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# Design and Development of Dual Mass Flywheel for Improving Energy Storage Capability

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**ABSTRACT**

**The rapid developments of vehicle technology over the last few decades, flywheels have been used to achieve smooth operation of machines. The early models where purely mechanical consisting of only a stone wheel attached to an axle. Nowadays, flywheels are complex constructions where energy is stored mechanically and transferred to an integrated motor/generator. The stone wheel has been replaced by a steel or composite rotor and magnetic bearings have been introduced. Today flywheels are used as supplementary UPS storage at several industries world over. Flywheels serve as kinetic energy storage and retrieval devices with the ability to deliver high output power at high rotational speeds as being one of the emerging energy storage technologies available today in various stages of development, especially in advanced technological areas, that is spacecrafts.**

**Today, most of the research efforts are being spent on improving energy storage capability of flywheels to deliver high power transfer, lasting longer than conventional battery powered technologies. This study solely focuses on exploring the effects of dual mass flywheel geometry for improving energy storage capability to deliver high power transfer per unit mass, as compared to conventional flywheel. Dual mass flywheel also reduces the weight of the flywheel using composite materials. In this study using the two spring two mass system to produce useful vibrations which will be employed to increase the inertia of the system and thereby enable to reduce the weight of existing flywheel or increase power output using existing weight of flywheel.**



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## I. INTRODUCTION

A flywheel is a mechanical device which is used as a storage device for rotational energy called as kinetic energy. It helps to resist changes in their rotational speed of engine, when fluctuating torque applied on shaft by source it helps to keep steady the rotation of the shaft. Flywheels have become the subject of extensive research as power storage devices for uses in vehicles. 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. Flywheel is basically a rechargeable battery. It is used to absorb electric energy from a source, store it as kinetic energy of rotation and then deliver it to a load at the appropriate time in the form that meets the load needs. As shown in Fig.1 a typical system consists of a flywheel, a motor/generator and controlled electronics for connection to a larger electric power system.

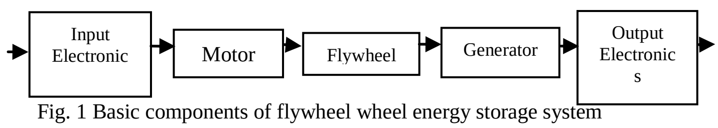


Fig. 1 Basic components of flywheel wheel energy storage system

Fig.1 shows basic components of flywheel energy storage system the input power may differ from the output power. It is converted by the input electronics into a form appropriate for efficiently driving a variable-speed motor. The motor rotates the flywheel, which stores mechanical energy that is rotational energy generally called as kinetic energy and this energy delivers to a load. The mechanical energy is then converted into electrical energy by the generator. The variable-frequency electronics output from the generator is converting into the electric power. Since the input and output are typically separated in a timely manner, mostly the motor and generator combine into a single machine, and place the input and output electronics into a single module, to reduce weight and cost. Modern high-speed flywheels differ from their forebears in being lighter and spinning much faster.

### *A. Introduction of duel mass flywheel*

If the power output of an engine is measured first with light flywheel and then again with the standard part on an engine dyno, not changes in power observed. At first it appears that the light flywheel has done nothing and was a total waste of cash. This is not the case. A dyno that shows maximum power at constant revolutions does not demonstrate what happens to an engine's power output in real life situations like acceleration. If an engine is accelerated on a dyno (talking about a rate of around 2000 rpm) it would show a power output is around 20%-25% less than at the constant revolution state. The reason for this is that when accelerating a vehicle the engine not only has to push the total mass of the car but the internal components of the engine need to be accelerated also. This tends to absorb more power as the extra power is used accelerating the internal mass of the engine components and is why a motor accelerating on a dyno will produce less power than at constant revolutions. Also it must be remembered that the rate of acceleration on the engine internals is much greater that the rest of the car. This would then suggest that by lightening the flywheel, less power would be required to accelerate it and therefore more power would be available to push the car along.

