[7] $7510\times(78.53)^2\left(\frac{3+0.23}{8}\right)(0.025^2+0.260^2-\frac{0.000625\times0.0676}{0.1425\times0.1425}\times0.1425^2)$	0.857
Resultant Stress	$\sqrt{\sigma_t{}^2{}_+\sigma_r{}^2} = \sqrt{1.077^2+0.857^2}$	1.376

Table:9 Calculation of various Functional values of optimized solid disk flywheel

Functional values	Formula	Calculation	Value
Angular velocity (ω)	$2\times\pi\times N/60$	$2\times\pi\times750/60$	78.53 rad/sec
Surface speed (v_s)	$\pi\times D\times N/60$	$\pi\times0.520\times750/60$	20.420 m/s
Energy stored in flywheel (E_k)	$\frac{1}{2}\times I_{total}\times\omega^2$[7]	$\frac{1}{2}\times1.7528\times78.53^2$	5.402 KJ
Specific energy(E_k,m)	E_k/M_{total}[7]	5.402/ 52	0.1039 kJ/kg
Energy Density (E_k,v)	$(E_k/M_{total})\times\rho$[7]	0.1039×7510	780.462 KJ/m^3

V. Drafting And Modelling Of Solid 60kg Flywheel



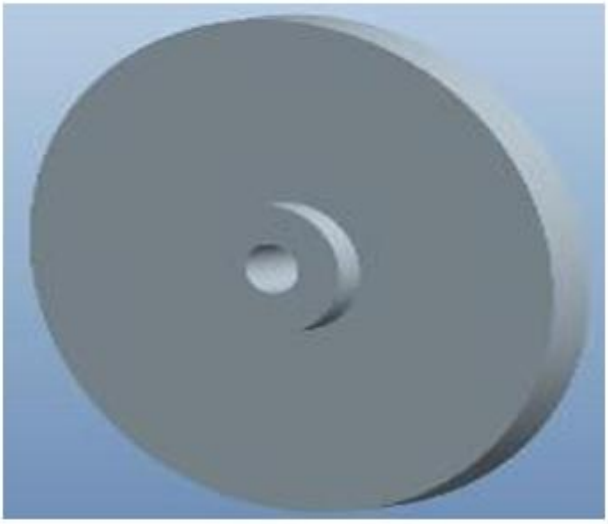


Fig.4. Drafting &Modeling of Solid Disk Flywheel

VI. Analysis Of Flywheel Using Ansys

6.1. Analysis OfExisting Flywheel

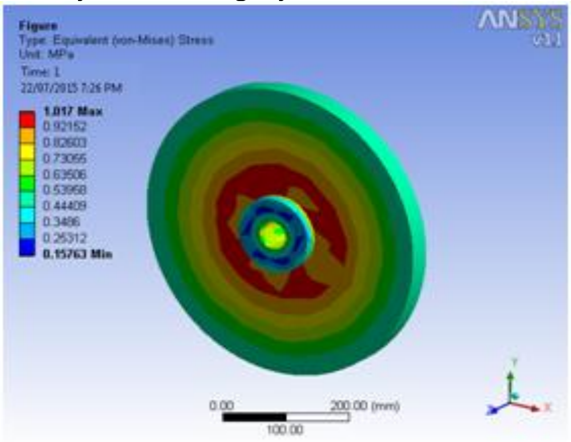


Fig.5. EquiVon Mises In Solid Flywheel

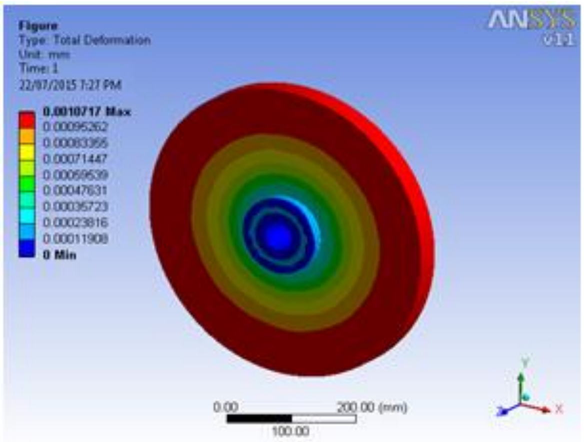


Fig.6.Deflection in Solid Flywheel

Table:10 Analysis of Existing Flywheel

Type of Flywheel	Load	Equi.Von-mises stresses(Mpa)	Total Deformation (mm)
Existing Flywheel	ω=78.53 rad/sec	1.017	0.00107

