Engine Dynamometer for Chalmers Vera Team

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ABSTRACT

Two members of the Chalmers Vera team; Patrik Nilsson and Fredrik Johansson, carried out this project where an engine dynamometer specifically designed for the team's own use was designed, built and developed. The dynamometer was designed in CAD to design the aluminium profile frame and package the components to try to achieve a portable equipment. It was manufactured using common tools and machines available to the students in the university.

An electronics system consisting of an Arduino, a power supply, a force transducer and a PC was developed including the software for the Arduino and the PC.

To validate the dynamometer, a Honda Gx35 engine was installed, tested and later fitted with Ecotrons fuel injection system, which was calibrated and measured.

The result was a working dynamometer. Some functionalities of the dynamometer were not fully achieved such as measurement of the torque by the load cell and brake inertia compensation.

The project taught the participants primarily programming and engine testing skills. The project was an application of previous knowledge in a complete system such as this dynamometer.

ACKNOWLEDGEMENT

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CONTENTS

1 INTRODUCTION

The present project is to develop a test equipment called a dynamometer, with the purpose of testing internal combustion engines as well as calibrating their EMS; electronic management systems. Such equipment is widely used in the field of engine development. The project is developed in connection with the Chalmers Vera team, the university's group of students who is participating in fuel efficiency competitions. Two members of the team; Patrik Nilsson and Fredrik Johansson takes part in this project.

The team has since 2006 designed, built, developed and competed with their vehicles “Vera” and later “Vera 3” in fuel efficiency competitions Shell Eco Marathon and Pisaralla Pisimmälle. Such competitions consist of running the teams' vehicles on a track and measuring the consumed fuel to conclude the winner. The result for the different classes and vehicles is compared by calculating an equivalent result presented in the term of kilometres travelled per litre of consumed fuel. To compete in the gasoline prototype class, initially, a commercially available Honda Gx35 engine was used, and later the team developed their own engine.

During engine development, especially during the installation and calibration of the fuel and ignition system, there was a need for test equipment, such as an engine dynamometer. Several engine development theses and projects were connected to the team. In some of these, a dynamometer could have been useful. To mention two of them: a project of developing an electrically operated valvetrain, and a development of the team's own EMS system. In these kinds of projects, a dynamometer could have been used for testing the developed components and systems. Another team related project was a fuel efficiency vehicle simulator which needed engine performance data as input, which could be measured with an engine dynamometer.

Three engine and drivetrain testing equipment's have been used by the team previously. A chassis dynamometer with a magnetic brake, a stationary engine dynamometer and, during recent years, small portable inertia rollers without measuring capabilities was the mainly used testing tool. Therefore, the need for a small and portable engine dynamometer was identified. Such equipment could allow for more testing opportunities with the engine outside the vehicle to assist the engine development and calibration. It could provide the students with an opportunity to gain knowledge and experience of engine testing, calibration and dynamometers. The dynamometer can be useful for the Chalmers Vera team or various following projects within the university.

2 PURPOSE

The Vera team had limited capability of engine testing and calibration. Further testing and calibration could improve the competition results and the learning opportunities for the students. An engine dynamometer could provide these abilities.

The purpose of the project is to develop, construct and validate an engine dynamometer for testing and calibration of the Chalmers Vera Team engine or other engines. In addition to the dynamometer itself, a side task was to design, build, develop and calibrate a fuel pressure regulation system for both the dyno and the Vera vehicle.

3 SCOPE AND DELIMITATIONS

The scope is to develop and build a dynamometer with an electronic control and measurement system. The dynamometer is meant to be able to be manufactured in the school workshop with common tools and machines available to the students. The prioritizations are portability and modularity. A fuel pressure regulator for the vehicle Vera's fuel injections system is included in the project as well.

The project had a set of limitations: firstly, testing the Vera engine itself was outside the scope due to the extra time needed and the possible interference with the team's work. The project also limited the addition of measurement equipment such as temperature sensors, flow meters etc., due to the fact that such measuring equipment would be specific to the tests in any following projects.

