DIDACTICAL TEST CELL FOR ALTERNATIVE INTERNAL COMBUSTION ENGINES

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Abstract. *The construction of a test cell for small alternative internal combustion engines for didactical purposes is described in the present work. The test cell uses a variable filling hydraulic dynamometer Go-Power DY-7D available at the Thermal Engines Laboratory of the Universidade Federal do Rio de Janeiro. Initially, an appropriate engine is specified and acquired. The engine-bench fixture and the engine-dynamometer coupling is designed and built. Besides, the original instrumentation of the test bench is modernized in order to allow digital data acquisition through appropriate software. A calibration procedure for the torque and rotational speed is developed and implemented. Results show the features of the engine test bench show and the different experiments that can be performed during classes.*

Keywords*: internal combustion engine, engine tests, dynamometric bench, thermal engines*

1. INTRODUCTION

Thermal engines are a class of devices that, among other features, generate power using heat as the energy source. The generated mechanical power is commonly used for a wide variety of applications with include transportation, electric power generation and machine driving. Thermal engines where combustion occurs within the power generation device are classified as internal combustion engines. Depending on the part of the operating cycle being considered, the working fluid usually found in internal combustion engines is air, fuel and combustion products. Alternative internal combustion engines, where the linear displacement of a piston driven by the expansion of combustion generated gases is converted into rotational displacement that drives the vehicle power train, are widely used for ground transportation applications. The basic cycle of the spark-ignition contemporary alternative internal combustion engines was introduced in 1876 by Nikollaus Otto. In 1892, Rudolf Diesel patented the compression-ignition engine (Heywood, 1998). The general requirements for the operation of internal combustion engines have significant evolved from the early times, specially in regards to environmental regulations and fuel prices and availability, leading to an increase need of engine tests.

Engine tests are usually performed to obtain data on power generated, emissions and fuel consumption, among other important engine working variables. Dynamometers are devices capable of apply a specific load on the engine output shaft and measure the torque being developed by the engine using the principle of angular momentum conservation. The load applied the on the engine output shaft can be used to drive or dissipate the power being generated by the engine. The dynamometer used in the present work is of the hydraulic type and capable only of dissipating the energy generated by the engine. In order to evaluate the power being developed by the engine, rotational speed measurements are also usually performed. Fundamental knowledge of basic aspects of design, installation and operation of engine test cell is required from engineering professionals working in the area, since safety and the quality of the obtained data are sensitive to different operational parameters.

Aspects of the mechanical recovery of an internal combustion engine test bench for didactical purposes are described in the present work. The test cell is based on a Go-Power DY-7D hydraulic dynamometer previously used for undergraduate teaching purposes with different engines and original analogical instrumentation. The migration to digital instrumentation and automatic data acquisition is also described. Tests are performed for a selected single cylinder engine and the obtained performance curve compared with data available from the engine manufacturer. Mechanical and operational aspects of the didactical test cell are discussed using the obtained results.

2. EXPERIMENTAL APPARATUS

2.1. Mechanical Aspects

An exploded view of the Go-Power DY-7D variable-filling hydraulic brake is shown in Fig.1. The load control valve is placed in the water inlet and a plate for testing engine mounting support is also available. The engine mounting support, hydraulic brake and load transducer are connected a dynamometer frame through rubber dampers. Inlet and outlet water connections and the load controlling valve are positioned in the dynamometer frame. Flexible hoses are used between the water connections and the hydraulic brake. The hydraulic brake is also equipped with a directional that controls air flow when load relief is necessary. Figure 2 shows different views and main parts of a Go-Power DY-7D dynamometer with original instrumentation.

