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Design and Optimization of a flywheel for the 4-Cylinder Diesel Engine



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Abstract

A flywheel releases stored energy by applying torque to a mechanical load, thereby decreasing the flywheel's rotational speed. This would be much essential under failure consideration due to stresses resulting from centrifugal effects. Different designs existed all intended to be easy and most economical to produce. The project involves the design and analysis of flywheel to minimize the radial and tangential stresses, the flywheel is subjected to a constant rpm. The objective of present work is to design and optimize the flywheel for the best material. Evaluation of the materials has been done by comparing the materials one on the other, out of which carbon fiber exhibited better results. Carbon fiber and Magnesium alloys are the best materials to be considered, as carbon fiber is light in weight and efficient. Magnesium alloy is equivalently efficient and economical as that of carbon fibre. Static analysis has been observed by applying angular velocity on to the flywheel. Analytical calculation as well as simulation is done for design of flywheel by varying different material on Ansys.

Keywords: Flywheel, Radial Stresses, Tangential Stress

1. Introduction

A basic machine motive gear mechanism or auto gear mechanism contains of varied transmission elements



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like gears, shafts and alternative components that operate along to modify the movement of associate in nursing automobile. Automobile or automotive gear mechanism consists of varied devices that facilitate in transmission power from the engine through the drive shaft to the driving axle of associate in nursing automobile. Gears, brakes, clutch, coupler and alternative machine transmission components work along for remodeling the speed quantitative relation between the engine and wheels of a vehicle. The machine gear mechanism incorporates varied elements, that area unit hooked up to the rear of the engine and used for distributing the facility from the engine to the drive wheels.

1.1 Flywheel:-

A flywheel is a machine component which is used in machines serves as a reservoir which stores energy during the period when the supply of energy is more than the requirement and releases it during the period when the requirement of energy is more than supply.

For example, in I.C. engines, the energy is developed only in the power stroke which is much more than engine load, and no energy is being developed during the suction, compression and exhaust strokes in case of four stroke engines. The excess energy is developed during power stroke is absorbed by the flywheel and releases it's to the crank shaft during the other strokes



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in which no energy is developed, thus rotating the crankshaft at a uniform speed. The flywheel is located on one end of the crankshaft and serves two purposes. First, through its inertia, it reduces vibrations by smoothing out the power stroke as each cylinder fires. Second, it is the mounting surface used to bolt the engine up to its load.

1.2 Function of a Flywheel:-

The main function of a fly wheel is to smoothen out variations in the speed of a shaft caused by torque fluctuations. If the source of the driving torque or load torque is fluctuating in nature, then a flywheel is usually called for. Many machines have load patterns that cause the torque time function to vary over the cycle. Internal combustion engines with one or two cylinders are a typical example. Piston compressors, punch presses, rock crushers etc. are the other systems that have fly wheel. Flywheel absorbs mechanical energy by increasing its angular velocity and delivers the stored energy by decreasing its velocity.



Fig.1.1. flywheel function

1.3 Structure of Flywheel:

The geometry of a flywheel may be as simple as a cylindrical disc of solid material, or may be of spoked construction like conventional wheels with a hub and rim connected by spokes or arms Small fly wheels are solid discs of hollow circular cross section. As the energyrequirements and size of the flywheel increases the geometry changes to disc of central hub and peripheral rim connected by webs and to hollow wheels with multiple arms.



2. Literature Review:

Sushama G.Bawane et al. [1], proposed flywheel design .They study different types of flywheel & use different types of material for the analysis purpose. By using FEA analysis suggested the best material for the flywheel.

Sagar M. Samshette [11] works on design Solid, Rim, Section-cut and six arm type flywheel maintaining constantweight. And simultaneously we calculate moment of inertia and kinetic energy of respective flywheel. He conclude that six arm type flywheel store more amount of kinetic energy as compare to solid, rim and section cut flywheel.

