Journal of KONES Powertrain and Transport, Vol. 21, No. 4 2014
ISSN: 1231-4005
e-ISSN: 2354-0133
ICID: 1130477
DOI: 10.5604/12314005.1130477

DESIGN OF A NEW ENGINE DYNAMOMETER TEST STAND FOR DRIVING CYCLE SIMULATION

Michał Kęder, Rafał Grzeszczyk

ODIUT Automex Sp. z o.o.
Marynarki Polskiej Street 55D, 80-557 Gdansk, Poland
tel.:+48 58 5220620, fax: +48 58 5220621
e-mail: michal.keder@automex.eu, rafal.grzeszczyk@automex.eu

Jerzy Merkisz, Paweł Fuć, Piotr Lijewski

Poznan University of Technology, Institute of Combustion Engines and Transport
Piotrowo Street 3, 60-965 Poznan, Poland
tel.:+48 61 6652207, fax: +48 61 6652204
e-mail: jerzy.merkisz@put.poznan.pl
pawel.fuc@put.poznan.pl, piotr.lijewski@put.poznan.pl

Abstract

Dynamic combustion engine test stand allows a very accurate analysis of the engine work. The prototype of such a system was developed and built in a cooperation of Poznan University of Technology with the ODIUT Automex company. The system consists of an asynchronous motor controlled by a regenerative variable-frequency drive with an ability to return braking energy back to the power system. Together they permit to set very precise work points of the combustion engine in every time moment, unlike test stands with eddy current dynamometer, which are only able to brake the engine. Measuring system is used to gather data from all sensors, especially torque sensor, which records the torque on a drive shaft. Sensors are connected to electronic boards, which provide signal processing, and data acquisition. Fuel mass flow meter with temperature and pressure control allows regulating the parameters of fuel supplied to the engine. A set of applications is used for test stand management and data presentation and visualization. Real conditions and vehicle dynamics are emulated using advanced models to allow a comprehensive research of the combustion engine on the test stand. The paper covers the description of developed system, its components, software and models adapted in emulation. Moreover, it provides schematics of the system as well as a block diagram of the vehicle dynamic model.

Keywords: *dynamic engine test stand, combustion engine, variable-frequency drive, induction motor, vehicle model*

1. Introduction

The salient goal of the PPHD (Pierwsza Polska Hamownia Dynamiczna) project is to develop and build a dynamic combustion engine test stand that will allow researching the engine in transient conditions. In a cooperation of Poznan University of Technology with the ODIUT Automex company, the first prototype with small combustion engine was designed and built within the project. The main difference between dynamic and static test stand is the possibility to set very precise work points of the combustion engine in every time moment thus the engine can be studied not only in specific fixed conditions but also in simulated real conditions. The emulation of the vehicle also gives opportunity of more accurate analysis of the engine work. The innovative structure of a stand allows the operator to manage the whole system from operator desk. The paper describes the designed system and its crucial components, such as the induction motor and variable-frequency drive. Moreover, the innovative modular software suite for test stand management and data analysis and visualization is also covered. Finally, models used to emulate the vehicle and real conditions are shortly presented.

2. Main system components

Designed prototype of the comprehensive dynamic combustion engine test stand consists of a series of essential components, i.e.:

- asynchronous (induction) motor, acting as an active brake,
- regenerative variable frequency drive, acting as a motor controller,
- torque sensor,
- drive shaft connecting the internal combustion engine with the dynamometer,
- data acquisition system for gathering data from sensors with a sample rate up to 100 Hz,
- fast measurement recorder with a sample rate up to 100 kHz,
- fuel mass flow meter with temperature and pressure control,
- data visualization system,
- test stand and research process management system,
- open Electronic Control Unit (ECU).

The schematic presented in Fig. 1. shows the system divided into separate components with all signal links between them.

