

## MODERNIZATION OF A COMBUSTION ENGINE TEST BENCH

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**Abstract.** The paper presents design, development and evaluation of an integrated system intended to improve scientific and academic use of the internal combustion test bench Rapido VEM-100, produced in Germany. The test bench is located in Biofuel Research Laboratory of Latvia University of Agriculture and it is intensively used for scientific research according to biodiesel use in compression ignition engines. Due to the special funds technicians of the laboratory have the possibility to improve this test bench replacing rheostat used in load adjustment with intentionally designed current controller and adding set of special sensors for scientific research supplied by *Kistler*. Analysis of this technical solution as also of the others has been discussed.

**Keywords:** current controller, sensors, test bench, combustion engine, biofuel.

### Introduction

Biofuel Research laboratory of Latvia University of Agriculture is the largest laboratory in Latvia, which last 15 years specializes on biofuel (biodiesel, bioethanol) research. During these years government grants have been received and all mentioned fuels and blends were investigated. Engine dynamical, economical and ecological parameters have been analyzed.

All the time scientific and educational work in laboratory was realized using legacy equipment and obsolete methods. For example, fuel consumption was determined by mass (gravimetric) method, when closed flask was previously filled with fuel, and while the engine was operated in determined conditions, the flask was opened and record of consumed fuel on the required time was obtained. All other parameters – power, torque, fuel mass consumption and specific fuel consumption – were calculated later using special formulas. The exhaust emissions of different parameters were measured using exhaust gas analysers. It means that all measurement system was not fully automatized allowing control for one person, but each scientific research required few more people for all measurement control. Therefore there is a necessity to create an engine test cell system, which will be a complex of machinery, instrumentation and services and ensure that all systems will work together as a whole.

There are different rules for test cell creation and these rules mainly depend on general purpose of this engine test cell. There are a lot of applications of such cells: development departments of engine and vehicle manufacturers, independent testing and development laboratories, training and educational facilities, etc. Usually engine test and development facilities represent a general element of investment for large companies (engine, vehicle or oil manufacturers) allowing different engine testing [1]. Scientific laboratories, as it is in this case, usually use dynamometers and engine mounting stands, which are adaptable for a wide range of engines, but without large number of changes. Biofuel Research laboratory of Latvia University of Agriculture works with diesel engine Ford Sierra 2.3L for last years with biodiesel and it different blends allowing tests under steady-state and transient conditions.

All experimental work is realized on internal combustion test bench Rapido VEM-100, produced in Germany. It consists of three main parts: 100 kW DC balancing machine including its powering and control equipment which is used to simulate various operating conditions of an engine being tested, measuring equipment to monitor the experimental data and the combustion engine itself.

The DC balancing machine (see Fig. 1) can be operated in two modes: driving and loading. Armature winding of balancing machine is connected to another DC machine, which is part of Leonard's system. 3-phase AC motor is on the other side of Leonard's system. In the driving mode the AC motor consumes 3-phase electrical grid power and drives DC generator, which powers the balancing machine to drive the engine under test. Exciting current in field winding for both DC machines is produced by separate generator and can be manually adjusted for each machine using rheostats. In loading mode the tested engine drives DC balancing machine and therefore it operates as a generator and in its turn drives the Leonard's system DC motor. Consequently the mechanical power of tested engine is converted and conducted back to the grid. It is also possible to sink the generated power to loading resistors and the Leonard's system is not operated.

Accordingly to nature of research the test bench in LUA's Biofuel Research laboratory is used mainly in loading mode with power sinking to loading resistors in order to simulate various working conditions of biofuel powered engines.

