THE ENGINE COMBUSTION ANALYSIS OF NEWLY DEVELOPING DIESEL TRACTOR ENGINE ZETOR Z1727 WITH COMMON-RAIL SYSTEM IN A FIRST FIRING WEEK

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Abstract: This article focuses on the research and development of diesel tractor engines. It deals with high pressure indication of newly developing tractor engine Zetor Z1727 with common-rail injection. The main goal is determination of development of combustion pressure in a cylinder, because knowledge of this parameter is very important for the basic engine adjustment. This paper provides also many evaluations of influences. It is the dependency of rail pressure and injection timing on the most problematical nitrogen oxides emissions and opacity, cylinder pressure variation and combustion noise level. The correct adjustment of those variables is the key to achieve optimal engine parameters, which also proved this measurement. Common-rail ECU has about 16 000 variables. There is a possibility to change almost everything and set many adjustments. This will be the subject of further research, because these data are only from measurement in first firing week and only ‘from the first cylinder.

Key Words: cylinder pressure, injection timing, rail pressure, combustion noise level, emissions

INTRODUCTION

Development and optimization of modern internal combustion engines is inconceivable without the knowledge of what is happening in the cylinders. Measurement and analysis of the variation in cylinder pressure is the only source of the data needed to optimize efficiency, engine output, emissions, noise of combustion and last but not least engine life (Blazek 2012). The better the data the more valuable the information that is derived. Reciprocating piston internal combustion engines are basically heat engines in that they essentially convert the chemical energy from the air-fuel mixture into mechanical work and heat by means of combustion (Blazek 2012). Developers aim to extract from the conversion as high a proportion of mechanical work as possible that is to maximize efficiency (Beroun 2013). The magnitude and variation with time of the cylinder pressure acting on the piston are significant in this respect.

MATERIAL AND METHODS

There are more demanding requirements on tractor engines, which manufacturers have to fulfill. The reason is necessity to pass all the requisites of homologation tests and simultaneously keep competitiveness of tractors. Therefore the manufacturers must use engines with modern injection systems and electronic engine control. Traditional Czech tractor manufacturer Zetor tractors used for many years injection system, which is nowadays historical - terraced injection pump with mechanical regulator of fuel charge. This injection system was innovated in 2014 by electromagnetic regulator of fuel charge. It enabled more precise motor management because of necessity to fulfill the highest emission standard Stage IV. Model series Proxima and Forterra are fitted with these engines, which are self developed by the company. Other series Major and Crystal are fitted with purchased engines Deutz with common-rail injection. The company would like to continue with self developed engines for the first two mentioned model series. That is why it is necessity to find common-rail system supplier and fitted the engines with this modern technology. This innovation will allow communication between common-rail ECU and many other ECUs via CAN-Bus (Bauer et al. 2013).

It also reduces fuel consumption, heat stress, power losses, wear and mainly negative influences on environment (Bauer et al. 2013). Research and development of this engine is the subject of this article and also of author´s dissertation.

Characterization of the engine

The engine is fitted with common-rail injection. During the measurement no aftertreatment was used. The combustion chamber is undivided and formed in the piston itself. Other selected parameters of the engine are available in Table 1.

Table 1 Selected parameters of measured engine

Manufacturer	Zetor
Type	Z 1727
Nominal power [kW / HP] – ECE 24 R 03	103 / 140
Aspiration of the engine	turbocharger with intercooler
Intercooling	air/air
Number of cylinders (disposition)	4 (inline engine)
Number of valves	16
Volume [cm^3]	4,156
Nominal engine revolutions [rpm]	2,200
Idle [rpm]	800
Compression ratio	17
Fuel	diesel
Maximum torque [Nm]	585
Cooling	fluid

Measurement chain

- Diesel tractor engine - mounted on a test bench and connected to a dynamometer,
- Electromagnetic eddy current dynamometer Schenck W230,
- Opacimeter AVL 439 and NO_x sensor connected to INCA via CAN-Bus,
- PC with software ETAS INCA V7.1 for calibration, diagnostics, and validation of automotive electronic systems,
- Current probe Fluke 80i-110s AC/DC (100A) – measures injection pulses of fuel injector and it is connected to KiBox,
- Kistler devices for engine combustion analysis
  - Piezoelectric cylinder pressure sensor 6056A – mounted in glow plug adapter 6542Q, which is mounted in cylinder head instead of glow plug. Sensor is connected to KiBox,
  - Crank angle adapter set 2619A – connected to inductive sensor on a crankshaft and also to KiBox,
  - System for combustion analysis KiBox® To Go 2893AK1,
  - PC with Kistler software KiBoxCockpit – connected to KiBox via ethernet.

