Evaluation of Repeatability of Rapid Compression Machine Under Selected Conditions

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Abstract

Tests using Rapid Compression Machine are utilized by many research and development units. The conducted tests involve mainly the processes of fuel combustion. Despite availability of many studies on the combustion process with the use of Rapid Compression Machine, what is noticeable is the lack of evaluation of repeatability of such system. This article presents an analysis of the uniformity of operation of Rapid Compression Machine in case of direct injection and combustion of gasoline. Also the characteristics of selected thermodynamic indexes of the system operation are presented. Additionally, the coefficients of variation of the proposed evaluation indexes of RCM operation were determined. The results obtained provide the basis for acceptance of the tests and repeatability of the combustion process conducted by such devices.

Introduction

Both development and research studies, apart from quite common in recent years, numerous simulation methods [1–3] still constitute a significant cognitive basis. It is associated with experimental tests using single- and multi-cylinder test engines and rapid compression machines [4–8]. The latter enable conductance of optical research of both, fuel atomization and combustion, in a single operation cycle of the heat engine. Such machines, due to the significant research capabilities, are now widely used in the analysis of the injection and combustion processes [9–11], as they reduce costs and increase the intensity of research compared to tests in which the transparent engines are used. Due to the cyclic characteristics of the combustion engines operation, the individual cycles vary insignificantly. The degree of repeatability of the combustion process while using RCM has not been recognized. These tests are a synthetic description of the unrepeatability of RCM operation expressed through presentation of the dispersion of the main indexes of the combustion process.

Conducting tests on the Rapid Compression Machine is made with an intention of adapting the obtained results for the combustion engines, which is why the criteria of uniformity of combustion engine operation are also the criteria for RCM [12–15]. It is assumed that the uniform operation of the combustion engine occurs at a coefficient of variation of mean indicated (or effective) pressure CoV (IMEP) below 5% (Coefficient of Variation).

Research methodology

The Rapid Compression Machine presented in Figure 1, reflecting the operating conditions of the spark ignition engine, was used to study the unrepeatability of the cycles of machine operation. Technical specification of machine used for a single combustion cycle is shown in Table 1. This system has a volume of about 500 cm^3, which is the typical volume of a cylinder of modern combustion engines. With the use of the combustion pressure sensor AVL GM1 installed on the head, the pressure characteristics in the cylinder were recorded. To this end, the system for acquisition of fast-varying signals IndiCom 621 by AVL was used. Tested were the consecutive 10 machine operation cycles.

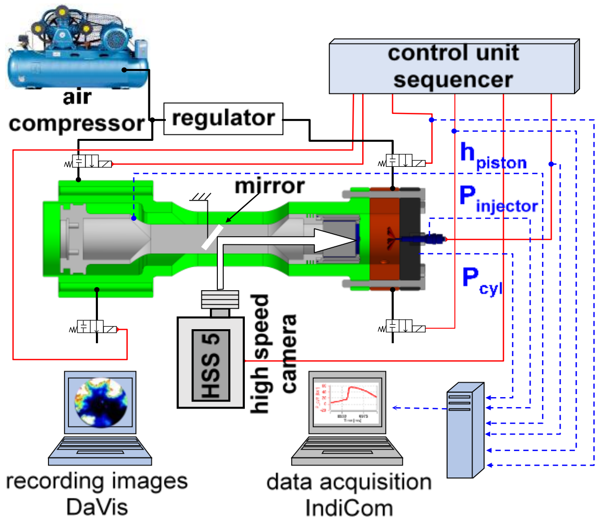

Fig. 1. Test stand.

In the tests was used measuring apparatus consisting of:

- The piezoelectric sensor of combustion pressure – GM11D by AVL, with the measuring range 0-20 MPa,
- The high-speed camera by LaVision, taking pictures with frequency of at least 10 kHz,
- Piston displacement sensor – contactless potentiometric displacement sensor – Megatron LSR 150 ST R5k,
- The system for acquisition of measurements of fast-varying signals,
- AVL IndiModul (using charge amplifier MicroIFEM).

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Table 1. Technical data of Rapid Compression Machine.