All engines have flywheels or weighted crankshafts that balance out compression and power strokes, maintain idle, aid starting and reduce component wear. If the flywheel is too light the motorcycle requires more effort to start, idles badly and is prone to stalling. Weight is not the important factor here but inertia. Due to inertia of flywheel energy is stored in it and is not directly proportional to flywheel weight. It’s possible to have a light flywheel with much more inertia than a heavier flywheel. Any power the motor develops must accelerate the flywheels before leaving the sprocket shaft and any used in bringing the flywheel up to speed is not available at the rear wheel. This will not show up on a steady-state or rear wheel dyno or simple desk-top dyno program but is detectable in a transient dyno that accelerates the engine at a specific rate (300 or 600 rpm per second are common). Flywheel inertia is stored when you revolve the engine slightly before letting the clutch out - this small amount of extra power helps in getting the motorcycle underway with minimal effort. By “borrowing” power for a few seconds the engine has to develop less to move from a standing start. Once the clutch is completely engaged, inertia can no longer be borrowed - the motorcycle can only use what it produces in “real time”. In any event except for when the clutch is slipped all flywheel weight reduces acceleration.

As per study the above discussion we can says that the flywheel inertia plays a major role in vehicle to optimized performance. The arrangement of the dual mass flywheel is a solution to the above problem statement where in the inertia is increased using two set of masses phased opposite to each other.

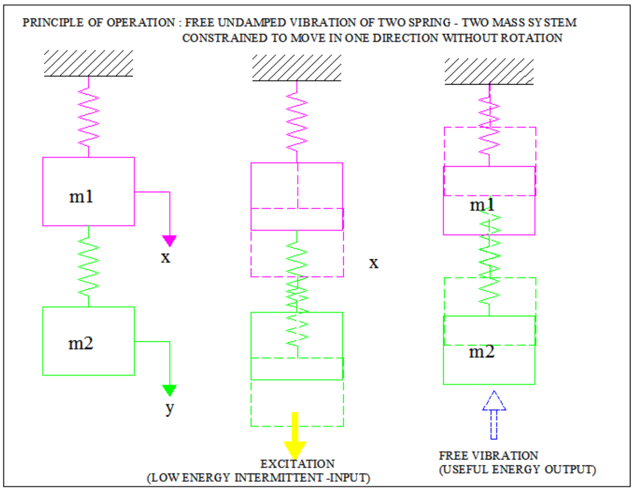


Fig.2 Mathematical model with two mass two spring system

The arrangement of the dual mass flywheel is best explained by the mathematical model below the model is a two spring two mass models graphically represented as below. The Fig. 1 shows free un-damped vibrations set up of two mass- two spring systems. As shown in the figure the input to the system is in the form of an low energy intermittent input from any power source (excitation), this results in free un-damped vibrations are set up in the system resulting in the free to and fro motion of the mass (m1) and (m2), this motion is assisted by gravity and will continue until resonance occurs that is the systems will continue to work long after the input (which is intermittent) has ceased hence the term free energy is used.

### *B. Problem statement*

In an ordinary conventional flywheel the engines ignition-induced rotational speed irregularity causes torsional vibration in the vehicles driveline also the fluctuations in engines speed. At a given speed the ignition frequency is equal to the natural frequency of the driveline so that extremely high vibrations amplitudes occur that causes rattle in transmission. Also more mass of flywheel increases the cost of engine.

### *C. Methodology*

In this study the two stroke petrol engine is used as a prime mover to run the test rig. In the planetary dual mass flywheel the torsional vibration damper is incorporated into the flywheel as a two arc spring and two masses on the conventional flywheel. For this purpose the flywheel is divided into a primary and a secondary mass hence the name exists “dual mass flywheel”. Transmission rattle is rectified by DMF. Again by reducing the mass and keeping the Inertia factor same will be able to optimize the dual mass flywheel giving the better results than that of conventional flywheel that is power output and efficiency of engine.

### *D. Objectives of project*

1. Development of mathematical model for optimization of flywheel mass to derive stipulated output power.
2. Design and development of inertia augmentation mechanism.

 

3. Design and development of optimized flywheel using inertia augmentation technique.
4. Test and trial on optimized flywheel using test rig.
5. Plot performance characteristic curves.

