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FLYWHEEL DESIGN AND COMPARATIVE STUDY

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Abstract : A flywheel is a mechanical device that stores rotational energy using the conservation of angular momentum. It is commonly used to provide continuous power output in systems where the energy source is not continuous. The purpose of this paper is to compare several flywheels designed for use in a hammering machine in various configurations.

***IndexTerms* - Flywheel, SolidWorks, Coefficient of Fluctuation of Speed (Cs), Coefficient of Fluctuation of Energy (ΔE), Mass moment of Inertia.**

I. INTRODUCTION

A flywheel used in machines serves as a reservoir that 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 the supply.

In the case of steam engines, internal combustion engines. reciprocating compressors and pumps, the energy is developed during one stroke and the engine is to run for the whole cycle on the energy produced during this one stroke. for example, in i.c. engines, the energy is developed only during power stroke which is much more than the engine load, and no energy is developed during suction, compression, and exhaust strokes in the case of four-stroke engines and during compression in the case of two-stroke engines the excess energy developed during a power stroke is absorbed by the flywheel and released to the crankshaft during other strokes in which no energy is developed, thus rotating the crankshaft at a uniform speed. A little consideration will show that when the flywheel absorbs energy, its speed increases, and when it releases, the speed decreases. Hence a flywheel does not maintain a constant speed, it simply reduces the fluctuation of speed.

In machines where the operation is intermittent like punching machines, shearing machines, riveting machines, crushers, etc., the flywheel stores energy from the power source during the greater portion of the operating cycle and gives it up during a small period of the cycle. Thus the energy from the power source to the machines is supplied practically at a constant rate throughout the operation.

II. PROBLEM STATEMENT

Conducting a comparative study on different types of Flywheel designed for a specific engine for a specific purpose.

III. LITERATURE REVIEW

[1]A Detail Review on Study of Flywheel:-
In this paper we have studied what the material of a flywheel could be like cast iron or carbon fiber. We studied the effect of load on break power and the result is that if the load increases break power increases. As well as load increases, volumetric efficiency also increases. In suction, compression and exhaust stroke power is taken from the engine.

[2] Composite flywheel material design for high- speed energy storage -
This study investigated the mechanical properties of materials suitable for flywheel high-speed energy storage. The study found that a hybrid composite of M46J/epoxy–T1000G/epoxy exhibited higher energy density compared to existing flywheel hybrid composite materials such as boron/epoxy–graphite/epoxy. The study used design and stress analysis to determine the maximum energy densities and shape factors for the flywheel. Analytical studies and CADEC-online software were used to evaluate the lamina and laminate properties. The findings of this study could contribute to further development of the flywheel as a promising application for energy storage due to significant improvements in composite materials and technology.

[3]Research on Structure for Flywheel Energy Storage System in Long Lifetime UPS:-This paper establishes the flywheel energy storage organization (FESS) in a long lifetime uninterruptible power supply. The Flywheel Energy Storage (FES) system has emerged as one of the best options. This paper presents a conceptual study and illustrations of FES units. After a brief introduction to the FES system and its theory of operation, the paper focuses on the important role of the FES system in enhancing the operation of the distribution network. Supported by illustrated circuits, the FES system in the improvement of the power quality of the network. A flywheel energy storage technology was ended, with a special focus on the progress in automotive applications. In order to improve the efficiency and lifetime, then it discusses a newly proposed design of the FES system that emerged recently, which includes the use of Superconducting Magnetic Bearings (SMB) and Permanent Magnetic Bearings (PMB). In conclusion, the paper analyzes the FES systems great potentials that could be exploited in improving the reliability of the electrical system

IV. METHODOLOGY

4.1 Types of Flywheel:-

Rim Flywheel: A rim flywheel consists of a heavy wheel with a rim that is attached to a central hub. The rim of the wheel is designed to store energy by rotating at high speeds. The rim flywheel has a high moment of inertia, which allows it to store a large amount of energy. This type of flywheel is commonly used in vehicles, such as cars and buses, to store energy from regenerative braking.