S. M. Dhengle et al. [2] shows the comparison between analytical stresses and FE stresses in Rim by varying no. of arms& comparison between FE stresses on arm and analytical calculated bending stresses in arms. They also had seen that as a number of arms increases from 4 to 8, the stresses in the arms go on reducing. This may be due to sharing of load by larger no. of arms shows the comparison of FE stresses and analytical bending stresses near the hub end of arm for 4, 6 and 8 arms flywheel under the influence of tangential forces on rim.PROBLE STATEMENT

3. Problem Statement:

3.1 Research Needs:

The efficiency of a flywheel is determined by the amount of energy it can store per unit weight. As the flywheel's rotational speed or angular velocity is increased, the stored energy increases however, the



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centrifugal stresses also increase. If the centrifugal stresses surpass the tensile strength of the material, the flywheel will fly apart. Thus, the tensile strength is an upper limit to the amount of energy that aflywheel can store.

Traditionally, flywheels are made of cast iron. From design considerations, because cast iron fly wheels are the cheap in cost, it can be given any complex shape without involving machining operations and cast iron flywheel has excellent ability to damp vibrations. However, cast iron has poor tensile strength compared to steel. The failure of cast iron flywheel is sudden and total. The machinability of cast iron flywheel is poor compared to steel flywheel. More recently, flywheels are made of high strength steels but they are limited to revolutions at 10,000 rpm.

Now-a-days cast iron is replaced by carbon fiber reinforced plastics due to the high tensile strength produced by the carbon fiber when compared to that with cast iron. Carbon fiber reinforced plastic (CFRP) Graphite-Fiber Reinforced Polymer (GFRP) is considered as an excellent choice for flywheels fitted on modern car engines due to rotating mass made of fiber glass resins or polymer materials with a high strength-to-weight ratio, a mass that operates in a vacuum to minimize aerodynamic drag, mass that rotates at high frequency, air or magnetic suppression bearing technology to accommodate high rotational speed 100000 rpm. But the drawback of carbon fibre reinforced plastics is that the cost of it comparatively more. Therefore the overall cost of the fabrication also increases.

Research has begun in this field about the use of different materials which places a good substitute for the carbon fiber reinforced plastics.

Taking a disc type flywheel of 4 strokes, 4 cylinder diesel engines, which is used to transmit the power of 2.25 kW at 2740 rpm. It has to be design and optimization by changing the materials. By identify the stress and deformations in flywheel from Theoretical and Numerical. As per given below inputs, Analysis which is best material for given design.Validate results by comparing theoretical and Numerical and plot best material for use as given design data.

3.2 Aspects Of Proposed Work:

The proposed research work is intended to exploit the advantages of using different materials in the design of flywheel and different properties of them are studied both theoretically and numerically. This provides basic understanding the behavior of the various materials and response in the following aspects are studied

- Variations in their Radial and Tensile stresses of the various materials along the radius of the flywheel and comparing one on another.
- Variations in their Radial and Tangential strains of the various materials along the radius of the flywheel and comparing one on another.
- Von Mises stress of the materials.
- Deformations of the materials.

4. Flywheel Design:

Flywheels are generally used for kinetic energy storage and have been around since the early times of man. Every object rotating around an axis stores some amount of kinetic energy and could in theory be called a flywheel. But the word flywheel is usually used for constructions whose main purpose is the storage of kinetic energy through rotation. This has led to the convention that the term flywheel describes a rotating, cylindrical object, usually of considerable mass, whose main purpose is to store energy or to increase the moment of inertia of a given system.

4.1 Design Approach

There are two stages to the design of a flywheel.

• First, the amount of energy required for the desired degree of smoothening must be found and the (mass) moment of inertia needed to absorb that energy determined.



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• Then flywheel geometry must be defined that caters the required moment of inertia in a reasonably sized package and is safe against failure at the designed speeds of operation.

4.2 **Design Parameters:**

Flywheel inertia (size) needed directly depends upon the acceptable changes in the speed.