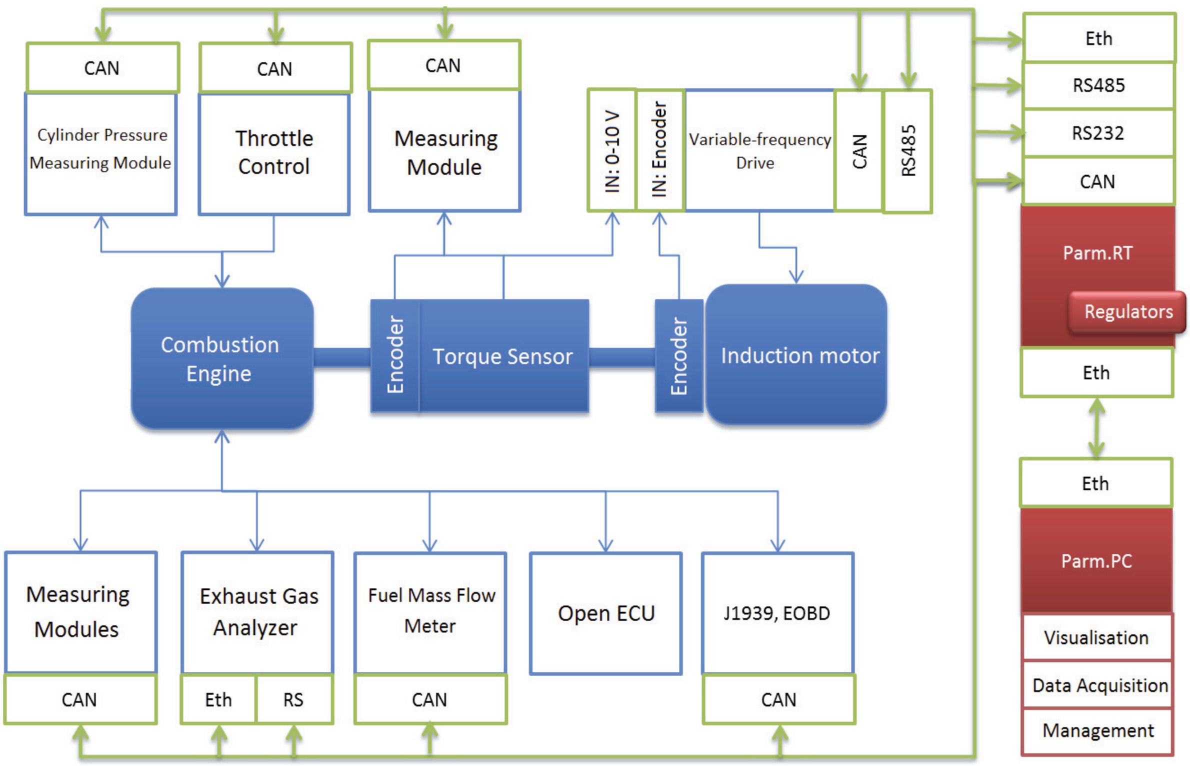

Fig. 1. Block diagram of the dynamic test stand system

The system control module is an application running on a ParmRT.PC computer, where the real time operating system Windows Compact 7 is installed. The program executes tasks related with connection to electronic boards, system safety and software implementation of regulation and simulation algorithms.

Electronic modules are connected together via CAN bus, RS232, RS485 or Ethernet. The main and leading interface is CAN bus and CANOpen communication protocol. Extra devices not compatible with CAN bus is connected directly to ParmRT.PC, which transfers data to CAN bus when needed.

User manages the system using Parm software suite, running on a Parm.PC computer. Apart from managing role, a set of applications provides modules used to visualize gathered data, change system parameters, execute automated procedures, data archiving and data real-time and post-processing.

The asynchronous motor is controlled by a regenerative variable-frequency drive equipped with torque and rotational speed control functions with feedback signal coming from torque sensor. Measurement data are gathered by specialized devices with a sample rate up to 100 Hz. Crucial parameters can be collected by a fast data acquisition recorder with a sample rate up to 100 kHz.

Depending on the type of the combustion engine, its throttle valve is controlled either by a servomechanism pulling mechanical linkage or by an electrical device sending a voltage signal to the ECU.

Fuel consumption is measured by a fuel mass flow meter with a temperature and pressure control feature. The whole system can be supplemented by an open ECU, exhaust gas analysers, air and fluid flow meters and other data sources.

The figure below shows a schematic of the prototype engine test stand.