Curved Arm Flywheel: A curved arm flywheel consists of a disc with several curved arms extending from its center. The arms are designed to store energy by rotating at high speeds. The curved arm flywheel has a relatively low moment of inertia, which makes it ideal for applications that require high-speed rotation, such as in gyroscopes and precision instruments.

Flat Disc Flywheel: A flat disc flywheel consists of a flat disc that is attached to a central hub. The disc is designed to store energy by rotating at high speeds. The flat disc flywheel has a medium moment of inertia, which makes it suitable for a wide range of applications, such as in power generation and energy storage systems.

4.2 Working Principle:

The turning moment of a four-stroke engine for different positions of the crank is only positive for the power stroke. An I.C. The engine produces power only during the power stroke. From the turning We can see the moment diagram (fig. 3.1); during suction, there is a negative turning moment due to cylinder pressure of less than 1 atmosphere.

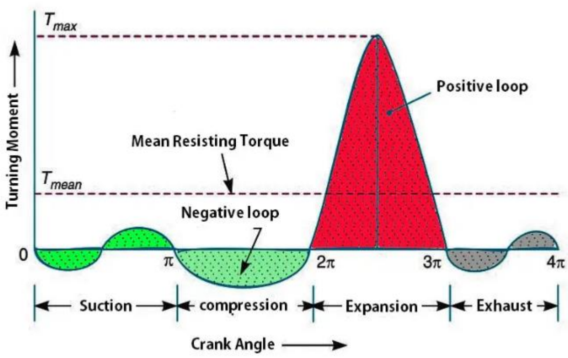

Fig. no. 3.2.1

Similarly, energy is taken from the crankshaft and flywheel to do work on the gasses; which results in a much higher negative turning moment. Then during the power stroke, we see a surge in positive turning moment; due to the expanding gas pressure. While during the exhaust stroke gas is released by working onto the gas; resulting in a negative turning moment.
From the given turning moment diagram; one can clearly see the torque/turning moment generated is much more than the mean torque. So there is this extra torque generated during the power stroke; which needs to be stored and then released using the flywheels. The energy stored by a flywheel with a very thin rim and mass “m” can be given by:-
$\Delta E = I\,\omega^2 (\omega_1-\omega_2)/\omega$ Or $\Delta E = I\,\omega^2\,Cs$

4.3 Calculations:

A single-cylinder, single-acting, four-stroke oil engine was referred to as the prime power source for the Flywheel. The Engine develops 20Kw of power at 300 rpm. The Engine has a Work-done ratio of Expansion to Compression of 2.3. And the purpose of the Engine-Flywheel system is to drive a Hammering Machine.

Given
Power (P)= 20 Kw = 20×10^3 W
N = 300 rpm; ω=31.42 rad/s
Tmean = 636.5 N-m
Work done per cycle (W) = 8000 N-m
We = Work done during Expansion

W_c = Work done during Compression

Work done during Suction and Exhaust is considered negligible, therefore net work done per cycle (W) =

$W = W_e - W_c$

$W = 0.565 W_e$

Therefore;

W_e = 14160 N-m

Calculating W_e in terms of T_{max}

$W_e = 1.571 T_{max}$

T_{max} = 9013 N-m

Similarly

Maximum Fluctuation of Energy ΔE = 12230 N-m

The purpose of the system is to drive a Hammering Machine, therefore referring to the permissible Coefficient of Fluctuation of Speed