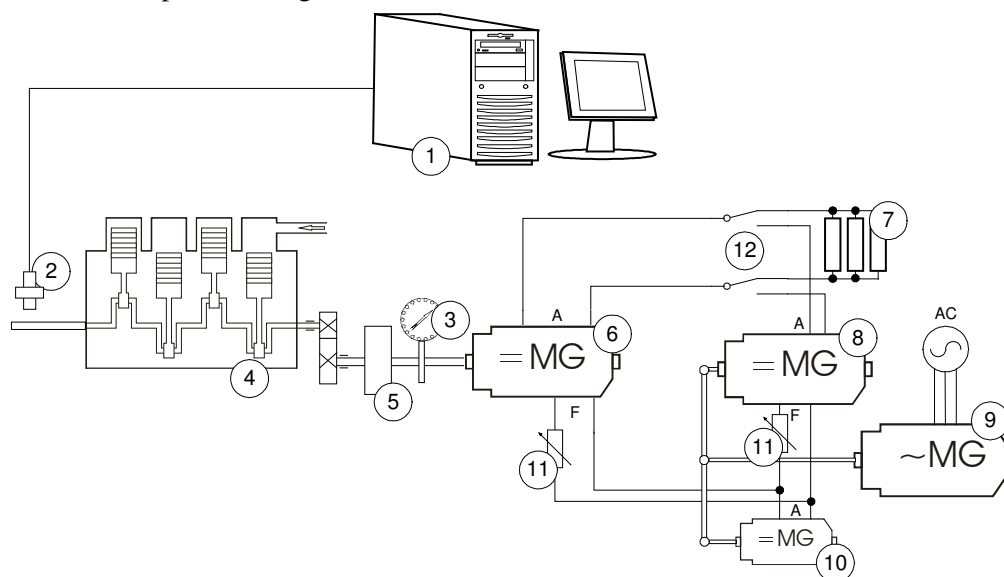


Fig. 1. **Rapido VEM-100 combustion engine the test bench:** 1 – computer; 2 – optical revolution sensor; 3 – dynamometer; 4 – tested engine with transmission; 5 – balancing DC machine shaft revolution sensor; 6 – balancing DC machine; 7 – loading rheostats; 8 – DC motor/generator; 9 – 3-phase AC motor/generator; 10 – DC exciting current generator; 11 – exciting current controlling rheostat

## Materials and methods

Improvement is connected with two things. The rheostat used in load adjustment by means of controlling exciting current in the loading machine has been replaced with intentionally designed current controller that improved the usability and reliability of the system. The measurement equipment added or replaced consists of coarse crankshaft and loading machine rotating tachometer and a set of special sensors for scientific research supplied by Kistler: crankshaft angle sensor, combustion and fuel injection sensors. The summary of components added is given in Table 1.

An engine test system is an assembly on an engine, a dynamometer and various sensors. As it is usually each of these sensors have its own control characteristics and suppliers, which complicate overall computerized control.

Table 1

### Summary of components added/replaced

Component added/replaced	Description
Keithley KPCI-3110 data acquisition board	Allows reading analog signal with 12-bit resolution at 1.25MS/s. Intended to read injection and combustion pressure sensors and crankshaft angle encoder. The board is operated using "TestPoint" software by <i>Measurement Computing</i> [2].
Kistler type 4065 piezoresistive injection pressure sensor with measuring chain	Includes piezoresistive pressure sensor and charge amplifier. Allows the measuring of diesel fuel injection pressure (up to 200 bar).
Kistler type 6052B1 high temperature piezoresistive combustion pressure sensor with measuring chain	Includes high temperature (up to 400 °C) piezoresistive pressure sensor and charge amplifier. Allows the measuring of combustion pressure (up to 250 bar).

Table 1 (continued)

Component added/replaced	Description
Balancing machine shaft revolution sensor	Allows measuring balancing machine shaft rotating speed (0-3000 rpm range, 50 rpm error). Default Rapido VEM-100 generating-type sensor is used, but the result is displayed in numerical form on separate LED display of control unit.
<i>Kistler</i> type 2613B crankshaft angle encoder with amplifier	Allows reading crankshaft angular position with 0.1-6° resolution, outputs squared signal, which is processed by data acquisition board. Can also be used for fine engine revolution speed measurement.
Inductive type revolution sensor	Based on pulse width measurement and allows coarse (1 rpm error) engine revolution speed measurement at speeds starting at 143 rpm. Outputs the result on separate LED display of control unit.
Switching-type exciting current regulator	Allows adjusting load on tested engine by controlling the exciting current of the balancing machine.
Control and monitoring unit	Enables manual control of exciting current regulator, displays engine and balancing machine rpm value.

