

EXHAUST EMISSION FEATURES OF VARIABLE COMPRESSION RATIO (VCR) DIESEL ENGINE

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Abstract

One of the important design parameters for internal combustion engines is the geometric compression ratio ϵ . It is defined by the ratio of the maximum volume of the combustion chamber V_{max} at the bottom dead centre (BDC) piston position and a minimum volume of the combustion chamber V_{min} at the top dead centre (TDC) piston position. Conventional engines have this parameter set unchangeable, what is not the solution ensuring optimal benefits coming from the heat release in the combustion process, especially under altering conditions of load and speed in which they perform powering the road vehicles. It is reflected mainly in exhaust emission problem. Despite a considerable progress, further improving the ecological and energetic performances of the piston engines faces severe system limits, elimination of which requires major changes in engine design, including conversion the fixed compression ratio into the flexible one. For such innovative engine designs with so-called variable compression ratio VCR feature the geometric compression ratio parameter is as the one of the operation regulators. Due to the new development prospect the paper scope is an analysis and showing some results for the impact of compression ratio on the emissions of selected exhaust harmful components for a direct injection diesel engine. The schematics and prototype solutions for VCR technology are briefly presented too.

Keywords: diesel engine, compression ratio, variable compression ratio VCR, exhaust emission, toxic compounds

1. Introduction

A development in combustion engines is forced mainly by environment protection demands, reflected distinctly in still tighten exhaust emission limits. They apply to such compounds as carbon monoxide CO, hydrocarbons HC, nitric oxides NO_x, and particulate matter PM. Developing measures on this area started as early as in the sixties of XX century. Till today, the huge progress has been already done. In last few years, the next ecological problem springs to affect the motor industry again. This is a pressure on engines fuel efficiency improving and CO₂ emission decrease owing to consideration of the carbon dioxide CO₂ as the main greenhouse gas, responsible for global warming effect. Hence, the strong pursuit of increasing engines energetic efficiency and substituting the petroleum fuels with renewable ones is commonly observable.

Synchronized realization of both strategies in combustion engines, i.e. reduction of exhaust toxicity and fuel consumption, is not an easy task. It stems from complex physical and chemical interactions in working cycle of piston engines, especially during combustion stage. Usually, improving exhaust cleanness usually claims resignation from high fuel efficiency, and vice versa, fuel consumption decreasing causes more toxic emission. This is because the present means of engine operation optimizing are close to the boundaries of their effectiveness, which have the character of systematic limitations. That's why there is an urgent need to find and develop new, non-conventional technical solutions in reciprocating engines construction and control of operation. Particularly it should focus on the combustion process, which must be clean and highly effective. Some recent works indicates the engine "downsizing" joined with high turbo charging ratio [1] or

new, low temperature combustion concepts including HCCI/PCCI (CAI) as the paths for setting the standards for engines technology in the near future [2]. But to take their advantages in the full range, introduction of some new mechanical solutions into the engines construction must be done. Among others a variable compression ratio VCR technology is concerned [6]. It can provide a very high potential on reaching high power density at low exhaust emission and fuel consumption.

2. VCR technology brief review

Various technologies for VCR have been and still are intensively studied by a few research groups worldwide. Some of them were adapted to engine research purposes or vehicle test prototypes [6] including:

- a) articulated monohead (Saab),
- b) piston of variable deck height (Daimler-Benz),
- c) eccentrics on crankshaft bearings (FEV),
- d) multilink rod-crank mechanisms (Nissan),
- e) secondary moving piston or valve in cylinder head (Ford),
- f) gear-based crank mechanisms (MCE-5)
- g) precisely shifted cylinder block - cylinder head assembly (Self-Developed Design).

Despite of many technical difficulties and practical feasibility, each solution has specific advantages, but drawbacks too. They are widely discussed and in [5, 6] and summarized in Tab. 1.

