ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
https://doi.org/10.17559/TV-20230315000440
Original scientific paper

Updating a Didactical Piston Engine Test Bench, from Analogue Instrumentation to Digital

Cornel Mihai TĂRĂBÎC, Grigore CICAN*, Gabriel DEDIU, Razvan Marius CATANĂ

Abstract: This paper presents a study on the transition of a didactic piston engine from analogue instrumentation to digital. The T81M piston engine, paired with the T82M dynamometer, both manufactured by Didacta Italia, underwent supplementary instrumentation to facilitate the experimental campaign. Additional sensors, including a speed sensor, thermocouples for exhaust and intake, and pressure sensors for intake and cylinder, were incorporated. A graphical interface was developed using LabView software to capture and store data obtained from experiments conducted with bioethanol fuel. The T81M piston engine features a quartz cylinder for visualizing different stages of the combustion process, and its piston operates without the need for lubrication due to the specific materials used in its construction. The experimental campaign involved starting the engine, maintaining it in idle mode for a few minutes, and gradually increasing the throttle needle while keeping the control lever fully open to reach the maximum regime step by step for data collection. The concluding phase of the experiment involved visualizing the combustion process in the cylinder for various piston positions and studying the flame's color. The digitalization of the T81M piston engine enhances its suitability for modern teaching experiments.

Keywords: analogue to digital; experiment; instrumentation; piston engine; quartz cylinder

1 INTRODUCTION

Piston engines continue to be widely utilized in the automotive, aviation, naval, and other industries requiring power generation. To conduct thorough studies on these engines, the use of test benches becomes imperative. Various fuels can be employed to investigate combustion and emissions [1]. Primarily, the exhaust section stands out as crucial for determining gas emissions in piston engines and can be equipped with instruments to collect comprehensive data [2]. Achieving an optimal level of instrumentation and raw data acquisition involves employing a methodology to assess the uncertainty of the process [3, 4]. Consequently, internal combustion engines are subjects of study at numerous esteemed universities worldwide, spanning both automotive [5] and aviation [6] domains.

To delve more effectively into the phenomena occurring in piston engines, advanced test benches are essential for highlighting the primary thermo-gasodynamic processes within the engine, as exemplified in [7]. Efficient study of these phenomena necessitates modern test benches equipped with instrumentation for data acquisition and subsequent post-processing [8]. In this context, various studies present didactic test benches for gas turbine engines [9, 10] and piston engines, elucidating a multitude of phenomena [11, 12]. Numerous studies analyze processes within reciprocating engines on test stands with a single cylinder [13, 14]. To visualize the optical processes occurring inside the piston engine, a quartz cylinder is essential, akin to methodologies explored in [15, 16].

This study aims to transition from an analog-instrumented test bench with a single quartz piston to a digitally instrumented test bench with a display for enhanced post-processing capabilities. It is well recognized that achieving precise instrumentation for piston engines represents a highly intricate process [17].

A didactic test bench serves distinct purposes compared to a modern test bench, yet it incorporates similar components such as the piston engine and the dynamometer. The primary objective is to contribute to scientific literature and establish a learning path for future specialists. An illustrative example of a didactic test bench within the vehicle domain is provided in [18], outlining the methodology for conducting an experimental campaign using the test bench. Detailed insights into the components involved in exploring transient processes, including the development of a simulation element and a graphical user interface based on LabVIEW, are presented in [19], referencing the aforementioned test bench.

Prior to implementing the methodology, it is essential to propose a model for algorithm verification through thermodynamic calculations and numerical simulations, typically executed using MATLAB/Simulink [20]. A specialized investigation concerning the second component of the test bench focuses on the electrical generator, which not only impacts the performance of the piston engine but also serves as the primary power-generating component [21].

2 THE CASE STUDY: T81M PISTON ENGINE

This case study was conducted on a didactic piston engine, specifically the Italia Didacta T81M, designed with unique features aimed at examining the engine's performance. The study's objectives included visualizing the combustion process using bioethanol or alternative fuels in the carburetor and assessing the utility of digital instrumentation for various types of studies, particularly in the context of didactical practical experiments.

The engine boasts a combustion chamber crafted from quartz and a piston made of graphitic cast iron, chosen for its exceptionally low coefficient of friction and resistance to high temperatures. Consequently, this internal combustion engine operates without the need for oil lubrication between the piston and the cylinder, essentially making it oil-free. Additionally, the piston is equipped with three rings, all made from the same material, serving to seal the space between the graphitic cast iron piston and the quartz cylinder.

The engine incorporates multiple features designed for studying the complex behavior of piston engines. Notably, the combustion chamber allows the flame to be visible to the human eye or a video camera, facilitating the analysis of the fuel-air mixture by observing the flame's color or studying the flame front. Additionally, it is equipped with a lever for manually adjusting the advance spark plug, offering a range from –20° to +20° RAC.

The engine's versatility is evident in its capability to handle various fuel scenarios, including the ability to mix two fuels or introduce water into the carburetor, with adjustable quantity control. Moreover, it can run on a range of fuels such as petrol, gasoline, methanol, ethanol, acetone, ether, propane, biofuels, etc., without requiring any modification to the engine structure. Bioethanol was the primary fuel used in the experimental campaign due to its lower heating value compared to gasoline, higher ignition temperature, and similar density under equivalent temperature conditions. For detailed characteristics of bioethanol spraying and a comprehensive comparison with gasoline, refer to [22].