*E. Scope*

1. Lowered weight of flywheel system will reduce system weight thereby leading to better fuel economy of vehicle and also reduce overall material cost.
2. Compact size: The size of the flywheel will lead to better cabin space of vehicle.
3. Engine life increases due to balanced power output.

## II. LITERATURE REVIEW

Bjorn Bolund, Hans Bernhoff, Mats Leijon et al [1] studied the use of flywheel. Nowadays flywheels are complex construction where energy is stored mechanically and transferred to and from the flywheel by an integrated motor or generator. The wheel has been replaced by a steel or composite rotor and magnetic bearings have been introduced. By increasing the voltage, current losses are decreased and otherwise necessary transformer steps become redundant.

Guangming Zhao, Zhengfeng Jiang, Lei Chen [2] studied that they have offered an investigation of DMF-CPVAs setup for isolating torsional vibration from engine. The simplified mathematical model of DMF-CPVAs setup is built based on the linear theory, the performance of the setup is analyzed and the result shows that using CPVAs on the DMF leads to an advantage of isolation vibration instead of just damping vibrations at a specific frequency could dampen vibrations over a range of frequencies.

Jake Amoroso [3] studied that energy storage is becoming increasingly important with the advent of individual electronic devices and the rising need to accommodate a greater population, which relies on these devices. This author proposes the use of flywheel energy storage in conjunction with differential absorption as a method for generating clean long lasting energy. As will be discussed later, the introduction of a new glass 50 times stronger allows the development of this new energy source. Without entering into a large discussion on flywheel design and technical considerations or differential absorption a small amount of background information shall be presented to familiarize the reader with the general theory behind the concept.

Ulf Schaper, Oliver Sawodny, Tobias Mahl and Uti Blessing [4] they studied that Dual Mass Flywheel (DMF) is used as oscillations damper in automobile for prevent gearbox rattling. This mainly includes a model for the two arc springs in the DMF and their friction behavior. Both centrifugal effects and redirection forces act radially on the arc spring which induces friction. A numerical simulation of the DMF model is compared to measurements for model validation. Finally the observability of the engine torque using the DMF is discussed. For this purpose a linear torque observer is proposed and evaluated.

Kevin Ludlum [5] studied that a flywheel is an energy storage device that uses its significant moment of inertia to store energy by rotating. Flywheels have long been used to generate or maintain power and are most identified with the industrial age and the steam engine. In one sense it can be thought of as a rechargeable battery that store energy in the form of mechanical energy instead of electrochemical. Flywheels have been gaining popularity as a possible replacement for chemical batteries in vehicles but until last year there was no record of a flywheels being used to increase the efficiency of a bicycle.

B. Demeulenaere et el. [6] studied that the cam-based centrifugal pendulum (CBCP) was introduced as a simple, cam based, input torque balancing mechanism. The differential equation that governs the CBCP cam design was derived and a methodology for solving it was developed. Furthermore, in a design example, the CBCP was applied to balance the input torque of a high-speed cam-follower mechanism, driving the slay of a weaving loom.

Tyler M. Nester et el. [7] describe results from an experimental investigation into the dynamic response of rotor systems fitted with centrifugal pendulum vibration absorbers. Two types of absorbers are considered which exhibit different types of nonlinear behavior. Systematic measurements of the rotor and absorber responses are taken for each type of absorber and compared against one another and against previously obtained theoretical predictions. The dramatic Influence of the absorber nonlinearity is demonstrated and the results allow one to draw conclusions about the selection of absorber parameters.

Rudolf Glassner, Kottes [8] studied that a dual mass flywheel for a drive train of motor vehicle includes a primary flywheel mass, a secondary flywheel mass and coupling device. The coupling device includes at least two pivot levers associated with secondary flywheel mass that interact with the controlled profile formed on the primary mass. The pivot levers are pretension against the controlled profile in radial direction by an elastic element. A control segment of elastic element is disposed radially inside the control profile.

