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Design and Development of Inertia Dynamometer for FSAE Application

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Abstract

This paper discusses the development process of a reliable & cost-effective inertia dynamometer for FSAE application.The testing procedure is to accelerate an inertial mass (flywheel) from rest to its maximum speed& calculate the engine power versus speed using the inertia of the flywheel and its rate of change of angular speed. The dimensions of the inertial load, bearings, shaft & foundation have been selected based on theoretical calculations & structural analysis. A Hall- effect sensor has been used to measure instantaneous speed during test. This data is logged through Arduino-Uno and processed using MATLAB and Ms-Excel. The results were satisfactorily similar to that from the power curve supplied by the OEM and engine model developed on Ricardo WAVE software hence proving the accuracy of the dynamometer.

1. Introduction

A dynamometer is a device used to measure the torque required to operate a driven load. Dynamometers have been used in the automobile industry since decades to improve the performance as well as efficiency of the engine through engine tuning and emissions testing [1,2]. The cost of an aftermarket dynamometer usually depends upon its type, size & data logging capabilities.

FSAE, being the largest engineering design competition in the world provides students with an opportunity to design and manufacture a race car based on a series of rules whose purpose is both to ensure onsite event operations and promote clever problem solving. Over the years, several researchers have worked on development of dynamometers for engine tuning and research purposes. Benjamine Miller et al. [3] designed a control system for a water brake engine dynamometer. Maitree et al. [4] conducted computer simulations for the safe design of inertia dynamometers. TDK motorsports [5] provided instructions for conducting safe & reliable dyno-testing. In this paper, the design, testing procedure & data acquisition for inertia dynamometer have been discussed.

2. Calculations

2.1 Inertia of Load

The acceleration time (idle speed to redline speed) should be at least4 seconds to record an accurate power curve.

$$\tau = I \times \frac{W_f - W_i}{T} \quad (1)$$

$$P = \tau \times W \quad (2)$$

$$E = \frac{I \times W^2}{2} \quad (3)$$

$$P = \frac{\Delta E}{T} = \frac{I \times (W_f^2 - W_i^2)}{2 \times T} \quad (4)$$

For engine, P = 25 kW; W_f = 222.4 rad/s; W_i = 52.3 rad/s; T = 4s.I = 4.28 kgm^2 (AISI 1040 Steel cylinder with m = 114 kg& D_l = 540 mm)

2.1.1 Diameter of Shaft (AISI 1040)

For a shaft subjected to both bending moment & twisting moment,

$$M_e = \frac{M + \sqrt{M^2 + T^2}}{2} \quad (5)$$

$$M_e = \frac{\pi}{32} \times \sigma \times d^3 \quad (6)$$

After calculating the force from the load & chain on the shaft, T = 55.7 Nm; M = 62.02 Nm; σ = 40 N/mm^2. Solving equations (5) & (6), we get d = 26.6mm or 30 mm.

2.2 CAD and Structural Analysis

A detailed CAD model consisting of dynamometer frame, engine mountings & accessories was prepared on SolidWorks. AISI 1040 steel was used for rectangular beams and scatter shield. It was decided to fix the frame to a depth of 6 inches into the ground with help of cement to absorb load and vibrations.

2.3 CAD and Structural Analysis

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Table 1: Engine Specifications

Design	1-cylinder 4-stroke engine, water cooled
Displacement	510.4 cm^3 (31.147 cu in)
Stroke	72 mm (2.83 in)
Bore	95 mm (3.74 in)
Compression Ratio	11.8:1
Idle speed	1950, 2050 rpm
Control	OHC, 4 valves controlled via rocker arm, drive via tooth/wheel chain
Primary transmission	32:76
Transmission Ratio	
1st Gear	14:36
2nd Gear	17:32
3rd Gear	19:28
4th Gear	22:26
5th Gear	24:23
6th Gear	26:21
Fuel injection	EFI (RON:97)

It was decided to fix the frame to a depth of 6 inches into the ground with help of cement to absorb load and vibrations.

