Effect of Injection Advance Angle on Auto-Ignition Delay and Response of Ad3.152 Ur Engine

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Abstract The paper presents the results of experimental investigations into the effect of injection advance angle in the AD3.152UR engine on auto-ignition delay time and engine response coefficient value. In the tests, the engine operated under the full load characteristics and was fuelled by commercial diesel oil. The injection advance angle ranged $\alpha_{\text{pw}} \in <13, 21> \text{ CA deg}$. The tests aimed to assess the engine ability to adapt to variable load conditions.

Keywords CI internal combustion engine, engine response, injection advance angle, auto-ignition delay

JEL R41, R49

1. Introduction

In positive ignition engines, the combustion process is initiated with spark-over across the spark plug electrodes. The start of combustion in compression ignition engines is related to injection advance angle and auto-ignition delay time.

In compression ignition engines, it is difficult to determine auto-ignition delay time because its value is affected, in a very complex manner, by multiple factors. A lot of dependencies and methods of determining the auto-ignition delay time are found, which is related to the necessity to specify the beginning of fuel injection and the start of the combustion process [1, 2, 3, 4].

The auto-ignition delay is the time that elapses from the fuel injection beginning to the instant of chain-thermal explosion of pre-flame reactions. In the indicator diagram that is manifested as the beginning of a quick rise in pressure and the working medium temperature, which results from the start of fuel combustion $\alpha_{\text{ps}}$ (point 3 in Fig.1). An increase in those quantities, caused by fuel combustion, is shown in the indicator diagram as a departure of the combustion pressure curve from the curve representing compression pressure [5].

The total auto-ignition delay time consists of two components: a physical one $\tau_{f}$ and a chemical one $\tau_{ch}$. The first component corresponds to the time necessary for the fuel spray to disintegrate into droplets, their partial evaporation and air/fuel vapour mixing. The other component, i.e. $\tau_{ch}$, represents the delay in auto-ignition of homogeneous gaseous mixture.

Taking into account that the chemical and physical processes occur simultaneously, with a slight shift in time, it is difficult to assess the duration of these components. The interrelation of both components is expressed by the dependence [1]:

$$\tau_{s} = \tau_{f} + \tau_{ch}$$  \hspace{1cm} (1)

where: $\tau_{s}$ – auto-ignition delay time , $\tau_{f}$ – physical component, $\tau_{ch}$ – chemical component of auto-ignition delay time

The value of auto-ignition delay time $\alpha_{\text{os}}$ is calculated from the dependence:

$$\alpha_{\text{os}} = \alpha_{\text{ps}} - \alpha_{\text{pw}} \text{ CA deg}$$  \hspace{1cm} (2)
where: $\alpha_{ps}$ – the start of combustion, $\alpha_{pw}$ – the beginning of fuel injection.

Auto-ignition delay affects the rate of combustion, and also that of pressure and temperature increase. Additionally, it influences the engine starting characteristics, the exhaust gas toxicity and noise. This time is of fundamental importance for the quality of the whole combustion process, especially for the process dynamics, which, in turn, affects the engine response.

Internal combustion engine response is a parameter determining the dynamic performance of the vehicle, i.e. such traction properties as the ability to climb a grade in different gears, or time necessary to complete an overtaking manoeuvre. Those quantities are directly related to the active safety of the vehicle. Engine with high response allows drivers to go in a particular gear at both low and high speeds, so that they do not have to continually change gear [6, 7].

Response is one of the most important indicators defining the in-service properties of the engine, which by definition [5, 6] specifies the engine ability to adapt to variable load operating conditions. The higher is the value of the response coefficient, the greater is the vehicle ability to accelerate, climb grades, etc. The current advancements in internal combustion engines are also associated with their increased response by applying pressure charging systems that operate in a wide range of engine rotational speeds, or high-pressure multi-stage fuel injection. The paper demonstrates the impact of injection advance angle on the value of the engine response coefficient [6, 7, 8].

