Investigation of Smart Profile of Flywheel

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Abstract- From study of previous research paper we conclude that performance of flywheel depends on the material strength, geometry (cross-section), and rotational speed. Present investigation deals with flywheel geometry and its kinetic energy storing capability.in this article we design Solid, Rim, Section-cut and six arm type flywheel maintaining constant weight. And simultaneously we calculate moment of inertia and kinetic energy of respective flywheel. From this study we conclude that six arm type flywheel store more amount of kinetic energy as compare to solid, rim and section cut flywheel.

Keywords – Flywheel, Mass, Moment of Inertia, Kinetic Energy.

I. INTRODUCTION

Flywheel is a rotating mechanical element which is used to store energy of rotational form [1]. Flywheels stores energy in a rotating mass depending on the inertia & speed of rotating mass [2].Flywheel acts as a reservoir by storing energy during the period when the supply of energy is more than the requirement and releasing it during the period when the requirement of the energy is more than the supply [3]. Flywheel provides an effective way to smooth out the fluctuation of speed [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]. A flywheel is a mechanical device with a significant moment of inertia used as a storage device for rotational energy [4]. 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[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 flywheel geometry and its kinetic energy storing capability.in this article we design Solid, Rim, Section-cut and six arm type flywheel maintaining constant weight. And simultaneously we calculate moment of inertia and kinetic energy of respective flywheel. From this study we conclude that six arm type flywheel store more amount of kinetic energy as compare to solid, rim and section cut flywheel.

II. DESIGN OF FLYWHEEL

For design the flywheel material are taken Gray Cast Iron, material property
Density (ρ) 7510 kg/m^3 [5],
Poisons ratio (υ) = 0.23[5], Flywheel velocity (N) =750RPM

A. *Design of Solid Disk Flywheel.*

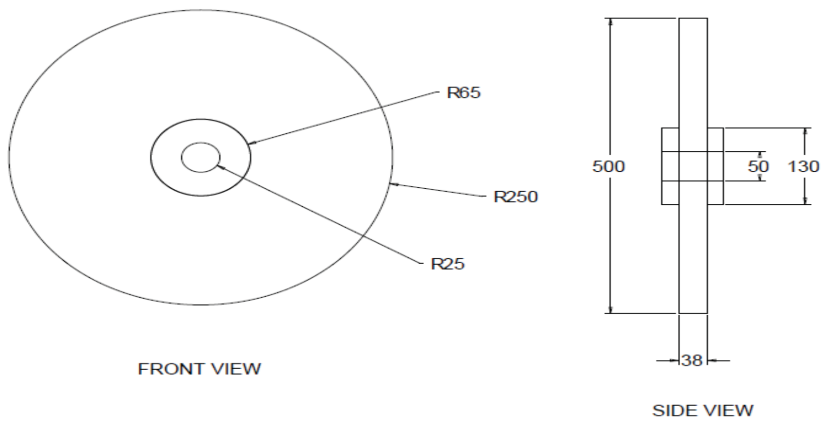

Figure 1. Solid Disk Flywheel

Various parameters of solid disk flywheel are given as follows.

Outer diameter of disk ($D_{o\ disk}$) = 500 mm
Inner diameter of disk ($D_{i\ disk}$) =130mm
Outer diameter of hub ($D_{o\ hub}$) = 130mm
Inner diameter of hub ($D_{i\ hub}$) = 50 mm
Width of hub (W_{hub}) =80mm
Width of disk (W_{disk}) =38 mm

Mass Calculation For Solid Disk Flywheel

Mass of hub of solid disk flywheel

$M_{hub} = ¼ \times \rho \times \pi \times W_{hub} \times (D_o^2{}_{hub} - D_i^2{}_{hub})$ ………..…..Eq(1)

$M_{hub} = ¼ \times 7510 \times \pi \times 0.080 \times (0.130^2 - 0.050^2) = 6.794$ kg

Mass of disk of solid disk flywheel

$M_{disk} = ¼ \times \rho \times \pi \times W_{disk} \times (D_o^2{}_{disk} - D_i^2{}_{disk})$ …………..Eq(2)

$M_{disk} = ¼ \times 7510 \times \pi \times 0.038 \times (0.500^2 - 0.130^2) = 52.246$ kg

Total mass of solid disk flywheel

$M_{total} = M_{hub} + M_{disk}$………………………………………………….. Eq(3)

$M_{total} = 6.794 + 52.246 = 59.04$Kg= 60 kg (Approx.)