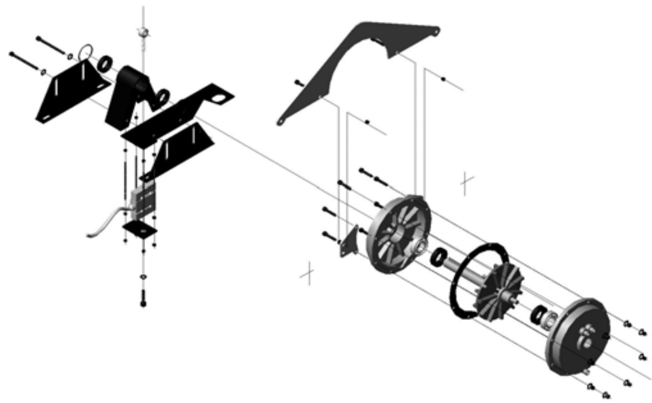
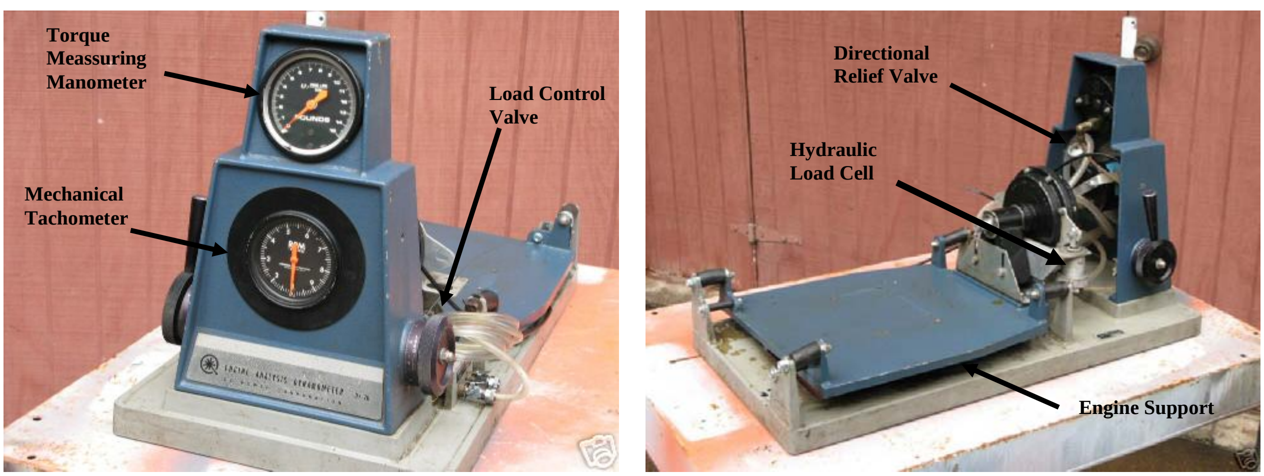


Figure 1 –Go-Power DY-7D Dynamometer - Exploded View



(a) *(b)*

Figure 2 – Dynamometer Go-Power DY-7D – Frontal and Lateral views.

Initially, the engine test bench used in the present work was subjected to corrective maintenance in order to eliminate excessive vibration of the hydraulic brake frame and water leakage. The maintenance was conducted by the technical staff of the Thermal Engines Laboratory of UFRJ that disassembled the hydraulic brake and identified the damaged parts. According to service reports, damages on the bearings and mechanical seals were identified while the rotor and casing condition were considered satisfactory. Pictures of the hydraulic brake rotor and casing taken during maintenance are shown on Fig.3. Bearings and mechanical seals were selected within the local market in order to replace the original parts. Some dimensional adjustments were necessary in order to allow the new parts to be mounted on the dynamometer brake.

In parallel with the maintenance effort, contacts with the Go-Power representatives were conducted and the original equipment data sheet and operation manuals were obtained. From the obtained material, the selection of engines suited for the dynamometer operational range, defined by a characteristic curve, was performed following technical and economical criteria. The characteristic curve defines the maximum torque the dynamometer can absorb for a given rotational speed. Dynamometer operational conditions above the characteristic curve are considered unsafe due to increasing water temperature, cavitation and mechanical integrity reasons. In the present work, operational conditions near the characteristic curves are also avoided in order to reduce the exposure of students to eventually risky conditions. Figure 4 depicts the dynamometer characteristics curves (darker lines) available from the equipment manuals.