Tab. 1. Different ways for realization of continuous variable compression ratio feature and their technical characteristics [5]

The principle for VCR	a)	b)	c)	d)	e)	f)	g)
Characteristics							
Combustion chamber integrity	N/C	N/C	N/C	N/C	↘↘↘	N/C	N/C
Crankshaft assembly kinematics	≠	N/C	≠	≠≠≠	N/C	≠≠≠	N/C
Mechanical losses	N/C	↘	N/C	↘↘	N/C	↗	N/C
Engine overall integrity	↘	↘	↘	↘	↘	↘	↘
Change of C.R. versus engine displacement stability	N/C	N/C	N/C	↘↘	N/C	N/C	N/C
C.R. control limits and accuracy	↑↑	↓↓↓	↑↑	↑	↑	↑↑	↑↑↑

Legend: ↗ – improvement, ↘ – deterioration, ↑ – high, ↓ – low, ≠ – different, "N/C" – no change(s)

To join the latest state-of-the-art research activity a self-developed, multi-cylinder VCR research engine has been designed [4, 7]. The project is based at the medium-duty truck engine of VD 14.5/12-2 SRW series. The change of combustion chambers volume due to shifting the cylinder block - head assembly perpendicularly to the crankshaft axis (according to Tab. 1, principle g), causes the variation of the engine compression ratio from 19 to 9. The four-cylinder version of the engine with cylinder block-head assembly actuation system based at the set of no-backlash roller screws is shown in Fig. 1.

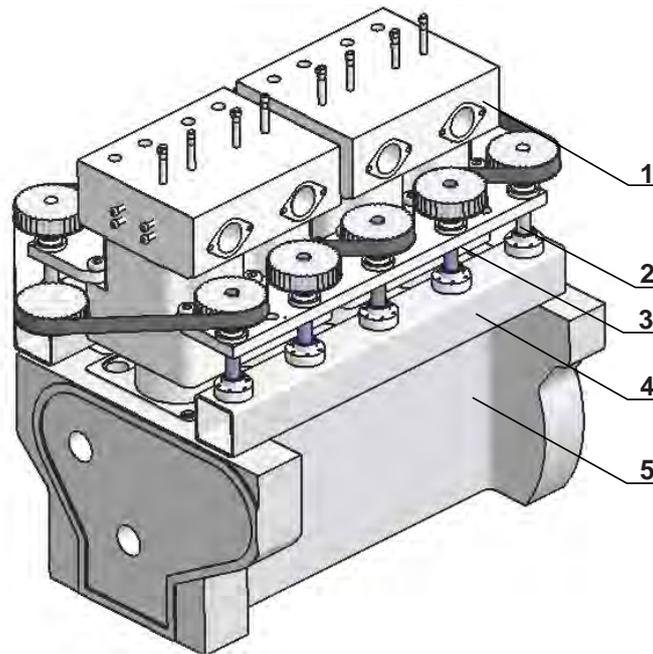


Fig. 1. Self-developed variable compression ratio engine layout: 1 - cylinder block-head assembly, 2 - set of synchronously driven roller screws, 3 - upper support of actuation system, 4 - bottom support of actuation system, 5 - crankshaft block

The engine may be used for detailed experimental studies on the effect of compression ratio on combustion and exhaust emission process, both for standard diesel/spark ignition mode and low temperature combustion regime. To narrow prospecting works for the optimum, a simulation tests should be performed earlier. Further, some calculation results for operational and exhaust emission parameters of the engine at various compression ratios are presented.

3. Simulation research

The Diesel-RK full cycle thermodynamic engine simulation tool [3] has been used for the calculations. Main features of program Diesel-RK are similar to other known programs like: WAVE (Ricardo Software), GT-Power (Gamma Technologies) and BOOST (AVL). However, Diesel-RK offers a true multi-zone model for diesel fuel spray mixture formation and combustion and includes fuel spray visualization tool. It allows multiparametric and multidimensional optimization of engine parameters with detail kinetic mechanism of NO formation.

The Diesel-RK internal mathematical model takes into account: engine geometry parameters; the shape of injection profile, including split injection; drop sizes; direction of each spray in the combustion chamber; the swirl intensity; the piston bowl shape; chemical reactions with harmful compounds emission; etc. Evolution of wall surface flows generated by each spray depends on the spray and wall impingement angle and the swirl intensity.

It makes possible to change the compression ratio by virtual moving the cylinder block-head assembly in the same way as in the real, self-developed engine (see Fig. 2). This functionality and user-friendly programming environment decided on its selection for the analysis.

In the program all engine data have been implemented including:

- piston stroke and cylinder bore,
- combustion chamber dimensions and geometry,
- direction of fuel spray,
- geometry of charge exchange system,
- actuation characteristics and timing of valves,
- fuel injection system parameters.