4 THEORY

During engineering development, testing can be of great use. Internal combustion engines can be tested in their application or using test rigs such as dynamometers where the engine is tested apart from the application. A dynamometer is using a brake to apply a load to an engine and absorb the energy produced to simulate its operating conditions for various testing purposes. By measuring various parameters such as torque, speed, emissions, temperature and fuel consumption one can study various aspects of the performance of an internal combustion engine.

There are several different testing cases. Steady-state testing means that one or more parameters such as engine speed, load, temperature, etc is fixed, to allow for measurements and adjustments of actuators during a stabilized condition. In this case, it can usually be simpler to see the effect of varying one parameter and keeping all else unchanged.

There is also dynamic testing where one or multiple conditions such as speed, load, temperature etc is changed during a measurement, this is called a transient condition. The characteristics of an engine can be different in transient and steady state conditions especially depending on the speed of the transient, so both testing cases can be useful during development and calibration.

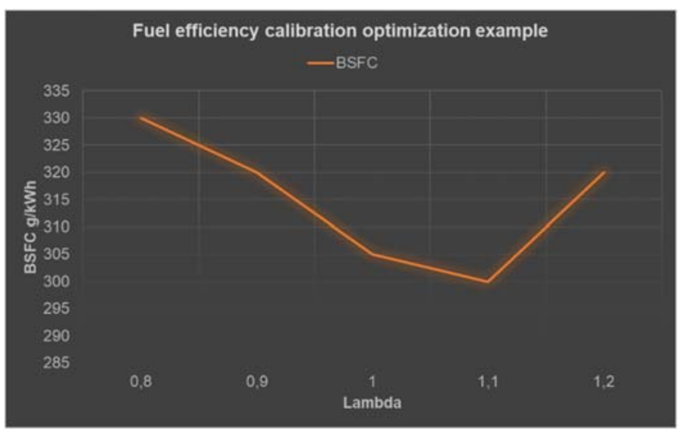

Figure 1 Example of fuel efficiency testing results

Dynamometers also allow for engine management systems calibration to achieve high performance in terms of fuel efficiency, power output, emissions etc. Calibration parameters can be adjusted to achieve the highest possible output in one or several performance parameters. For example, the pulse width of the fuel injector determines the amount of fuel that flows into the engine based on the fuel pressure and the injector specification. It determines the operational air to fuel ratio of the engine, often presented as lambda. By varying the fuel amount calibration parameter and measuring the engine torque and power output it is possible to adjust this parameter in a way to achieve the highest output per consumed fuel, that is the lowest possible fuel consumption. This is exemplified in figure 1 where the BSFC; brake specific fuel consumption is plotted as a result of lambda. The figure was created to provide an example.

During engine warmup or engine speed changes transients there might be different requirements on the EMS system's calibration parameters than in steady state operation. EMS Control strategies can have a base calibration for steady state conditions and transient compensations.

Further testing, verification and calibration might be needed when an engine is installed in the application due to the difference of testing an engine using a separate testing equipment and in its installation in an application such as a vehicle. The environment in which the engine is operating can be different due to the installation, air flow, cooling etc.

There are several different ways the dynamometers brake can absorb the energy from the engine. Some commonly used ways are by water and electricity. Water brakes are basically water pumps working with a restriction. Electric brakes are generators of electric energy.

5 METHODOLOGY

5.1 CONCEPT PLANNING AND DESIGN CONSIDERATIONS

During the design phase, the first task was the concept generation. The aspect of portability and modular construction were considered since it could be useful for the team to be able to use the dynamometer outdoors due to limited availability of time in a dedicated engine test cell. The portability was considered to depend on several characteristics, size, weight and the dependency on external systems. The aim in terms of portability was to build a dynamometer small enough to fit on a table or similar, and light enough to be carried by two persons and to minimize the dependency on other systems, such as connecting to power outlets, pressurized air, water or some other sort of system. The modular construction was also considered since different engines or engine mounting options, as well as the wish to add additional equipment, could arise in the future.

The reason why an engine dynamometer was built instead of a chassis dynamometer was that the team already had inertia rollers. Moreover, testing on such equipment can be expensive and complex due to wear on other components such as tires, freewheel, chain drive etc. An engine dynamometer generally focuses more on developing the engine with less consideration of the drivetrain or the engine’s installation in the application. An engine dynamometer can also allow for parallel work, since the vehicle does not need to be available for one specific task.

