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Development of Cost Effective Chassis Dynamometer For Engine Output Power Measurements

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Abstract— Measurement of output power from an engine is an important step in analysis of engine performance. Currently, dynamometers are used to measure the brake power of engines at varied loads. However, these devices are often expensive and sophisticated. Therefore there is a need to develop an extremely cost effective device for brake power measurement. In this work, a chassis dynamometer is designed and fabricated for testing a two wheeler vehicle. The drive axle weight is up to 800 kg. The dynamometer is primarily made out of mild steel and uses worn out car tires to function as rollers. The device is found to be extremely cost effective and reliable as compared to the existing dynamometers.

Keywords— *Brake power, chassis dynamometer, engine performance.*

I Introduction

A dynamometer is an energy-absorbing device used for measuring force, torque or power. It is also capable of applying controlled load on a vehicle under test. A dynamometer consists of an absorption unit and usually includes a means for measuring torque and rotational speed. An absorption unit consists of a rotor in housing which is coupled to the engine or other equipment under test and is free to rotate at any speed required for the test. Some means is provided to develop a braking torque between the rotor and housing of the dynamometer. The means for developing torque can be frictional, hydraulic or electromagnetic. By knowing the torque applied and the speed at which the prime mover is running at, it is possible to calculate the power that it is generating. While most dynos use eddy current braking or AC/DC motor braking, the dyno designed and discussed in the present paper uses frictional braking (rope brake).
There are two main types of dynamometers for testing power in automobiles, namely engine dynamometer and chassis dynamometer. An engine dynamometer is coupled directly to an engine to measure the output power whereas the chassis dynamometer derives power from the wheels of the vehicle.

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Due to the losses (frictional losses, inertia losses, or slippage losses), the output derived at the wheels of the vehicle is always less than the output power provided by the engine. As the chassis dynamometer accounts for the losses in the transmission system, it results in the most accurate measure of power of the vehicle. Therefore it is considered as a better system for measuring speed, acceleration etc.
A basic comparison of the different braking assemblies is shown in table 1 [1]:

Table 1: Comparison of braking systems

Brake Type	*Simplicity of Design*	*Power Range*	*Cost Efficient*	*Total Score*
Eddy Current	*1*	*4*	*1*	*6*
Frictional Brake	***5***	***4***	***4***	***13***
Water Brake	*2*	*3*	*4*	*9*
Engine Dynamometer	*3*	*5*	*2*	*10*
Magnetic Powder Brake	*1*	*3*	*1*	*5*
Fan Brake	*5*	*3*	*4*	*12*
Hydraulic Brake	*4*	*3*	*3*	*10*
1 = Worse/Low, 5 = Best/High, 3 = Moderate				

II Working of the present system

A Brief history of Dynamometers

Table 2 gives some milestones **[3]** in dynamometer development to put this important tool into perspective. There have been several developments and improvements made since 1931,
Raksit Thitipatanapong et al [1] used a hydrostatic loading design. The paper states that the hydrostatic dynamometer was proposed as low-cost dynamometer for Thailand. The dynamometer was equipped with commercial hydraulic part that widely used in industrial process. A 150-kW of dynamometer equipped with hydrostatic devices were introduced that could absorb torque more than 400 Nm.
Malik M. Usman Awan et al. [2] designed and constructed a Frictional-Brake Absorption type Dynamometer using electrical strain gauges in order to calculate the power output of low speed prime movers like Wind Turbine, Micro Hydro Turbines, etc They conclude that “a broader picture of a FBA (Friction Brake Absorption) Dynamometer is that it helps to evaluate the existing models of different low speed primers like Wind Turbines, Cross Flow Turbines, etc.

Table 2 – Past accomplishments in the field of dynamometers

Year	Achievement
1758	John Smeaton, who was the first to refer to himself as a civil engineer, used a rope-brake dynamometer on windmills. When the rope got hot, he cooled them with water.
1780	Scottish engineer James Watt, using a similar rope brake dynamometer made the first reference to "horsepower".
1821	Gaspard de Prony invented the prony brake, which was a braking device around a shaft using blocks of wood to rub against the metal shaft.
1822	Plobert and Faraday made the first reference to "brake horsepower" when working with a prony brake dynamometer.
1877	William Froude referenced the first use of a hydraulic dynamometer. This sluice gate dyno was working at 1997 brake horsepower and 90 rpm. That had a braking torque of 116,536 pounds-feet (158,002 Nm).
1931	Martin and Antony Winther invented the eddy current absorber dynamometer.