$C_s = 0.200$

Mass moment of Inertia = I

$\Delta E = I \omega^2 C_s$

I = 61.95 kg-m²

For Rim Flywheel: $I = m k^2$

The radius of Gyration is assumed as 0.5m

Therefore m = 247 kg

For Flat Disc Flywheel: $I = \frac{1}{2} m k^2$

Similarly, the Radius of Gyration is assumed to be 0.5m

Therefore m = 494 kg

From the above-calculated data, 3 Flywheels were designed

- Simple Rim Flywheel
- Curved Arm Flywheel
- Flat Disc Flywheel
-

For each Flywheel 3 different materials were used, they are

- Gray Cast Iron (ρ = 7200)
- Cast Carbon Steel (ρ = 7800)
- Aluminium Alloy AISI 1060 (ρ = 2700)

As the materials differed for flywheels the thickness and width of the Rim (for Rim Flywheels) and the thickness of the Disc (for Flat Disc Flywheels) differed but they were derived in the same way.

For Rim Flywheel: $A * 2\pi R * \rho = m$

$A = b * t$ (where = width; t= thickness; and b/t = 2)

Therefore the thickness and width were calculated as

Gray Cast Iron (ρ = 7200)

b = 12.2 cm; t = 6.1 cm

Cast Carbon Steel (ρ = 7800)

b = 14.2 cm; t = 7.1 cm

Aluminium Alloy AISI 1060 (ρ = 2700)

b = 23.8 cm; t = 11.9 cm

For Flat Disc Flywheel: $t * \pi R^2 = m$

Gray Cast Iron (ρ = 7200) t = 8.7 cm

Cast Carbon Steel (ρ = 7800) t = 8.06 cm

Aluminium Alloy AISI 1060 (ρ = 2700); t = 2.5 cm

These Flywheels were then simulated in SolidWorks and the Stress and Strain acting on the Flywheels deformations were measured.

4.4 Model:

Fig. 2 Simple Rim Flywheel

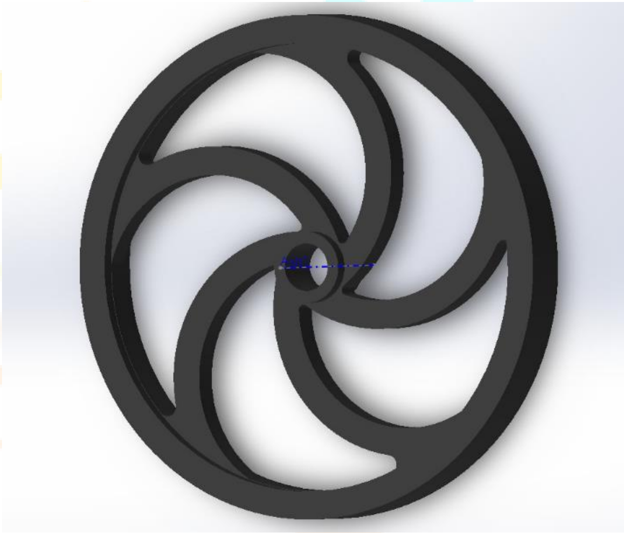

Fig. 3 Curved Arm Flywheel

Fig. 4 Flat Disc Flywheel

V. RESULT AND DISCUSSION

All the 3 flywheels with the 3 materials each were simulated in SolidWorks. Centrifugal force was applied to the Flywheel with reference to the axis through the center, the force was applied by giving the flywheel an angular velocity of 31.42 rad/s. The inner wall of the shaft hole was referred to as Fixed Geometry and the deformations were scaled to a factor of 1200%. Two extra nodes (mid-way on the arm and outer surface of the flywheel) were also placed to calculate the stress, strain, and deformation at those points. Some of the Deformation Graphs can be seen below.