Moment of Inertia Calculation For Solid Disk Flywheel

Moment of Inertia of hub of solid disk flywheel

$I_{hub} = 1/8 \times M_{hub} \times (D_o^2{}_{hub} + D_i^2{}_{hub})$….. ………………...Eq(4)

$I_{hub} = 1/8 \times 6.794 \times (0.130^2 + 0.050^2) = 0.0164$ kg-m^2

Moment of Inertia of solid disk flywheel

$I_{disk} = 1/8 \times M_{disk} \times (D_o^2{}_{disk} + D_i^2{}_{disk})$ .. …………….……...Eq(5)

$I_{disk} = 1/8 \times 52.246 \times (0.500^2 + 0.130^2) = 1.743$ kg-m^2

Total Moment of Inertia of solid disk flywheel is

$I_{total} = I_{hub} + I_{disk}$….. …………………………………....Eq(6)

$I_{total} = 0.0164 + 1.743 = 1.7594$ kg-m^2

B. Design of Rim Flywheel

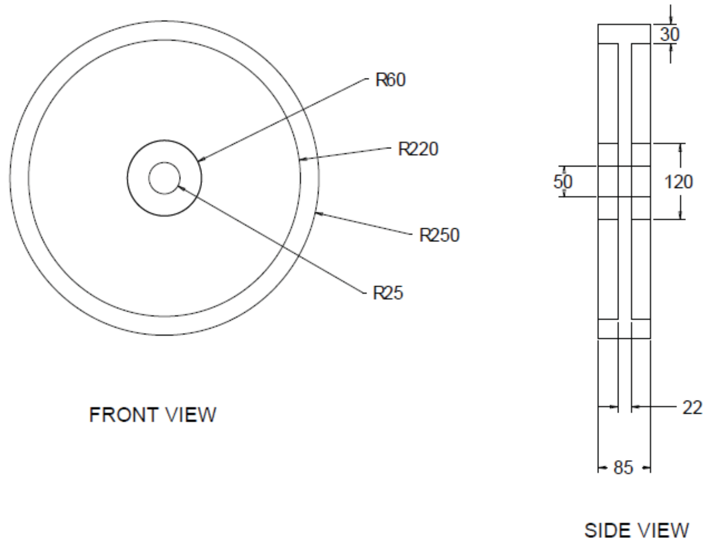

Figure 2. Rim Flywheel

Various parameters of rim flywheel are given as follows.

Outer diameter of rim($D_{o\ rim}$) =500mm
Inner diameter of rim ($D_{i\ rim}$) =440mm
Outer diameter of hub ($D_{o\ hub}$) = 120mm
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}) = 22mm
Thickness of rim (T_{rim}) = 30mm

Mass Calculation For Rim Flywheel

Mass of hub of rim flywheel

$M_{hub} = ¼ \times \rho \times \pi \times W_{hub} \times (D_o{}^2{}_{hub} - D_i{}^2{}_{hub})$

$M_{hub} = ¼ \times 7510 \times \pi \times 0.085 \times (0.120^2 - 0.050^2) = 5.966$ kg

Mass of rim of rim flywheel

$M_{rim} = \rho \times \pi \times W_{rim} \times D_{o\ rim} \times T_{rim}$.. …..………………....Eq(7)

$M_{rim} = 7510 \times \pi \times 0.085 \times 0.030 \times 0.500 = 30.081$ kg

Mass of plate of rim flywheel

$M_{plate} = ¼ \times \rho \times \pi \times W_{plate} \times (D_o{}^2{}_{plate} - D_i{}^2{}_{plate})$……….. Eq(8)

$M_{plate} = ¼ \times 7510 \times \pi \times 0.022 \times (0.440^2 - 0.120^2) = 23.253$ kg

Total mass of rim flywheel

$M_{total} = M_{hub} + M_{rim} + M_{plate}$…………………………………..…. Eq(9)

$M_{total} = 5.966+30.081+ 23.253 =59.3$Kg= 60 kg(Approx.)