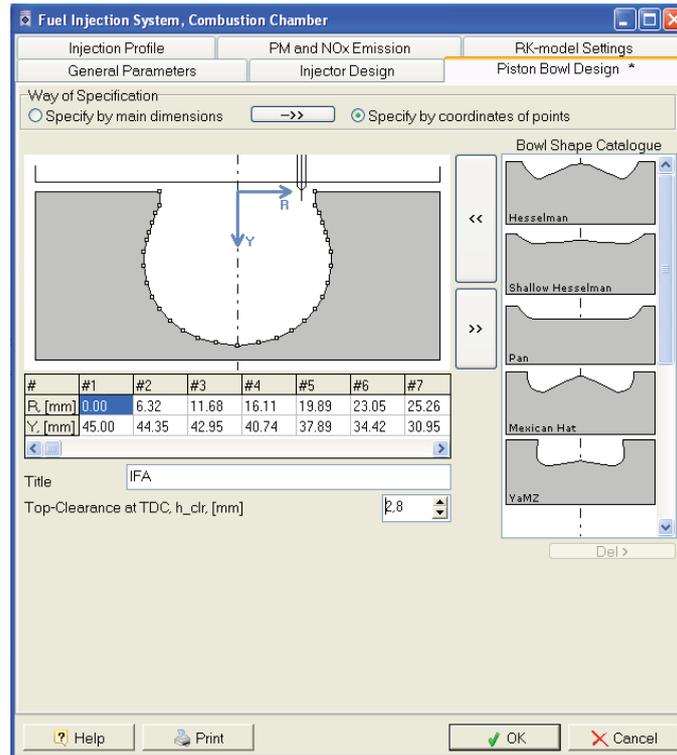


Fig. 2. Diesel-RK window for setting engine parameters including piston bowl shape and compression ratio as the clearance between the piston deck and the head at top dead centre (TDC) crankshaft position

Amount of fuel injected per cycle, start of fuel injection, and maximum fuel injection pressure have been varied for matching the model output parameters with experimental data. It can be noticed that very high consistency of both data has been achieved (Fig. 3), what goes to show a proper engine working mapping by the program.

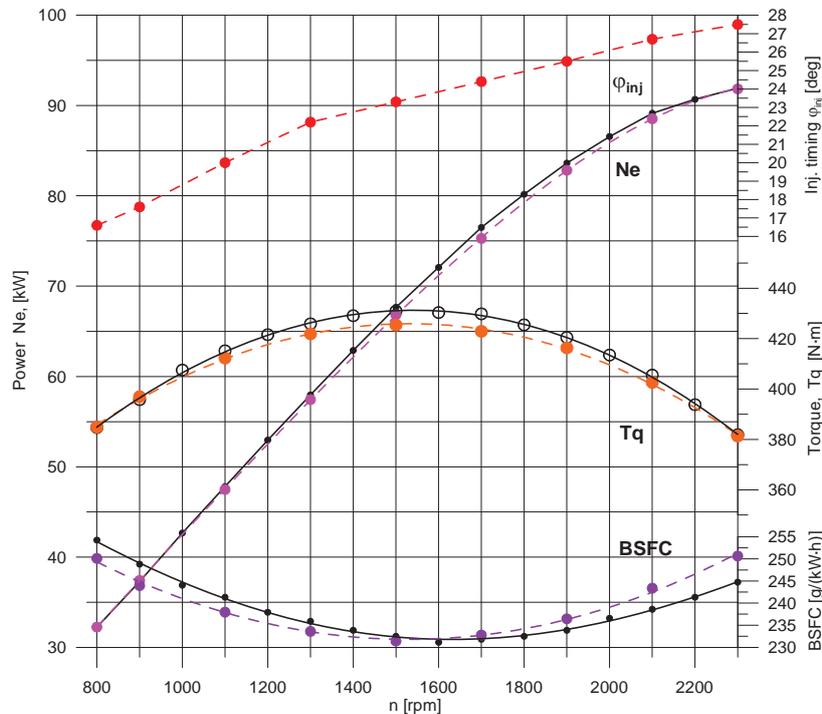


Fig. 3. Validation of the research engine parameters at CR = 18, solid lines (—) - experimental data, dashed line (---) - calculation data

Next, the simulation for different loads, speeds and compression ratio values has been performed. Figure 4 presents some results for full load engine operation at 1300 rpm of crankshaft speed. For these conditions, the optimal value of compression ratio lies in 15-17 with regard to CO₂ emission. Considering PM emission and exhaust smoke, CR = 17 seems to be better. Unfortunately, NO_x emission reaches the maximum value then, according to the common rule, which marks emission tendencies of these two compounds as opposed one another. For simultaneous reduction of both, a detailed optimization study should be done, where the variable compression ratio feature can broaden its range and amplify the effect significantly.

