

Conference Paper

Inertial Dynamometer for Shell Eco-marathon Engine: Validation

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Abstract

This paper aims to validate the construction of an inertia dynamometer. These types of dynamometers allow easy characterization of internal combustion engines. To validate the dynamometer, tests were carried out with the same engine (Honda GX 160) installed in the UBIAN car and kart, which after calculating the inertia and measuring engine acceleration in each test performed, allows to create the torque characteristic curve from the engine.

Keywords: Inertia, Dynamometer, Torque, Flywheel, UBIAN

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1. Introduction

This work was performed at the University of Beira Interior in order to study the engine currently used at UBIAN car. This is a car build by a team that participate in Shell Ecomarathon. The engine used is Honda GX 160 [1].

This article intends to focus on demonstrating and validating a simple system of engine characterization. To make this validation three types of tests will be performed: the first one coupling the engine on inertia dynamometer; the second one is done using the whole vehicle; a third test, performed on a go kart, will be used as a control test.

2. Dynamometers

For the study and development of internal combustion engines, it is important to know their performance characteristics. It is only possible to know if there has been an improvement in engine performance if it is possible to make comparisons with the modifications and adjustments made.

The fastest way to quickly characterize an engine is by using dynamometers. These can be divided in two groups: brake dynamometers and inertia dynamometers. Within these, we can also distinguish between those intended for testing engines (engine

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dynamometers, where the engine is directly coupled to the dynamometer) and those for testing vehicles (chassis dynamometers) [2].

2.1. Inertial dynamometer

Inertia dynamometers that was used in this work consist of a flywheel with a specific mass which is connected to the engine by a mechanical transmission. The inertia flywheel is a steel disc that, when put in rotation around an axis perpendicular to its plane and positioned in his own centre, it is applies a force counteracting the designated movement, inertia [3].

2.2. On Car tests

The car in question, the UBIAN, was built at UBI to participate in the Shell Eco-marathon in 2019.

UBIAN car and go-kart tests use car inertia as a load applied to the engine; This inertia produces a driving force that opposes the linear motion of the vehicle and its acceleration, characterizing this acceleration, we can also characterize the torque on the drive wheel and vehicle engine.

These tests are performed on a zero-slope track so that the inclination does not influence the tests.

3. Data Acquisition

Data acquisition is done directly to the engine in the dynamometer test and in the car by the control unit, which we implemented in the engine in question.

An EMU Black from Ecumaster was used.

To ensure high noise immunity the USB connection has galvanic isolation allowing a 25Hz data frequency.

In addition to the USB connection, the EMU Black has a CAN and serial connection module that can be used for data logging, from where we get the engine speed as a function of time. By obtaining this data the engine torque is then calculated.

The kart data acquisition is done differently: a GPS application is used which gives us the linear velocity as a function of time.

This method is very practical and easy to use; however, it has clear disadvantages as it is a very low frequency data acquisition in the order of 1 Hz which makes it difficult to obtain reliable results.

4. Inertial Dynamometer, UBIAN Car, Go Kart and Engine Characterization

4.1. Inertial dynamometer

In order to calculate the torque, it is first necessary to estimate the inertia of the flywheel. Flywheel moment of inertia was estimated based on its dimensions and material density, being a steel with a density of 7841 kg/m³. Its inertia is the product of half the mass of the disk by the radius squared, obtaining the value of 0.0744827 Kg.m².

$$I_v = \frac{1}{2} * M * R^2 \quad (1)$$

I_v = Flywheel inertia (kg.m²)

M = Total disk mass (kg)

R = Flywheel radius (m)

The transmission between the engine and the flywheel is made by a centrifugal clutch followed by a chain drive (standard Honda GX160 gearbox). The gearbox has a reduction of 2:1 and is connected to the flywheel using a toothed belt for transmission with a ratio of 4:1 higher than the input speed, ie the flywheel speed is twice the engine.

Therefore, the final gear ratio will be twice the engine speed, as can be seen in Figure 1, which is the comparison between the speed of the engine and the flywheel simultaneously in one of the tests performed. Is possible to see the engine idle speed which is approximately at 1200 rpm; after setting the throttle to 100% the engine speed begins to increase and stabilizing at approximately 2000 rpm and reaching the clutch balance point between engine and flywheel speed, which is increasing almost linearly from 0 rpm to 4000 rpm. It is from 13 seconds that the engine starts to accelerate together with the flywheel, so between 13 and 26 seconds describe very similar curves, which is the range of values to consider for direct engine characterization. At 26 seconds the throttle is set to 0% where deceleration occurs and the end of the test.