(a)

(b)

(c)

(d)

Figure 3 – Hydraulic Brake Interns - Rotor (*a* and *b)* and Casing (*c* and *d*) after maintenance

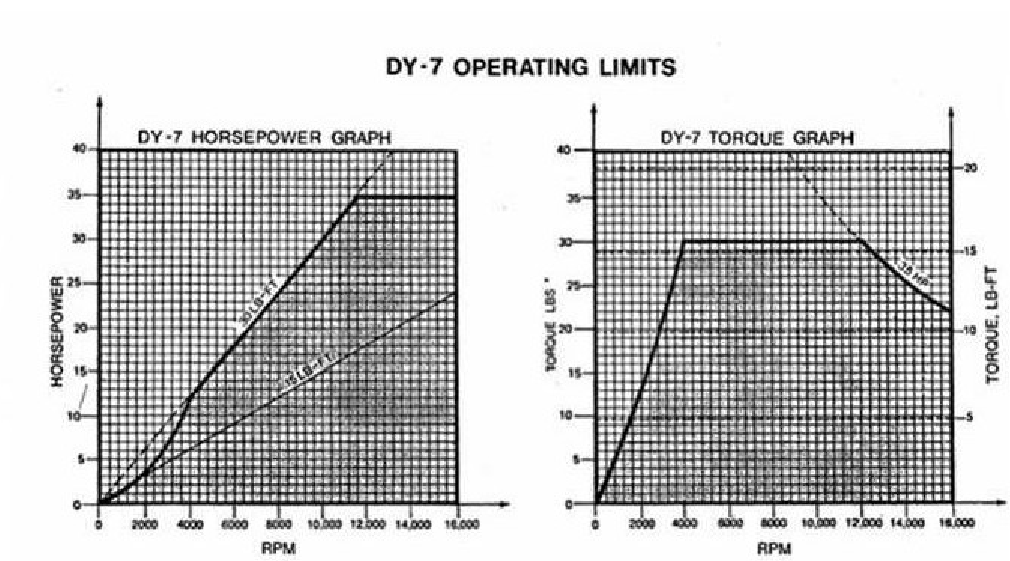


Figure 4 – Original dynamometer characteristic curves obtained from equipment manuals.

For the engine selection process, performance and characteristic data were obtained from of small-engine manufacture home pages and compared with dynamometer curves and features. A list of applicable engines and main engine characteristics are shown in Tab.1. For the present work, the use of Honda GX120-T1 as the testing engine is described.

Table 1 – Candidate engines and main characteristics

Engine Model	**Fuel**	**Maximum Power**	**Maximum Torque**	**Specific Fuel Consumption**	**Dry Weight**
Honda GX120-T1	Gasoline	4.0 HP @ 4000 RPM	7.5 Nm @ 2500 RPM	230 g/CVh	13.2 kg
Branco B4T-5.5H	Gasoline	5.5 HP @ 3600 RPM	11.0 Nm @ 2500 RPM	230 g/CVh	15.0 kg
Yanmar NG137	Gasoline	3.4 HP @ 3600 RPM	12.5 Nm @ 2500 RPM	220 g/HPh	19.7 kg
Branco Diesel BD5.0	Diesel	4.7 HP @ 3600 RPM	8.2 Nm @ 2500 RPM	220 g/HPh	19.7 kg
Branco 4T 2.5H	Gasoline	2.5 HP @ 3600 RPM	4.0 Nm @ 2500 RPM	200 g/HPh	13.0 kg

The selected engine data is used in the design of the engine-dynamometer coupling and of the engine support plate. The coupling connects the test engine to the hydraulic brake, should withstand the transferring power and accommodate small misalignments of the system. In order to address the specifications, a RADEX – NN25 steel disk coupling manufactured by KTR was selected. For the steel disk coupling, lozenge-shaped stainless-steel blades are used as flexible elements allowing for angular and axial misalignments. The blades are superposed and bolted by two ends to each coupling flange. The bundle of blades deform continuously during operation. Flanges and connecting bolts were mechanically designed for power transmission using analytical (Shigley, 1984) and numerical techniques via the Finite Element Method. An alignment procedure was developed in order to guarantee that maximum allowed radial and angular misalignments are not exceeded. The developed procedure makes use of a dial indicator and a milling machine table. Further details of the alignment procedure are available from Nascimento, 2008. For safety purposes and to allow the use of the coupling as a teaching tool, a bipartite coupling protective case was also designed. Although not explored in the present work, axle alignment is an import task Engineering professionals are involved. Therefore, the engine test bench can also be used for teaching and demonstration of alignment techniques, if proper instrumentation is available and installed. A picture of the general disk coupling connecting the engine to the hydraulic brake is shown in Fig.5.