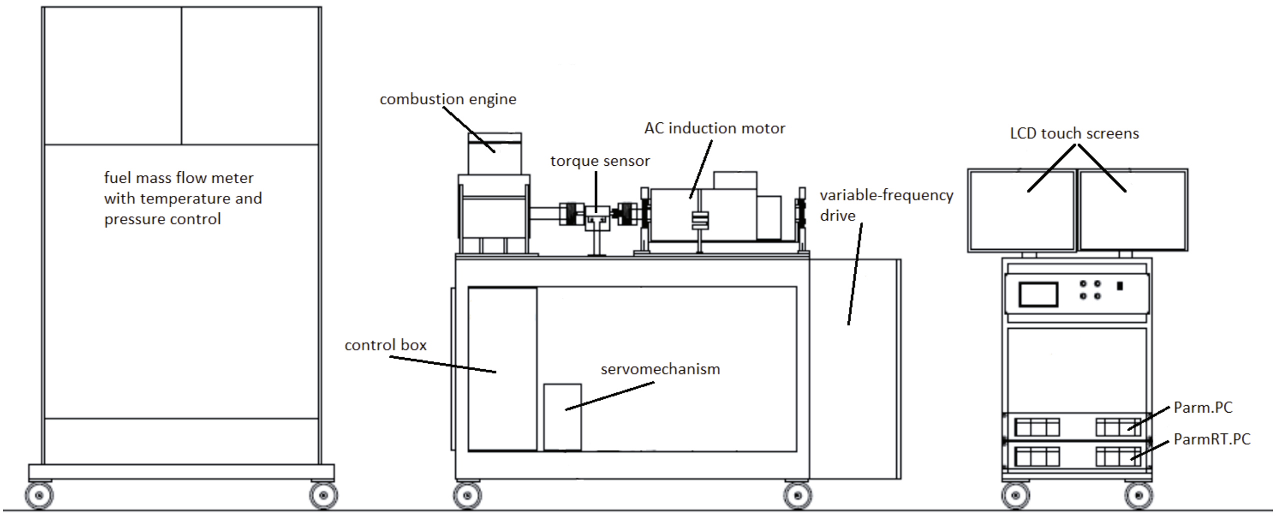

Fig. 2. Schematic of the first prototype test stand

2.1. Asynchronous motor

Asynchronous motor plays an active brake role in dynamic combustion engine test stand. For the prototype project, the most desirable was an induction motor with squirrel-cage rotor and forced air-cooling. It is a proven concept, widely used and provided by many manufacturers. Moreover, many suppliers offer variable-frequency drives dedicated and optimized for specific motors. Last but not least, there are well-documented algorithms used to control such motors.

In dynamic engine test stand, the induction motor apart has to fulfil a set of additional requirements compared to a standard design of such device. Apart from power, which is 10 kW for the prototype, required motor features are listed below:

- ability to cooperate with a fast switching frequency of a variable-frequency drive, enhanced isolation, isolated bearings,
- forced air cooling generated by a built-in ventilator – it is less troublesome than water cooling but the device size is slightly bigger,
- 3x400 V power supply,
- design allowing continuous operation in whole speed range (S1),
- optional double-sided shaft which gives the ability of testing two separate combustion engines on a stand just by reconnecting the drive shaft on one or another side,
- fully integrated incremental encoder with 1024 cycles per revolution,

– fully integrated motor winding temperature sensor,
– maximal rotation speed not less than 7500 rpm in a case of testing petrol engine and at least 4000 rpm in a case of diesel engine,
– rotation speed gradient 8000 rpm/s within assumed torque and rotor inertia characteristics,
– rotor inertia not more than 0.5 kg*m^2 – it depends on motor characteristics and the type of tested combustion engine,
– torque characteristic depends on the type of tested combustion engine, but it results from demanded power range – the motor has to have as flat torque characteristic as possible, with possibly highest nominal speed.

Regarding to the above-mentioned reasons, the Siemens SIMOTICS M-1PH8 11 kW motor was chosen to build the proof-of-concept stand for small internal combustion engine.