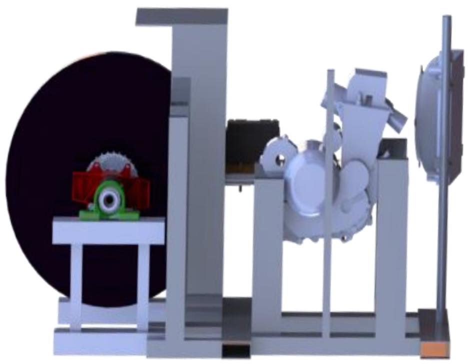

Fig. 1: CAD model on SolidWorks

Fig. 2: In-house built Dynamometer

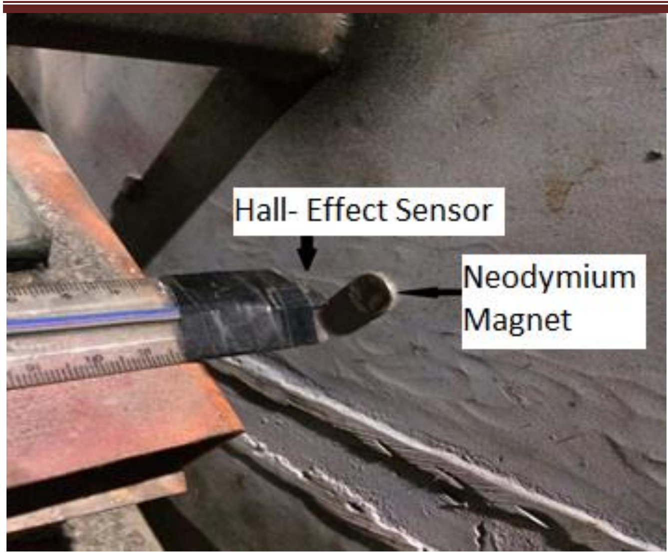

Fig. 3: Placement of Hall- Effect Sensor and Neodymium Magnet

Von- Mises theory was applied to calculate the developed stresses and deflection in the shaft. The deformation shown in fig. 4 is 700 times exaggerated but its magnitude is under safe limits.

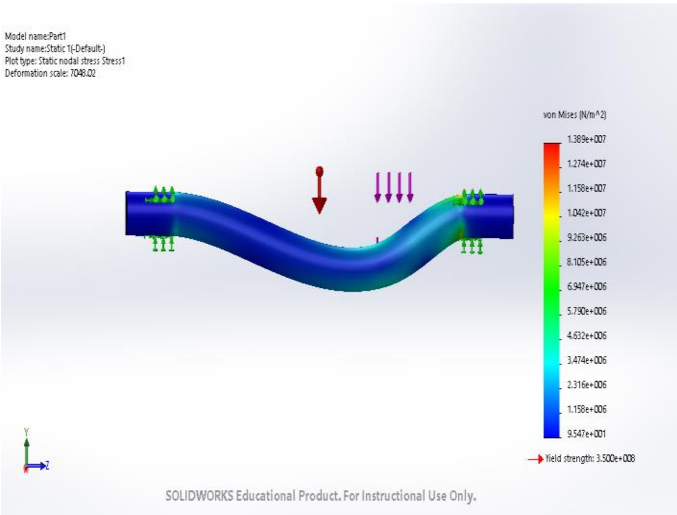

Fig. 4: Structural Analysis of Shaft

4. Test Procedure

A standardized testing procedure was imperative for accurate results. The following steps were adopted:

1. Proper arrangements for firing the engine reliably were made.Engine Speed, Throttle Percentage and Time were logged throughout the process.
2. The engine was kept on the 6th gear to ensure minimum torque and allowed to attain steady speed.
3. The throttle was instantly floored to WOT allowing the engine to rev-up to its redline (8,250 rpm). The throttle was held for sometime before stopping the engine.
4. The flywheel was allowed to stop with the clutch depressed till it stops.
5. A disk brake can be used to stop the flywheel quickly.

5. Data Logging and Analysis

A Hall-effect sensor & Neodymium magnets were used to record the speed of flywheel. Arduino Uno microcontroller was used for data acquisition.

The accuracy of the engine RPM was confirmed through the On-Board Diagnostic Tool (OBD II). The RPM Vs Time data was processed by curve fitting method using MATLAB. The power curve and Torque curve were plotted with the help of equation (1) and (2) respectively.

```
void loop() {
 val = analogRead(potPin);

 //Serial.println(val);

 if(val>100)
 {
  if(val>700)
  {
   time1 = micros();
   rot_time = time1 - time2;
  //Serial.println(rot_time);

  if(rot_time>7000)
  {
    RPM1 = 2*3.14*1000000 / rot_time; //rpm in rad/sec
    Serial.println(RPM1);
    del_RPM = abs(RPM1 - RPM2);
    avg_RPM = (RPM1+RPM2)/2;
    RPM2 = RPM1;
    power = (4*1000000*del_RPM*avg_RPM)/(1000*rot_time); //power in KW
    Serial.print(avg_RPM);
    Serial.print(" ,");
    Serial.println(power);
  }
```

Fig. 5: Arduino Code

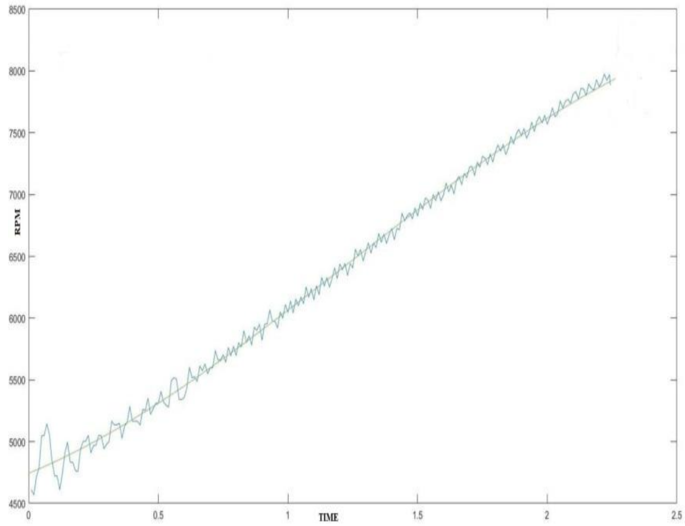

Fig. 6: Curve Fitting on MATLAB

Engine simulation software Ricardo WAVE was used to develop power curves under the same setting for comparison with the results obtained from inertia dynamometer.