Measurement methodology

This measurement is not determined by any standard, because it was performed in a first firing week with brand new engine, which was fitted with new injection system common-rail. Indicated was the first cylinder and only main injection was turned on. Employees of common-rail system supplier and engineers from the tractor company decided that the engine will be set on constant revolutions and load while injection timing (before/after top dead center – BTDC/ATDC) and rail pressure will be change as can be seen in Table 2. These engine revolutions were chosen, because economical regime and lowest fuel consumption are both reached. Load value is exactly in the middle of maximal torque that means half engine load. Evaluated parameters are most problematical pollutants in exhaust gases at diesel engines - opacity and nitrogen oxides emissions (Macek 2007), as well as combustion noise level. Evaluation of cylinder pressure characteristic is performed only for the lowest and the highest rail pressures to better show the differences.

Table 2 Input measurement values

Engine speed [rpm]	1,480
Engine load (torque) [Nm]	295
Rail pressure [bar]	900; 1,100; 1,300; 1,500
Injection timing due to the TDC [°CA]	-18, -16, -14, -12, -10, -8, -6, -4, -2, 0, 2

RESULTS AND DISCUSSION

For a diesel engine, fuel injection pressure and injection timings are very important parameters, which influence the engine performance, emissions, and combustion (Agarwal 2013).

The dependency of rail pressure and injection timing on the cylinder pressure characteristic

The most important parameter of engine combustion analysis is variation of cylinder pressure as it was mentioned above. Heat supply from burning of air-fuel mixture results in a change of pressure in the cylinder. This variable can be measured by today's measurement technology with the required accuracy. Cylinder pressure variation is a representative indicator of the combustion process as well as the way of energy conversion in the engine. How the rail pressure and injection timing affects the cylinder pressure characteristic can be seen in Figure 1 and Figure 2.