The present study's objectives are

- To design and build a Chassis Dynamometer that provides a consistent and reliable data which enables testing and tuning of automobile transmission systems.
- To fabricate the Chassis dynamometer at the lowest possible cost without compromising quality.
- To serve as a permanent test equipment in the automobile workshop for testing the vehicles for academic or professional purposes.

B *Working principle*

A two wheeler dynamometer with a motorcycle mounted on it for the test (refer fig.1), consists of a roller on which the rear wheel of the motorcycle is mounted. The roller is connected to a braking system which inturn transmits the data to the control

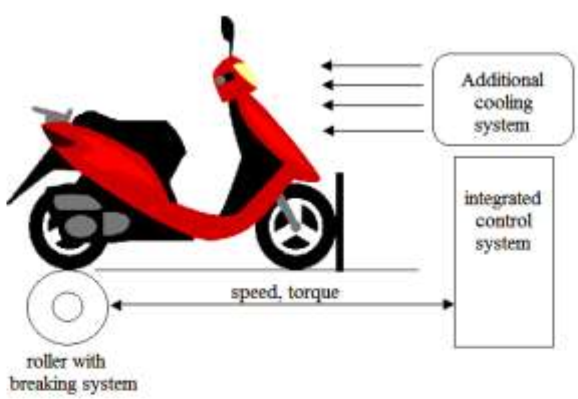

Fig.1: Layout of basic chasis dynamometer for a two wheeler under test.

system. A control system has a hold over the speed and torque in other words the data of the speed and torque can be viewed and thereby controlled by interface through the control system. Most systems also have additional cooling systems to simulate the cooling conditions that the vehicles would experience in real world testing. Engine dynamometers (dynos) are quite common, especially in educational institutions, where engine testing is part of the curriculum. Tuning of transmission is a special science, and as such to do at a professional level requires very detailed and precise data. Hence, the dynamometers available in a market are very expensive. They contain very delicate parts that are specially designed to provide high quality data. They provide data like air flow rates, fuel flow rates, air to fuel ratios, temperatures measured at different points, along with basic data like torque and speed. However, for the student teams at institution level, the skills required are generally limited, and they do not require very complex data to tune cars. Instead, for most of the tuning, a constant torque is sufficient along with real time speed values. Hence, the concept is to build a dyno which provides only the data like speed and torque is needed. The effort of the present work is to make the dyno as cost effective as possible, rather than making it unnecessarily complicated by incorporating systems that are not required.

III Methodology

Our premise when designing the dynamometer was to have it as simple as possible to ensure low costs, while aiming for reasonably high accuracy. A basic comparison of the different types of braking arrangements that can be used is as shown in Table 3 [2] Therefore, after summing up all the major factors of the different standard types of dynamometers in practice, it came up with the conclusion of opting for a Frictional Brake Absorption Dynamometer (FBAD) due to its mechanical design simplicity, good power absorption, and cost efficiency. Under frictional brake, there were 2 main systems – rope brake and prony brake.

Of the two, rope brake was selected as it did not require having a set of different weights to load the dyno. Instead, it can simply measure the tension in the rope to determine the brake torque being applied. One of the major amenities that make this project possible is the use of trenches. These trenches are mainly used to carry out work below a vehicle without having to lift the vehicle too high, and at the same time ensuring ample working space below the vehicle. The preliminary design was made using CATIA V5 just for generating design components, and the analysis of the parts were carried out analytically. The vehicle is restrained while testing by use of chains attached to the rear end of the dynamometer. The final setup of the dyno will consist of the following parts as shown in fig.2:

1. Frame, 2. Bearings, 3. Shaft, 4. Hub
5. Roller, 6. Braking assembly, 7. Spring balance

The material selection for the parts depends mainly of their suitability to carry out the required function and their cost effectiveness. The frame is made entirely of mild steel as it is easily available in different shapes and sizes. Additionally, it can easily be welded, hence making the fabrication easier. The frame consists of C-shape sections to take up the main load of the entire system and the load of the vehicle mounted on it. There are smaller L-shaped sections used to make the lateral bracing, and to provide an anchor point for the brake rope. The dimensions of the C-sections are standardized and a size that was wide enough to hold the plummer block inside it was selected. The final dimension used was 75 x 40 x 5 mm, (width x height x thickness). The bearings used are plummer blocks of SKF6210 with 2 inches inner diameter. The shaft is a hollow mild steel pipe. Shaft as close as possible to 2 inches was selected to ensure the best possible fit. Since all the available pipes were specified by their inner dimensions, A standard available pipe with 1¾ inch inner diameter and with ¼ inch wall thickness was used.

Table 3 – Comparison of braking arrangements

Type	Eddy Current	Electric	Hydro-kinetic	Hydrostatic
Speed limit	High	DC – medium AC – High	None	High (depends on pump)
Applicable torque range	Low-high	DC – Low-medium AC – Low-high	Medium – high	Very low – medium
Polar Inertia	Moderate	High	Low	Very low
Size for same capacity	Moderate	Large	Moderate	Small
Transfer Function	Linear	Linear	Non-linear	Linear
Control	Current	Frequency/current	Mechanical/electrical	Mechanical/electrical
Regenerative	No	Yes	No	No(optional)
Drive	No	Yes	No	Yes (optional)
Maintenance	Low	Low	Moderate	High

The braking assembly consists of a rope tied at one end to a spring balance to measure its tension and to an eye bolt at the other end to change its tension when required (fig.2 and fig.3a). The rope used is a nylon rope of 8 mm diameter. The rope is wrapped around the shaft 2 times to provide optimal braking as shown in fig. 3b. Water is continuously poured over the rope to provide cooling and also to provide a certain amount of lubrication. The use of eye-bolts is critical as it allows easy fastening of the rope in the eye. Additionally, it has a long threaded section that allows a nut to be tightened. The tightening of the nut increases the tension in the rope, hence increasing the braking torque.

The bearing was designed to fit a shaft of 2” dia (50.8 mm), however, the shaft available had a outer diameter of 48 mm. Hence, to make up for the extra material to fill the gap, straight line welds on the surface of the pipe were made to increase its diameter at certain points. The welds were then filed down till the shaft fits perfectly into the bearing as shown in Fig. 4.

Eccentricity of the hub – There is a possibility of the holes being drilled eccentric causing the entire roller to be eccentric and producing high amount of vibrations during rotation. The concentricity was checked by lowering a plumb to almost touch the tire surface. When the tire is rotated, the distance from the surface to the plumb can be measured. As can be seen in Fig. 5, on 180^0 rotation of the tire, there is a negligible change between the plumb and the tire surface, indicated by the red lines. The final budget details are tabulated in Table 4

Fig.2-The parts of a roller assembly

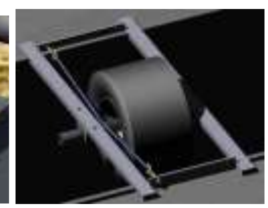

Fig.3a -The Catia model of the single roller unit

Fig. 3b - The final prototype of the single roller unit

Fig. 4–welds to account for difference in diameter

Fig. 5 - Experiment to check eccentricity of hub overcome.

IV Design validation

Main Components of the dynamometer to be designed are : Shaft, Bearings, Bolts and Frame

Table 4 - Details of the final budget of the project.

Part	Cost (in Rupees)
Frame	1721
Bearings	3000
Shaft	950
Tyres (rollers)	1200
Hub	422
Chain (for restraining)	287
Rope and eyebolts (Braking assembly)	100
Spring balance(s)	200
Total	**7980**

A *Shaft*

Material: Mild steel
Outer Diameter = 48 mm
Thickness = 6 mm
Length (l) = 450mm
a = 76.2 mm
b = 228.6 mm

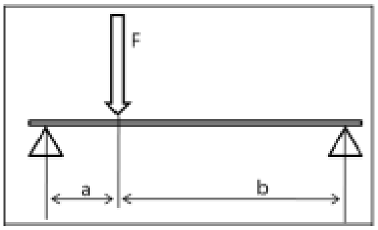

Fig. 6 – Loading condition of shaft

Considering only static bending [4],

$$\sigma = \frac{My}{I}$$

Where σ = Yield stress of material; M = Bending moment; y = distance to extreme fibre; I = Second moment of area

$$I = \frac{\pi(D^4-d^4)}{64} = \frac{\pi(48^4-36^4)}{64} = 178128.30 \text{ mm}^4 \quad [4]$$