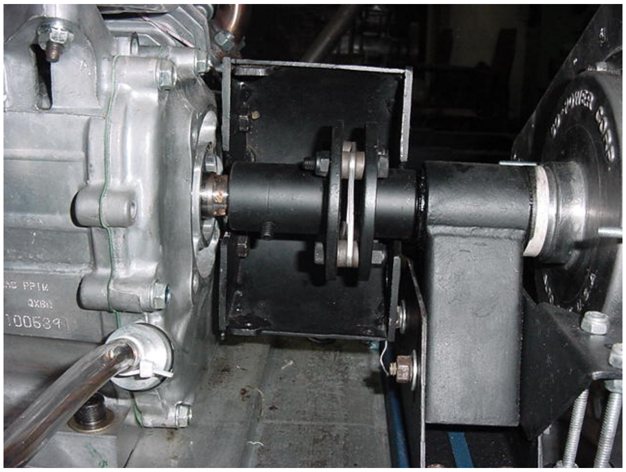


Figure 5. Disk coupling with flanges and protective case

An Aluminum base-plate was introduced to allow easy engine interchangeability and different experimental setups. The test engine was connected to the Aluminum plate using the fixing points specified by the manufacturer. Matching holes were drilled on the engine support plate of the dynamometer and on the base-plate. Bolts are then used to connect the engine support and base plates. The introduction of the base-plate also lead to an increase of the hydraulic brake vertical position that facilitates the assembly of engines on the dynamometric bench.

2.2. Instrumentation

The original dynamometer instrumentation included a hydraulic load cell and a mechanical tachometer for torque and rotational speed measurements, as shown in Fig.1. A detailed diagram of the hydraulic load cell is also shown in Fig.6. Besides being unsuited for digital data acquisition, the original dynamometer instrumentation was prone to excessive reading oscillations and was found beyond repair during preliminary evaluation. Therefore, migration to digital instruments and data acquisition was taken. The hydraulic load cell and the mechanical tachometer were replaced by an electronic load transducer and a tachogenerator. Signal from the new instruments are conditioned and sent to a digital computer.

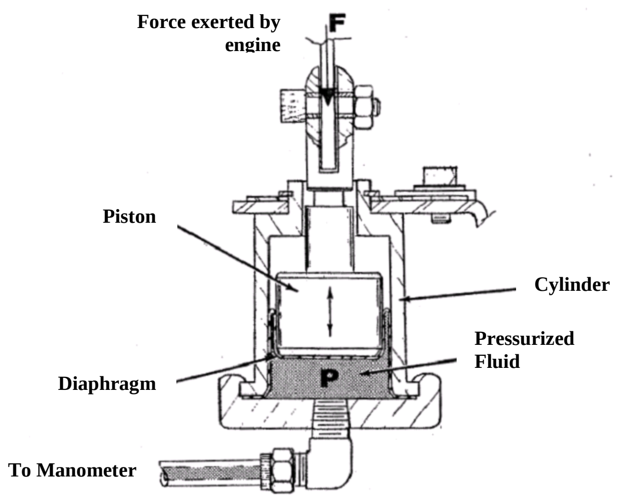
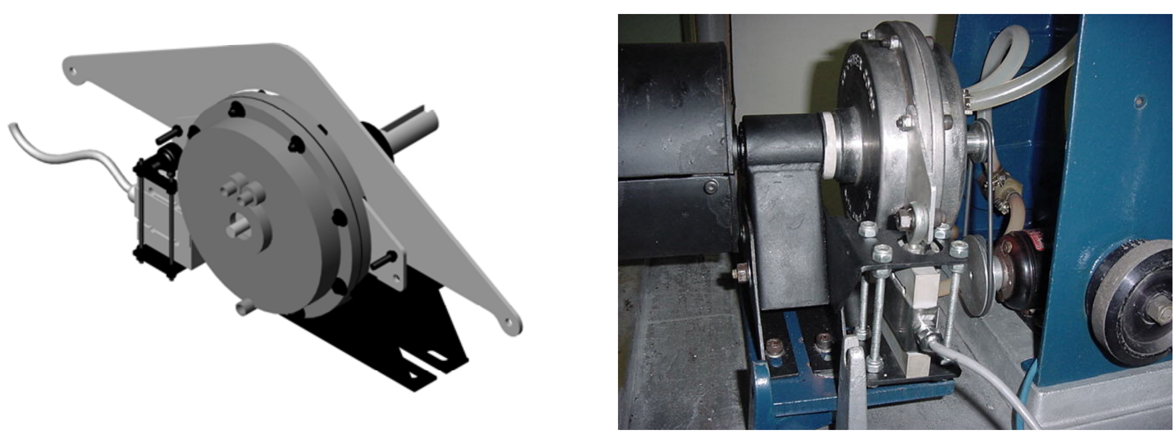