Moment of Inertia Calculation For RimFlywheel

Moment of Inertia of hub of Rim flywheel

$I_{hub} = 1/8 \times M_{hub} \times (D_o{}^2{}_{hub} + D_i{}^2{}_{hub})$

$I_{hub} = 1/8 \times 5.966 \times (0.120^2+0.050^2) = 0.0126$ kg –m^2

Moment of Inertia of rim of Rim flywheel

$I_{rim} = 1/8 \times M_{rim} \times (D_o{}^2{}_{rim} + D_i{}^2{}_{rim})$ …………………..Eq(10)

$I_{rim} = 1/8 \times 30.081 \times (0.500^2 + 0.440^2) = 1.667$ kg-m^2

Moment of Inertia of plate of rim flywheel

$I_{plate} = 1/8 \times M_{plate} \times (D_o{}^2{}_{plate} + D_i{}^2{}_{plate})$ ……………...Eq(11)

$I_{plate} = 1/8 \times 23.253 \times (0.440^2 + 0.120^2) = 0.604$ kg-m^2

Total Moment of Inertia of rim flywheel is
$I_{total} = I_{hub} + I_{rim} + I_{plate}$………………..........................Eq(12)
$I_{total} = 0.0126 + 1.667 + 0.604 = 2.283$ kg-m^2

C. Design of Section Cut Flywheel

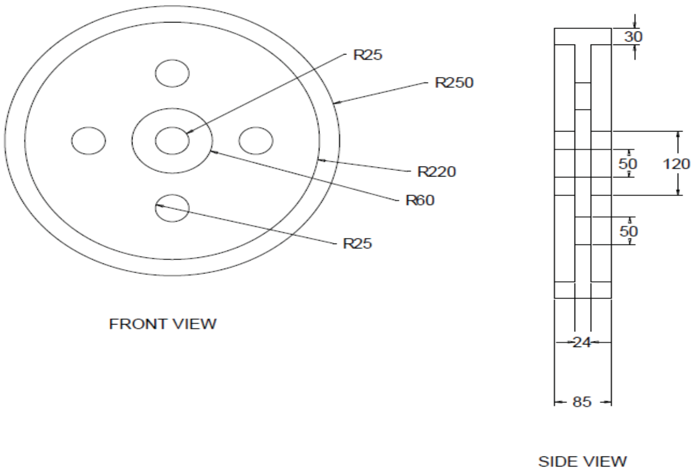

Figure 3.Section Cut Flywheel

Various parameters of section cut flywheel are given as follows

Outer diameter of rim ($D_{o\ rim}$) =500mm
Inner diameter of rim ($D_{i\ rim}$) =440mm
Outer diameter of hub ($D_{o\ hub}$)=120mm
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}) = 24 mm
Thickness of rim (T_{rim}) =30mm
No. of holes (i) = 4
Radius of hole (r) = 25 mm

Mass Calculation For Section Cut Flywheel
Mass of hub of section cut flywheel
$M_{hub} = ¼ \times \rho \times \pi \times W_{hub} \times (D_o{}^2{}_{hub} - D_i{}^2{}_{hub})$
$M_{hub} = ¼ \times 7510 \times \pi \times 0.085 \times (0.120^2 - 0.050^2) = 5.966$ kg

Mass of rim of section cut flywheel
$M_{rim} = \rho \times \pi \times W_{rim} \times D_{o\ rim} \times T_{rim}$
$M_{rim} = 7510 \times \pi \times 0.085 \times 0.030 \times 0.500 = 30.081$ kg

Mass of plate of section cut flywheel
$M_{plate} = ¼ \times \rho \times \pi \times W_{plate} \times (D_o{}^2{}_{plate} - D_i{}^2{}_{plate})$
$M_{plate} = ¼ \times 7510 \times \pi \times 0.024 \times (0.440^2 - 0.120^2) = 25.367$ kg

Mass of cylindrical disk (M_c) = $\rho \times \pi \times r^2 \times W_{plate}$……… Eq(12)
$M_c = 7510 \times \pi \times 0.025^2 \times 0.024 = 0.353$ kg
For 4 disks
$M_{c\ (total)}) = 4 \times 0.353 = 1.415$ kg

Final mass of plate $M_{final(plate)} = M_{plate} - M_c$………………….. Eq(13)
$M_{final(plate)} = 25.367 - 1.415 = 23.952$ kg

Total mass of section cut flywheel
$M_{total} = M_{hub} + M_{rim} + M_{final(plate)}$

$M_{total} = 5.966 + 30.081 + 23.952 = 59.999$Kg = 60 kg (Approx.)