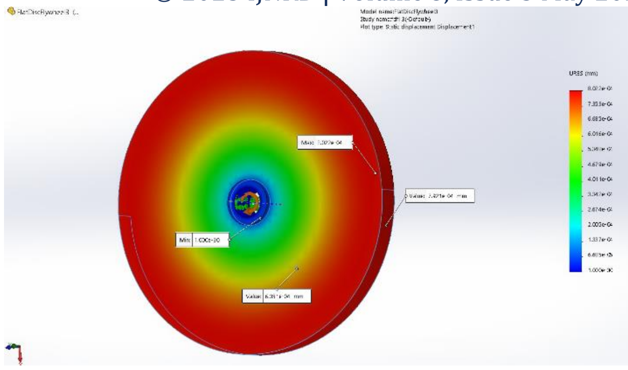

Fig. 5 Flat Disc Flywheel Deformation

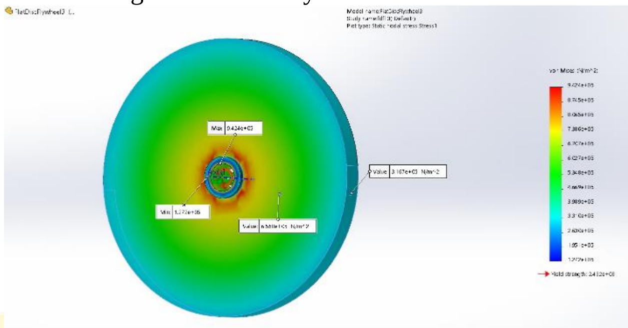

Fig. 6 Flat Disc Flywheel Stress

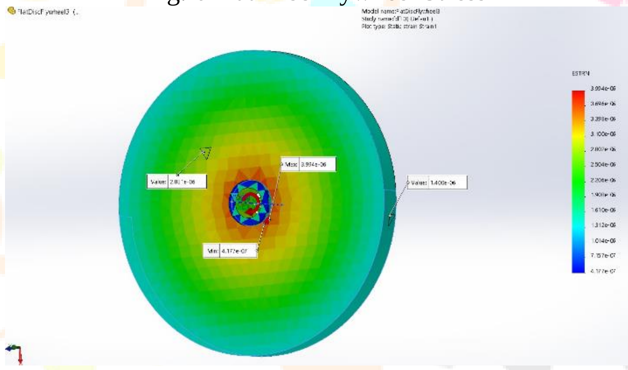

Fig. 7 Flat Disc Flywheel Strain

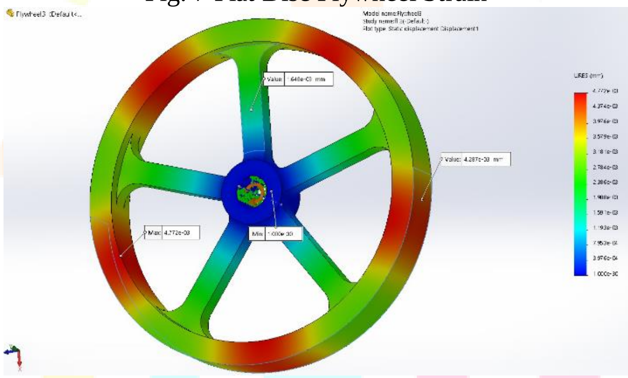

Fig. 8 Rim Flywheel Displacement

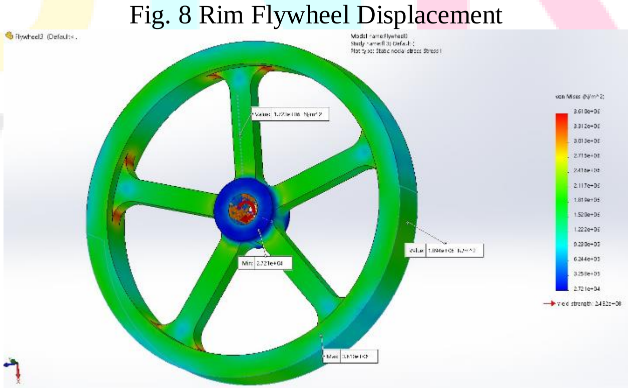

Fig. 9 Rim Flywheel Stress

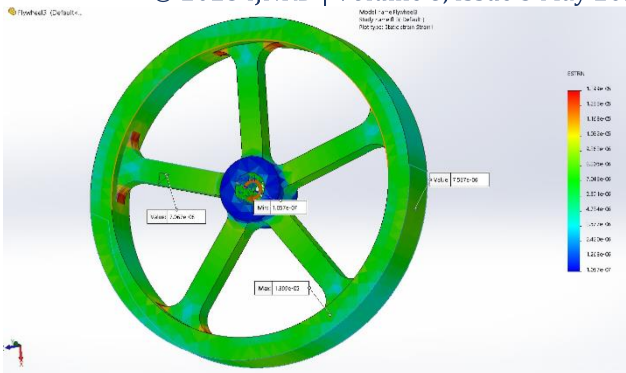

Fig. 10 Rim Flywheel Strain

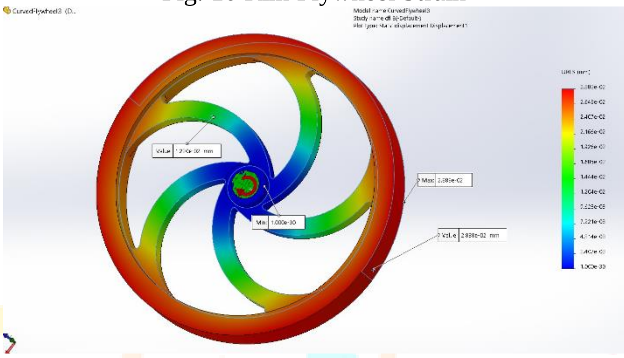

Fig. 12 Curved Arm Flywheel Displacement

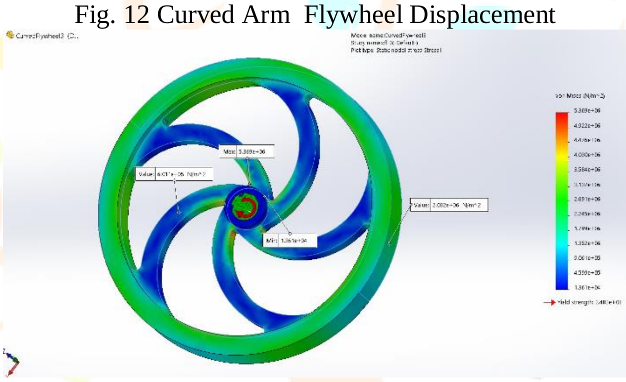