Figure 1 Development of cylinder pressure at rail pressure 900 bar

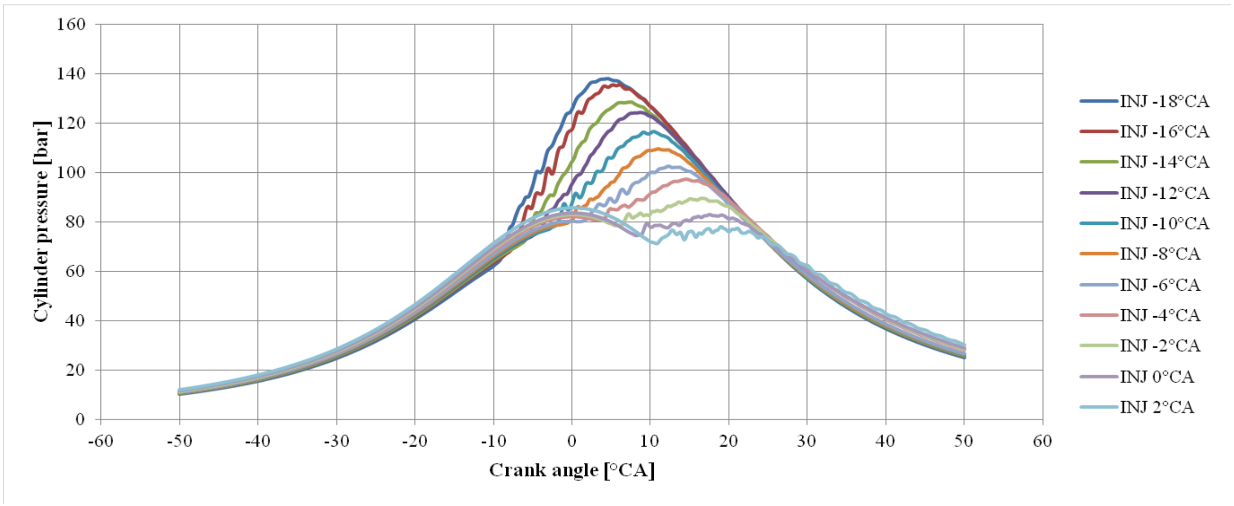
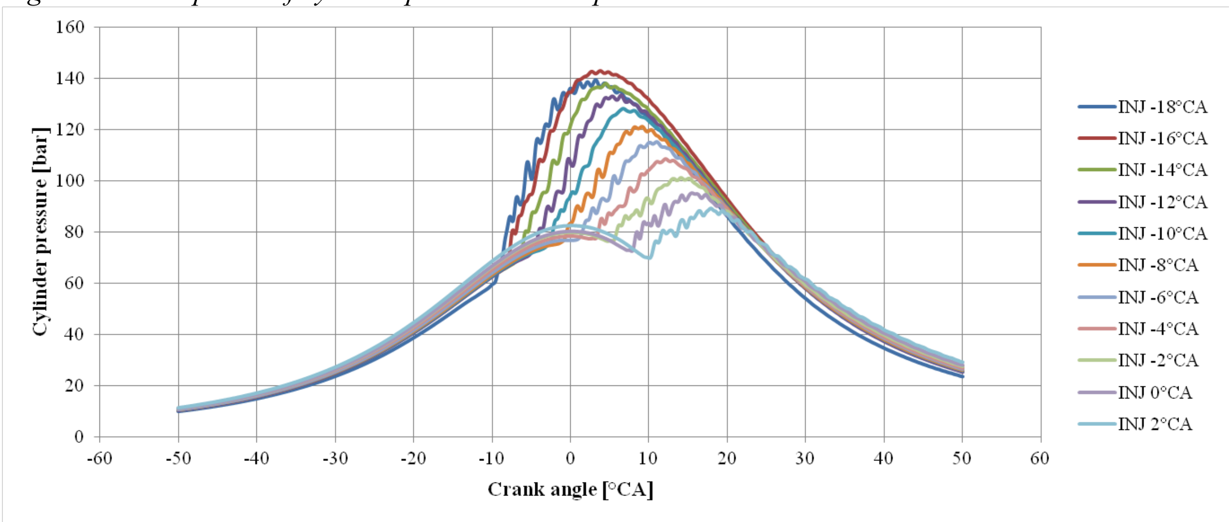


Figure 2 Development of cylinder pressure at rail pressure 1500 bar



The combustion engine reaches the best parameters when the maximum pressure in the cylinder is achieved a little bit after top dead center (6–10° ATDC). Good example could be cylinder pressure at injection timing 16 degrees before TDC in both Figures. Moving the start of injection closer to TDC causes increase of cylinder pressure and end of combustion far away after TDC (see Figures 1 and 2). That means - lower values of maximal cylinder pressure, increasing temperatures in exhaust, longer delay deflagration and lower efficiency too. Typical example of huge delay deflagration can bee seen in Figure 2 for injection timings from 8 degrees before TDC to 2 degrees after TDC. My recommendation is adjust the injection timing of this main injection between 18–14° before TDC. The exact value depends mainly on NO_x and opacity and on specific fuel consumption too. The evaluation for these two pollutants will be performed in the next section. Unfortunately the specific fuel consumption was not measured. Avinash Kumar Agarwal (2013) published similar measurement, but with different values of constant engine speed, injection pressures and injection timings. However the development of cylinder pressure for various injection timings is quite similar.

The dependency of rail pressure and injection timing on nitrogen oxides (NO_x) and opacity

These two emissions constituents are the most problematical at diesel engines and they are also legislatively limited. Measurement results can be seen in Figures 3 and 4.