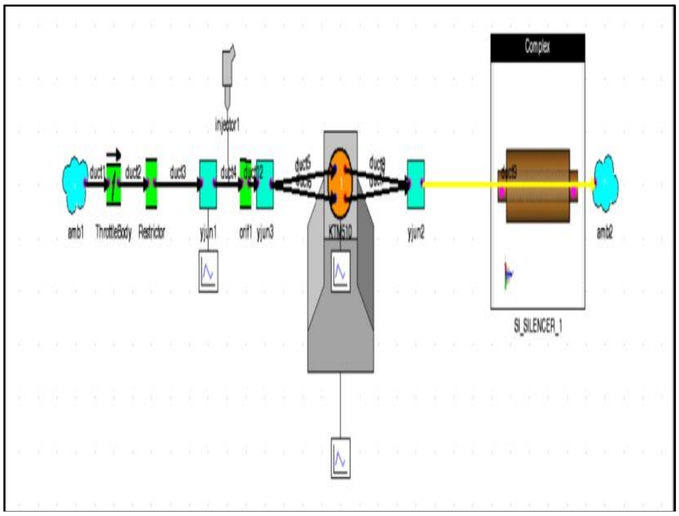

Fig. 7: Engine model developed on Ricardo WAVE

6. Result and Discussions

From the Fig. 8 and Fig. 9 it is observed that the power & torque curves obtained from the in house developed dynamometer are almost like the simulated Power curve. Slight discrepancy can be

due to the limited logging frequency of Arduino Uno. A better microcontroller will result in more accurate results.
The maximum power is 35 kW at 7000 rpm & the maximum torque is 37 N-m at 6300 rpm.

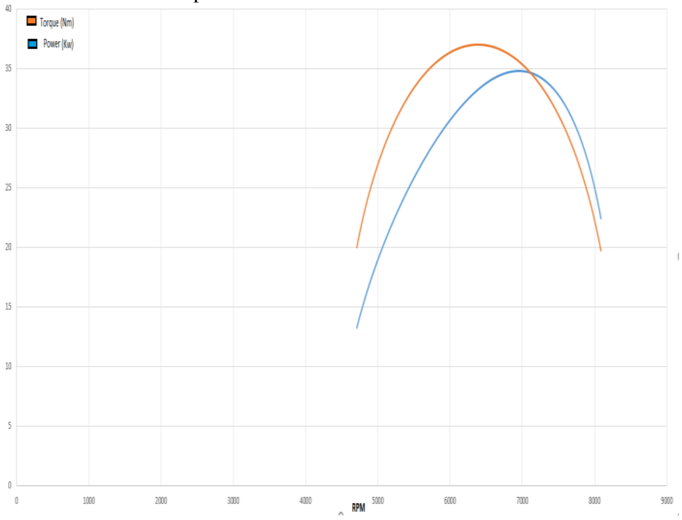

Fig. 8: Obtained Power and Torque Curve

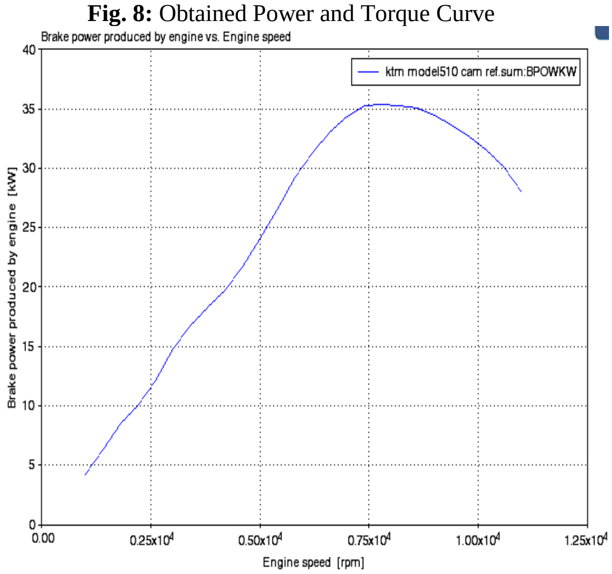

Fig. 9: Simulated Power Curve

7. Conclusions

From the power curves developed through inertia dynamometer and Ricardo WAVE model, we can conclude that the design is accurate. The developed dynamometer is economical, reliable and easy to develop. Hence, this could be utilized by SAE teams for enhancing the performance of the engine and further development of their respective designs.

Nomenclature

P Power (kW)
Ʈ Torque (N-m)
I Inertia (Kg m^2)
T Time (s)
W Angular Velocity (rad/s)
m Mass (kg)
D Diameter of load (mm)
d Diameter of shaft (mm)
M Moment (N-m)
T Twisting Moment (N-m)
σ Allowable Stress (N/mm^2)

Subscripts

i Initial
f Final
l Load
s Shaft
b Bending
t Twisting
e Equivalent

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