4.2.1 Speed fluctuation:

The change in the shaft speed during a cycle is called the speed fluctuation and is equal to $\omega_{max}\text{-}\omega_{min}$

 $\mathbf{F}_{l} = \boldsymbol{\omega}_{max} - \boldsymbol{\omega}_{min}$

We can normalize this to a dimensionless ratio by dividing it by the average or nominal shaft speed (ω_{ave}) .

 $C_f = (\omega_{max} - \omega_{min})/\omega$

Where

 C_f =coefficient of speed fluctuation ω_{ave} =Average or mean ω = nominal angular velocity The coefficient is a design parameter to chosen

by the designer and it must be small.

4.2.2 Design equation:

The kinetic energy in rotating system is given by

$$\mathbf{K} \cdot \mathbf{E} = \frac{1}{2} \mathbf{I} \omega^2$$

The change in KE is given as $K.E = E_2 - E_1 = \frac{1}{2}I_m (\omega_{max}^2 - \omega_{min}^2)$

$$\omega_{avg} = \frac{(\omega_{max} + \omega_{min})}{2}$$

K.E =
$$\frac{1}{2}$$
I_S (2 ω_{avg}) (**C**_f ω_{min}^{2}) = **E**₂-**E**₁

Thus the mass moment of inertia I_m needed in the entire rotating system in order to obtain selected coefficient of speed fluctuation is determined using the relation

K.E =
$$\frac{1}{2}$$
I_S (2 ω_{avg}) (**C**_f ω_{avg})

 $I_{\rm S}$ =K.E/ ($C_{\rm f} \omega_{\rm avg}^2$)

For solid disc geometry with inside radius r_i and outside radius r_o , the mass moment of inertial_m is

$$I_{\rm m} = {\rm mk}^2 = \frac{{\rm m}}{2} [({\rm r}_0)^2 + ({\rm r}_i)^2]$$

The mass of a hollow circular disc of constant thickness t is

$$m = W/g = \rho \pi [(r_0)^2 + (r_i)^2]t$$

From the above two equations

 $I_{m} = \frac{\pi \rho}{2} [(r_{0})^{4} + (r_{i})^{4}]t$

The above equation can be used to obtain appropriate flywheel inertia I_m corresponding to the known energy change K.E for a specific value coefficient of speed fluctuation C_f ,

4.2.3Torque Variation and Energy

The required change in kinetic energy K.E is obtained from the known torque time relation or curve by integrating it for one cycle.



Stresses in Flywheel: Flywheel being a rotating disc, centrifugal stresses acts upon its distributed mass and attempts to pull it apart. Its effect is similar to those caused by an internally pressurized cylinder

 $\begin{array}{lll} \mbox{Radial stress } \sigma_r = & \rho \omega^2 \left[\frac{3+\mu}{8} \right] \left[r_0^2 + r_i^2 - \frac{r_0^2 r_i^2}{r^2} - r^2 \right] \end{array}$



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Tangential stress $\sigma_{\theta} = \rho \omega^2 \left[\frac{3+\mu}{8}\right] \left[r_0^2 + r_i^2 - r_0^2 r_0^2 - 1 + 3\mu 3 + \mu r^2\right]$

The maximum tensile and radial stresses are Equal and both occur at (r=0)



fig.4.2 Stresses in a flywheel



Design consideration for flywheel:

- Flywheels are rotating devices that store rotational energy in applications such as automotive transmissions.
- It must be stores maximum energy per unit volume/mass at a specified angular velocity.

μ

=

- The stresses must not exceed the limit value
- It should good machinability
- Good fatigue resistance
- Cheap in cost

Where ρ = Density of the material kg/m³

Poissions ratio

R = Outer radius in mm

4.2.4Torque Time Relation without Flywheel:

A typical torque time relation, for example of a mechanical punching press without a flywheel in shown in the figure.