5.2 DESIGN & DEVELOPMENT

The design phase included CAD; computer-aided design modelling in Autodesk inventor and programming in the environments Arduino & Processing. All of which were freely available to the students. Many of the commercial components were available as CAD files that could be imported to the CAD assembly together with the parts that were designed in the project. The CAD tool was mainly used for packaging purposes rather than development. Packaging was important due to the attempt to minimize the size and weight of the dynamometer.

5.2.1 Frame

The frame was constructed from extruded aluminium profiles readily available from a supplier Aluflex. They were chosen to minimize manufacturing time and allowing for increased modularity. The profiles were equipped with slots which allowed for easy installation and position adjustment of the various components. Most of the frame’s components were available to order from the supplier Aluflex and only needed minor modification such as drilling and sawing to adapt to the application. Figure 2 illustrates the CAD model to show the layout of the dynamometer, where the extruded aluminium profiles make up the frame.

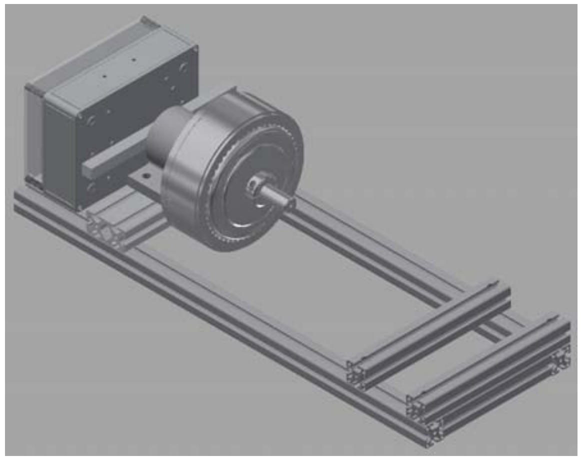

Figure 2 CAD model of the dynamometer

During the project, the Honda Gx35 engine was mounted on a generic engine mount that was supplied with the engine. It was attached to the frame's cross beams. The brake and engine were possible to adjust in any axis of the dyno. Adjustment in the horizontal plane was made possible by the slots in the extruded profiles and the position in the vertical direction could be adjusted by shimming. This allowed for flexibility of the mounting to allow for alignment of the power transfer shaft.

5.2.2 Brake

The dynamometer's brake is one of the main design aspects. The different options (water, electric, magnetic) were weighed against each other in several aspects. The different brakes have merits and demerits for the project. Depending on the test condition, the inertia of the brake can be important. Steady state tests could benefit from a brake with higher inertia to allow for smoother operation and more stable engine speed, but speed transient tests might need a brake with less inertia to properly simulate the conditions.

An electric brake can regenerate the power back to the grid for an added environmental benefit. In the case of this subject, it was less feasible since a fixed installation might be needed and cooperation with the grid owner was mandatory. Electric brakes can also drag the engine, minimizing the need for a starter motor and allowing for drag tests, something that was less prioritized in this project, since such a test rig can be built specifically for that purpose.

The downside of both water or electric brakes was that they needed a separate power or heat exchanger, and a separate medium (water or electricity).

A third option, a magnetic brake, which uses a steel rotor inside an air gap close to a field coil, was considered. By applying current to the coil, a flux field is created, and the rotor is restrained. Hence, a magnetic brake has no need for an external secondary energy dissipation system, since the heat dissipation occurs within the unit itself.

The magnetic brake from the previously built chassis dyno was available for use. The magnetic brake was a Magtrol HB-1750M-2. The maximum rated torque was 13 Nm and the maximum rated speed of the brake was 6000 rpm (Magtrol), perhaps a bit on the low side of what was needed. However, if the Vera engine would be tested in a high engine speed condition, a gear could be fitted to increase the rpm capacity of the dynamometer.