Park et al. [9] studied that a dual mass flywheel for a vehicles includes a primary flywheel connected to a crankshaft of an engine, a damper housing integrally formed in a circumferential direction of primary flywheel a secondary flywheel is connected to input shaft of a transmission and rotatably mounted on hub of primary flywheel; driven fingers integrally formed on a second flywheel and inserted vertically into the damper housing to be forced by a damper spring. The damper spring comprises two springs sets symmetrically disposed within the damper housing, one end of each damper springs being driven by the stoppers which are integrally formed on primary flywheel, while the other end of the spring sets drive the driven fingers of the secondary flywheel. The primary and secondary flywheel is integrally provided with projections for preventing the damper spring from being excessively compressed and damaged. The damper spring comprises a plurality of springs, each having different spring coefficients and the damper spring is supported by a plurality of sliding guides or blocks.

Robert Hebner [10] studied that the efforts on improved flywheel designs and flywheel materials to meet energy storage requirements for the grid. University of Texas's initial effort focused on determining the power and energy requirements for a flywheel energy storage system at various points on the grid. UT-CEM researchers used real-world data from a newly developed community in Austin, TX to analyze the effect of energy storage at the home level, transformer level and the community distribution level. With requirements defined, an optimization code was developed for sizing a flywheel energy storage system for the grid.

## III. Experimental Setup And Procedure

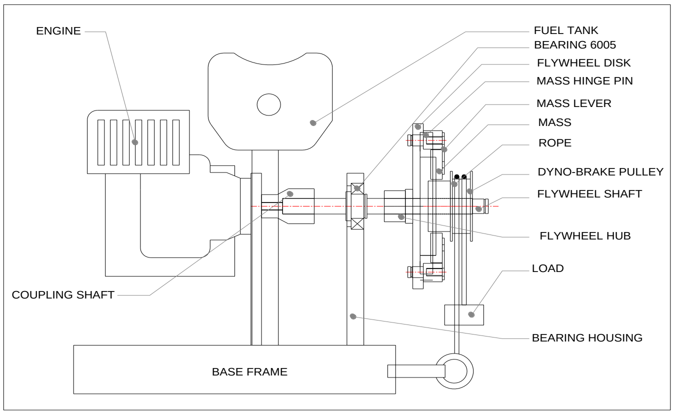


Fig. 3 Experimental test rig of dual mass flywheel

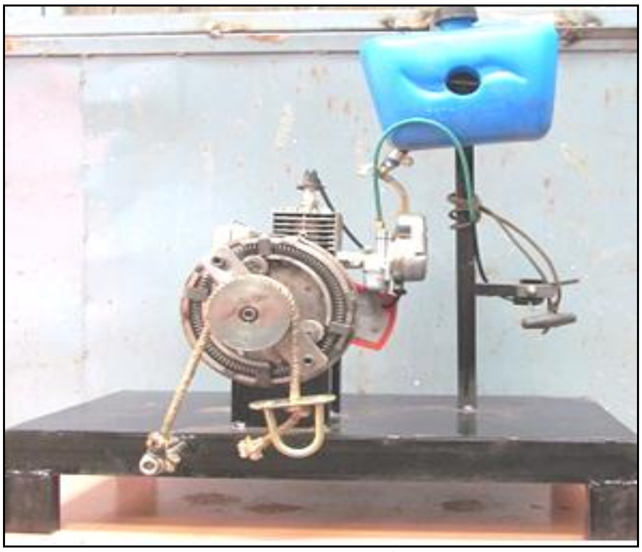

Fig. 4 Photograph of dual mass flywheel test rig

Fig. 3 shows that the set up of dual mass flywheel test rig which consist of two arc spring & two masses added on conventional flywheel with using two stroke petrol engines to run the test rig. The conventional flywheel with spring mass stem that is dual mass flywheel is mounting on shaft called as flywheel shaft; the flywheel shaft is coupled with engine by muff coupling called as coupling shaft also the flywheel shaft is guided by bearing with bearing housing. The dyno brake pulley is mounting on flywheel shaft in the series with dual mass flywheel.