To assess the engine's performance, an electric dynamometer, the T82M, is employed. This dynamometer utilizes an electric brake as a generator, extracting power from the motor shaft and converting it into electricity. This method is widely favored for its accuracy in measuring engine torque and power (expressed in horsepower) and eliminates the need for water cooling and fixed engine outlets. Specifically designed for compatibility with the T81M engine, the T82M employs electrical measurement to precisely gauge the motor torque. The dynamometer can function as both a generator, activated by a switch, and as a starter, utilizing an external power source.

The operating regimes available for study range from the idle speed, N_idle = 1000 rpm, to a minimum speed of N_0 = 500 rpm, and up to a maximum speed of N_max = 3200 rpm. The engine parameters are as follows: one cylinder (n_c = 1), a stroke length of s = 0.0508 m, a cylinder diameter of D = 0.41275 m, and a compression ratio of $\varepsilon = 3$.

During the initial instrumentation phase, the engine utilized a set of sensors, including a tachometer for speed readings, manometers for cylinder and carburetor pressure, and an ammeter and voltmeter for power determination in generator mode. Readings from these sensors were manually recorded or video-recorded, introducing the possibility of human error and imprecise data. Additionally, the use of lengthy hoses for pressure monitoring introduced delays at the beginning of tests.

Following the upgrade, the engine is equipped with analog instrumentation at the dynamometer, capable of measuring pressure in the chamber for all four processes (intake, compression, combustion, exhaust), manifold pressure, crankshaft speed, air-cooling pressure, torque, current, and voltage for power calculation. The system also includes different relay-type commands to enhance control. The Italia Didacta T81M and the electric dynamometer T82M, before the digitalization process, are depicted in Fig. 1.

The T81M engine employs two control strategies for regime adjustment. The first involves using a control lever, allowing the operator to vary the dosage of the fuel mixture (air and fuel) near the intake valve. Maintaining a constant fuel dosage while rotating the control lever changes the carburetor pressure. The second method utilizes the throttle needle to adjust the fuel quantity in the mixture. By keeping the control lever constant and adjusting the throttle needle position, the working regime is altered, leading to changes in flame color across three categories: stoichiometric, rich fuel, and low fuel cases.

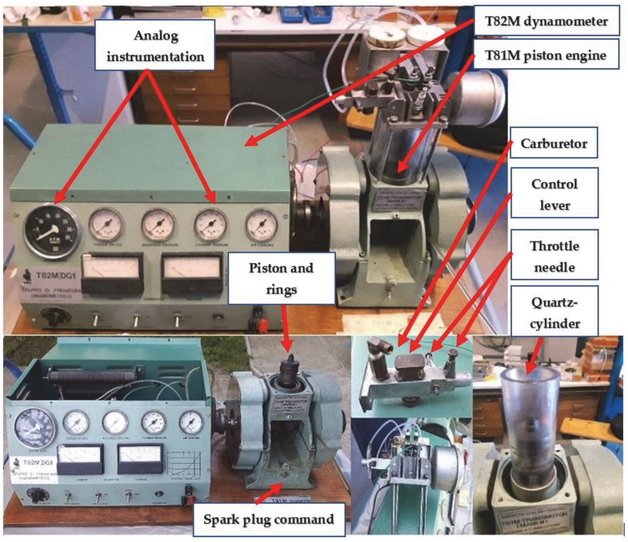


Figure 1 Italia Didacta piston engine T81M and the electric dynamometer T82M

The transformation process involves adding supplementary instrumentation to the test bench, including a thermocouple in the intake manifold section, a pressure sensor in the intake manifold section, a pressure sensor for the manifold section, a speed sensor mounted at the crankshaft, a specialized pressure sensor in the cylinder section, a pressure sensor in the extended exhaust pipe, and a thermocouple in the extended exhaust pipe. To support this instrumentation, a data acquisition system is required, capable of acquiring data at a specific minimum rate. A graphical interface is also necessary for real-time data processing and storage, enabling the observation of running engine parameters.

This upgrade of the test bench opens up additional opportunities for the Engine Laboratory at the National University of Science and Technology POLITEHNICA Bucharest to conduct studies on the burning process using different fuels and mixing properties, visualization through the quartz cylinder, water injection, vibration studies, chemical composition analysis for uncommon fuels, and examination of NOx emissions, among other aspects.

In the field of didactical piston engine research, there is a lack of materials concerning data acquisition and test benches for mono-cylinder engines. This paper introduces a methodology for didactical engines that can enhance the understanding of specialized students in a more intuitive and scientific manner. Compared to a brand-new installation consisting of the piston engine, instrumentation, dynamometer, and main control unit, which primarily focuses on results, this upgrade provides solutions specifically for determining the theoretical and real thermodynamic cycle. It allows the study and comparison of main parameters and performances.

One of the main objectives is to specialize future engineers for automotive, aeronautical, or naval piston engines, enabling them to comprehend functionality, anticipate potential issues, and develop direct solutions to problems. The selection of instrumentation and data acquisition methods is based on the complexity of the experimental campaign and the engine's functionality.

3 MATERIALS AND METHODS

3.1 The Instrumentation from the Analogic Method to Digital

To comprehensively study the engine's behavior, it is essential to acquire specific parameters integral to the analysis of piston engine performances. Consequently, sensors have been strategically installed to measure key pressures, including the inlet pressure (p_0), carburetor pressure (p_1), cylinder pressure (p_3), and exhaust pressure (p_4). Similarly, temperatures are monitored through sensors measuring the inlet temperature (T_0) and exhaust temperature (T_4). Additionally, a speed sensor has been incorporated to measure and record the engine speed (N). Fig. 2 visually represents the parameters that are measured and utilized for display in the study.