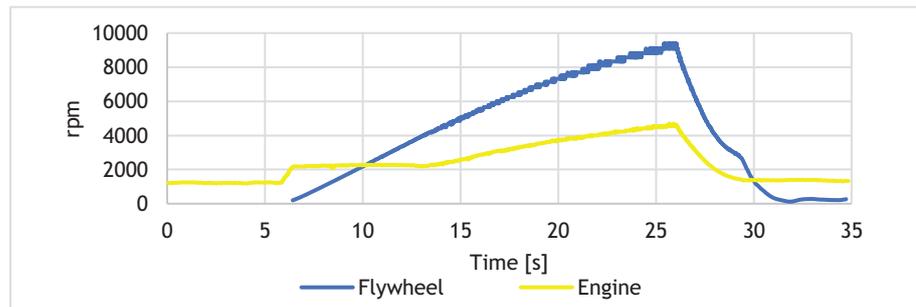


Figure 1: Engine and flywheel acceleration.



Figure 2: Engine on the inertial dynamometer.

4.2. UBIAN Car

As explained earlier all vehicles have an associated inertia. There are several ways to calculate the inertia of a car [4]. Calculation forms are based on vehicle characteristics, such as vehicle mass and wheel radius.

So, to get the UBIAN inertia we went to measure the total mass including the driver, which is 243 kg, the wheel radius is 0.28 m and the gear ratio from engine to wheel is 10:1. So, the body equivalent inertia is the wheel radius squared multiplied by the mass divided by the gear ratio also squared, where:

$$I_c = \frac{R^2 * M}{i^2} \tag{2}$$

I_c = Body inertia (kg.m²)

R = Wheel radius including tire height (m) M = Total body mass (kg)

I = Engine to wheel drive ratio

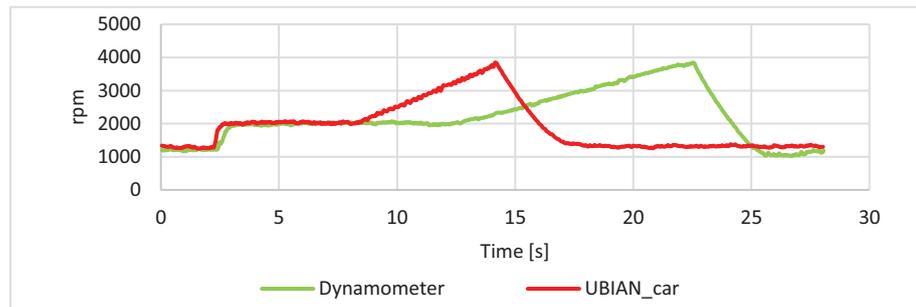


Figure 3: Comparison between the acceleration of the engine on the dynamometer and on the car.

The imposed gear ratio of 10 times lower car wheel speed compared to engine speed allowed limiting the car speed to 40 km/h, being the maximum allowed for UBIAN. But as we can see from the graph in Figure 3, there has been a decrease in acceleration time compared to the dynamometer test, these decrease in acceleration time, causes a reduction in the points acquired by the datalogger but due to the datalogger’s 25 Hz acquisition rate allows us to acquire enough points to characterize this acceleration.



Figure 4: UBIAN during the Shell Eco Marathon London 2019.

4.3. Go kart

Go kart inertia is calculated as previously done in the car. The mass of the vehicle is 190.5 kg including the driver, the final drive is 5.231 and the wheel radius is 0.139 m. The

inertia is calculated as done in the car by applying equation 2, and a value of 0.13451 kg/m² is obtained.

4.4. Engine Inertia

All internal combustion engines have a certain associated inertia due to moving parts inside such as the flywheel, clutch and crankshaft. Often this is not mentioned because they are engines of high power, so it becomes less relevant [5]. With everything in low power engines, we have concluded that we should consider it having a significant value and that it will be added to the inertia of both the flywheel and the vehicles.

Compared to the flywheel, an engine inertia corresponds to 19% of the flywheel inertia, making a difference of approximately 5% in the calculation of torque. An internal engine inertia is then estimated by measuring the acceleration time from the engine to its maximum speed of 5000 rpm, where you get a maximum acceleration of 398.879 rad/s² at 3256 rpm.