Figure 6. Original hydraulic load cell from Go-Power DY-7D Operating Manual.

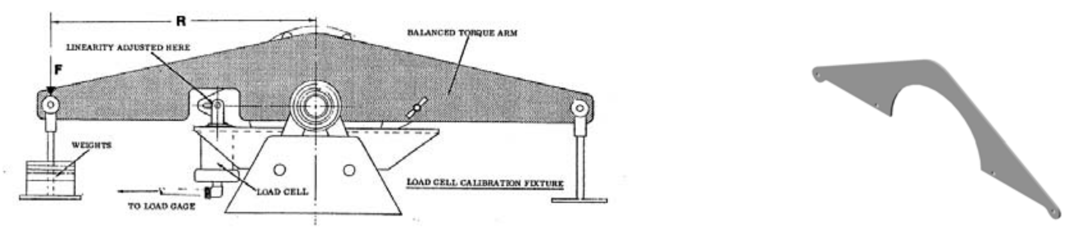
For the original load cell, the pressure of a hydraulic fluid is increased by the engine generated force applied to a piston through a torque-arm. The pressure increase is measured by an analogical manometer connected to the load cell. Calibration was achieved varying the torque-arm length using an oblong hole. The hydraulic load cell was replaced by an electronic load transducer equipped with strain gages. The maximum torque data available from the engine manual leads to a measured force estimate that should fit within the transducer response range.



(a) *(b)*

Figure 7. Load measurement system assembled into the dynamometer.
Sketch with calibration arm *(a)* and picture after assembly *(b)*.

For the Honda GX-120T1 engine being considered in the present work, the manufacturer reports a maximum torque of 7.5 Nm. For a torque arm length of 0.001m, the maximum load is 75 N. With the load value, the load cell CSA-10 manufactured by MK-Controle was selected. The CSA-10 is designed for a nominal load of 98.1 N, supports a maximum load of 147.2 N and has a sensitivity of 2.0 mV/V. It is worth mentioning that the physical dimensions of the CSA-10 also allowed a load cell assembly in the dynamometer similar to the original one. A signal conditioner from MK-Controle was also used to amplify and filter the signal obtained from the load cell. The output from the conditioner is on the 0 to 10V range. For the electronic load transducer, a new support and load arm were mechanical designed using the Finite Element Method to verify the deformations for the maximum engine load. To ensure that load is transmitted orthogonally to the transducer, a ball-joint was used to connect the load cell to the load arm. For the static and dynamic calibration of the load cell, a calibration arm was designed. Figure 8 shows sketches of the original and design calibration arms. For static calibration, a series of known weights are placed at a given distance of the hydraulic brake axis. The weights are placed at the same side of the dynamometer as the load cell. The known torque is compared with the load cell measured value generating calibration values that are used in the data acquisition program. For the dynamic calibration, the know weights are placed on the opposite side of the load cell and weights are added until the load cell indicates a zero-torque value.



(a) *(b)*

Figure 8. Sketch of the original calibration arm assembled in the dynamometer *(a)* GO-POWER DY-7D Operation Manual and of the proposed calibration arm *(b)*.

The mechanical tachometer that equipped the dynamometric bench was replaced by a tachogenerator Elinco 5000. Tachogenerators produce a voltage signal proportional to the rotational speed an input axle is subject. The Elinco 5000 has an operational range from 0 to 3000 RPM and sensitivity of 5 mV/RPM. Since the Honda GX120-T1 has a maximum rotational speed of 4500 RPM, a 2:1 pulley transmission is used to connect the hydraulic brake and tachogenerator shafts. A picture of final arrangement of the tachogenerator and the developed transmission system is shown in Fig.9.