Fig. 13 Curved Arm Flywheel Stress

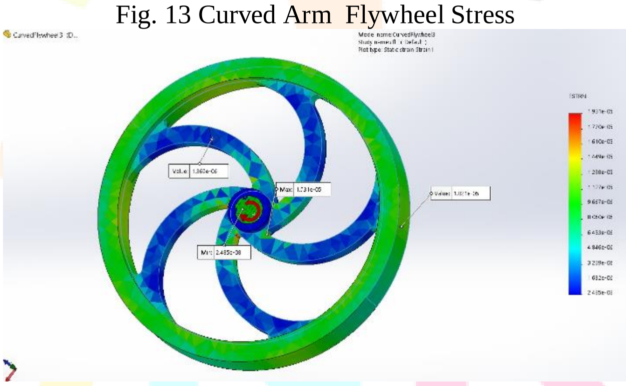

Fig. 11 Curved Arm Flywheel Strain

The Data Derived from the above Graphs is tabularised and presented below in Table 1,2,3

Material	Gray Cast Iron			
Configuration		Stress ()	Strain	Deformation
	Min	2.17E+04	1.31E-06	1.00E-30
	Max	3.35E+06	3.90E-05	1.40E-02
	Node1	1.40E+06	1.72E-05	4.52E-03
Rim Flywheel	Node2	8.48E+05	1.14E-05	7.24E-03
	Min	1.73E+04	1.68E-07	1.00E-30
	Max	3.39E+06	5.22E-05	9.02E-02
	Node1	4.09E+05	1.93E-06	4.06E-02
Curved Arm Flywheel	Node2	1.04E+06	1.59E-05	8.83E-02

