Transport and Communications, 2014; Vol. II. DOI: 10.26552/tac.C.2014.2.1
ISSN: 1339-5130

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 $\alpha_{ww} \in$<13, 21> 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 α_{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 τ_f, and a chemical one τ_{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. τ_{ch}, represents the delay in auto-ignition of homogeneous gaseous mixture.

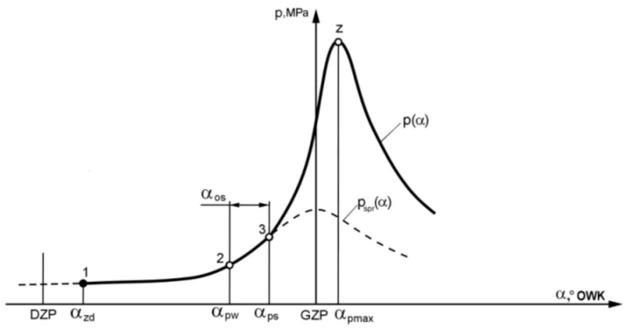


Figure 1. Auto-ignition delay time in the developed indicator diagram, where: α_{pw} – the beginning of fuel injection, α_{ps} – the start of fuel combustion, $p(\alpha)$ – combustion pressure curve, $p_{spr}(\alpha)$ – compression pressure curve, α_{os} (α) – auto-ignition delay time [1]

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]:

$$\tau_s = \tau_f + \tau_{ch} \quad (1)$$

where: τ_s – auto-ignition delay time , τ_f – physical component, τ_{ch} –chemical component of auto-ignition delay time

The value of auto-ignition delay time α_{os} is calculated from the dependence:

$$\alpha_{os} = \alpha_{ps} - \alpha_{pw} \text{ , CA deg} \quad (2)$$

where: α_{ps} – the start of combustion, α_{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:

$$e = e_M \cdot e_n \qquad (3)$$

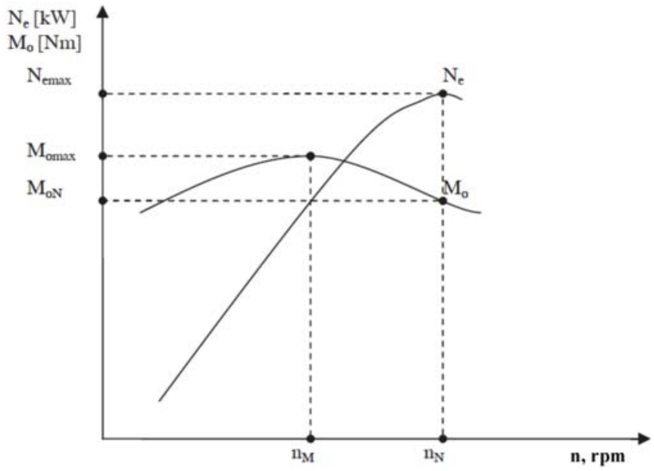
The coefficient of engine torque response e_M is the ratio of the maximum torque value M_{omax} to the torque at which the engine generates the rated power M_{oNemax}:

$$e_M = \frac{M_{omax}}{M_{oNemax}} \qquad (4)$$

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_{Nemax} to the rotational speed at which the engine produces the maximum torque n_{Momax}:

$$e_n = \frac{n_{Nemax}}{n_{Momax}} \qquad (5)$$

Figure 2. The engine full-load characteristics: M_{omax} – maximum torque,



N_{emax} – maximum effective power, n_M –rotational speed at the maximum torque, n_N – rotational speed at the maximum power [6]

2. Object and range of experimental investigations

Tests were performed on three-cylinder, compression ignition Perkins AD3.152 UR AD3.152 UR engine with direct fuel injection into the combustion chamber [9]. Investigations were conducted on the engine test bench equipped with a water brake and control-measurement unit. A block diagram of the test bench is shown in Fig. 3.