σ = 100 MPa for mild steel [4] , y = 24 mm

Considering offset loading, $M = F\frac{ab}{l} = F(57.15)$

Where F is the maximum load capacity of the dynamometer (to be calculated)

Therefore, $100 = \frac{57.15 \times F \times 24}{178128.30}$

∴ F = 12986.9 N = 1323.84 kg

Since there are 2 shafts, Max drive axle weight taken by shaft = 2647.58 kg

B *Bearings*

Bearing type: SKF(6210) , deep groove ball bearings;
Size = 2 inches
$P = XVF_r + YF_a$ [4]
$F_a = 0$, V = 1.2 , X = 1,
C = 20595 N [4]
F_r is the maximum load capacity of the dynamometer (to be calculated)
Assuming 20 million revolutions,
C/P = 2.71 [4]

Fig. 7 – Sample Plummer block

$$F_r = \frac{P}{XV} = 6333.02 \text{ N}$$

Therefore, P = 7599.63 ,
F_r= 645.57 kg

Since there are 4 bearings, Maximum drive axle weight allowed = 2582 kg

C *Bolts*

Material : Mild steel ; Size : M16
Tensile loading, σ = F/A , where σ = 19 Mpa [4] , Stress area A= 157 mm^2
F is the maximum load capacity of the dyno (to be calculated)
F = 19 x 157 = 2983 N = 304.08 Kg
Since there are 8 bolts being used, maximum drive axle weight allowed = 2432.6 Kg

D *Frame*

Material : Mild steel ; Dimensions : C section
Arrangement : Simply supported central loading
Length = 1000 mm

$$\sigma = \frac{My}{I} \ [4]$$

σ = 100 Mpa

$$\text{CG:} \quad \bar{y} = \frac{(2\times40\times6\times20)+(63\times6\times37)}{(2\times40\times6)+(63\times6)} = 27.49 \text{ mm}$$

y = 40 – 27.49 = 12.51 mm

$$I = \frac{BC^3-bh^3+aC^3}{3} = 126248.4 \text{ mm}^4 \ [4]$$

$$M = \frac{Fl}{4}$$

Where F is the maximum load capacity of the dynamometer (to be calculated)

M = F x 1000/4 = 250 F

$$\sigma = 100 \text{ Mpa} = \frac{MY}{I}$$

Therefore, F = 4036.72 N i.e., F = 411.49 Kg
Since there are 4 members,
Total weight bearing capacity = 1645.96 Kg
By choosing the smallest value (shaft) = 1345 Kg
Assuming Factor of safety = 1.5
Maximum drive axle weight that can be supported on dynamometer = 896.67 Kg

E *Torsional Strength of Shaft*

Max torsional shear stress due to torsional loading,

$$\tau = \frac{16T}{\pi d^3} \times \left(\frac{1}{1-k^4}\right)$$

τ = 71 Mpa ,Therefore, T = 1053967 Nmm
Maximum torque bearing capacity of dynamometer= 1053.967 Nm

V Result Analysis

A *Calibration*

The initial testing began with the calibration runs. The method of loading the dynamometer is by tightening the nut on the eye-bolt to increase tension in the brake rope. The torque for each length of exposed thread was calculated by rotating the shaft using a rod of known length and a spring balance. However, for various reasons, the calibration readings were not repeatable, i.e. for the same reading of exposed thread; different values of torque were obtained in different readings. These may be due to the reasons as: Slipping of the knot and Plastic deformation (extension of the rope). The effect of these factors on Fig.7a shows clear yield in the rope, which could be because of the knot slipping or due to permanent expansion Fig. 7b shows the case where there is no yield in the rope, but due to plastic deformation, there is a permanent set. For this purpose, it was not possible to have a pre-calibrated rope brake system. Instead, a spring balance was added on the rope brake to measure its tension. Hence, by reading its tension and the diameter of the shaft being known, the amount of resisting torque being applied to the wheels of the test vehicle was calculated.