2.2. Variable-frequency drive

Variable-frequency drive controls induction motor and is the crucial element of the whole system. Considering the specific usage, it is not easy to find a manufacturer, which builds drives that can meet the requirements of dynamic engine test stand. Besides hardware demands (e.g. 300 Hz output frequency) a possibility to cooperate with manufacturer is essential during the phase of testing and optimization of control algorithms. Moreover, in order to design an active idle, i.e. compensation of induction motor inertia, the drive has to respond very fast to demanded torque. The variable-frequency drive has to have the ability to connect feedback from torque sensor mounted on a shaft and built-in safety procedures in case of safety-related events.

Regarding fast drive response, for the described application the most accurate drive is the one that implements the DTC (Direct Torque Control) method. In the prototype, stand TWERD MFC710 18.5 kW variable-frequency drive was chosen accompanied by the active rectifier MFC710/AcR 11 kW with built-in sinus filter that enables returning of braking energy back to the power system.

3. Software

The dynamic engine test stand software can be divided into three main groups:
– Parm – software suite for stand management and visualization,
– ParmRT – control software for the real time operating system,
– Firmware – software for microcontroller-driven designated modules.

Figure below presents a simplified diagram of the system software with all connections between groups described above.

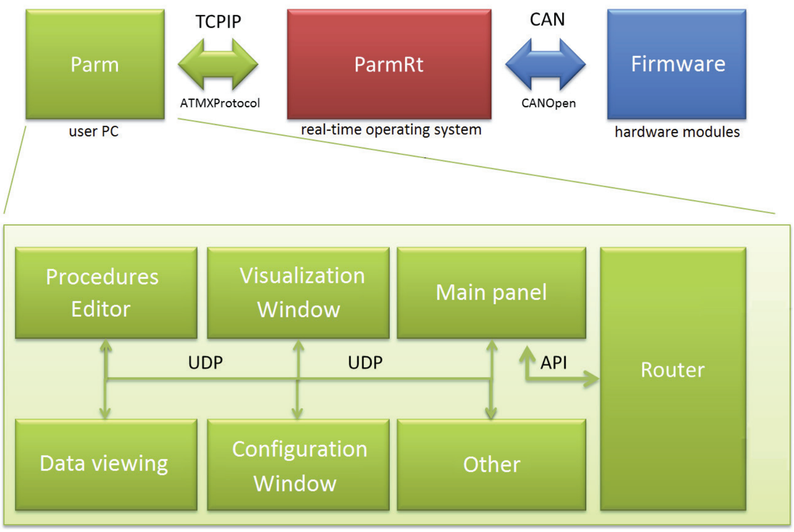

Fig. 3. Diagram of the software modules

3.1. Parm

Innovative software suite for dynamic engine test stand management has a modular structure. Modules communicate with each other via Ethernet, using UDP protocol, thus it is possible to add new modules with new functions flexibly and with minimum effort. Main modules of the suite are listed below.

– ParmControl

The role of the ParmControl is to present all essential parameters of the system to the user. It consists of management console, providing controls allowing user to change current set points, which are responsible for controlling the engine and the active brake. What is more, there are different graphical controls displaying system essential parameters, e.g. engine speed, current torque, oil pressure, coolant temperature etc. User can easily start and stop the engine using a provided button as well as manage the fuel mass flow meter through a dedicated control tab. Moreover, chosen parameters can be recorded with adjustable parameters, e.g. sampling rate.

– Configuration window

All configurable system parameters are gathered in Configuration window, a part of the main application. The user has the ability to add and remove new sensors to the system, as well as change names, units and ranges of related parameters. Furthermore, parameters can be scaled using either a linear or a multi-point function. Another usage of the module is defining mathematical formulas, which are calculated in real-time from given parameters. The window is designed to simplify whole configuration process and all most important features are directly available. Moreover, there are defined several password-protected access levels which allow to give different configuration permissions to the users.

– ParmLive

The module can be launched in many instances. Its main feature is graphical representation of recorded parameters. There are different ways of displaying acquired data in real-time, e.g. on a chart or a digital control with different styles. What is more, the module is highly configurable, i.e. the user can choose which parameters are shown on the screen as well as change style of controls or their arrangement. Furthermore, in a multiscreen system there is a possibility to show one visualization window in each screen, that way increasing the amount of displayed parameters.