### A. Theoretical Analysis Of Conventional And Dual Mass Flywheel

Effect of increased inertia of Dual mass flywheel

The effect of inertia augmentation can be seen by the difference in the fluctuation of energy in the Dual mass flywheel and the Conventional flywheel.

Since, Maximum fluctuation of energy of Conventional flywheel,

$$\Delta E_{cnv} = m R^2 \omega_{cnv}^2 Cs$$ (1)

Where, m = mass of flywheel =1.9 kg

R= Mean Radius of rim = 68 mm =0.068

N1= Maximum average speed of conventional flywheel in rpm

N2= Minimum average speed of conventional flywheel in rpm

$\omega_{cnv}$ = mean angular speed of dual mass flywheel

$$\therefore \omega_{cnv} = \frac{2\pi\,(N1+N2)}{2}$$ (2)

$$\therefore \omega_{cnv} = \frac{2\pi\,(1315+910)}{2}$$

$$\therefore \omega_{cnv} = 6990 \ \text{rad/sec}$$ *(i)*

Coefficient of fluctuation of speed Cs,

$$Cs = \frac{(N1-N2)}{N}$$ (3)

Where,

$$N = \frac{(N1+N2)}{2} = 1112$$ *(ii)*

$$\therefore Cs = \frac{(1315-910)}{1112} = 0.364$$ *(iii)*

$$\Delta E_{cnv} = m R^2 \omega_{cnv}^2 Cs$$

$$\therefore \Delta E\ cnv = 1.9 \times 0.068^2 \times 6990^2 \times 0.364$$

$$\therefore \Delta E\ cnv = 156.25\ KJ$$ *(iv)*

Similarly, Maximum fluctuation of energy of Dual mass flywheel,

$$\Delta E_{dmf} = m R^2 \omega_{dmf}^2 Cs$$

Where, m =mass of flywheel =1.9 kg

R= Mean Radius of rim = 68 mm =0.068

N1= Maximum average speed of dual mass flywheel in rpm

N2= Minimum average speed of dual mass flywheel in rpm

$\omega_{dmf}$ = mean angular speed of dual mass flywheel

$$\therefore \omega_{dmf} = \frac{2\pi\,(N1+N2)}{2}$$

$$\therefore \omega_{dmf} = \frac{2\pi\,(1430+930)}{2}$$

$$\therefore \omega_{dmf} = 7414 \ \text{rad/sec}$$ *(v)*

Coefficient of fluctuation of speed Cs,

$$Cs = \frac{(N1-N2)}{N}$$

Where,

$$N = \frac{(N1+N2)}{2} = 1180$$ *(vi)*

$$\therefore Cs = \frac{(1430-930)}{1180} = 0.423$$ *(vii)*

$$\Delta E_{dmf} = m R^2 \omega_{dmf}^2 Cs$$

$$\therefore \Delta E\ dmf = 1.9 \times 0.068^2 \times 7414^2 \times 0.423$$

$$\therefore \Delta E\ dmf = 204.27\ KJ$$ *(viii)*

From equation (iv) and (viii) effectiveness of dual mass

| Sr. No. | Loading | | Unloading | | Average |
|---|---|---|---|---|---|
| | Load (Kg) | Speed (rpm) | Load (Kg) | Speed (rpm) | Speed (rpm) |
| 1 | 1.5 | 1430 | 1.5 | 1420 | 1425 |
| 2 | 2.0 | 1400 | 2.0 | 1390 | 1395 |
| 3 | 2.5 | 1370 | 2.5 | 1360 | 1365 |
| 4 | 3.0 | 1320 | 3.0 | 1310 | 1315 |
| 5 | 3.5 | 1280 | 3.5 | 1290 | 1285 |
| 6 | 4.0 | 1250 | 4.0 | 1240 | 1245 |
| 7 | 4.5 | 1210 | 4.5 | 1210 | 1210 |
| 8 | 5.0 | 1190 | 5.0 | 1180 | 1185 |