Moment of Inertia Calculation For Section Cut Flywheel

Moment of Inertia of hub of Section Cut flywheel
$I_{hub}= 1/8 \times M_{hub}\times(D_o{}^2{}_{hub}+ D_i{}^2{}_{hub})$
$I_{hub} = 1/8 \times 5.966\times (0.120^2+0.050^2) = 0.0126$ kg –m^2

Moment of Inertia of rim of section cut flywheel
$I_{rim}= 1/8\times M_{rim}\times(D_o{}^2{}_{rim}+ D_i{}^2{}_{rim})$
$I_{rim} = 1/8 \times 30.081 \times(0.500^2 + 0.440^2) = 1.667$ kg-m^2

Moment of Inertia of plate of section cut flywheel
$I_{plate}= 1/8\times M_{plate}\times(D_o{}^2{}_{plate}+ D_i{}^2{}_{plate})$
$I_{plate} = 1/8 \times 25.367 \times(0.440^2 + 0.120^2) = 0.659$ kg-m^2

Moment of Inertia of circular hole of section cut flywheel
$I_c= M_c\times r^2/ 2$…………………………………………..Eq(14)
$I_c = 0.353 \times 0.025^2/2 = 0.00011$kg –m^2
$I_{c\ (final)}=4\times 0.00011$
$I_{p\ (final)} = 0.000441$ kg-m^2

$I_{p\ (final)}= I_{plate}- I_{c\ (final)}$ ………………………………….Eq(15)
$I_{p\ (final)} = 0.659 – 0.000441 = 0.658$ kg-m^2

Total Moment of Inertia of section cut flywheel
$I_{total} = I_{hub} + I_{rim} + I_{plate(final)}$
$I_{total} = 0.0126 +1.667+0.658 = 2.337$ kg-m^2

D. Design of Six Spoke Flywheel

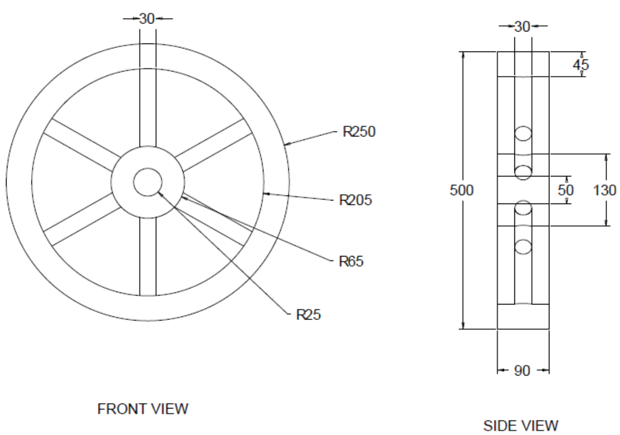

Figure 4. Six Spoke Flywheel

Various parameters of spoke type flywheel are given as
Outer diameter of rim ($D_{o\ rim}$) =500mm
Inner diameter of rim ($D_{i\ rim}$) = 410mm
Outer diameter of hub ($D_{o\ hub}$) = 130mm
Inner diameter of hub ($D_{i\ hub}$) = 50mm
Width of hub (W_{hub}) = 90mm
Width of rim (W_{rim}) = 90mm
Thickness of rim (T_{rim}) = 45 mm
No. of spoke (i) = 6
Diameter of spoke (D_{spoke}) = 30 mm

Mass Calculation For Six Spoke Flywheel
Mass of hub of six spoke flywheel

$M_{hub} = ¼ \times \rho \times \pi \times W_{hub} \times (D_o{}^2{}_{hub} - D_i{}^2{}_{hub})$
$M_{hub} = ¼ \times 7510 \times \pi \times 0.090 \times (0.130^2 - 0.050^2) = 7.644$ kg