Quantity	Value
Piston stroke	81 mm
Cylinder diameter	80 mm
Cylinder volume	407 cm^3
Compression chamber volume	66.5 cm^3
Air supply method	Solenoid valves
Exhaust fumes outlet	
Method of forcing piston movement	Pneumatic
Geometric compression ratio	min. 6.8
Actual compression ratio	6.8 ÷ 14
The piston movement speed	30 ÷ 70 m/s
Fuel injection	Direct, multiple

The assessment of RCM operation repeatability

The assessment of the uniformity of Rapid Compression Machine operation was performed on the basis of the analysis of the indicated pressure as a function of time. On the basis of the coefficient of variation the non-uniformity in obtaining operation indexes of the RCM was determined as: the maximum combustion pressure Pmax, the angle of maximum combustion pressure aPmax, indicated mean effective pressure (IMEP), thermodynamic beginning of combustion AI05 (determined on the basis of a 5% threshold of heat release) and end of the combustion AI90 (defined as the 90-percent value of the maximum heat release).

The initial comparison of a Rapid Compression Machine operation was based on the analysis of the correlation between the measuring results obtained for piston stroke, changes in combustion chamber volume and indicated pressure, presented in Figure 2. Piston movement was enforced by the sequencer. Due to the lack of a crank mechanism, the signal analysis was carried out in reference to the duration of the cycle.

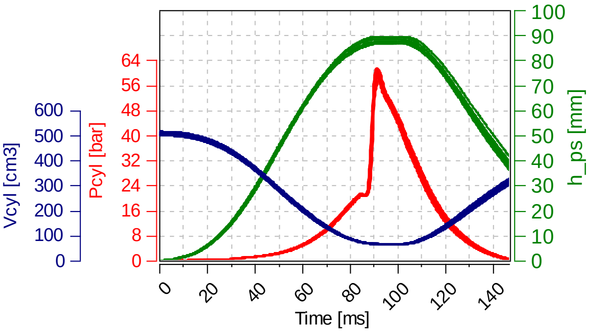

Fig. 2. The results of the measurements of the combustion pressure, piston stroke and cylinder capacity for 10 consecutive cycles of operation of RCM.

The evaluation of the Rapid Compression Machine operational indexes was carried out for a defined strategy of fuel injection with the use of a proprietary concept of the direct injection with the use of two injectors [16–19]. In Figure 2 can be observed a significant qualitative repeatability of the pressure characteristics in the combustion chamber. The coefficient of variation CoV used to assess the repeatability is defined as CoV(x) = std / mean [%] where: std is the standard deviation of a dataset, and mean is the mean of the dataset, the result is a percentage value of the measure of variation in the distribution of characteristics.

For the analysis were selected 10 consecutive operation cycles, for which the dispersion of the analyzed values is shown in Figure 3.

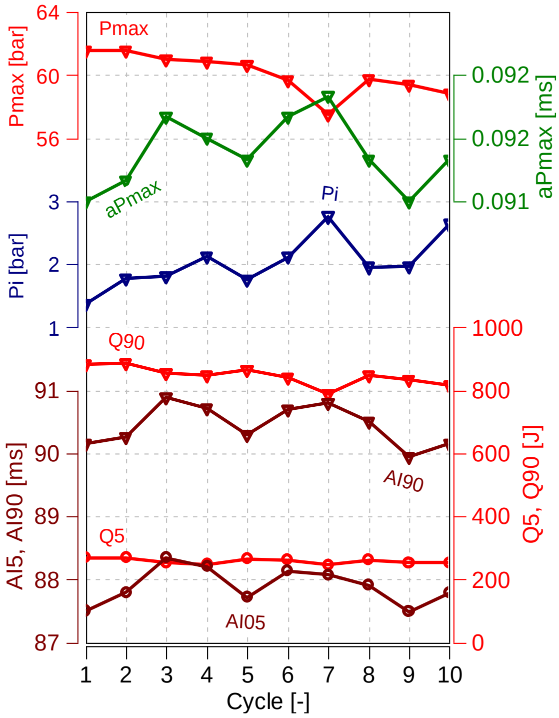

Fig. 3. Dispersion of the analyzed values for RCM.

The non-uniformity of RCM operation can be characterized by several parameters, including e.g. the value of the maximum combustion pressure. Figure 4 shows the difference between the values of pressure achieved in the combustion chamber of the RCM. The maximum pressure level achieved was above 61 bar while the lowest registered maximum pressure value amounted to 57.5 bar. The difference of about 4 bar gave the coefficient of variation CoV(Pmax) equal to 2.15%.

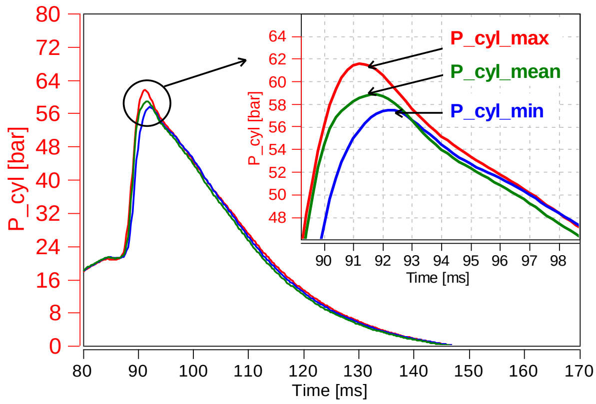

Fig. 4. Analysis of the combustion pressure for selected cycles of Rapid Compression Machine operation.