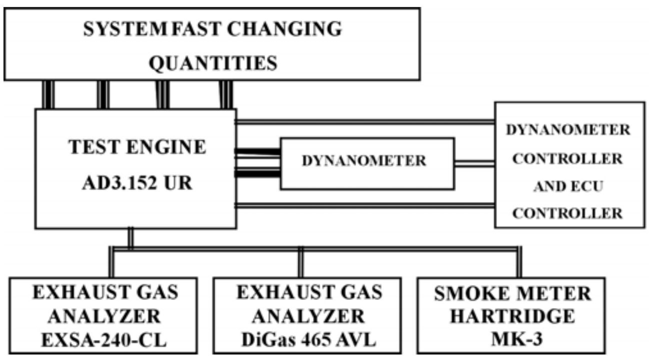


Figure 3. Block diagram of the test bench [10,11]

The basic parameters and specifications of the AD3.152 UR engine are presented in Table 1.

Table 1. *Basic specifications of the engine [10]*

Compression ignition AD3.152 UR engine		
Parameter	Unit	Value
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	dm^3	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 α_{ww} = 13, 17 and 21 CA deg.

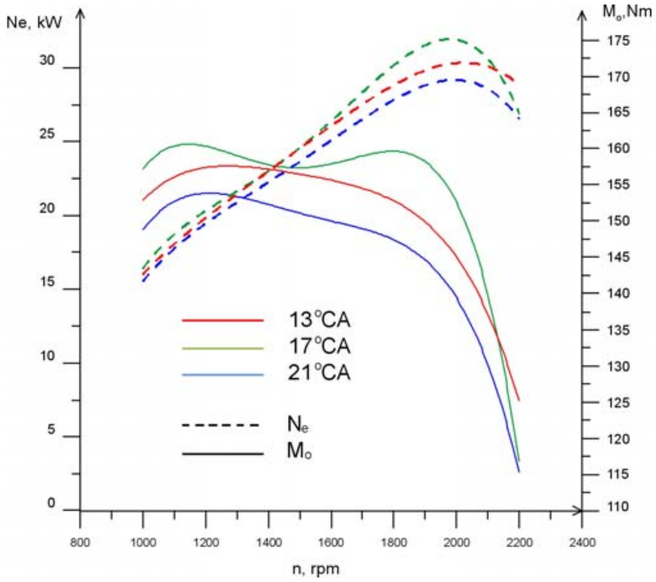


Figure 4. Full load characteristics of the effective power and torque in AD3.152 UR engine fuelled by diesel oil, for three injection advance angles α_{ww} = 13, 17 and 21 CA deg

Table.2. Auto-ignition delay time and torque response, rotational speed response, and the response of the AD3.152 UR engine operating at the injection advance angle α_{ww} = 13 CA deg

n, rpm	α_{pw}	α_{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			
1800	348.82	355.80	6.98			
2000	348.25	357.18	8.93			
2200	348.25	357.20	8.95			

Table 3. Auto-ignition delay time and torque response, rotational speed response, and the response of the AD3.152 UR engine operating at the injection advance angle α_{ww} = 17 CA deg

n, rpm	α_{pw}	α_{ps}	Auto-ignition delay time	Torque response	Rotational speed response	Engine response
1000	341.3	349.6	8.3	1.031	1.428	1.472
1200	341.9	349.2	7.3			
1400	342.9	351.2	8.3			
1600	343.3	352.4	9.1			
1800	344.3	353.8	9.5			
2000	345.1	354.4	9.3			
2200	345.3	354.8	9.5			

Table 4. Auto-ignition delay time and torque response, rotational speed response, and the response of the AD3.152 UR engine operating at the injection advance angle α_{ww} = 21 CA deg

n, rpm	α_{pw}	α_{ps}	Auto-ignition delay time	Torque response	Rotational speed response	Engine response
1000	339.46	348.75	9.29	1.092	1.428	1.559
1200	339.64	348.75	9.11			
1400	–	–	–			
1600	341.67	350.15	8.48			
1800	343.27	355.78	12.51			
2000	343.67	355.78	12.11			
2200	343.95	355.78	11.83			

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=2000rpm, and the maximum torque for n=1400 rpm. The computed value of the engine rotational speed response was e_N=1.428,
- the highest value of the engine torque response, equal to e_M=1.092, was obtained for the injection advance angle α_{ww}=21 CA deg, the lowest value, namely e_M=1.031, was found for α_{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 α_{os}=12.51 CA deg, was found for α_{ww}=21 CA deg,
- the highest value of the engine response, e=1.559, was obtained for the injection advance angle α_{ww}=21 CA deg.

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