After performing the same procedure, but with the engine coupled to the flywheel from the dynamometer, obtaining a maximum acceleration of 18,951 rad/s² at 3256 rpm. Applying the equation of torque is defined a system of two equations:

$$\begin{cases} T = Im * \alpha v \\ T = (Im + Id * i) * \alpha c \end{cases} \quad (3)$$

T = Torque (N.m)

Im = Engine internal inertia (kg.m²)

αv = Engine acceleration at no load (rad/s²)

Id = Disk inertia (kg.m²)

αc = Accelerated engine with load (rad/s²)

i = Transmission Ratio

After solving the system, an internal engine inertia of approximately 0.014859 kg.m² is obtained.

5. Obtained Results

Several tests were performed on the dynamometer, on the car and on the go kart, from these tests we make an average that allowed us to reduce the external interferences like eventual malfunctions or variations of the engine parameters in results.

The tests were performed with accelerations from 1000 rpm where the engine was idling to the maximum speed reached by the engine at 5000 rpm, but the useful engine speed range for calculating engine torque is only between 2500 and 3500 rpm. It is from 2500 rpm that, as we can see in Figure 5, the engine starts to stabilize the rotation speed these means de that the centrifugal clutch stops slipping, and the engine is under full load; at 3500 rpm, the torque of this engine abruptly drops, and it is not efficient to use it in after this rotation.

The results for the different executes tests between the 2500 and 3500 rpm are shown below.

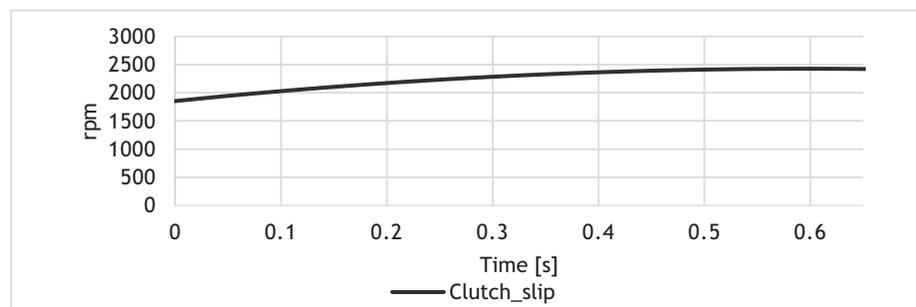


Figure 5: Characterization of the clutch slipping.

5.1. Torque calculation

After obtaining the engine speed (rpm) values as a function of the time (s) given to us by the control unit data logger, we can do the calculations to get the engine torque values.

The first step is convert rpm to rad/s with the following equation:

$$\omega = \frac{N * \pi}{30} \tag{4}$$

N = Engine speed (rpm)

ω = Angular engine speed (rad/s)

The second step is to create an angular velocity plot as a function of time, so that a trend curve with these values can be plotted, obtaining a 3rd degree polynomial equation.

The third step is to obtain the angular acceleration (rad/s^2) being the first derivative of the equation in order to time obtained previously and then the acceleration value for each time value is calculated.

Finally, the engine torque is calculated with the following equation:

$$T = \alpha m * (I + Im) \tag{5}$$

T = Engine torque (N.m)

αm = Angular acceleration of the engine (rad/s^2)

I = Inertia (kg.m^2)

Im = Internal engine inertia (kg.m^2)

i = Transmission Ratio

5.2. Inertial Dynamometer

The average torque obtained from the tests on the inertial dynamometer is 5.6 N.m and have reach a maximum torque at 2950 rpm with 6.5 N.m on the test shown on Figure 6.

On Figure 7 it is possible to see the average from tests performed on the inertial dynamometer and the trend line that is used to characterize the torque produced by the engine. The trend line is a polynomial of second degree that achieve a 0.994 coefficient of determination.

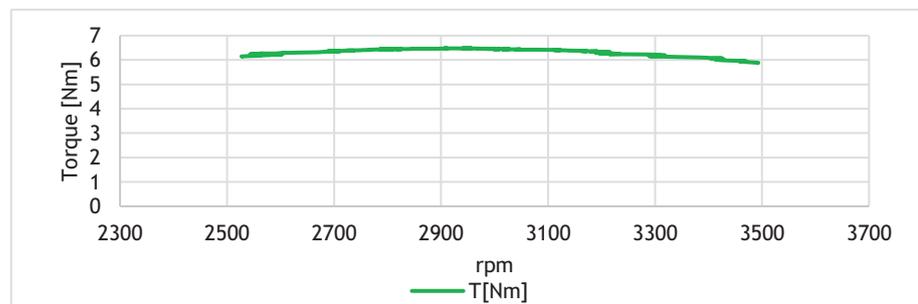


Figure 6: Test with the maximum torque performed on the inertial dynamometer.