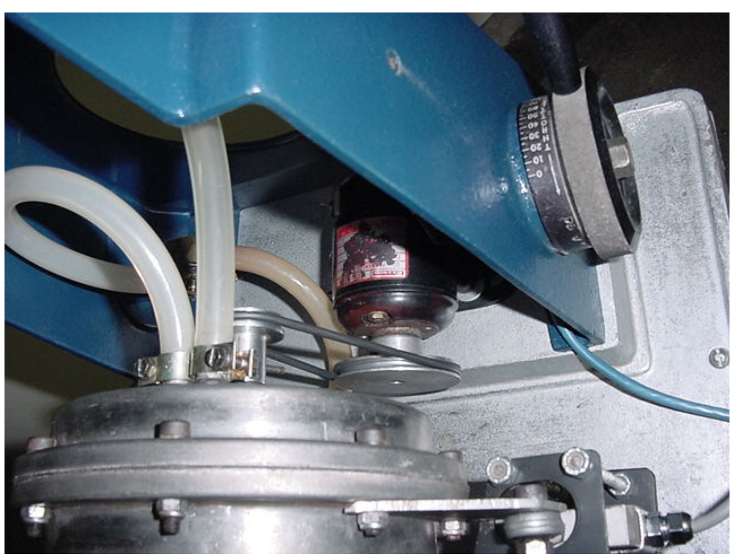


Figure 9. Final arrangement of the tachogenerator and the developed transmission system

Besides transducers for torque and rotational speed measurements, temperature sensors were also added to the dynamometric bench. Initially, sensors were position to measure air inlet, lubricant oil, cylinder outside wall and water exit temperatures. Temperatures associated with the engine are important test parameters that students can monitor during experiments. The dynamometer manufacturer recommends that the exit water temperature should not exceed 40^{o}C to avoid cavitation. For the temperature being measured, K-type thermocouples were used.

3. EXPERIMENTAL RESULTS

For the present work, five tests were performed in order to evaluate the repeatability of the obtained characteristic curves of the Honda GX-120T1 engine. For the tests, different required standard deviations and stabilization times were considered. The brazilian standard for stationary engines NBR-6396 (ABNT) requires that stable working conditions be kept for at least 10 minutes. The NBR-6396 standard also recommends the use of stabilizations periods between 30 and 120 minutes for each operation condition (torque and RPM). For a didactical test, the stabilization times are not practical, since different operational conditions are required to evaluate the engine characteristic curve. Therefore, shorter stabilization times based on the amount of data samples collected and on the standard deviation required from the data samples. The observed stabilization times were 35 s, 68 s and 75 s. Atmospheric conditions during tests, summarized in Tab.2, are used to correct the measured torque and power data through a reduction factor. The measured data is divided by the reduction factor leading to an effective torque and power value. With the corrections, the measured characteristic curve of the engine can be compared with the manufacture informed engine data. Table 2 also shows standard atmospheric conditions.

Table 2. – Ambient and atmospheric conditions during tests and standard atmospheric conditions

Date/Standard	Temperature (^{o}C)	Pressure (hPa)	Relative Humidity (%)	Reduction Factor
08/212008	*28.0*	*1013.0*	*60*	*1.0000*
08/222008	*25.4*	*1018.0*	*78*	*1.0050*
08/26/2008	*25.2*	*1013.5*	*77*	*1.0060*
08/27/2008	*21.0*	*1013.7*	*69*	*1.0300*
NBR-6396	*20*	*1013.3*	*60*	*1.0000*
SAE-J1349	*15.6*	*1013.3*	*0*	*1.0620*

Ambient pressure and humidity data were obtained for the meteorological station at the Rio de Janeiro International Airport. Ambient temperatures were measured near the dynamometric bench.

For the results shown in the present work, the torque and rotational speed uncertainty are considered as twice the standard deviation specified for data acquisition. Therefore, for each operational point of the characteristic curve, bars indicating the 95% confidence interval are indicated. Engine generated power corresponds to the product of the engine torque and the corresponding rotational speed. The power uncertainties are calculated by propagation of the torque and RPM uncertainties.