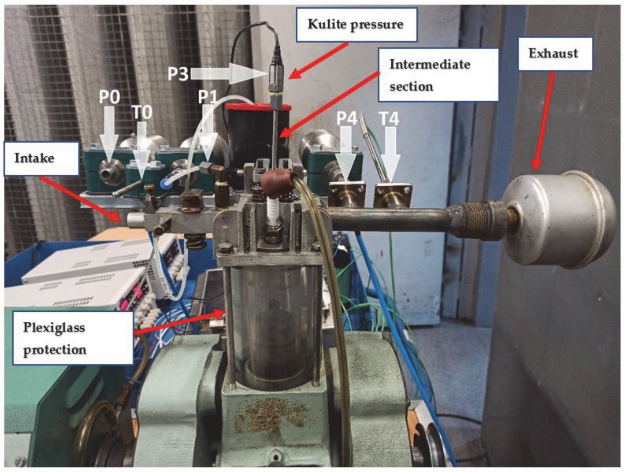


Figure 2 The T81M instrumentation

To measure and record the engine speed, a speed sensor has been incorporated, as illustrated in Fig. 3.

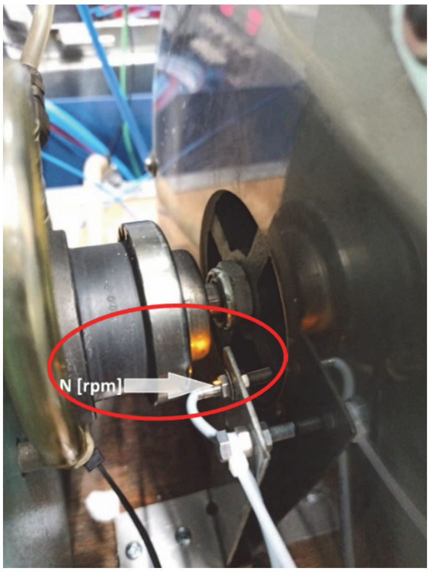


Figure 3 The speed sensor mounted on the shaft

To ensure accurate speed measurement, an inductive proximity sensor provided by "Kulite" [23] has been utilized to read the metal material on the motor shaft. This sensor can be positioned in proximity to the metal surface to capture every cycle, ensuring mechanical protection [24]. Although this limits the detection distance, careful mounting allows the sensor to function without interference from nearby metal objects. The sensor is equipped with an LED light that activates with each rotation to ensure its functionality.

Pressure, a crucial parameter for the thermodynamic cycle of a piston engine, is measured using a specialized pressure transducer. The selection of the transducer type is based on factors such as the measuring range, working environment (liquid or gaseous), and the required response time for signal transmission.

For ambient pressure and carburetor pressure of the combustible air mixture, a model provided by General Electric [25] is employed. This transducer boasts high accuracy (±0.04 % at full scale), a robust construction resistant to overpressure and explosions, and is made from stainless steel. It has a short response time, with a maximum frequency response up to 3.5 kHz, making it suitable for various applications. The specified supply voltage is 7-28 VDC, and the output signal is 4-20 mA (linearized). The measuring range for p_0 is 0÷2 bar absolute, and for p_1 and p_4, it is 0÷10 bar (gauge pressure), with a current consumption of less than 30 mA.

For data acquisition from the cylinder, an ultra-fast pressure transducer from Kulite [26] has been employed, selected for its technical specifications suitable for measuring pressure during compression, combustion, and expansion, considering the maximum reaction time of the transducer.

Ambient and exhaust temperatures are measured using two special thermocouples type K from CaomPascani [27] with a specific design. These thermocouples are directly connected to the specific module, eliminating the need for additional elements to facilitate their operation.

3.2 Data Acquisition System

The testing phase involves the development of a test program in LabVIEW, structured around the data acquisition system and the specified limitations of the engine [28]. To implement the acquisition system, careful consideration is given to the sensors and transducers used in the experimental testing. Fig. 4 illustrates the general scheme of the acquisition system and instrumentation, aligning with the engine's requirements. The module for the CompactDAQ chassis and other types of PLCs plays a crucial role in converting signals from transducers/probes into a unified and common signal in the programming section of the chassis.

A CompactDAQ NI-9189 chassis [29] serves as the platform for mounting the module and facilitating the connection between the LabVIEW software and the module for receiving or sending information. It can be programmed using DAQmx logic and features internal synchronization for acquiring data at a specified rate.

This PLC provides several essential functions:

- Power bus modules
- Communication between the central unit and I/O modules through communication ports
- A total of 8 modules for analog/digital input/output
- Internal synchronization for data acquisition across all modules.

Several modules are utilized to fulfill the objectives of the paper within this framework.

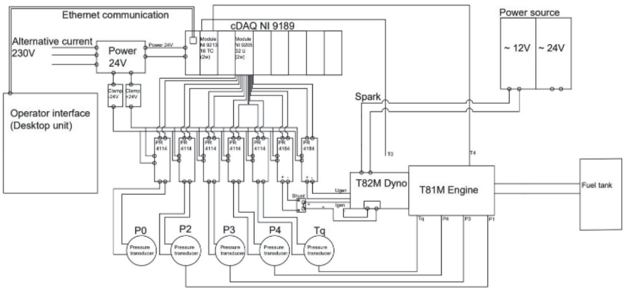


Figure 4 The general scheme of the data acquisition system and instrumentation

NI-9213 Thermocouple Analog Input Module

The NI-9213 Thermocouple Analog Input module [30] is specifically designed for receiving information from various types of thermocouples, with a configurable acquisition rate per channel or collectively for all channels. It is exclusively used for thermocouples. Key technical specifications include:

- Accepted thermocouple types: Type J, K, T, E, N, B, R, S (with Type K and Type T being the most commonly used in testing).
- Aggregate acquisition rate is 75 S/s for all channels, allowing for a slow but precise reading in testing.
- Accepts only thermocouples with 2 wires.