Flat Disc Flywheel	Min	1.69E+05	1.47E-06	1.00E-30
	Max	8.262+05	1.02E-05	2.40E-03
	Node1	5.61E+05	6.26E-06	1.72E-03
	Node2	3.15E+05	4.03E-06	2.371-03

Table 2. Gray Cast Iron

Material	Cast Carbon Steel			
Configuration		Stress (N/m^2)	Strain	Deformation (mm)
Rim Flywheel	Min	2.72E+04	1.06E-07	1.00E-30
	Max	3.61E+06	1.40E-05	4.77E-03
	Node1	1.72E+06	7.07E-06	1.65E-03
	Node2	1.85E+06	7.54E-06	4.287-e03
Curved Arm Flywheel	Min	1.36E+04	2.49E-08	1.00E-30
	Max	5.37E+06	1.93E-05	2.89E-02
	Node1	6.01E+05	1.37E-06	1.22E-02
	Node2	2.08E+09	1.02E-05	2.84E-02
Flat Disc Flywheel	Min	1.27E+05	4.18E-07	1.00E-30
	Max	9.42E+05	3.99E-06	8.02E-04
	Node1	6.57E+05	2.83E-06	6.35E-04
	Node2	3.17E+05	1.40E-06	7.92E-04

Table 3. Cast Carbon Steel

Material	Aluminium Alloy AISI 1060			
Configuration		Stress	Strain	Deformation
Rim Flywheel	Min	5.13E+03	5.72E-08	1.00E-30
	Max	1.17E+06	1.37E-05	4.58E-03
	Node1	8.29E+05	1.05E-05	2.02E-03
	Node2	5.64E+05	7.311e	7.31E-06
Curved Arm Flywheel	Min	6.94E+02	1.59E-08	1.00E-30
	Max	1.87E+06	1.79E-05	2.29E-02
	Node1	1.06E+05	1.39E-06	8.84E-03
	Node2	5.31E+05	7.69E-06	2.27E-02
Flat Disc Flywheel	Min	7.18E+04	4.63E-07	1.00E-30
	Max	3.54E+05	3.97E-06	8.01E-04
	Node1	2.13E+05	2.61E-06	5.80E-04
	Node2	1.09E+05	1.42E-06	7.90E-04

Table 4. Aluminium Alloy AISI 1060

By comparing the above-derived data, it can be observed that the minimum stress that can be observed in all three Flywheels is in the Curved Arm Flywheel, at the same time, maximum stress observed is also Curved Arm Flywheel. Though moving on the stress concentration in Curved Arm Flywheel seen by observing the deformation fig is on the Rim itself as well as the where the arms are joined at the center hub. As most of the stress concentration is at the rim and very less at in the arms the possibility of failure occurring in the Arms decreases quite a bit.

While on the other hand in Simple Rim Flywheel the stress concentration is distributed quite equally in the Arms and Rim. But, observing the Flat Disc Flywheel, barely any stress can be seen at the outer edge of the flywheel, almost all the stress is concentrated near the center.

VI.Conclusion

As per the study on the rim flywheel, the Curved Arms Flywheel experience less stress than Straight Arms in the flywheel arms as they are more flexible, but The Straight Arm Flywheel experience less Stress on average.

Due to these reasons Curved Arm Flywheels could be said to be more preferable to than the Straight Arm Flywheels, but Straight Arm Flywheel are still the most used flywheels for various reasons, one of the primary resons being that the stress is equaly divided through the whole structure, because of this risk of failure decreases, as well as that the Straight Arms are easier to cast and Lighter. Similarly comparing Flat Disc Flywheel, the moment of Inertia of a rim is more than that of a disc of the same mass as the mass is distributed farther away from the center in a rim, so to get the same amount of inertia we require greater mass in a flat disc Flywheel, which means more material used, which equals greater material cost.

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