The torque and power characteristic curves for the Honda GX-120-T1 engine are shown in Fig.10 and 11. The characteristic curves available from the engine are also depicted in Fig.10 and 11 for narrower RPM range than the measured data. Manufacture and measured data show good agreement over the range of RPM where bith curves are available. The steep decrease of engine torque and power is absent of the engine manufacture characteristic curve but captured by the experimental data.

The flat torque curve shown in Fig.10 is typical for stationary engines and brings difficulties for the evaluation of the RPM associated with the maximum torque. Nevertheless, the rotational speed for maximum power can be obtained from Fig.11 since a steep decrease on engine power is observed around 3500 RPM. Results for the measured and manufacturer power after correction for ambient conditions are shown in Tab.3. Deviations between manufacturer-informed and measured power are also shown in Tab.3 and a maximum deviation of 4.9% was observed. The observed deviations can be explained by the controlled conditions of the lubricant oil, fuel and air and by the standardized stabilization times that the manufacturer should follow during tests.

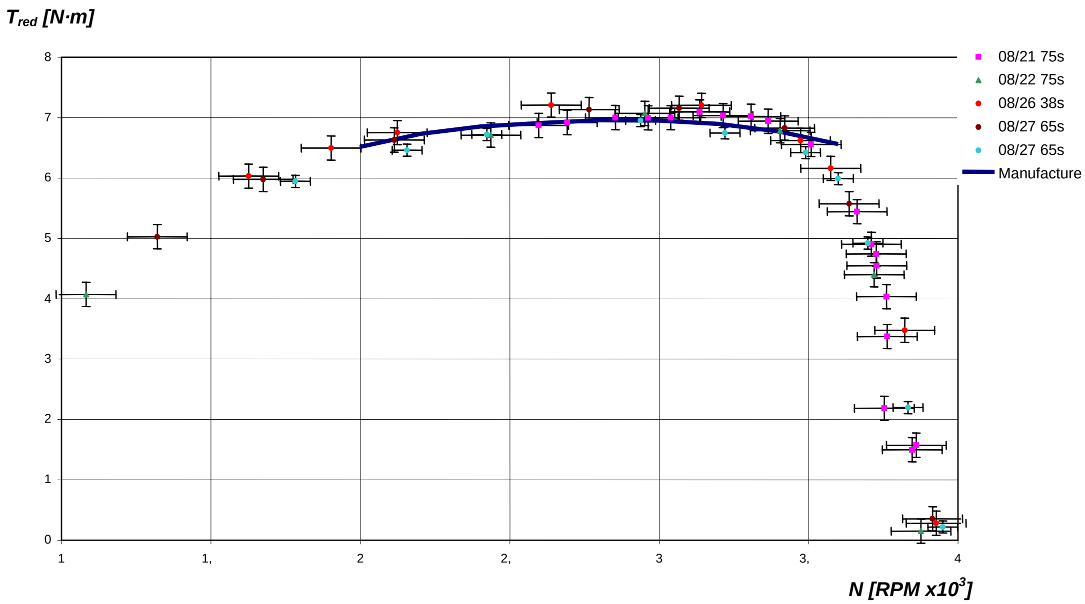


Figure10. Power vs RPM characteristic curve – Measured and manufacture data for Honda GX120T1