## Results and discussion

The modernization of the test bench can be spitted into two parts: installing a set of off-the-shelf products and developing own solution for load adjustment and engine revolution measurement. The inductive type revolution sensor, exciting current regulator and control and monitoring unit are developed by authors in Institute of Agricultural Energetic, Faculty Engineering, LUA. The control and monitoring unit is the centre of the system and is based on PIC16F874 microcontroller. As the control and monitoring unit is to be used mainly by students in labs it is arranged to be easy in use and ergonomical. Coarse load adjustment can be performed using rotating potentiometer and fine – with push buttons. The sensor values are displayed on 70 mm LED displays.

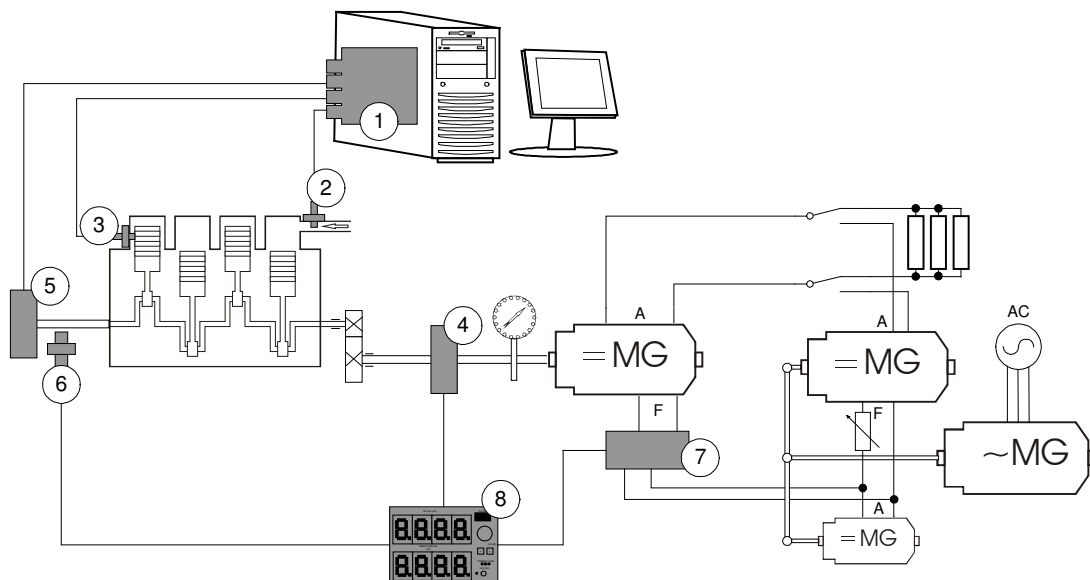


Fig. 2. Components added/modified on the test bench (shaded parts included in the modernisation): 1 – data acquisition board; 2 – injection pressure sensor; 3 – combustion pressure sensor; 4 – balancing DC machine shaft revolution sensor; 5 – crankshaft angle sensor; 6 – crankshaft revolution sensor; 7 – balancing DC machine exciting current regulator; 8 – control and monitoring unit

Load adjustment is performed by controlling exciting current of balancing DC machine. The balancing DC machine has two exciting wirings: connected in series with armature wiring and

independent parallel wiring, see Fig. 3. Rheostat originally used to control the exciting current in parallel wiring has been replaced with switching-type (pulse width modulated - PWM) DC current regulator [3].