5.3. UBIAN car

The average torque obtained from tests on the car is 6.0 N.m and have reach a maximum torque at 2918 rpm with 6.4 N.m on the test shown on Figure 8.

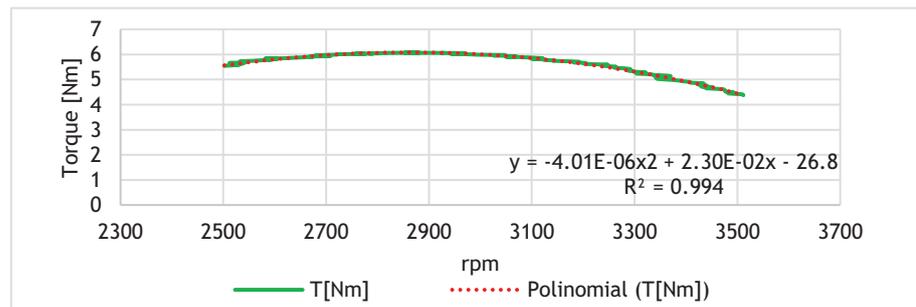


Figure 7: Average torque from the tests performed on the inertial dynamometer.

On Figure 9 is possible to see the average from tests performed on the UBIAN car and the trend line that is used to characterize the torque produced by the engine. The trend line is a polynomial of second degree that achieve a 0.974 coefficient of determination.

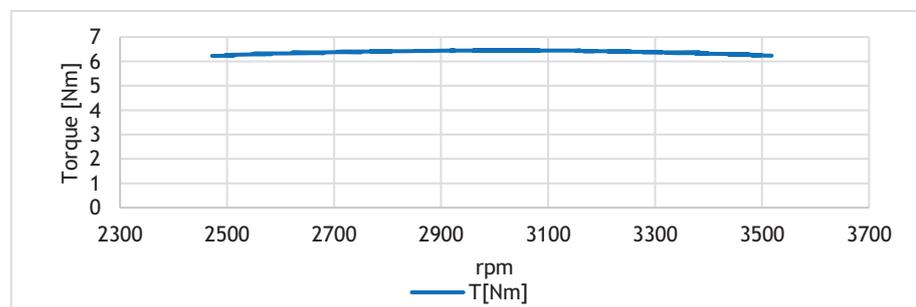


Figure 8: Test with the maximum torque performed on the UBIAN car.

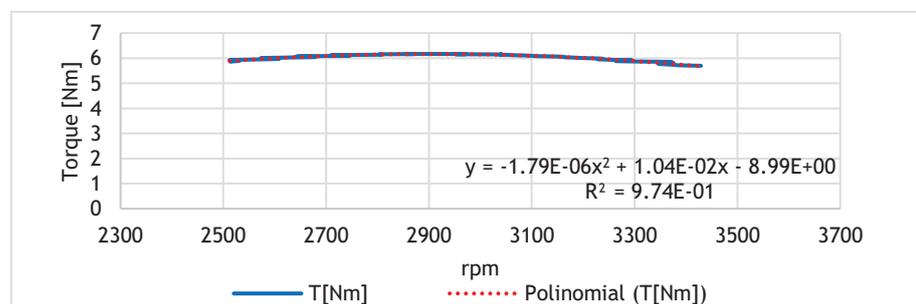


Figure 9: Average torque from the tests performed on UBIAN car.

5.4. Go kart

The torque calculation on the go kart test is very similar to what was done in previous tests, the difference now is the way the data acquisition was done. These were collected by a GPS application allowing us to know the linear velocity versus time and not the angular velocity of the engine.

After obtaining the linear velocity we calculated the kart acceleration by calculating the trend time velocity vs timeline, as in previous tests.

In this case, the torque, is also calculated with equation 5, being the angular acceleration of the engine equal to the linear acceleration, multiplied by the transmission ratio divided by the wheel radius. So, the equation is as follows:

$$T = \frac{a}{R} * i * (Ik + Im) \tag{6}$$

T = Engine torque (Nm)

a = Linear acceleration (m/s²)

Ik = Inertia of the kart (kg.m²)

Im = Internal engine Inertia (kg.m²)

i = Transmission Ratio

R = Wheel radius (m)

The average torque obtained from the tests on the go kart is 5.9 N.m and have reach a maximum torque at 2500 rpm with 6.7 N.m on the test shown on Figure 10.

On Figure 11 is possible to see the average from tests performed on the go kart and the trend line that is used to characterize the torque produced by the engine. The trend line is a polynomial of second degree that achieve a 1 coefficient of determination.