| Sr. No. | Load (Kg) | Speed (rpm) | Torque (N-m) | Power (Watt) | Efficiency % |
|---|---|---|---|---|---|
| 1 | 1.5 | 1425 | 0.47 | 70.27 | 34.28 |
| 2 | 2.0 | 1395 | 0.63 | 91.72 | 44.75 |
| 3 | 2.5 | 1365 | 0.78 | 112.1 | 54.73 |
| 4 | 3.0 | 1315 | 0.95 | 129.7 | 63.27 |
| 5 | 3.5 | 1285 | 1.10 | 147.8 | 72.13 |
| 6 | 4.0 | 1245 | 1.25 | 163.7 | 79.87 |
| 7 | 4.5 | 1080 | 1.41 | 159.7 | 77.95 |
| 8 | 5.0 | 930 | 1.57 | 152.8 | 74.58 |

flywheel over conventional flywheel

$$(\varepsilon) = \frac{\Delta E\ dmf}{\Delta E\ cnv} = \frac{204.27}{156.25} = 1.30$$

(4)

Thus the Dual mass flywheel is 1.3 times effective than the Conventional flywheel.

*A. Experimental analysis conventional flywheel*

Engine Speed = 1300 rpm;

Engine Power = 205 watt

TABLE I
OBSERVATION TABLE FOR CONVENTIONAL FLYWHEEL

TABLE II
RESULT TABLE FOR CONVENTIONAL FLYWHEEL

Sample calculations:

a) Output Torque = W × 9.81 × Radius of dyno- brake pulley

$\therefore T_{o/p} = 4 \times 9.81 \times 0.032 = 1.26$ N-m *(ix)*

b) Output power $= \frac{2\pi N\ Top}{60}$ (5)

$\therefore P_{o/p} = \frac{2\pi\ 1155 \times 1.26}{60} = 152.39$ watt *(x)*

c) Efficiency $= \frac{\text{Output power}}{\text{Input power}} \times 100$ (6)

$\therefore$ Efficiency $= \frac{152.39}{205} \times 100 = 74.33\%$ *(xi)*

*B. Experimental analysis of dual mass flywheel*

Engine Speed = 1300 rpm

Engine Power = 205 watt

Sample calculations:

a) Output Torque = W × 9.81 × Radius of dyno- brake pulley

$\therefore T_{o/p} = 4 \times 9.81 \times 0.032 = 1.26$ N-m *(xii)*

a) Output power $= \frac{2\pi N\ Top}{60}$

$\therefore P_{o/p} = \frac{2\pi\ 1250 \times 1.26}{60} = 164.93$ watt *(xiii)*

Efficiency $= \frac{\text{Output power}}{\text{Input power}} \times 100$

$\therefore$ Efficiency $= \frac{164.93}{205} \times 100 = 80.45\%$ *(ix)*

| Sr. No | Loading | | Unloading | | Average |
|---|---|---|---|---|---|
| | Load (Kg) | Speed (rpm) | Load (Kg) | Speed (rpm) | Speed (rpm) |
| 1 | 1.5 | 1310 | 1.5 | 1320 | 1315 |
| 2 | 2.0 | 1270 | 2.0 | 1280 | 1275 |
| 3 | 2.5 | 1240 | 2.5 | 1250 | 1245 |
| 4 | 3.0 | 1210 | 3.0 | 1200 | 1205 |
| 5 | 3.5 | 1180 | 3.5 | 1190 | 1185 |
| 6 | 4.0 | 1150 | 4.0 | 1160 | 1155 |
| 7 | 4.5 | 1010 | 4.5 | 1030 | 1020 |
| 8 | 5.0 | 900 | 5.0 | 920 | 910 |

| Sr. No. | Load (Kg) | Speed (rpm) | Torque (N-m) | Power (Watt) | Efficiency % |
|---|---|---|---|---|---|
| 1 | 1.5 | 1315 | 0.470 | 64.858 | 31.63 |
| 2 | 2.0 | 1275 | 0.627 | 83.83 | 40.89 |
| 3 | 2.5 | 1245 | 0.784 | 102.33 | 49.92 |
| 4 | 3.0 | 1205 | 0.941 | 118.85 | 57.98 |
| 5 | 3.5 | 1185 | 1.098 | 136.36 | 66.52 |
| 6 | 4.0 | 1155 | 1.255 | 151.89 | 74.10 |
| 7 | 4.5 | 1020 | 1.412 | 150.90 | 73.62 |
| 8 | 5.0 | 910 | 1.569 | 149.59 | 72.98 |