– ParmDataLab

Data gathered during recording are presented in the stand-alone module. It allows exporting data to popular file types, e.g. CSV, MS Excel and text files. The user can than import data to the most often used applications, such as MS Excel, Matlab, Scilab, where they can be further processed. Moreover, the application gives the user opportunity to watch gathered data on charts as well as in table. Last but not least, there is a cataloguing feature, which allows grouping recorded data into separate experiment units.

– ParmProcEditor

This innovative standalone application allows user to create procedures, which carry out tests on researched combustion engine. There is a possibility to design a cycle that consists of different steps, which can change current engine and brake set points. Moreover, every step has its flexibly configurable end conditions as well as alarm thresholds. Finally, every automatic procedure gives user the opportunity to modify the list of parameters recorded during a test.

3.2. ParmRT

ParmRT is an application executed on a ParmRT.PC, where a real-time operating system is installed. Its role is to start and maintain communication with connected devices using different digital interfaces, such as CAN, RS232, RS485, Ethernet. What is more, the module transfers data coming from devices to Parm application, where they are presented. Engine and brake regulators algorithms as well as vehicle model are also implemented. Moreover, there are general-purpose regulators, which can control extra processes, e.g. coolant temperature. ParmRT is responsible for monitoring crucial parameters, informing the user about exceeding alarm thresholds and performing user defined actions.

3.3. Firmware

Separate group of software is firmware developed for microcontroller-driven modules. The active dynamometer test stand uses modified ATMX2000 devices manufactured by ODIUT Automex company. Devices are designed for static engine test stands, but after modifications, they were adapted to use in the project. These modifications are based on changing the configuration process and simplification and limiting frames sent by devices.

There was also designed data protocol to communicate with variable-frequency drive that uses CAN interface and does not support CANOpen protocol.

4. Vehicle model

Emulating vehicle is one of the salient tasks of dynamic combustion engine dynamometer. It allows calculation of engine load torque as a function of road conditions, current velocity and driver control inputs. Taking into consideration computer performance, the simulation in real-time requires a not very computationally complex and rather simple model but simultaneously such that simulates all of essential vehicle and environment features, i.e. inertia, aerodynamic drag, rolling resistance, tire slip, road slope, powertrain losses etc.

The assumption of the model is the ability to emulate any vehicle. This solution allows testing transient states of the combustion engine and resulting exhaust gas emission for any environmental conditions.

The task of controlling the active brake in such way that it emulates target vehicle powertrain is not trivial. In every time moment torque delivered to the engine should be equal to the one applied during real operation in vehicle with assumed throttle position and actual road conditions. To accomplish this task, differential equations describing powertrain, vehicle and environment conditions have to be calculated in real – time as a part of an induction motor control algorithm. To sum up, dynamic model has to have sufficient complexity and dynamic brake torque has to be controlled in wide range of bandwidth [3].