B *Test on TVS Wego*

Given below are the results of the test on a TVS Wego. The Wego is rated for an 8HP engine, and during the test, the power peaked at around 6HP at ¾ throttle. Throttling was not done beyond ¾ power as a safety precaution. The power vs throttle curve is shown in Fig. 8. The inference from it is that there is no power transmission to wheels till around 1/3 throttle. Following which, the power increases almost linearly. The throttle positions were marked as divisions on the throttle handle between 0 and full throttle. 12 divisions were chosen for this test, hence every division is 1/12th throttle.

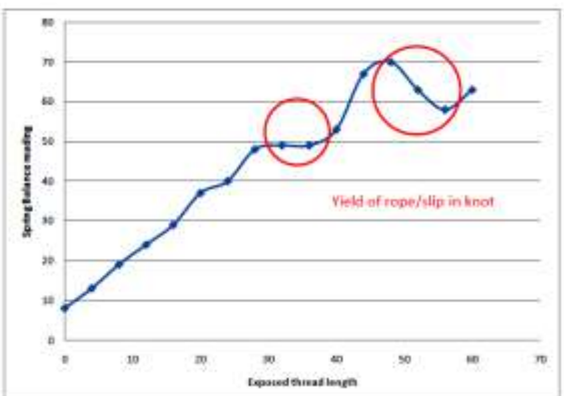

Fig.7a– Graph showing yield in rope due to knot Slipping

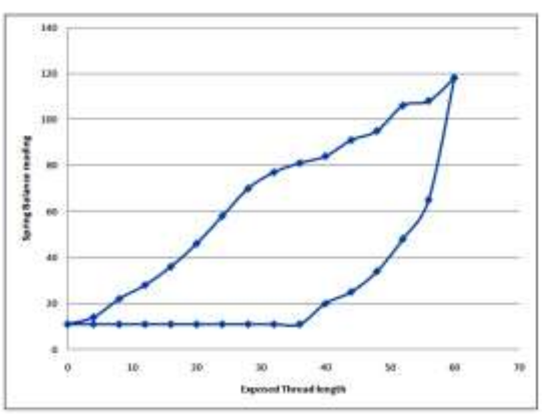

Fig.7b– Graph showing overall plastic deformation due to extension and knot slip

VI Conclusion

The present work aimed to design and fabricate a chassis dynamometer and to use it to test vehicles. Fabrication was done after the completion of the design and analysis. The total cost price of the dynamometer was under Rs.8000, making it

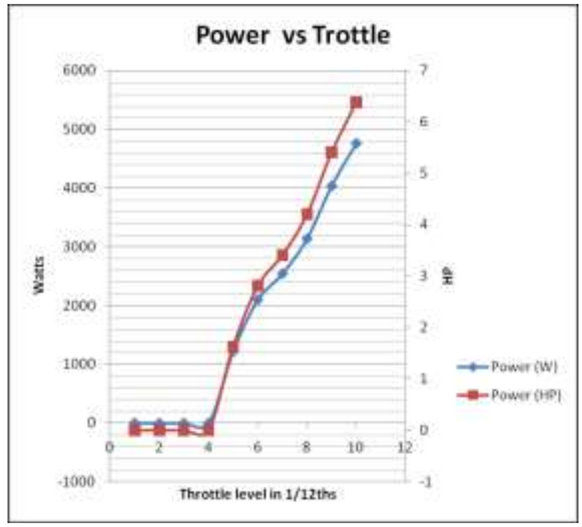

Fig. 8 – Power vs throttle curve for TVS Wego

extremely cost efficient. Despite its low cost, the dyno is capable of withstanding vehicles with a drive axle weight of upto 800kg. The dyno is made primarily out of mild steel and uses worn out car tires to function as rollers. The vehicle is restrained to the dyno and run normally. The readings of torque are inferred from the spring balances provided and the speed is measured using a digital tachometer. With the readings of torque and speed, the output power can be calculated. The completion of the test on the TVS Wego shows that the data from the dyno is reliable and the dyno is functioning as expected. Hence the project served its purpose to show that sophisticated testing equipment can be simplified and constructed at a low cost, but can still yield reliable data. Additionally, The dynamometer has a wide scope of future study.

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