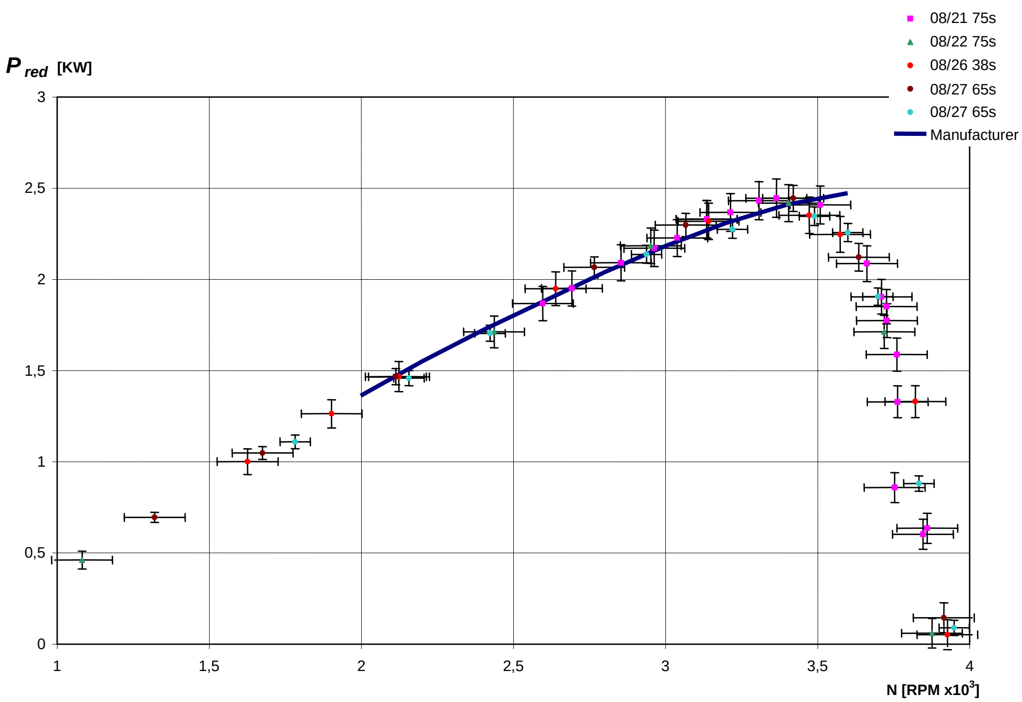


Figure10. Power vs RPM characteristic curve – Measured and manufacture data for Honda GX120T1

Table 3. Measured maximum reduced power, RPM and deviations from manufacturer data

Date	P_{max} [kW]		RPM @ P_{max}	
	Measured	Deviation [%]	Measured	Deviation [%]
08/21/2008	*2.45 ± 0.10*	*-0.8*	*3360 ± 100*	*-6.6*
08/22/2008	*2.42 ± 0.10*	*-2.0*	*3404 ± 100*	*-5.4*
08/26/2008	*2.35 ± 0,10*	*-4.9*	*3470 ± 100*	*-3.6*
08/27/2008	*2.45 ± 0.07*	*-0.8*	*3420 ± 100*	*-0.8*
08/27/2008	*2.35 ± 0.04*	*-4.9*	*3490 ± 50*	*-5.0*
Manufacturer	*2.47*	-	*3600*	-

Comparison between the average measured and manufacturer data was also made and results are shown in Tab.4 for different RPM. The maximum deviation between measured and manufacture data is 12%. Besides, higher deviations are found near the low and high RPM limit of the engine operational range.

Table 4. Average measured reduced power and torque and deviations from manufacturer data

RPM	P_{med} [kW]			T_{med} [Nm]		
	Measured	Manufacturer	Deviation (%)	Measured	Manufacturer	Deviation (%)
2000	*1.32*	*1.36*	*-2.9*	*6.29*	*6.51*	*-3.3*
2200	*1.51*	*1.55*	*-2.5*	*6.57*	*6.73*	*-2.3*
2400	*1.71*	*1.72*	*-0.5*	*6.80*	*6.85*	*-0.7*
2600	*1.89*	*1.89*	*0.0*	*6.94*	*6.91*	*0.8*
2800	*2.06*	*2.04*	*1.0*	*7.03*	*6.95*	*1.2*
3000	*2.22*	*2.18*	*1.8*	*7.06*	*6.95*	*1.6*
3200	*2.34*	*2.31*	*1.3*	*6.97*	*6.89*	*1.2*
3400	*2.40*	*2.41*	*-0.4*	*6.75*	*6.77*	*0.3*
3600	*2.17*	*2.47*	*-12*	*5.77*	*6.56*	*-12*

4. CONCLUSIONS

A small engine test bench for didactical purposes was designed and tested. The dynamometric bench was mechanically evaluated and corrective maintenance was performed. Original bench instrumentation was replaced by electronic transducers that allow digital data acquisition. The operation of the refurbished dynamometric bench was reliable, safe and economical for all the obtained engine regimes. Besides providing students with the opportunity of obtained an engine characteristic curve, the developed bench allow for other experiments provided proper instrumentation is available. Natural extensions include fuel and air consumption and engine emissions analysis.

5. ACKNOWLEDGEMENTS

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