The sensitivity of the module varies depending on the type of thermocouple, as outlined in Tab. 1 below:

Table 1 NI-9213 module reading characteristics [30]

Thermocouple type	High precision reading / 1S/s	High speed reading / 75S/s	Sensitivity / µV/°C
J	< 0.02 °C	< 0.25 °C	52.5
K	< 0.02 °C	< 0.25 °C	41.2
T	< 0.02 °C	< 0.25 °C	20.7
E	< 0.02 °C	< 0.25 °C	54.8
N	< 0.02 °C	< 0.35 °C	40.9
B	< 0.15 °C	< 1.2 °C	12.6
R	< 0.15 °C	< 2.8 °C	10.5
S	< 0.15 °C	< 2.8 °C	10.5

NI-9205 Voltage Analog Input Module

The NI-9205 Voltage Analog Input module [31] facilitates the reception of voltage information with 32 channels, usable within certain signal levels. This module allows for a configurable acquisition rate per channel or collectively for all channels and is versatile in reading pressures, level meters, and input of digital commands passed through signal converters due to predefined device outputs.

Key technical specifications include:

- Accepted signal domains: ±200 mV, ±1 V, ±5 V, ±10 V, or other domains with respect to compensation.
- Aggregate acquisition rate: 250 kS/s for all channels, enabling a high-speed read for a small number of channels used in testing.

For each accepted signal level, the module provides data on disturbing signals, accuracy at full scale, and sensitivity, as outlined in Tab. 2 below. Sensitivity is described as the lowest voltage difference that the module can detect, and it is a function of noise.

Since the output signals from sensors are of different types and the NI module inputs must be of the same type, specific conversions are necessary, which can be accomplished using signal converters.

Table 2 NI-9205 module reading characteristics [31]

Signal domain	Accuracy at full scale	Disturbing signal	Sensitivity
±10 V	6230 µV	240 µVrms	96.0 µV
±5 V	3230 µV	116 µVrms	46.4 µV
±1 V	690 µV	26 µVrms	10.4 µV
±0.2 V	174 µV	10 µVrms	4.0 µV

Signal Converter PR 4114

The PR 4114 converter [32] serves as a universal converter designed for reading various parameters, including current, voltages, potentiometers, thermoresistors, and thermocouples. It allows the configuration of the output signal in terms of either current or voltage, depending on the requirements of the PLC module.

This converter facilitates the connection of analog input signals of multiple types, making it versatile for use in acquisition systems for testing engines. When connecting the outputs, the manufacturer's provided scheme is utilized, offering the flexibility of transmitting both current intensity-type signals and voltage-type signals preset at certain standard values. The PR 4114 converter is a valuable component in adapting different sensor outputs to the specific input requirements of the NI modules in the testing setup.

Signal Converter PR 4184

The PR 4184 signal converter [33] is utilized for special parameters such as torque, fuel flow, position, sensors with current signals, and acceleration sensors. This converter provides a programmable signal output rate within the range of ±300 VDC and ±100 mA. It is adaptable for both current intensity and voltage cases, offering a broader range of values that can be preset through specific programming of the converters.

This converter allows for connection using the scheme provided by the manufacturer, offering flexibility in transmitting both current intensity-type signals and voltage-type signals. The presets can be configured to align with specific standard values or within a field chosen by the user, tailored to the application's requirements. The PR 4184 signal converter is an essential component for adapting various sensor outputs to meet the specific input demands of the NI modules in the testing setup, particularly for parameters such as torque, fuel flow, position, and acceleration.

3.3 The Graphical Interface

The graphical interface pertains to the front panel created in LabVIEW software, designed for testing and visualization purposes. It includes indicators for sensors and transducers to convey information to the operator. Prior to the commencement of the actual testing process, two simulations will be conducted. The first simulation aims to verify the data flow with appropriate definitions and the acquisition rate of data. The second simulation ensures that the parameters are defined in correspondence with the required limitations. Tab. 3 outlines the domain for the acquired parameters.

The simplified scheme for the Virtual Instrument (VI) program is presented in Fig. 5.

Table 3 Parameters domains for the graphical interface

Name	Type of sensor	Domain	Acquisition rate
T_0	Thermocouple type T	–50 ÷ 250 °C	10 S/s
T_4	Thermocouple type K	0 ÷ 1300 °C	10 S/s
p_0	Absolute pressure transducer	0 ÷ 2 bar	620 S/s
p_1	Gauge pressure transducer	0 ÷ 10 bar	620 S/s
p_3	Absolute pressure transducer	0 ÷ 25 bar	620 S/s
p_4	Gauge pressure transducer	0 ÷ 10 bar	620 S/s
U_g	Tension using signal converter	0 ÷ 25 V	620 S/s
I_g	Current using signal converter	0 ÷ 30 A	620 S/s
N	Inductive proximity sensor	0 ÷ 40000 Hz	620 S/s
T_q	Absolute pressure transducer	0 ÷ 2 bar	620 S/s