Mass of rim of six spoke flywheel
$M_{rim} = \rho \times \pi \times W_{rim} \times D_{o\ rim} \times T_{rim}$
$M_{rim} = 7510 \times \pi \times 0.090 \times 0.045 \times 0.500 = 47.776$ kg

Length of spoke (L_{spoke}) = $D_{i\ rim}/2 - D_{o\ hub}/2$
$L_{spoke} = 0.410/2 – 0.130/2 = 0.140$ m

Mass of spoke of six spoke flywheel
$M_{spoke} = ¼ \times \rho \times \pi \times L_{spoke} \times D_{spoke}{}^2$…………………...Eq(16)
$M_{spoke} = ¼ \times 7510 \times \pi \times 0.140 \times 0.030^2 = 0.7431$ kg
For 6 spokes $M_{spoke\ (total)} = 6 \times 0.7431 = 4.4586$ kg
Total mass of six spoke flywheel
$M_{total} = M_{hub} + M_{rim} + M_{spoke(total)}$
$M_{total} = 7.644+47.776+4.458=59.878$Kg = 60 kg(Approx)

Moment of Inertia Calculation For Six Spoke Flywheel

Moment of Inertia of hub of six spoke flywheel
$I_{hub} = 1/8 \times M_{hub} \times (D_o{}^2{}_{hub} + D_i{}^2{}_{hub})$
$I_{hub} = 1/8 \times 7.644 \times (0.130^2+0.050^2) = 0.01853$kg –m^2

Moment of Inertia of rim of six spoke flywheel
$I_{rim} = 1/8 \times M_{rim} \times (D_o{}^2{}_{rim} + D_i{}^2{}_{rim})$
$I_{rim} = 1/8 \times 47.776 \times (0.500^2 + 0.410^2) = 2.496$ kg-m^2

$L_{cg} = L_{spoke}/2 + D_{o\ hub}/2$
$L_{cg} = 0.140/2 + 0.130/2 = 0.1175$

Moment of Inertia ofspoke of six spoke flywheel
$I_{spoke} = M_{spoke} \times (1/12 \times L_{spoke}{}^2 + L_{cg}{}^2)$
$I_{spoke} = 0.7431 \times (1/12 \times 0.140^2 + 0.1175^2) = 0.01147$ kg-m^2

Total moment of Inertia of six spoke flywheel
$I_{total} = I_{hub} + I_{rim} + (i \times I_{spoke})$
$I_{total} = 0.01853 + 2.496 + (6 \times 0.01147) = 2.583$ kg-m^2

III. CALCULATION FOR KINETIC ENERGY

Angular velocity (ω) = $2 \times \pi \times N/ 60$
$= 2 \times \pi \times 750 / 60$
$\omega = 78.53$ rad/sec

1)Energy stored in soild flywheel (E_k) $= ½ \times I_{total} \times \omega^2$
$E_k = ½ \times 1.7594 \times 78.53^2 = 5.402$ KJ
2)Energy stored in rim flywheel (E_k) $= ½ \times I_{total} \times \omega^2$
$E_k = ½ \times 2.283 \times 78.53^2 = 7.039$ KJ
3)Energy stored in section cut flywheel (E_k) $= ½ \times I_{total} \times \omega^2$
$E_k = ½ \times 2.337 \times 78.53^2 = 7.206$ KJ
4)Energy stored in six spoke flywheel (E_k) $= ½ \times I_{total} \times \omega^2$
$E_k = ½ \times 2.583 \times 78.53^2 = 7.964$KJ

IV. RESULT

Table -1 Functional value of Flywheel

Functional values	Solid	Rim	Web	Arm
Mass(Kg)	60	60	60	60
Moment of inertia(I) Kg-m^2	1.7594	2.283	2.337	2.5769
Kinetic energy (ΔE) stored KJ	5.402	7.039	7.206	7.945

V. CONCLUSIONS

- From comparison it is found that energy stored into the flywheel is increasing from solid to spoke type flywheel.
- Smart design of flywheel geometry has significant effect on its performance.
- Amount of kinetic energy stored by six spoke flywheel is greater than any other flywheel.
- To obtain certain amount of energy stored; material induced in the spoke flywheel is less than that of other flywheel, thus reduce the cost of the flywheel.

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