There were limited performance data available from previous testing of the Vera engine to make calculations for the brake requirements. However, results from a previous thesis where simulations were performed showed that the output of the Vera engine was approx. 2 Nm and 1750 W (Albinsson, Ljung Edin, Ericsson, Fredriksson, Johansson, Lindgren, (2010) ECO-marathon engine, Development of an energy efficient internal combustion engine). The torque rating of the magnetic brake can therefore be considered sufficient for the Vera engine.

To check that the maximum power capacity of the brake is sufficient we can calculate the maximum power absorption from the torque and the rotational speed as in Equation 1, the formula for calculating engine power. The inputs are the engines output torque (T) and rotational speed (N).

$$P = T * N * 2 * \pi \qquad \text{Equation 1}$$

Entering 13 Nm and 6000 rpm as per the brake specification, we calculate the maximum absorption power to be 8168 watts, which is sufficient for the maximum power output of the Vera engine.

Another aspect of the brake is the capacity of heat dissipation. The Magtrol brake is rated at a kinetic power rating at a continuous 350W and a 5-minute intermittent rating of 1200W (Magtrol). This is due to the limits of the coil and bearing temperatures, which shouldn't exceed 100 °C (Magtrol). This power absorption capacity is in the low end for continuous operation of even a small engine.

The maximum power output of the Vera engine is above the continuous power ratings of the brake. However, since the Vera engine's operating conditions during a competition aren't continuous full power, the average power output is far below the maximum output power. The low average output compared to the maximum power of the engine can be achieved either by throttling or a pulse and glide strategy. Many teams in the competition use a pulse and glide strategy, which means that the engine is ran under full power for a short period of time, and for the remaining part it is kept off. Pulse and glide can be superior to throttling due to that it allows for the engine to have lower pumping losses and the use of a throttle unit is not needed.

To calculate the power absorption requirements, we can calculate the average power output on the crankshaft for the Vera engine by Equation 2, the formula to calculate the average power used from fuel consumption. The inputs are the heat capacity of the fuel when burnt (c_p), the volume of fuel (l), the time (t) and the efficiency of the engine (η_{eff}). The Vera teams' recent results are in the range of 349 to 1243 km per consumed litre of fuel (Chalmers Vera team). The lowest result is corresponding to the highest average power output.

$$W = \left(\frac{c_p * l}{t}\right) * \eta_{eff} \qquad \text{Equation 2}$$

Entering the heat capacity of gasoline (9.1kwh/l), the amount of consumed fuel during an attempt (typical track length 17,9km / the worst result 349 km/l), and the time for an attempt (45 minutes) while assuming an efficiency of 40% the output power is calculated to 236,4 W. It is below the continuous power ratings of the brake. Calculating for the best result 1243 km/l the average power output would be 66,377 W. However, since Magtrol claims that the values of the brake specification in terms of power handling might vary ± 50%, it is difficult to calculate the power absorption in a specific condition. Testing can therefore be of use.

One aspect of the Vera engine is that the heat dissipation characteristics can be designed in relation to the average power output to keep the engine at a steady operating temperature during a competition attempt. In some cases, it might need a cooling system, in other cases, insulation might be needed to keep the temperature of the engine. Therefore, in addition to the ratings of the brake the cooling or in some cases insulation of the engine also is a restriction of the testing intensity in terms of average power output.

If needed it was also considered to enhance the cooling capacity of the brake with a cooling fan or similar. According to Magtrol, the values in service may vary as much as ±50 % due to mounting, ventilation, temperature etc. It could therefore be possible to add a fan or other cooling system to aid cooling capacity.

5.2.3 Power transfer

To transfer the power from the engine to the brake various systems could be used such as a shaft, gear, chain, belt etc could be used. A shaft was determined to be the more convenient option due to several reasons. Firstly, it allowed the engines centre to be in line with the brake, allowing for a narrower design. It also minimizes the radial and axial loads on the crankshaft. Since the team previously experienced difficulties with the strength and durability of the crankshaft it could mean increased effort to design a power transfer system that allowed for prolonged testing with minimal fatigue or load on the crankshaft. As mentioned before, an engine dynamometer's purpose can be to simplify the testing to allow for focus on testing a specific aspect such as combustion. Complex systems then can interfere with the testing.