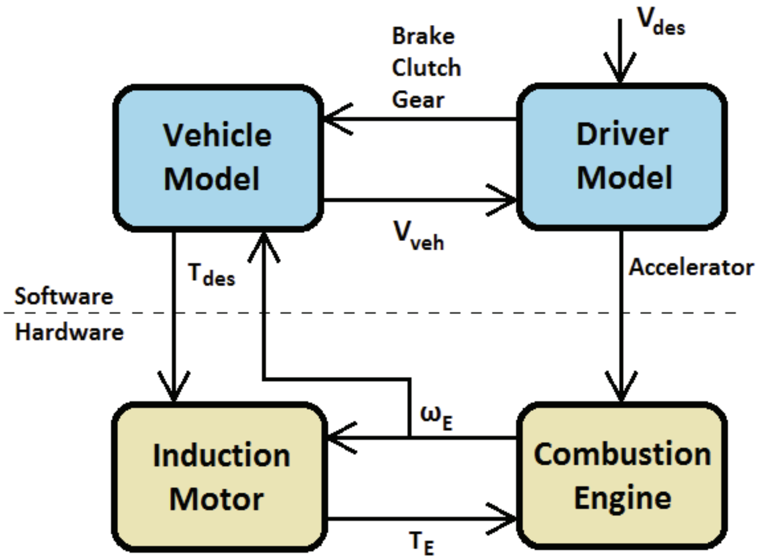

Fig. 4. Vehicle emulation on a dynamic engine test stand

Figure 4. presents schematic of vehicle dynamics emulator on dynamic engine test stand. The simulated engine torque T_{des} is applied to the combustion engine using an induction motor and measured using a torque sensor (T_E). The measured engine speed ω_E is an input for induction motor and vehicle model. The driver model calculates required vehicle model input signals to follow a given speed trajectory V_{des}, current calculated vehicle speed V_{veh} is an output of the vehicle model. Driver emulation allows to manually generating signals such as throttle position, clutch press force and selected gear [2]. Manual control is an extra feature of the system, as in normal conditions automatic procedures are used to obtain repetitive results. Repeatability of results is especially important during researches using standard tests, which are designed to verify compliance with combustion engine emission norms.

Developed model and control algorithms has to operate in real time, thus it is mandatory to provide a constant sampling period equal to 2 ms. This requirement makes the emulation very resource-demanding because it is impossible to use adaptive methods for solving differential equations, which are able to correct accuracy of calculations in moments sensitive to big integration steps. To meet the requirement, the time spent on input and output processing as well as all calculations has to be shorter than selected sampling period. It is obligatory to ensure a safety reserve, which will be a protection against calculations not meeting required time frame. Taking into consideration above prerequisites, the model and control algorithms have to be simplified to meet the requirements of the real-time operation [1].

The vehicle model designed within the project has a modular structure. Every element represents its related vehicle part or subsystem and exchanges data only with adjacent modules. The resulting system is very flexible and gives the possibility to introduce modifications and extensions easily.

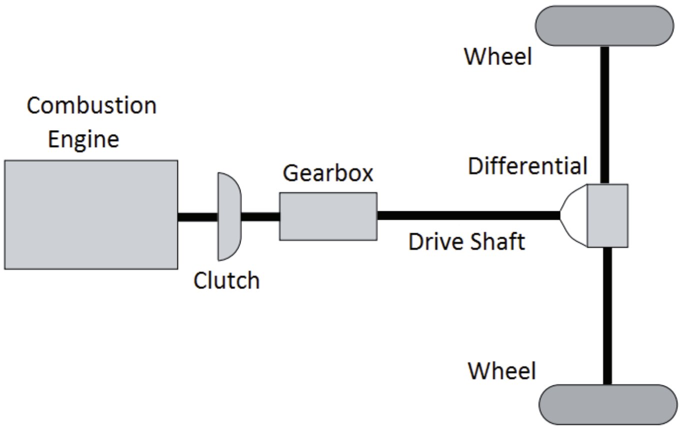

Fig. 5. Schematic of the vehicle dynamics model

Figure 5 shows the schematic of the vehicle dynamics emulator. Driver simulation model has the option that manually generates signals, such as throttle position, clutch pressing force and selected gear [4]. However, this feature is an additional feature of the designed system, as in normal operation conditions the stand is controlled automatically to produce repeatable and comparable results. It is especially important when testing the engine using standard emission test cycles to verify exhaust emission of the engine.

5. Conclusions

Within the INNOTECH-K2/IN2/61/182935/NCBR/12 project co-financed by NCBR the prototype of the dynamical combustion engine test stand was designed and built. It allows to carry out engine tests in transient conditions and implemented models simulate real vehicles and road-driving conditions. The developed software suite is flexible, simple to use and allows to monitor and record data acquired from sensors.

References

[1] Leonhardt, S., Schmidt, Ch., Voigt, K., Isermann, R., *Real-Time Simulation of Drive Chaines for Use in Dynamical Engine Test Stands*, American Control Conference, pp. 521-527, Chicago 1992.

[2] Schmidt, M., Kessel, J. A., *Model-based torque controller for dynamical engine test stands*, Proceedings of the American Control Conference, Vol.5, pp. 3245-3249, San Diego 1999.

[3] Shafai, E., Geering, H. P., *Emulation of Vehicle Dynamics on an Engine Test Bench*, American Control Conference, pp. 1969-1976, Pittsburgh 1989.

[4] Voigt, K. U., *A control scheme for a dynamical combustion engine test stand,* International Conference on Control, Vol. 2, pp. 938-943, Edinburgh 1991.