The presented in Figure 5 dispersions of the values analysed are diverse in terms of distribution. Processes with high repeatability are characterized by high numerousness in small number of ranges. The values with the highest repeatability are: aPmax, AI90, AI05, AI90, the ranges of which are concentrated in and around the average value. The indexes with higher dispersion of values are: Pmax, Q5, Q90.

The next stage of the evaluation was the assessment of the repeatability of the mean indicated pressure and the quantity of heat released and rate of its release. The values of the indicated pressure were determined based on the following equation: $Pi=(\Sigma P\_cyl*\Delta V)/(V_{End}-V_0)$ where: V_0 is the volume of the cylinder when the piston starts to move and V_{End} is the cylinder volume when the decompression ends. Figure 6 presents the analysis of the heat release. The marked external boundaries cover the area where the changes occurred marked as Qmax and Qmin and dQmax and dQmin.

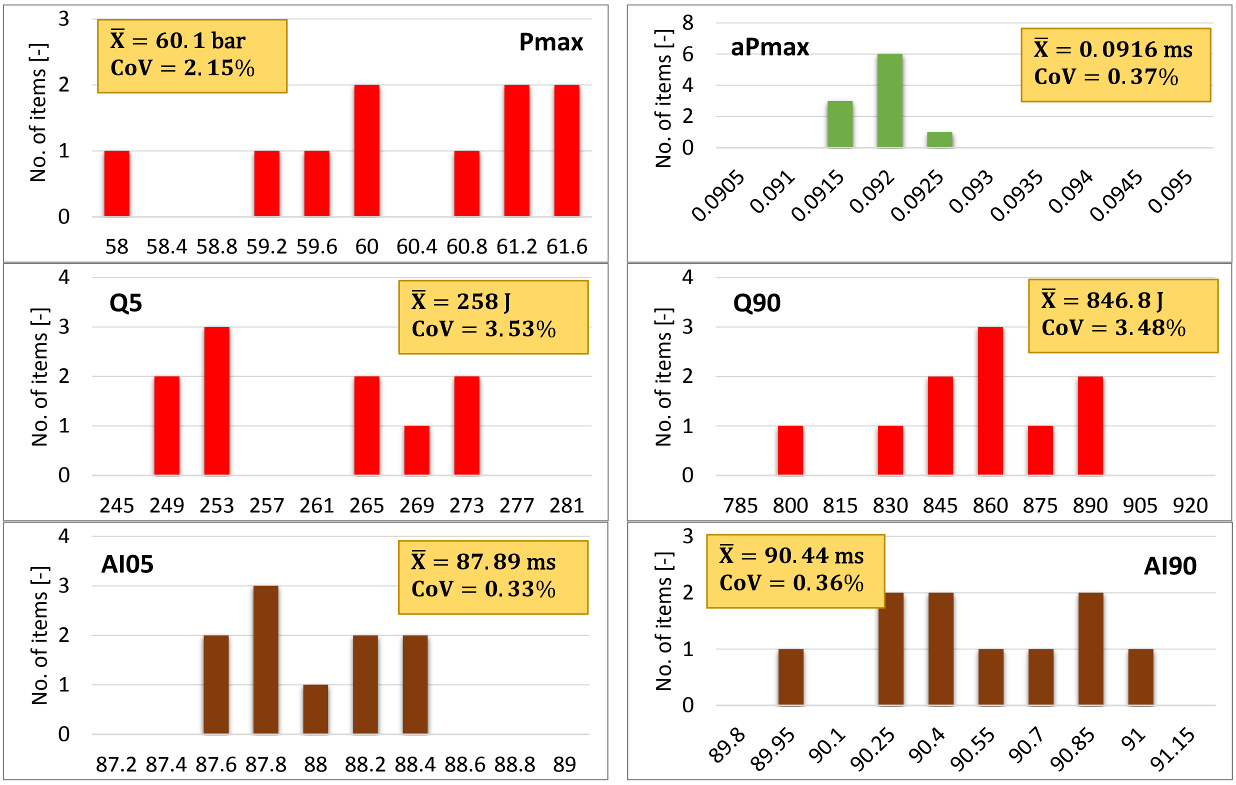

Fig. 5. Evaluation of ranges of variability of the characteristic parameters of Rapid Compression Machine operation.