One consideration while designing power transfer systems for dynamometers is the energy loss and therefore repeatability between tests. The power transfer can have some losses in the case of using rubber couplings, chain drive, gear drive or similar. The losses depend on mounting, lubrication, design, wear etc. This type of shaft does not require lubrication and since the frame was designed to allow for adjustment to achieve a straight shaft then the losses could be kept at the same level, increasing the repeatability of the tests.

A shaft and couplings were borrowed from the engine dynamometer in Chalmers for testing purposes. As a reference shafts with this type of couplings were used in another dyno at Chalmers as well as in other companies with success. Later due to excessive vibration during testing the shaft was redesigned with a ball bushing and alignment protrusion in each end to keep the shaft aligned, this was common practice on other dynamometers.

5.2.4 Torque measurement

Since torque measurement transducers can be expensive a load cell was considered to be more cost effective and allow for a more compact installation. The brake was mounted in two housed bearings, to allow it to rotate freely. A lever was then attached to the brake. In one end of the lever, a load cell could be attached. The load cell could then be fixed to the frame. In this case, the rotation of the brake was restrained by the lever and the load cell and the force could be measured by the load cell. With the lever length the torque could be calculated.

The brakes maximum braking torque capacity is 13 Nm (Magtrol), the maximum force applied on the load cell can therefore be calculated with the lever length of 110mm. The maximum force was calculated to approx. 118,18 N or 12,03 kg.

A load cell with a built-in power supply was chosen for simplicity and compactness. A load cell with model number CTSAMP6310K5-5V was purchased from AEP transducers which had the capacity of 10 kg and a signal output ± 5 V (AEP Transducers). The capacity of 10 kg is suitable since the narrower the range of the measurement the higher accuracy can be achieved. This is due to that the analog to digital converter in a measurement equipment usually has a finite amount of digital levels which represents the analog voltage and therefore determines the resolution of the measurement of the input signal.

In the opposite end of the lever from the load cells fixation point, a couple of weights were used to balance the assembly to minimize any offset reading.

5.2.5 Electronics

The electronics main components were an Arduino microcontroller, a Windows PC and a current supply to the magnetic brake. The electronics overview is shown in figure 3. Arduino is an open-source electronics platform based on an AVR microcontroller including hardware and software. It was chosen because of its wide availability, relatively low price and previous experience within the team. A PC is typically readily available among the students and can be connected to the Arduino over a serial port and receive, process, store and display the data efficiently.

Figure 3 The dynamometers electronics

Some accessories like a power supply, some minor electronic components etc were necessary to complete the electronics system. The Arduino read a hall sensor, the potentiometer to manually set braking torque and a lambda meter. The Arduino sent the data over USB using serial communication to the PC where the PC software processed the data. The current supply was connected to the PC with serial communication so that the output current could be read and set remotely from the PC.

The brake needs a current of up to 500-600 mA to energize the windings and provide full braking torque. Initially, the Magtrol 5250 current regulated power supply was used but due to some issues with a broken semiconductor another current supply was bought. The new equipment was a lab supply with a USB and serial port remote control (Velleman LABPS3005D) was used which could communicate with the software used for the dynamometer. Its current and voltage capacity of 0-30V and 0-5A (Velleman) exceeded the Magtrol 5250 specifications of 24V and 0-1000mA (Magtrol).

5.2.6 PC Software

A PC software was developed for several purposes; to read, process and log the measured data from the Arduino as well as control the amount of braking torque by utilizing the current supply. A PC is fast and convenient at handling large amounts of data, so therefore as much as possible of the data handling was put on the PC.

The software was written in the programming language Processing which is related to Arduino. This was chosen based on the team members previous experience and that it was somewhat simple and available for free.

The software also provided a graphical user interface for the user to read the real-time data, displayed in figure 4. It is important during engine testing to quickly provide information to the user. A visual scatter plot of the engine speed and torque was used to visualise the torque and power. A set of measured parameters were displayed in the lower part of the window.

The software saves a text file with the filename of the date and time the measurement was started. The file consists of the measured and calculated data: engine speed, current supply amperage, torque, measured lambda and watt. Saving measurements allow for post-processing and analysis of the data that might be more difficult to perform in real time.