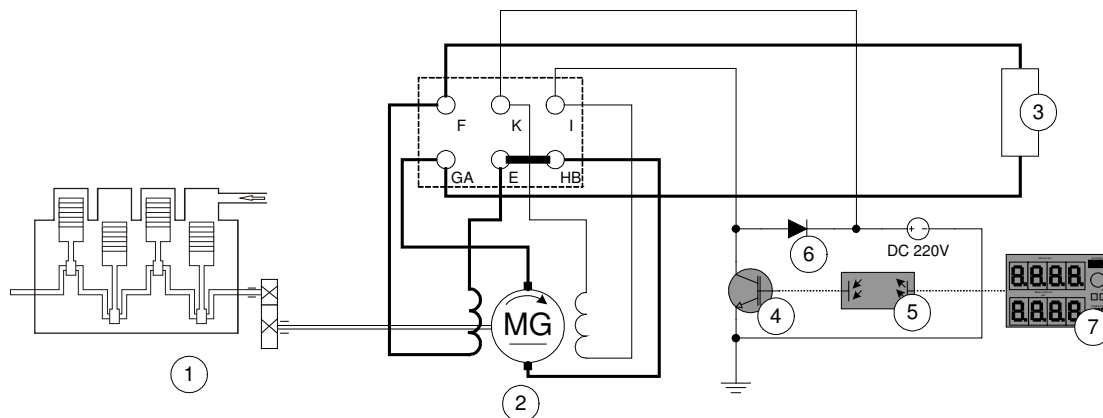


Fig. 3. **Exciting current regulator (shadowed parts included in the modernisation):** 1 – tested engine with gearbox; 2 – balancing DC machine; 3 – loading resistors; 4 – IGB transistor; 5 – optical isolation circuit; 6 – protection diode; 7 – control and monitoring unit; thin wires – exciting (DC 220 V, <5.1 A); bold wires – power lines (DC 460 V, <218 A); dashed wires – control signal

In the base of the current regulator is IXYS IXSH 24N60 IGB transistor with high side connected load (balancing machine exciting wiring). IXSH 24N60 IGBT is capable to conduct voltages up to 600 V and current up to 40 A. It is enough to perform switching of exciting current (DC 220 V, <5.1 A) with single element, though an active heat-sink is used as the exciting wiring is inductive load. In addition there is a protection diode in parallel to the load.

The transistor is isolated from control unit using optocoupler. PWM is performed at 1.22 kHz with 10-bit resolution i.e. there are 1024 current levels possible. However due to optocoupler's slow switch on and off times the pulse width should be limited to 9.8 – 97.6 % of full adjusting range, thus avoiding operating the IGBT in half-opened state.

The inductive-type engine crankshaft revolution sensor is based on *Omron* E2E2-X14MD proximity switch. Pulse width measurement technique is used in order to obtain crankshaft rotation speed. A steel tappet has been attached to the shaft and the proximity sensor detects it every revolution; thus a squared signal waveform is emitted. The period of the waveform is inversely proportional to the rotating speed in desired measurement units.

The period (width) between falling edges of two pulses is measured and stored as a 16-bit timer value by PIC16F874 using built-in hardware capture module. The 16-bit value then should be converted to seconds (taking into account the clock speed of microcontroller's timer clock), inversed and multiplied with desired time unit. In our case (rotating speed  $n$  in rpm) the formula is as following:

$$n = \frac{60}{REG \cdot TMR_T \cdot 10^{-6}} [\text{rpm}], \quad (1)$$

where  $REG$  – 16-bit register value incremented by timer clock;

$TMR$  – clock period of timer,  $\mu\text{s}$  (Timer1 on PIC16F874 at 20 MHz, clock source – command cycle and 1:8 prescaler – 1.6  $\mu\text{s}$ ).

The microcontroller rounds the result to nearest integer as floating-point operations are not supported by hardware, but implementation in software will demand excessive memory and computation time. Thus precision of the device is  $\pm 1$  rpm. Lowest measurement value is limited by maximum  $REG$  value and in our case: 572 rpm. The measurement low limit does not trouble experiments with internal combustion engines.

The control and monitoring unit centralizes both solutions mentioned above, features crankshaft revolution speed and exciting current level (in percent) LED displays and in addition outputs digitally the value of original Rapido VEM-100 generator type DC balancing machine shaft rotating speed

sensor. There is also a RS232 serial communication port, that is not supported by device's software yet, but can be programmed to use remote control, advanced engine loading scenarios, data logging etc.

### **Conclusion**

The modernization is very important due to the necessity to ensure educational and scientific work. The created measurement system will allow information gathered through sensors process and log through data acquisition system and provide all information on computer screen. Thus it will be possible to improve the quality of experiments held and study process of related students as well in Biofuel Research Laboratory.

The modernized combustion engine test bench in LUA's Biofuel Research Laboratory can be used to investigate a wide range of characteristics of combustion engines – not only dynamical (power, torque), economical (fuel consumption) and ecological (exhaust gas composition), but now also combustion characteristics. It will allow analyze the changes and interconnectedness of all those characteristics using different fuels and it blends in the future.

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