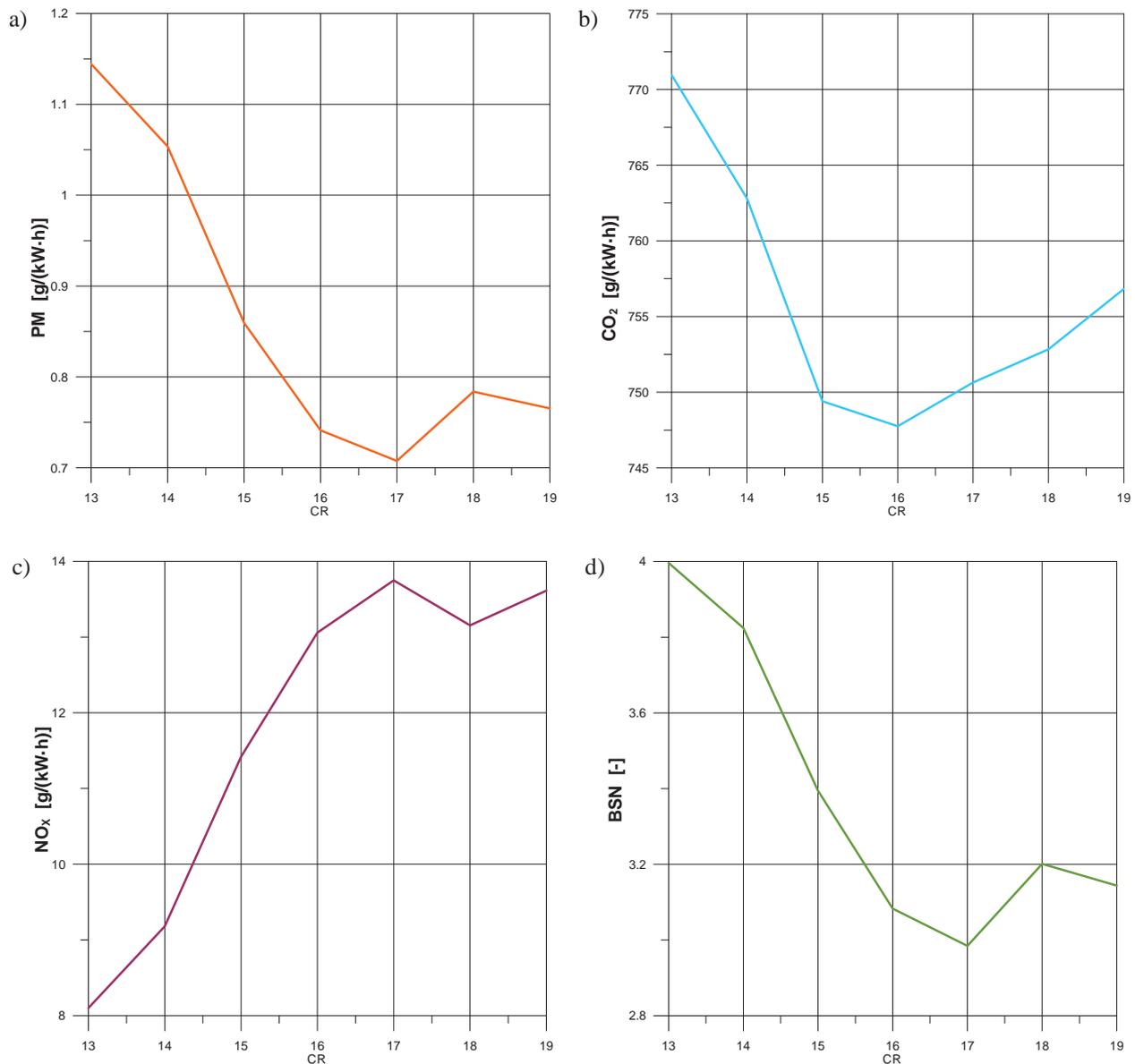


Fig. 4. Effect of variable compression ratio on harmful exhaust components emission at 1300 rpm of crankshaft speed and full load; a) - PM, b) -CO₂, c) - NO_x, d) - Bosch Smoke Number BSN

4. Conclusions

Variable compression ratio technology is the promising means for combustion engine development. Presented study proves that it can break a severe limitation of fixed compression ratio engines, giving an effective regulator for combustion process managing according to the present and further environmental restrictions and fuel economy demands.

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