The software could set the current setpoint for the current supply to allow for braking of the engine by using a serial communication protocol over USB to remotely send instructions for current output setpoints from the PC. Initially, a command was sent to set a maximum voltage for the current supply and activate the current output channel. During operation of the dyno commands were sent to set a current to achieve a desired braking torque.

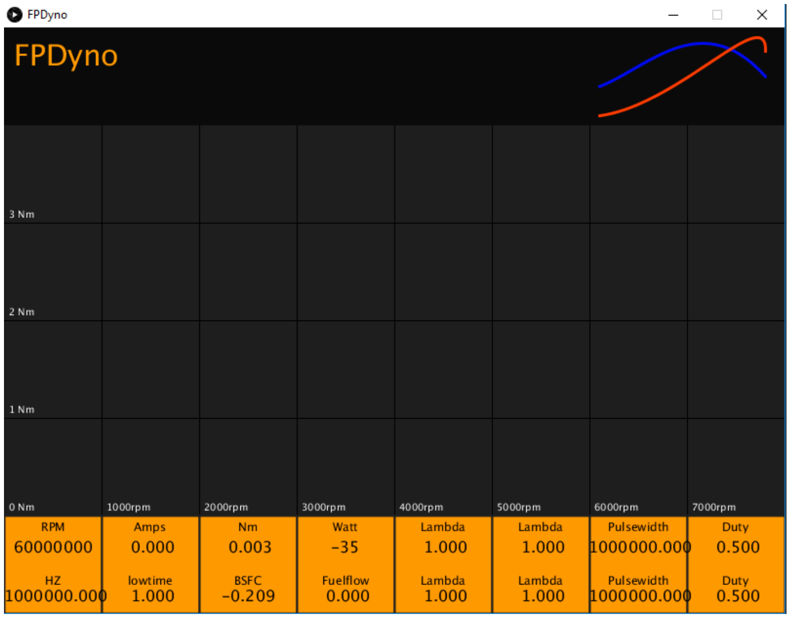

Figure 4 The PC software's graphical user interface

In addition to the measurement of the force transducer, the braking torque was estimated from the requested current. The datasheet of the brake provided a graph for the current to torque relationship. It was approximated as a polynomial by the help of another student's MATLAB script (Håkan Richardsson). The torque was then calculated from the applied current and displayed and logged in the data file.

The torque and engine speed were used to calculate the power output, which together with the injector pulse width could calculate the BSFC, brake specific fuel consumption.

5.2.7 Arduino Software

Due to the relatively small calculation capacity of an Arduino compared to a PC, the Arduino software was kept minimalistic to avoid any speed issues. The pseudocode is shown in Figure 5.

In this case, two interrupts are triggered by the injectors pulse rising and falling edge. On the rising edge, when the injector is opening, the analog measurements are taken and printed to the serial port, including the time the injector signal was low which indicates that the injector was closed. Later on, the falling flank when the injector is closing the injector pulse width is calculated and sent over the serial port.

This allows the PC to know the engine speed from the fact that the injector opens once every revolution or once every other revolution depending on the fuel injection system strategy. It also detects the injector opening time, from which the fuel flow can be calculated by using the injector specifications. The raw analogue values are mapped to the sensor specifications in the PC software to present the data in physical terms.

A check is performed in the falling edge interrupt to avoid misdetection of the signal flanks. The variable “ok” is set to 1 during the rising edge so that the second interrupt knows if the first interrupt occurred.

```
void eventrising() // interrupt on injector rising flank
{
  lowtime=micros()-timelow; // time since last injection
 pot=analogRead(A0); // read brake potentiometer
 lambda=analogRead(A5); // read lambd measurement
 Serial.print(pot); // Write data to serial port
 Serial.print(',');
 Serial.print(lambda);
 Serial.print(',');
  Serial.print(lowtime);
  Serial.print(",");
  timehigh=micros();  // Reference for next interrupt
  ok=1; // set check
}
void eventfalling() // interrupt on injector falling flank
{
  if (ok==1) { // check if a rising event happened before
  hightime=micros()-timehigh; // injectors pulse time
    timelow=micros(); // reference for next interrupt
  Serial.println(hightime); // Write data to serial port
  }
  ok=0; // reset check
   }
```