Figure 3 The dependency of rail pressure and injection timing on NO_x

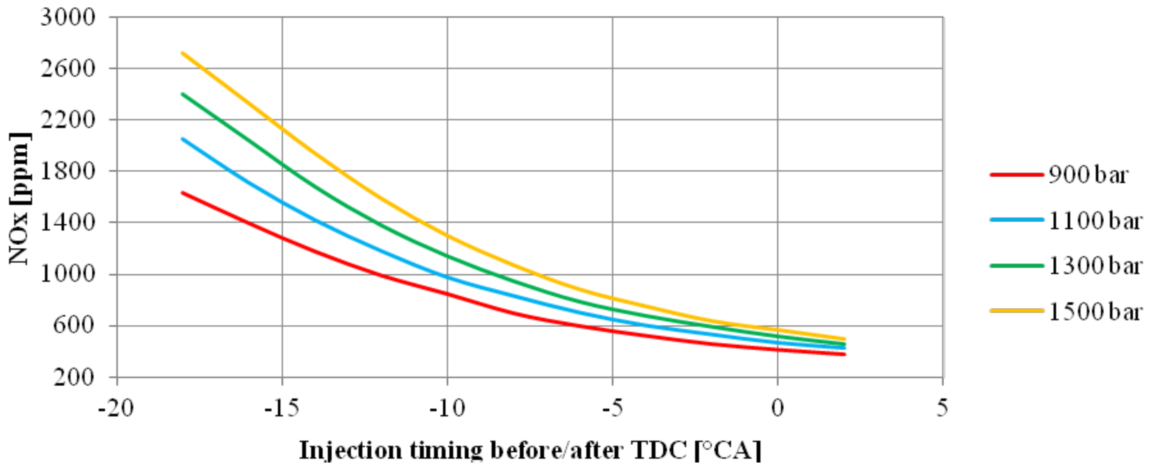
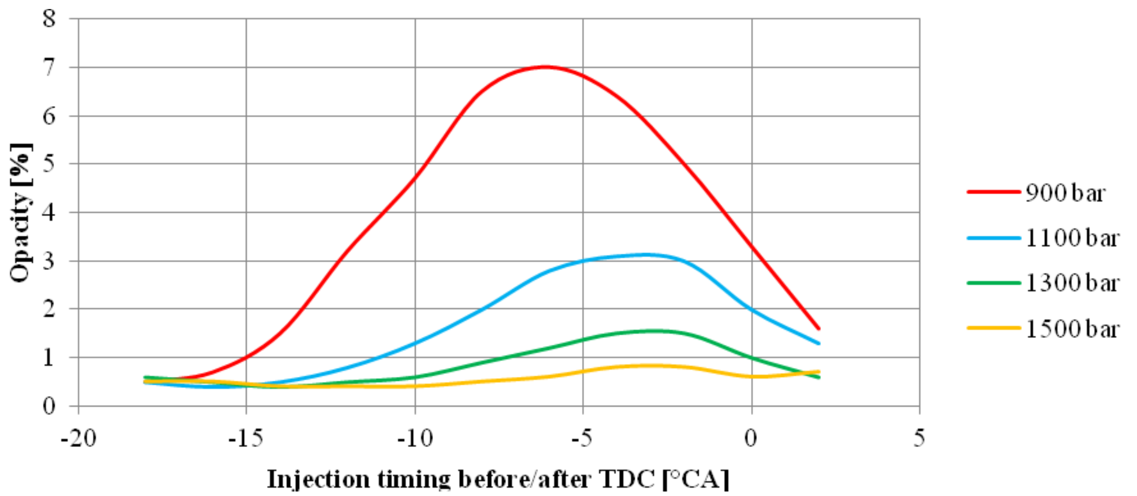