TABLE III
OBSERVATION TABLE FOR DUAL MASS FLYWHEEL

TABLE IV
RESULT TABLE FOR DUAL MASS FLYWHEEL

*C. Graphical representation*

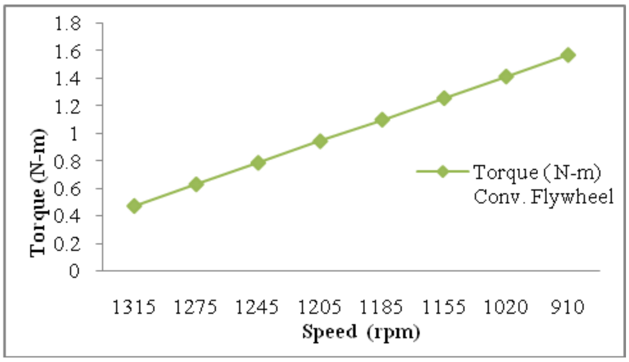


Fig. 5 Torque vs. speed for conventional flywheel

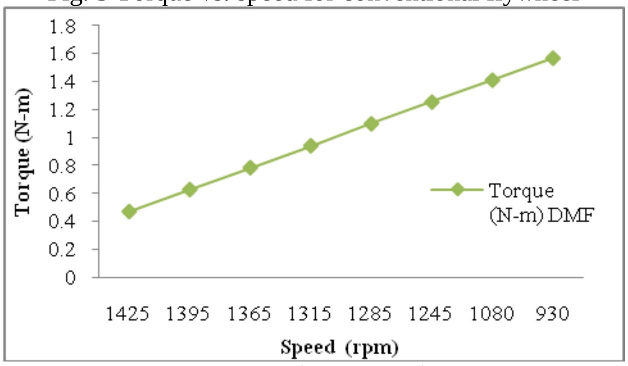


Fig. 6 Torque vs. speed for dual mass flywheel

 