Figure 5 Pseudocode of the microcontroller program

5.2.8 Fuel pressure regulator

The project also included to design, build and calibrate two fuel pressure regulators, one for the dynamometer and one for the team's vehicle. It was similar in concept to the one previously used on the vehicle but was redesigned for compactness, lightness and simplicity. A fuel pressure regulator can be needed in the vehicle to keep a constant fuel pressure since the injection system used by the team used did not have fuel pressure compensation. The fuel pressure is set to achieve a good spray pattern from the

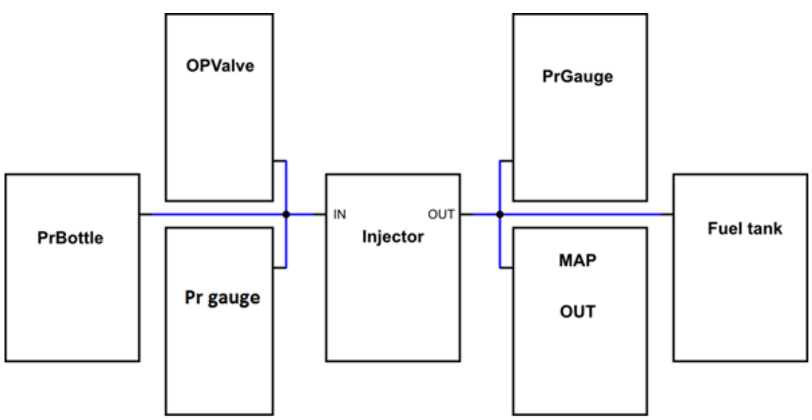

Figure 6 The layout of the fuel pressure regulation system

injector and suitable injector opening times. The layout of the regulator is displayed in Figure 6. A pressurised chamber, usually a plastic soda bottle was pressurized to 5 bar to supply air to a primary pneumatic distribution block by a plastic pressure hose and couplings. The primary distribution block also connects a pressure gauge, a pressure relief valve, a Shrader valve for filling and the input to the fuel injector. The fuel injector is used as an on/off valve to open and let air through to a second distribution block. The second block is connected to another pressure gauge, a pressure sensor and the fuel tank. The pressure in the fuel tank side is monitored and the injector opened when the pressure is dropped below a setpoint to allow more air to flow into the fuel system and increase the pressure.

The injector is controlled by an Arduino microcontroller, which reads the pressure sensor on the fuel tank side and opens the injector to allow air to flow from the high-pressure chamber to the fuel tank to reach the desired pressure.

5.3 MANUFACTURING

The main point of the manufacturing is that the dyno was designed to be manufactured using common tools, machines and processes available to students at the university during similar projects. These were: Band saw, mill, lathe, drill, sheet metal bender as well as common hand tools. The partly completed dynamometer is shown in Figure 7.

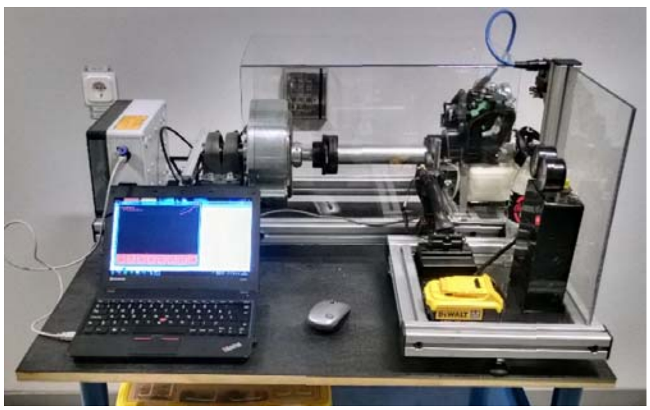

Figure 7 The assembled dynamometer during development

5.4 TESTING

To test and evaluate the dynamometer, a Honda Gx35 35 cc spark-ignited gasoline engine was used. It was available from the university and similar in size to the Vera engine. For reference, its power output is; 1,0kW @ 7000 rpm and 1,6Nm at 5500 rpm (Honda). The purpose of the testing was to see if the dyno worked properly in terms of braking capacity, electronic sensing and control and if there were unexpected issues. The stock carburettor and ignition system were kept intact initially for simplicity while the dynamometer itself was evaluated, however, the air filter was omitted. Several basic tests were made, such as sweeping the speed of the engine to check for vibrations, full power tests and full braking tests.