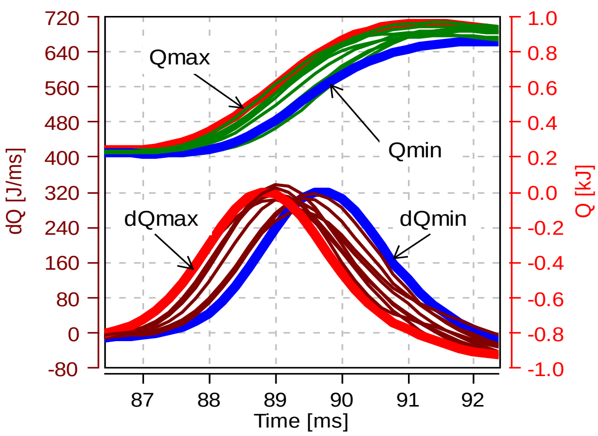

Fig. 6. Characteristics and rate of heat release for 10 measuring cycles.

In this way, the process of heat release was presented not only through the maximum values obtained during each test cycle, but also through the difference ΔQ = Qmax – Qmin, which is graphically depicted in Figure 7.

The most significant differences were achieved for the range from 88.8 to 90 ms of the duration of the cycle, which corresponds to combustion. However, the determined values CoV(Q5) and CoV(Q90) amounting to, respectively, 3.53% and 3.48%, indicate the uniformity of the heat release. In addition, the calculated time of uniformity of occurrence of the 5% threshold of heat release CoV(AI05) and end of combustion CoV(AI90) (defined as the 90 percent threshold of heat release) amounting to 0.33% and 0.36% indicate a high repeatability of these indexes.

The rates of heat release presented in Figure 8 define the fastest and the slowest heat increase in the chamber of the Rapid Compression Machine for the analyzed 10 measuring cycles. Figure 9 presents the ranges of variability concerning the rates of heat release and indicated pressure. The maximum rate values were achieved for the range of variability of CoV(dQmax) = 5.31% slightly exceeding the limits, and to CoV(Pi) = 20.3% significantly exceeding the limits quoted in the referenced literature, while the time of occurrence of dQmax, despite the presented in Figure 8 dispersion equal to 0.8 ms, reached CoV(adQmax) amounting to 0.36%, which is an acceptable value.

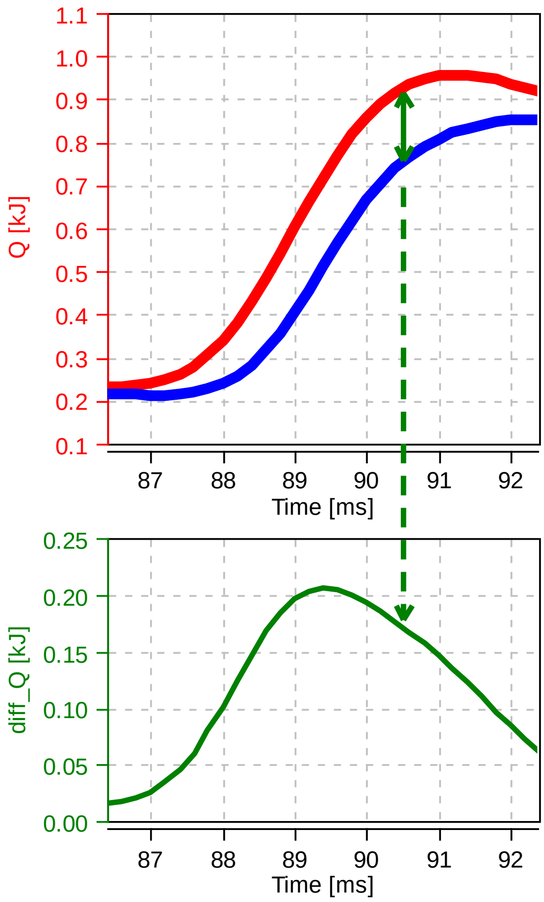

Fig. 7. Delta of the heat release characteristics for the selected maximum and minimum characteristics.