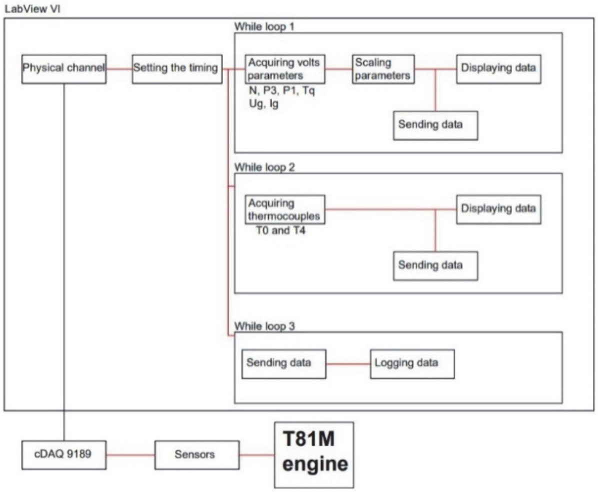
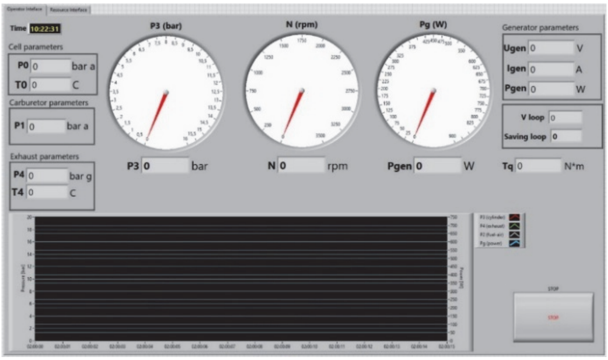


Figure 5 The simplified scheme for the program VI

The programming was structured based on the cDAQ chassis channels and modules, taking into account the settings from the sensors. To ensure synchronization and accommodate the slower rate of acquiring data for temperatures, the program was organized into three separates while loops. In order to efficiently save data at the maximum rate defined in the first while loop, the third loop was specifically created.



Time 10:22:31
P0 0 bar a
T0 0 C
P1 0 bar a
P4 0 bar g
T4 0 C
P3 0 bar
N 0 rpm
Pgen 0 W
Tq 0 N*m
Ugen 0 V
Igen 0 A
Pgen 0 W
V loop 0
Saving loop 0

Figure 6 The graphical interface used for testing

Utilizing the diagram presented in Fig. 5 as a reference, a graphical interface was developed. This interface is employed for real-time monitoring of the parameters of interest during engine testing, as illustrated in Fig. 6. The synchronized loops and organized program structure contribute to an effective and responsive monitoring system for the testing environment.

Due to the high-speed data acquisition, a graph has been generated to visualize pressure values and, particularly, the power, with a specific focus on the pressure within the cylinder. To calculate the engine power (P_g), the following formula was employed, utilizing measured parameters such as current (I_g) and tension (U_g) generated by the dynamometer:

$$P_g = I_g \cdot U_g \tag{1}$$

To assess the stability of the acquisition rate, two parameters have been incorporated into the interface. The rate for tension parameters, labeled as *V* loop, and the rate for the logging loop, designated as *Saving* loop, are assigned with distinct values. This setup serves to verify whether the program is operating at the designated rate and whether it is sufficiently fast to capture all transient processes.

4 EXPERIMENTAL RESULTS

To validate the instrumentation and the graphical interface, a series of tests were conducted by running the engine on bioethanol at various speeds, with an attempt to reach the maximum regime. As the engine operates in an "unstable" mode, stabilization at a constant regime was challenging. Consequently, data was obtained from several points during the experiments. The tests were performed with the T82M dynamometer configuration set to "Start" mode. Prior to conducting the experiments, all sensors and instrumentation lines were meticulously checked with the appropriate metrological equipment and visualized through the LabView interface.

The experimental campaign comprised various working regimes, including the idle mode, idle mode with slight acceleration, and slightly higher regimes. Since the manual provides data only for the idle mode with gasoline fuel, the obtained values are approximate. It is important to note that the intermediate section between the Kulite sensor used for acquiring cylinder pressure and the actual burning chamber may cause a decrease in value, thereby influencing the work volume and impacting friction forces. Additionally, during the tests, the advance spark plug was set to +20° RAC.

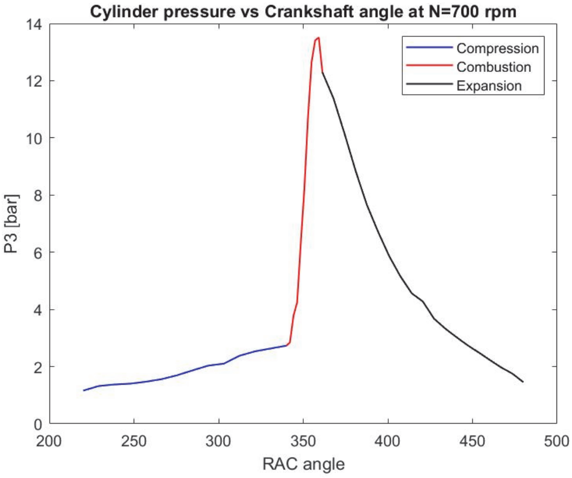


Figure 7 The cylinder pressure at the *N* = 700 rpm

In Fig. 7, the data obtained from the cylinder pressure at the regime of $N = 700$ rpm is presented.

At this regime, the ambient temperature (T_0) is 27.5 °C, and the exhaust temperature, as well as the ambient pressure (p_0) is 1.142 bar. The carburetor pressure shows a variation between 0.998 bar and 1.002 bar, with an average of 1.000 bar. In Fig. 8, the data obtained from the cylinder pressure at the $N = 900$ rpm regime is presented.

At this regime, the ambient temperature (T_0) is 27.5 °C, and the exhaust temperature, along with the ambient pressure (p_0), is 1.146 bar. The carburetor pressure exhibits a variation between 0.997 bar and 1.001 bar, with an average of 0.999 bar. In Fig. 9, the data obtained from the cylinder pressure at the $N = 1000$ rpm regime are presented.