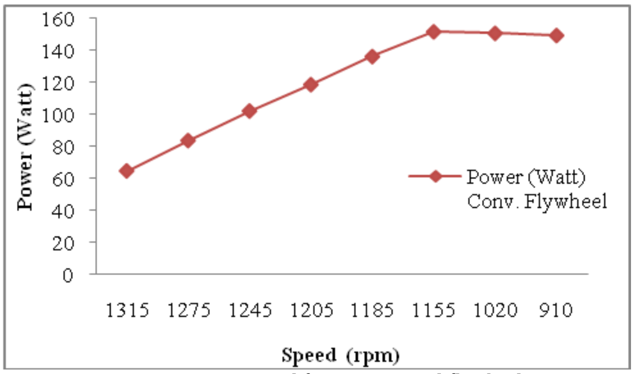


Fig 7 Power vs. speed for conventional flywheel

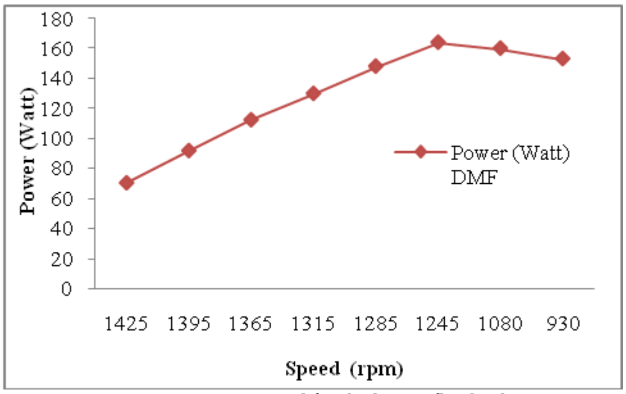


Fig.8 Power vs. speed for dual mass flywheel

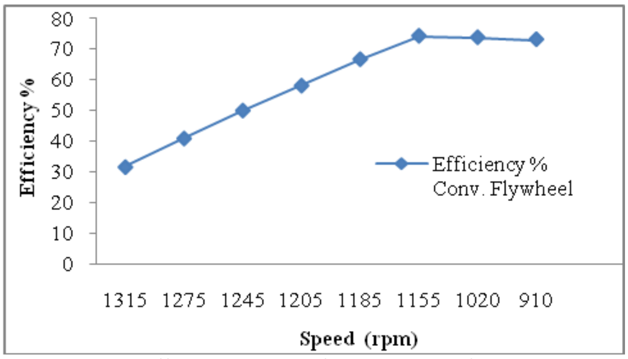


Fig. 9 Efficiency vs. speed for conventional flywheel

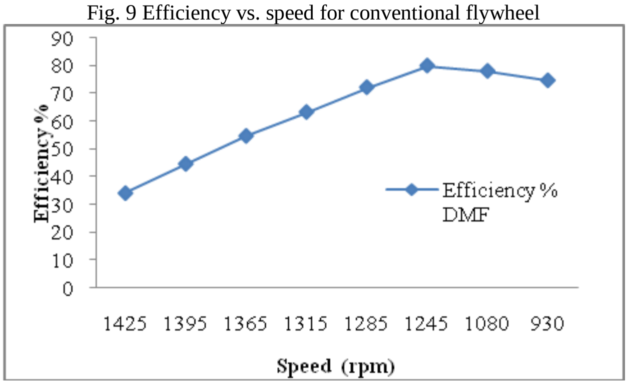


Fig. 10 Efficiency vs. speed for dual mass flywheel

B. Result And Discussion

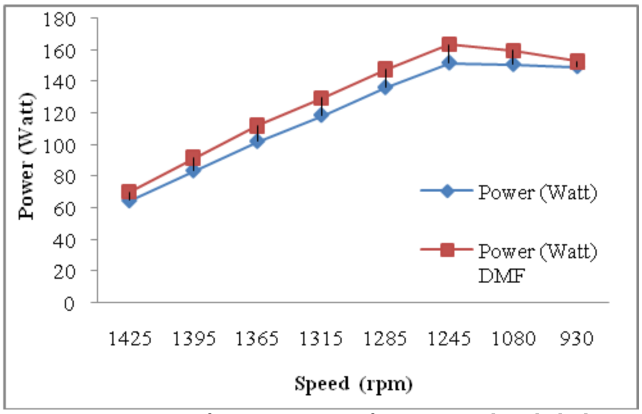


Fig. 11 Comparison of power output of conventional and dual mass flywheel

Fig. 11 shows that by using the Dual mass flywheel the power output is increased by 7 to 8 % approximately.

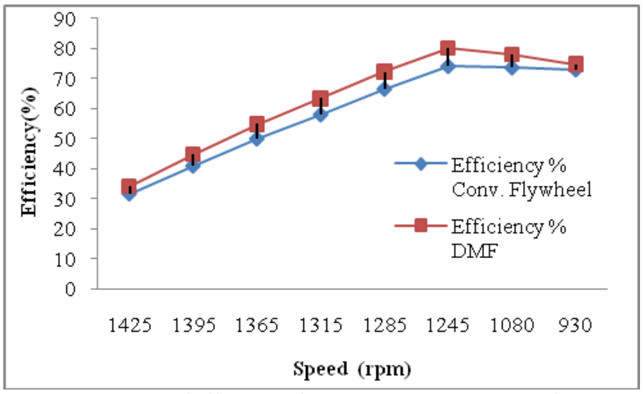


Fig. 12 Comparison of efficiency of conventional and dual mass flywheel

Fig. 12 shows that the Dual mass flywheel is 5 to 6 % efficient than the conventional flywheel which also result in increase in fuel economy of the engine.

## IV.CONCLUSION

It is observed that there is approximately 7 to 8 % increase in power output by using the Dual mass flywheel as compare to conventional flywheel and also observed that the Dual mass flywheel is 5 to 6 % efficient than the conventional flywheel which will also result in increasing fuel economy of the engine.

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