Figure 4 The dependency of rail pressure and injection timing on opacity

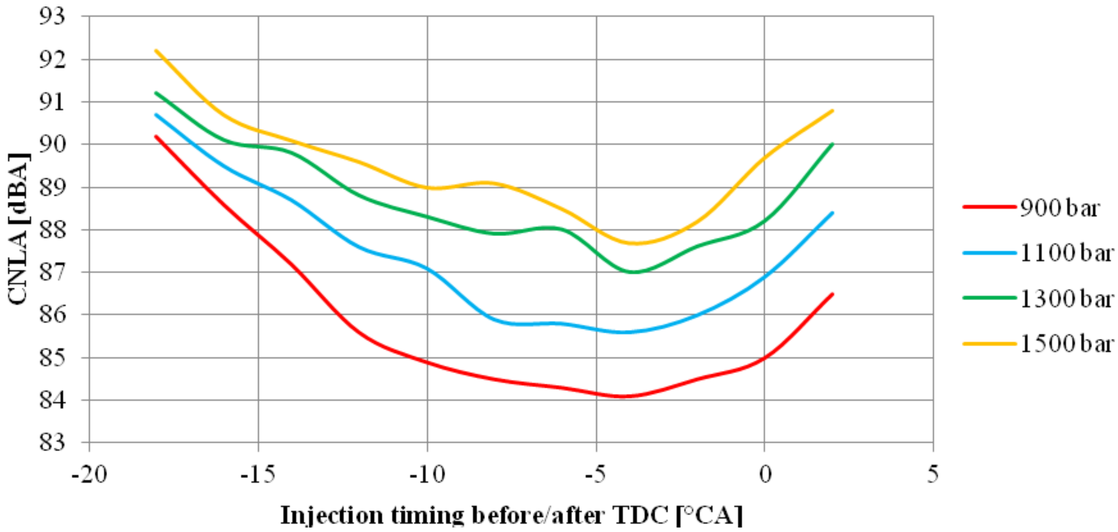


According to my recommendation the injection timing should be between 18–14° before TDC. Opacity is very low in this area, but NO_x emissions are very high. The values of NO_x must be about 1800 ppm in order to reduce them by aftertreatment to fullfil the emission standard Stage IV. Therefore it is appropriate to set the rail pressure on 1300 bar, because the dependency of the rail pressure on maximal cylinder pressure is negligible at these angles of injections as can be seen from Figures 1 and 2. The exact value of injection timing should be at 15 degrees before TDC and exactly the same value recommends also Agarwal (2013). Nitrogen oxides and opacity, which represents particulate matters, have to be reduced by aftertreatment, as without these devices it is not possible to fulfill any emission standards. Proper adjustment of injection timing and rail pressure can decrease these pollutants a lot (see Figure 3 and 4). Interesting is also the influence of rail pressure on opacity. The lowest values are reached at rail pressures 1500 bar and 1300 bar. The reason is probably better comminution of fuel due to high pressure. Same results of emissions published also Agarwal (2013).

The dependency of rail pressure and injection timing on combustion noise level

The legislative is not concerned only with emissions of gaseous and particulate pollutants in exhaust gases, but also with mechanical pollutants, where factors such as noise and vibration belong. Measurement chain for combustion analysis can also measure combustion noise level through the cylinder pressure sensor. The value is filtered in accordance with the sensitivity of the human ear (A-filtered or A-weighting [dBA]). The same filtration is used at the homologation tests. Measured values can be seen in Figure 5.

Figure 5 The dependency of rail pressure and injection timing on combustion noise level



The rail pressure and injection timing influences the combustion noise level (see Figure 5). The lowest values are reached at injection timing 4 degrees before TDC for all rail pressures. The high pressure in the rail causes also high level of combustion noise. The reason is a sharper increase of cylinder pressure at high rail pressures as can be seen from Figures 1 and 2. The same cylinder pressure-fuel injection pressure relationship published also Agarwal (2013). The combustion noise level at optimal engine adjustment (rail pressure 1300 bar, injection timing 15° before TDC) according to cylinder pressure characteristic and emissions is 90 dBA. These values were measured while only the main injection was turned on. The inclusion of pre-injection can decrease combustion noise level by 8 dBA at least.

CONCLUSION

Combustion analysis of engine pressure indication is regarded as a basic tool in engine development and is the key to improving efficiency, increasing engine output, reducing emissions and prolonging engine life. For most applications combustion analysis data is shown relative to top dead center of the power stroke. The most important source of information in indication is the cylinder pressure curve (see Figure 1 and 2).

Unambiguous conclusion of performed measurement is the fact that the rail pressure and injection timing significantly influences all of evaluated parameters of a given diesel tractor engine. The rail pressure should be adjusted on 1300 bar and injection timing on 15 degrees before TDC to reach the best parameters of the engine according to results of this measurement.

ACKNOWLEDGEMENT

This work was supported by the project no. IP 38/2015 „Analysis of combustion pressures of diesel tractor engine Zetor Z1717 Stage IV“ and financed by Internal Grant Agency of Mendel University in Brno, Faculty of Agronomy.

This research has been realized in collaboration with workplace of Research and Development of Zetor Tractors and with Swiss company Kistler, which loaned the measurement chain.

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