At this regime, the ambient temperature (T_0) is 27.5 °C, and the exhaust temperature, as well as the ambient pressure (p_0), is 1.185 bar. The carburetor pressure displays a variation between 0.998 bar and 1.002 bar, with an average of 1.000 bar.

In Fig. 8, the data obtained from the cylinder pressure at the regime of $N = 900$ rpm is presented.

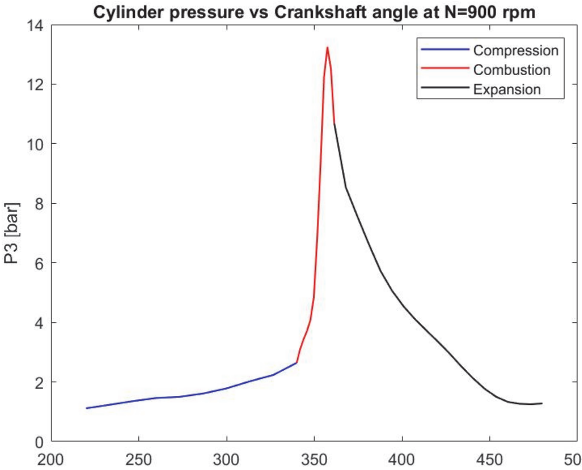


Figure 8 The cylinder pressure at the N = 900 rpm

In Fig. 9, the data obtained from the cylinder pressure at the regime of $N = 1000$ rpm is presented.

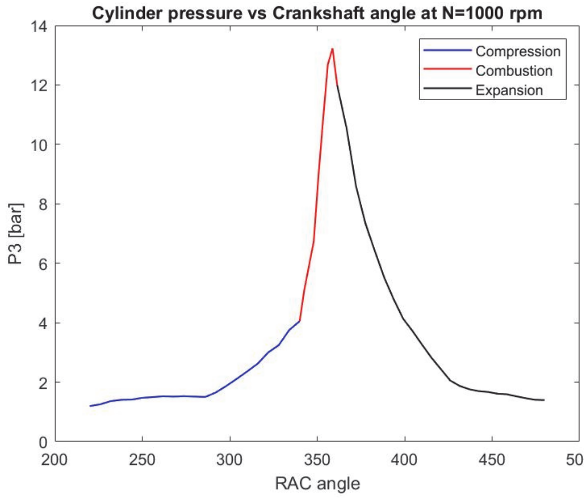


Figure 9 The cylinder pressure at the N = 1000 rpm

In Fig. 10, the data obtained from the cylinder pressure at the $N = 1200$ rpm regime is presented.

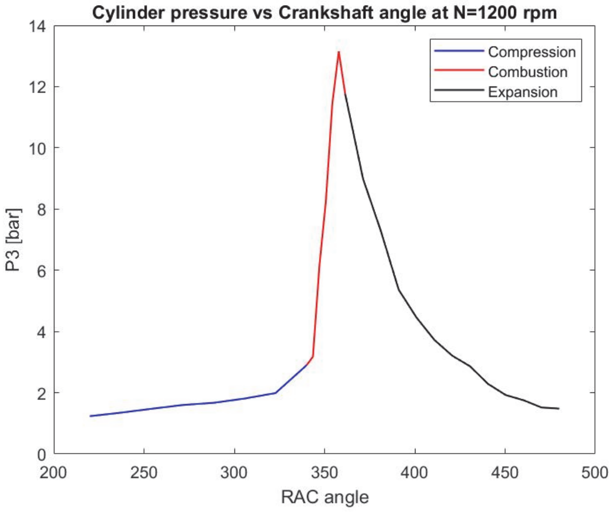


Figure 10 The cylinder pressure at the N = 1200 rpm

At this regime, the ambient temperature (T_0) is 27.5 °C, and the exhaust temperature, along with the ambient pressure (p_0), is 1.114 bar. The carburetor pressure shows a variation between 0.997 bar and 0.999 bar, with an average of 0.998 bar.

Due to the cylinder being made of quartz, visualization was conducted at different positions of the piston to capture stages of the combustion process at the idle regime. This includes observing the beginning of the combustion process that ignites the spark plug and progresses to the exhaust gas on the exhaust manifold. The visualization results are presented in Fig. 11.

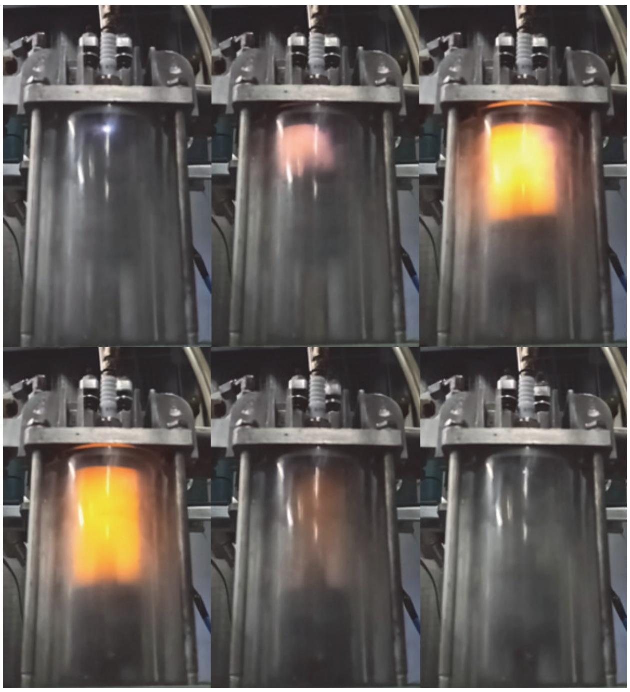


Figure 11 Visualization of the flame front at different positions of the piston

Using this method, visible combustion can be studied based on the color of the flame, allowing for experimentation with various air-fuel mixtures and even the addition of water. Another avenue for exploration involves studying combustion with two different fuels, given the engine's capability to run on various fuel types. This approach enables the determination of performance and the exploration of possibilities for minimizing emissions in the lower emission range.