The power handling capacity of the brake was interesting to investigate. It was however limited time to measure the internal temperature of the brake to check if the temperature of the bearings or windings were below values recommended by Magtrol.

During testing the PC and Arduino software were developed further to try to solve some bugs that were found.

5.4.1 EFI system calibration

After the dynamometer itself was validated the test object, the Honda Gx35 engine was fitted with a purpose-built small engine EFI kit from a company called Ecotrons. The kit included ignition and fuel injection parts to run a Honda Gx35, the only change that was performed was that the fuel pump, pressure regulator and accessories were not used due to the fuel system described in this report was already available.

The purpose of fitting the Gx35 engine with fuel injection was to practice calibration as a part of the testing. The EMS system was installed, and the engine started. The dyno could be used to brake the engine while a calibration parameter was adjusted. The output from the dyno and the sensors could be read while making changes to the calibration. This was a part of the testing of the dyno itself as well as a practice in a dyno's typical use.

6 RESULTS

The achieved results were a working engine dynamometer and a PC software with data logging and control capabilities.

The torque and the power absorption capacity of the brake were sufficient to allow enough time to take measurements with the Honda Gx35 engine. However, it wasn't checked if the internal temperature of the

Figure 8 Results from testing the Honda Gx35 engine on the dynamometer

components inside the brake exceeded the recommended temperature.As presented in Figure 8 the maximum recorded torque of the Gx35 engine 1,565 Nm is close to its specification of 1.6 Nm (Honda).

The Arduino microcontroller and its software were able to record data and send it to the PC. The PC and its software were able to receive, process and save the data from the microcontroller, provide a graphical user interface and send commands to the power supply to set the braking current. However, the PC software had bugs that made it sometimes freeze or crash. The Arduino microcontroller and its software sometimes made misdetections of the reading of the fuel injector signal.

Reading the load cell was found to be difficult, the torque measurements was not satisfactory.

Therefore, the torque readings were taken from the estimation torque, i.e. the calculated torque from the current output and the brake specification.

The dynamometer was light and small enough to be carried by two persons. The light weight was an issue when performing tests due to the fact that the vibrations from the engine moved the dyno so that it needed anchoring to the table during testing. The tests before the power transfer shaft were redesigned and did not have the ball bushings and alignment protrusions resulted in very high vibrations induced by the shaft. One of the couplings for the power transmission shaft was damaged during testing and therefore a larger version was ordered from Centaflex, which worked for the remaining part of the project.

A downside of the current supply was that it sometimes froze, maybe due to a limitation of the frequency of the sent instructions.

7 DISCUSSION

One of the main aspects of the dynamometer is its brake. The magnetic type of brake used in the project was convenient for this low power application. It could be that an even smaller version could be used, depending on the usage conditions of the brake.

The accuracy of the reading of the load cell was low. It could be due to engine vibrations; a single cylinder engine can produce strong torsional vibrations. It might be possible to solve this issue by increasing the sampling rate of the microcontroller or include a hardware and or software filtering. However, the estimated torque was a cheaper and less complex way of achieving results.

Method wise, a more suitable current supply option could have been investigated, perhaps a commercial unit such as a purpose-built brake controller unit with built-in speed regulation. More time could have been spent on investigating prices and availability.

The transient torque compensation by inertia did not work very well. Had more time been available, then the software could have been developed even further.

One function that could be implemented in the PC software was a calculator of average absorbed braking power. It could be simple to implement and allow for the user to manage the testing procedures to stay below the power dissipation capacity of the magnetic brake.

8 CONCLUSION

The project mainly taught the participants programming and engine testing skills. The challenges of the project were to apply previous knowledge in a complete system and developing software.

The dynamometer worked for its intended basic purpose, however, there were some possible improvement points. Further time would be needed to develop the dynamometer even more.

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