In the absence of fly wheel surplus or positive energy is available initially and intermedialty and energy absorption or negative energy during punching and stripping operations. A large magnitude of speed fluctuation can be noted. To smoothen out the speed fluctuation fly wheel is to be added and the fly wheel energy needed is computed as illustrated below:

Design procedure for flywheel in CATIA:-

- Sketch is made in the sketcher module as per measurements (fig 2).
- The sketch is sent to part module to make a solid part.
- By using revolve command the sketch is revolved and an disc is obtained.
- The five holes are made by using pocket command with respect to the circles made on the disc plate and a circular array is made with respect to the centre hole.
- Gear tooth is made by using groove command and circular array command (fig .3)



Fig.4.4. Sketcher of Flywheel



Fig. 4.5 Part model of Flywheel

Selection of materials: Gray cast iron: Gray cast it

Gray cast iron:Gray cast iron is made by re melting iron. It is an alloy of Carbon and iron. Small amounts of silicon, phosphours, manganese and sulphur are also present in it. The reason behind its popularity are ability to make complex shapes and low cost.

High Strength steel 4340:

AISI 4340 alloy steel is a heat treatable and low alloy steel containing chromium, nickel and molybdenum. It



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has high toughness and strength in the heat treated condition AISI 4340 alloy steel has good ductility and formability in the annealed condition.

Carbon fiber reinforced plastic:

Carbon fibers are usually combined with other materials to form a composite. When combined with a plastic resin and wound or molded it forms carbonfiber-reinforced polymer which has a very high strength-to-weight ratio, and is extremely rigid although somewhat brittle. However, carbon fibers are also composited with other materials, such as with graphite to form carbon-carbon composites, which have a very high heat tolerance.

Magnesium alloys (AZ91A):

Magnesium and magnesium alloys are nonferrous metals with low density, good ductility, moderate strength and good corrosion resistance. Its high specific toughness and rigidity, good machinability, castability and weldability with known methods are maked it attractive for industry. These magnesium alloys have a relatively low density and can help improve fuel efficiency.

Titanium Alloys(6Al4V):

Titanium isa "formidable" material having high strength and toughness. Titanium is an abundant earth element, but it is difficult to refine. Titanium is quite expensive, and since it is not widely used, the introduction of a single new product can result. Designing with titanium taking all factors into account has resulted in reliable, economic and more durable systems and components, which in many situations have substantially exceeded performance and service life expectations.

Beryllium alloy:

Beryllium is as an alloying element, that are used to make components, which are inert, stable, and do not give off emissions during use. Beryllium-containing alloys are only used in critical locations in products where they provide a design solution based upon

S. No	Material	Density p (kg/m³)	Young's Modulus E (GN/m²)	Poissions Ratio μ	Ultimate Tensile Strength σ _{ut} (N/m ²)	Yield Strength _{σy} (MN/m ²)	Cost (\$/kg)
1	Gray Cast	7510	101	0.23	430	276	1.19
	Iron						
2	High	7800	210	0.29	1550	1240	0.25
	Strength						
	Steel						
	4340						
3	Carbon	1600	150	.28	550	200	110
	Fiber						
	reinforced						
	plastic						
	(CFRP)						
4	Mg-Alloy	1740	44.12	0.35	250	160	1.48
5	Titanium	4500	100	.36	950	910	16.25
	Alloy						
	(6A14V)						
6	Beryllium	2900	245	0.12	500	360	315.00
	alloy						

reliability, miniaturization, improved energy management and /or extending the service life.

Table.: Materials and their properties

S.No	Material	Total Mass Kg	Mass Moment of Inertia kg-mm ²	KE N-mm	Efficiency of the flywheel (K.E/Mass) J/Kg
1	High Strength Steel 4340	10.8113	0.10671	4413.14	408.1976
2	Gray Cast Iron	10.4093	0.10274	4249.06	408.1976
3	Titanium Alloy (6Al4V)	6.23727	0.06156	2546.04	408.1976
4	Beryllium alloy	4.01958	0.03967	1640.78	408.1976
5	Mg-Alloy	2.41175	0.0238	984.469	408.1976
6	CFRP	2.2177	0.02189	905.258	408.1976