5 CONCLUSION

In this paper, a didactic piston engine underwent instrumentation to upgrade its configuration from analog to digital. A data acquisition system was constructed based on this instrumentation, accompanied by a graphical interface for real-time visualization of key parameters. The recorded values from the engine instrumentation were graphically presented, particularly during operation at varying speed regimes unstable revolutions, ranging from minimum speed to idle, and a slightly higher idle speed. The evolution of the flame front in the cylinder was captured from the moment of spark occurrence, and images of the spark plug in the cylinder were obtained in six consecutive sequences. The cylinder pressure exhibited slight variations due to the intermediate section used for measurement between the Kulite sensor and the piston chamber.

This study underscores the significance of instrumenting a piston engine, emphasizing that data storage facilitates post-processing and in-depth analysis. With this upgrade, the engine is poised to be used in a modernized manner in the laboratories of the Faculty of Aerospace Engineering at the National University of Science and Technology POLITEHNICA Bucharest. The range of experiments and their accuracy can be expanded, preparing the laboratories for various studies, including visualizing the flame front for specific green fuels, exploring differences in air-fuel ratios and their implications on the combustion process, and investigating transient processes.

As future work, the following considerations can be explored:

- Testing the engine with the dynamometer configuration set on "Load" to measure torque.
- Testing the engine with the dynamometer configuration set on "Generator" to measure generated power.
- Testing the engine with different control strategies, specifically using the throttle needle while maintaining the control lever at different positions.
- Testing and comparing the engine's performance with various types of fuels.
- Investigating water and gasoline injection in the carburetor.
- Measuring noxious substances to compare different fuel recipes used in piston engines.
- Developing an algorithm for the theoretical and real thermodynamic cycle based on the obtained data.

Acknowledgements

The data presented and analyzed in this report were obtained with the help of COMOTI's Research and Experiments Center in the field of Acoustic and Vibrations staff and facility. This work was carried out through the Core Program within the National Research, Development, and Innovation Plan 2022-2027, implemented with the support of MCID, project No. PN23.12.07.01.

6 REFERENCES

[1] Tatarynow, D., Longwic, R., Sander, P., Zieliński, Ł., Trojgo, M., Lotko, W., & Lonkwic, P. (2022). Test Stand for a Motor Vehicle Powered by Different Fuels. *MDPI Applied Sciences*, *12*(20), 10683. https://doi.org/10.3390/app122010683

[2] Czarnigowski, J. A., Skiba, K., Rękas, D., Ścisłowski, K., & Jakliński, P. (2021). Bench Tests for Exhaust Gas Temperature Distribution in an Aircraft Piston Engine with and without a Turbocharger. *Advances in Science and Technology Research Journal*, *15*(3), 155-166. https://doi.org/10.12913/22998624/139688

[3] Catana, R. M., Grigore, C., & Dediu, G., (2017). Gas Turbine Engine Starting Applicated on TV2-117 Turboshaft. *Engineering, Technology & Applied Science Research*, *7*(5), 2005-2009. https://doi.org/10.48084/etasr.1315

[4] Pochet, M., Jeanmart, H., & Contino, F. (2020). Uncertainty quantification from raw measurements to post-processed data: A general methodology and its application to a homogeneous-charge compression-ignition engine. *International Journal of Engine Research*, *21*(9), 1709-1737. https://doi.org/10.1177/146808741989269

[5] https://www.me.psu.edu/assets/docs/sample-syllabus/ME-431.pdf

[6] http://www.aero.pub.ro/en/bachelor-programs-2/

[7] Avishek, R., Chakravarthy, S. R., & Pramod, S. M. (2011). An optical test rig for incylinder flow diagnostics. *Proceedings of the 38th National Conference on Fluid Mechanics and Fluid Power*, 15-17.

[8] Ahmed, T. R., Rashid, A. A., Saiful, A. Z., Abdalrazak, T. R., & Wasiu, B. A. (2022). A review of free piston engine control literature - Taxonomy and techniques. *Alexandria Engineering Journal*, *61*(10), 7877-7916. https://doi.org/10.1016/j.aej.2022.01.027

[9] Léonard, O., Thomas, J. P., & Borguet, S. (2008). Ten Years of Experience with a Small Jet Engine as a Support for Educatio. *Journal of Engineering for Gas Turbines and Power*, *131*(1), 012303. https://doi.org/10.1115/1.2967487

[10] William, L. & Chin, H. L. (2012). Gas Turbine Engine Testing Education at Western Michigan University. *Aerospace Research Central, 45th AIAA Aerospace Sciences Meeting and Exhibit*. https://doi.org/10.2514/6.2007-703

[11] Xiang, R., Chenxing, S., Zhiwei, G., & Chengqing, Y. (2022). A review of online condition monitoring and maintenance strategy for cylinder liner-piston rings of diesel engines. *Mechanical Systems and Signal Processing*, *165*(1), 108385. https://doi.org/10.1016/j.ymssp.2021.108385

[12] Saravanan, C. G., Vikneswaran, M., Prasanna, S. R. Y., Edwin, V. G., Sasikala, J., Ashok, K., & Muthukumaran, N. (2022). Experimental study of feasibility of orange peel oil as a partial replacement for gasoline fuel in SI engine with and without MAO coated piston. *Fuel*, *315*(1), 123173. https://doi.org/10.1016/j.fuel.2022.123173