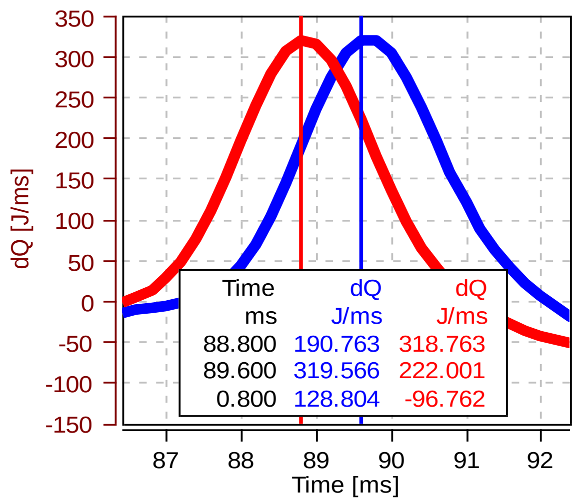

Fig. 8. The analysis of the variability of the heat release rates.

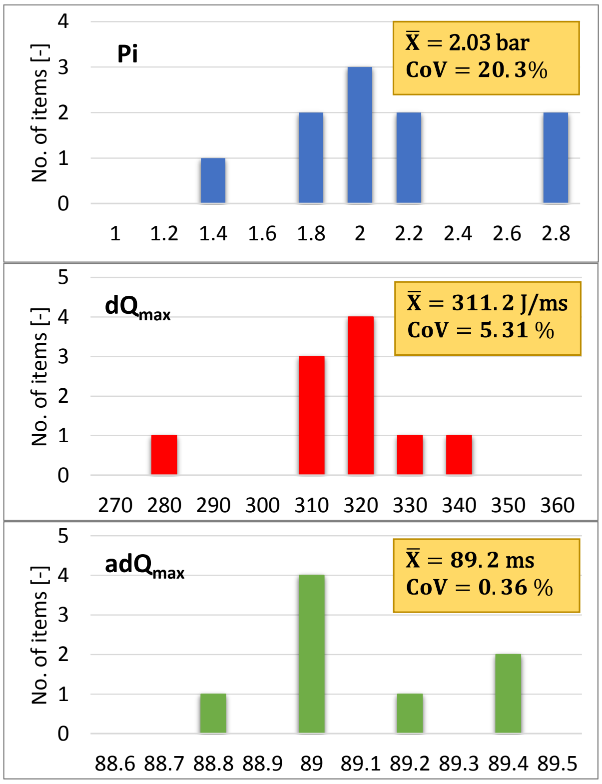

Fig. 9. Evaluation of ranges of variability of the indicated pressure and heat release rates for Rapid Compression Machine.

Summary

The indexes of the operation uniformity analyzed in the paper are shown in Figure 10 and in Table 2. Assuming an acceptable range of CoV at the level below 5%, it was found that indexes such as: Pmax, aPmax, Q5, Q90, AI05, AI90 and dQmax meet the assumptions confirming uniformity of operation of the Rapid Compression Machine. The most repeatable indicators proved to be: aPmax, AI90, AI05 oraz adQmax, reaching COV < 0,4%.

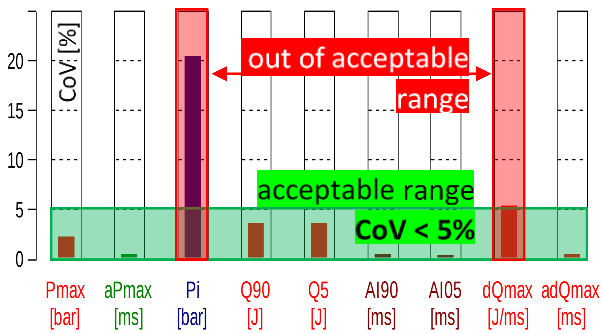

Fig. 10. Comparison of the unrepeatability of the operational indexes of RCM.

One of the indicators analyzed, not fulfilling the range, is the IMEP(Pi), the significant non-uniformity of which is caused by the unrepeatability of the very combustion process. Although dQmax also exceeded the scope of CoV under 5%, this value is small and can be considered to fulfill repeatable value of RCM. The authors on the basis of the analysis confirmed the validity of the tests of combustion with the use of Rapid Compression Machine.

Table 2. Values of the analyzed indexes of operational unrepeatability for RCM.

Value		Min	Max	Mean	CoV
P_{max}	bar	57.5	61.5	60.1	2.15
aP_{max}	ms	0.0912	0.0922	0.092	0.37
Pi	bar	1.38	2.76	2.03	20.3
Q5	J	245.1	270	258.1	3.53
Q90	J	789.5	887.1	846.8	3.48
AI05	ms	87.49	88.35	87.89	0.33
AI90	ms	89.94	90.89	90.44	0.36
dQ_{max}	J/ms	275.19	334.79	311.2	5.31
adQ_{max}	ms	88.8	89.8	89.2	0.36

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