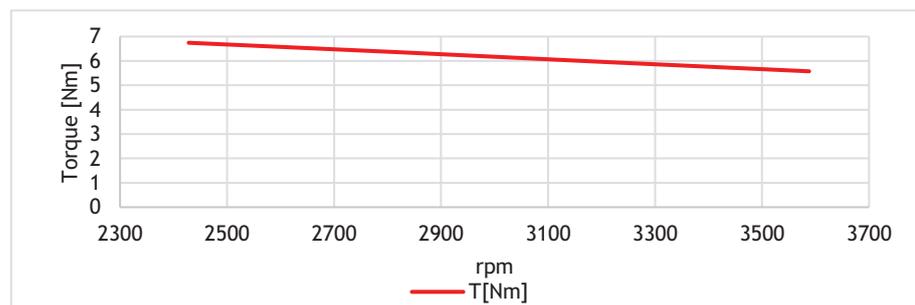


Figure 10: Test with the maximum torque performed on the go kart.

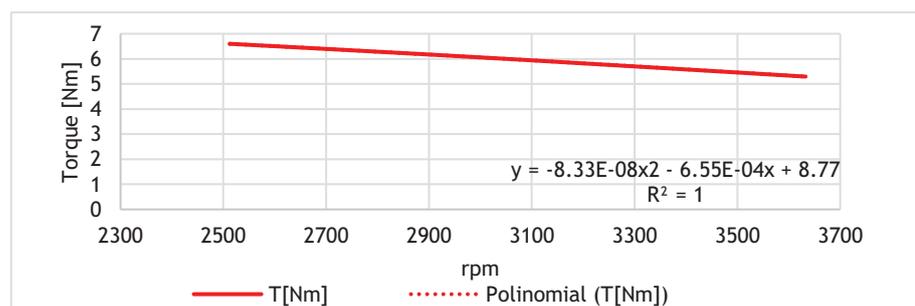


Figure 11: Average torque from the tests performed on go kart.

6. Results Discussion

As we can see in the different tests practically all graphs have torque values between 5 Nm and 6.5 Nm, so was we can observe on Figure 12 these three methods match the obtained results and give similar torque characteristic curves.

The go kart tests served to validate the values we thought were too low for the Honda GX 160, according to the manufacturer, who says the engine torque is 10 Nm [6]. In car and dynamometer tests we use the same engine and in go kart tests we use a second engine although the same model. Torque values were obtained in the same order of magnitude as previous tests, we can therefore say that the maximum useful torque of the motor is 6 Nm.

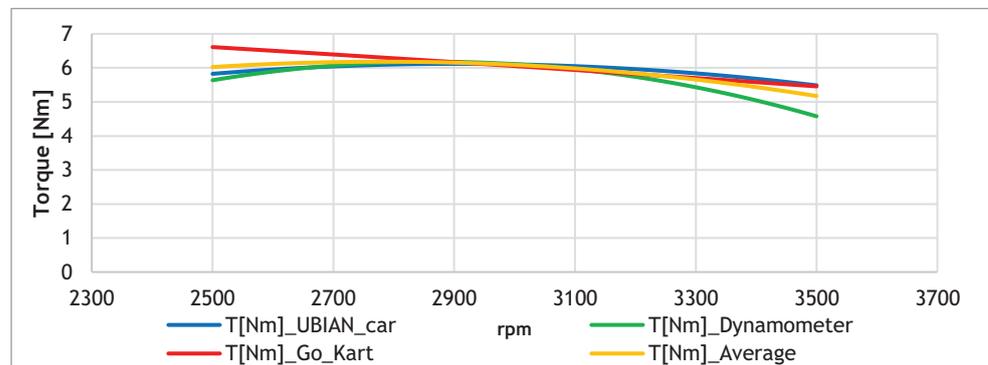


Figure 12: Comparison between the tests performed on UBIAN car, dynamometer, go kart and the average from these three tests.

7. Conclusions

We can then conclude that the objective of the work was achieved, we can see the graph of Figure 12 that all as torque curves in the different tests almost overlap and the obtained curves from the tests performed on UBIAN and dynamometer are typically characteristic curves from internal combustion engines, the characteristic torque obtained from the test performed on go kart differs slightly from the others because the GPS acquisition rate used is only 1 Hz, but in terms of magnitude this curve gives corroborative results from the other curves.

The use of the inertia dynamometer is then valid, allowing the quantification of modifications and tunings in the Honda GX 160.

Acknowledgment

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