6.2.Analysis Of Optimal Flywheel

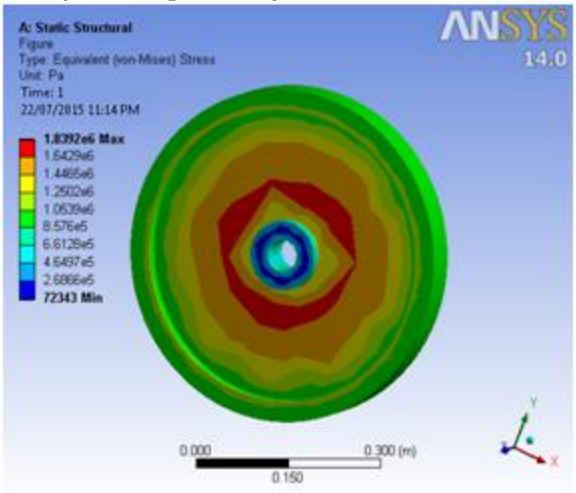


Fig.7. Von-Mises inOptimal

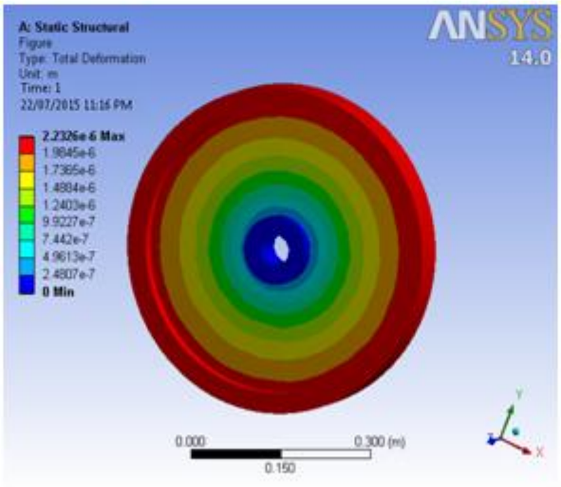


Fig.8. Deflection in Optimal Solid

Table:11 Analysis of Optimal Flywheel

Type of Flywheel	Load	Equi.Von-mises stresses(Mpa)	Total Deformation (mm)
Optimal Flywheel	ω=78.53 rad/sec	1.1349	0.00122

VII. Result And Discussion

The results obtained for the existing and optimal flywheel on the basis of their functional values and equivalent maximum Von- mises stresses and total deformation available into the flywheel.

Optimization methods show minimum mass and maximum energy for the flywheel. Results obtained from graphical method for mass minimization of solid disk flywheel gives 52Kg mass 0.260m optimal radius with thickness of 0.325 m.

Table:12 Functional Values of Existing & Optimal Flywheel

Functional values	Moment of inertia(I) (Kg-m^2)	Kinetic energy (ΔE) stored (KJ)	Specific Energy (KJ/kg)	Specific Density (KJ/m^3)
Existing Flywheel	1.7594	5.402	0.090	679.029
Optimal Flywheel	1.7594	5.402	0.1039	780.462

Table:13 Analysis of Existing & Optimal Flywheel

Type of Flywheel	Load	Equi.Von-mises stresses(mpa)	Total Deformation (mm)
Existing Flywheel	ω=78.53 rad/sec	1.017	0.00107
Optimal Flywheel	ω=78.53 rad/sec	1.1349	0.00122

VIII. Conclusion

- Minimum mass obtained for solid disk flywheel by Graphical Method is 52 kg with optimal radius 0.2604 m and thickness 0.0325 m.
- We are able to stored same amount of Kinetic Energy in 52Kg solid flywheel as that of stored in 60 kg solid flywheel by graphical optimization technique.
- By graphical optimization technique we success to save 12% material.
- Using analytical method resultant stress of existing & optimal solid disk flywheel are 1.296Mpa & 1.3763Mpa respectively. It shows that stresses are in permissible range.
- Using FEM resultant stress of existing & optimal solid disk flywheel are 1.017Mpa & 1.134Mpa respectively. It shows that stresses are in permissible range.
- Total deflection obtained for existing & optimal solid disk flywheel is 0.00107mm & 0.00122 respectively. It shows that deflections are in permissible range.

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