Table: calculations of Design parameters of theflywheel for various materials



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Part model of Flywheel

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Complete meshing of flywheel



Boundary conditions of flywheel in Ansys

5. Results & Discussions

5.1 Results from Theoretical calculations:



Comparison of mass of the flywheel



Comparison of Kinetic Energy of the flywheel



Radial stresses of the Flywheel from theoretical calculations



Tangential stresses of the Flywheel theoretical calculations

Material 1: Beryllium Alloy



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Deformation Be-Alloy



Equivalent stresses of Be-Alloy



Equivalent strains of Be-Alloy



Radial stresses of Be-Alloy



Tangential stresses of Be-Alloy



Radial and tangential strains of Be-Alloy



Results of Radial Stresses from Ansys



Results of Tangential Stresses from Ansys

Material	Max / Min	Displacement u mm	Radial Stress or N/mm ²	Tangential Stress σt N/mm ²	Von Mises Stress ov N/mm ²	Radial Strain e _r	Tangential Strain ε _θ	Equivalent strain
Beryllium	max	6.86×10-4	1.49	3.84	5.49	1.33×10-5	5.38×10-5	2.24×10-6
alloy	min	2.03×10-6	0.71	1.51	0.20	2.80×10-6	6.38×10-6	8.79×10-7
CEPD	max	5.67×104	0.97	1.89	2.62	4.03×10-6	8.66×10-6	1.75×10-5
CIAr	min	2.28×10-6	0.45	0.67	0.05	2.78×10-6	3.33×10-6	4.01×10-7
Gray Cast	max	4.06×10-3	4.39	9.92	12.91	3.07×10-5	9.27×10-5	1.28×104
Iron	min	7.22×10-6	2.19	2.77	0.31	2.02×10-5	2.48×10-5	3.44×10-6
High	max	1.97×10-3	4.76	10.28	12.64	1.39×10-5	3.99×10-5	6.02×10-5
Strength Steel	min	8.99×10-	2.18	2.76	0.21	9.56×10⁵	1.14×10-5	1.35×10-6
Mg Allow	max	2.02×10-3	1.10	1.9	2.63	1.36×10-5	3.34×10-5	5.96×10-5
Mg-Alloy	min	1.71×10-5	0.48	0.59	0.01	9.31×10 ⁻⁶	1.11×10-5	1.21×10-6
Titanium	max	2.29×10-3	3.01	5.45	6.70	1.53×10-5	3.44×10-5	6.70×10-5
Alloy (6Al4V)	min	1.32×10 ⁻⁴	1.23	1.52	0.05	1.05×10-5	1.25×10-5	1.36×10-6

Results from Ansys



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Total deformation of the flywheel vs. materials from FEM



Radial Stresses of the flywheel vs. materials from FEM



Tangential Stresses of the flywheel vs. materials from FEM



Von Mises Stresses of the flywheel vs. materials from FEM



Radial Strain of the flywheel vs. materials from FEM



Tangential Strain of the flywheel vs. materials from FEM



Deformations of the flywheel vs. materials comparing the Ansys and Theoretical results





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Radial stressof the flywheel vs. materials comparing the Ansys and Theoretical results



Tangential stresses of the flywheel vs. materials comparing the Ansys and Theoretical results



Radial strain of the flywheel vs. materials comparing the Ansys and Theoretical results



Tangential strain of the flywheel vs. materials comparing the Ansys and Theoretical results

6. Conclusion :

This optimization is carried out between the various materials, to find the minimum mass and respective

values of stresses along radius by conducting static analysis.

From the analysis, it is clear that, Carbon Fiber is the best material it is having low mass as compared to the other material and also the stresses and strains in the carbon fiber is also low compared to the other materials.

Magnesium alloy is also the best material which is capable of withstanding stresses that are developed within the flywheel. From the analysis, by using the magnesium alloys we can reduce the stresses 77% when compared to H S steel, 75% when compared to cast iron, also by using Magnesium alloys we can reduce the mass upto 75%.

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