The coefficient value is determined on the basis of full-load characteristics, Fig. 2 which contains the power and torque curve. It is done by determining the values of rotational speed response coefficient $e_n$ and torque response coefficient $e_M$. The product of those coefficients gives the value of the engine response $e$ which is specified by the dependence:

$$e = e_M \cdot e_n$$

The coefficient of engine torque response $e_M$ is the ratio of the maximum torque value $M_{\text{max}}$ to the torque at which the engine generates the rated power $M_{\text{Nemax}}$:

$$e_M = \frac{M_{\text{max}}}{M_{\text{Nemax}}}$$

The coefficient of the rotational speed response $e_n$ gives the ratio of the engine rotational speed at which the engine generates the maximum effective power $n_{\text{Nemax}}$ to the rotational speed at which the engine produces the maximum torque $n_{\text{Momax}}$.
Table 1. Basic specifications of the engine [10]

| Parameter                        | Unit | Value   |
|----------------------------------|------|---------|
| Compression ignition AD3.152 UR engine |      |         |
| Cylinder arrangement             |      | in-line |
| Number of cylinders              |      | 3       |
| Type of injection                |      | Direct  |
| Cylinder working order           |      | 1 – 2 – 3 |
| Compression ratio                |      | 16.5    |
| Cylinder bore                    | mm   | 91.44   |
| Piston travel                    | mm   | 127     |
| Engine cubic capacity            | dm³  | 2.502   |
| Connecting rod length            | mm   | 223.80+223.85 |
| Maximum engine power             | kW   | 34.6    |
| Rotational speed at maximum power| rpm  | 2250    |
| Maximum torque                   | Nm   | 168.7   |
| Rotational speed at maximum torque| rpm | 1350    |
| Static angle of injection advance| CA deg | 17     |
| Idle rotational speed            | rpm  | 750±50  |

The tests aimed at measuring fast-varying quantities, including in-cylinder pressures and the injector needle lift, and those quantities that are necessary to compute the response indicators of the engine operating under full-load characteristics for three injection advance angles, i.e. 13, 17 and 21 CA deg. In the tests, the AD3.152 UR engine was fuelled by Ekodiesel Ultra D commercial diesel oil (DO). On the basis of real indicator diagrams, the start of combustion was determined. The graphs of the injector needle lift were used to determine the beginning of the fuel injection. Those quantities made it possible to determine auto-ignition delay time. On the basis of full load characteristics, the coefficients of engine response were determined.

3. Experimental results

Figure 4 shows the full load characteristics taken for three injection advance angles. Tables 2, 3 and 4 present the results of computations of auto-ignition delay time, torque response, rotational speed response, and the response of the AD3.152 UR engine operating at the injection advance angle $\alpha_{\text{sw}} = 13, 17$ and 21 CA deg.

| n, rpm | $\alpha_{\text{pw}}$ | $\alpha_{\text{ps}}$ | Auto-ignition delay time | Torque response | Rotational speed response | Engine response |
|--------|----------------------|----------------------|--------------------------|-----------------|---------------------------|-----------------|
| 1000   | 344.7                | 351.56               | 6.86                     | 1.089           | 1.428                     | 1.555           |
| 1200   | 345.14               | 352.96               | 7.82                     |                 |                           |                 |
| 1400   | 346.26               | 354.37               | 8.11                     |                 |                           |                 |
| 1600   | 347.42               | 355.78               | 8.36                     | 1.089           | 1.428                     | 1.555           |
| 1800   | 348.82               | 355.80               | 6.98                     |                 |                           |                 |
| 2000   | 348.25               | 357.18               | 8.93                     |                 |                           |                 |
| 2200   | 348.25               | 357.20               | 8.95                     |                 |                           |                 |
4. Conclusions

On the basis of the experimental results, the following conclusions can be drawn:

- A change in the injection advance angle does not change the rotational speed that corresponds to the generation of the maximum power or achieving the speed of the maximum torque,

- The maximum values of the effective power and torque in the engine operating at three settings of the injection advance angle occurred for the same rotational speeds, i.e. the maximum power for n=2000 rpm, and the maximum torque for n=1400 rpm. The computed value of the engine rotational speed response was $\varepsilon_n=1.428$.

- The highest value of the engine torque response, equal to $\varepsilon_M=1.092$, was obtained for the injection advance angle $\alpha_{ww}=21$ CA deg, the lowest value, namely $\varepsilon_M=1.031$, was found for $\alpha_{ww}=17$ CA deg.

- With an increase in the injection advance angle, the value of auto-ignition delay grows. The highest value of this quantity, namely $\alpha_{os}=12.51$ CA deg, was found for $\alpha_{ww}=21$ CA deg.

- The highest value of the engine response, $e=1.559$, was obtained for the injection advance angle $\alpha_{ww}=21$ CA deg.

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