[13] Vergel, M. O., Valencia, G. O., & Duarte J. F. (2021). Experimental study of emissions in single-cylinder diesel engine operating with diesel-biodiesel blends of palm oil-sunflower oil and ethanol. *Case Studies in Thermal Engineering*, *26*(1), 101190. https://doi.org/10.1016/j.csite.2021.101190

[14] Xinyu, L., Aleš, S., Ho, L., Y., Sanghoon, K., Qing, N. C., & Evatt, R. H. (2021). Performance and emissions of hydrogen-diesel dual direct injection (H2DDI) in a single-cylinder compression-ignition engine. *International Journal of Hydrogen Energy*, *46*(1), 1302-1314. https://doi.org/10.1016/j.ijhydene.2020.10.006

[15] Manoj, A. B., Saravanan, C.G., Vikneswaran, M., Edwin, V. J., & Sasikala, J. (2020). Visualization of in-cylinder combustion using endoscope in spark ignition engine fueled with pine oil blended gasoline. *Fuel*, *263*(1), 116707.

https://doi.org/10.1016/j.fuel.2019.116707

[16] Velavan, A., Saravanan, C.G., Vikneswaran, M., James, E. G., & Sasikala, J. (2020). Visualization of in-cylinder combustion flame and evaluation of engine characteristics of MPFI engine fueled by lemon peel oil blended gasoline. *Fuel*, *263*(1), 116728. https://doi.org/10.1016/j.fuel.2019.116728

[17] Osman, A., Raj, K., Xiaoye, H., & Ming, Z. (2011). Precise instrumentation of a diesel single-cylinder research engine. *Measurement*, *44*(7), 1261-1278. https://doi.org/10.1016/j.measurement.2011.03.028

[18] Dionysia, V. (2018). *Didactic Test-Bench of a Vehicle's Engine*. Department of Control and Computer Engineering, Politecnico di Torino.

[19] Han Y. (2018). *Didactic Test-Bench of a Car's Engine*. Department of Control and Computer Engineering, Politecnico di Torino.

[20] No, S. Y. (2014). A Review on Spray Characteristics of Bioethanol and Its Blended Fuels in CI Engines. *Journal of ILASS-Korea*, *19*(4), 155-166. https://doi.org/10.15435/JILASSKR.2014.19.4.155

[21] Feng, H., Song, Y., Zuo, Z., Shang, J., Wang, Y., & Roskilly, A.P. (2015). Stable Operation and Electricity Generating Characteristics of a Single-Cylinder Free Piston Engine Linear Generator: Simulation and Experiments. *MDPI Energies*, *8*(2), 765-785. https://doi.org/10.3390/en8020765

[22] No, S. Y. (2014). A Review on Spray Characteristics of Bioethanol and Its Blended Fuels in CI Engines. *Journal of ILASS-Korea*, *19*(4), 155-166. https://doi.org/10.15435/JILASSKR.2014.19.4.155

[23] https://cdn.sick.com/media/pdf/1/51/351/dataSheet_IM05-1B5PSVU2S_6049735_en.pdf

[24] https://www.sick.com/ag/en/inductive-proximity-sensors/inductive-proximity-sensors/imm/im05-1b5psvu2s/p/p300351

[25] https:/www.bakerhughesds.com/sites/files/cozyhq596/files/2018-11/eng-unik_5800-5900.pdf

[26] https://kulite.com//assets/media/2022/03/ETL-634-312.pdf

[27] http://www.caom-automatizari.ro/produse/termocupluri-tehnice.html

[28] Armando, P., Gisela, M., Rogelio, R. I., Conrado, G., Marcos, C., & Jose, R. (2019). Development and implementation of virtual instrumentation based on LabView applied to compression ignition engines operated with diesel-biodiesel blends. *MethodsX*, *6*(1), 2782-2792. https://doi.org/10.1016/j.mex.2019.09.024

[29] https://www.ni.com/pdf/manuals/376607a.pdf

[30] https://www.ni.com/docs/en-US/bundle/ni-9213-specs/page/overview.html

[31] https://www.ni.com/docs/en-US/bundle/ni-9205-specs/page/overview.html

[32] https://www.prelectronics.com/products/multifunctional-devices/4100/universal-transmitter-4114/

[33] https://www.prelectronics.com/products/multifunctional-devices/4100/universal-uni-bipolar-signal-transmitter-4184/

Contact information:

Cornel Mihai TĂRĂBIC
National Research and Development Institute for Gas Turbines COMOTI,
220D Iuliu Maniu, 061126 Bucharest, Romania
Faculty of Aerospace Engineering,
National University of Science and Technology Politehnica Bucharest,
1-7 Polizu Street, 1, 011061 Bucharest, Romania
E-mail: cornel.tarabic@comoti.ro

Grigore CICAN
(Corresponding author)
National Research and Development Institute for Gas Turbines COMOTI,
220D Iuliu Maniu, 061126 Bucharest, Romania
Faculty of Aerospace Engineering,
National University of Science and Technology Politehnica Bucharest,
1-7 Polizu Street, 1, 011061 Bucharest, Romania
E-mail: grigore.cican@comoti.ro; grigore.cican@upb.ro

Gabriel DEDIU
National Research and Development Institute for Gas Turbines COMOTI,
220D Iuliu Maniu, 061126 Bucharest, Romania
E-mail: gabriel.dediu@comoti.ro

Razvan Marius CATANĂ
National Research and Development Institute for Gas Turbines COMOTI,
220D Iuliu Maniu, 061126 Bucharest, Romania
E-mail: razvan.catana@comoti.ro