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# Adjustment parameters of an internal combustion engine working with methane

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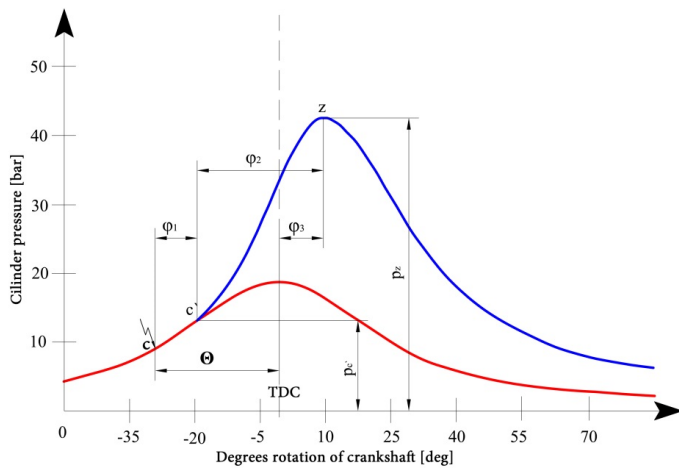
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**Abstract:** The paper presents a study of the variation of ignition advance when the engine works with methane and a comparison with values when the engine runs on gasoline. It is known that methane has a lower burning velocity than gasoline, and therefore, to obtain a maximal efficiency from the working process (the maximum value of cylinder pressure  $p_z$  should be 7-15 degrees after TDC), ignition advance should be increased, as for different operating regimes this angle should be increased with different values. A gasoline engine has been studied and were measured and analysed the ignition advance at work with gasoline and methane, with optimal air-fuel ratio ( $\alpha$ ) for both fuels. Three-dimensional graphics of ignition advance variation across the rpm and load range were made. In conclusion, on the basis of the experiments, a table is produced, which presents the values of coefficients for change of base parameters of ignition advance for all engine operating modes, in dependence on rpm and load of the engine.

## 1. Introduction

As it is known, methane has a lower burning velocity than gasoline [1, 2]. If a methane fuel system is added to a spark-ignition (SI) engine and to make it possible to use the maximum engine efficiency, it is necessary to change the angle of the electric spark in the direction of increase. Under standard conditions (1 bar of Absolute Pressure, temperature of 15 °C and air-fuel ratio of  $\alpha = 0.8$  and 1) the burning velocity according to the technical data is respectively  $V_g = 54.8$  cm/s and  $V_g = 72.0$  cm/s while with methane it is  $V_m = 49.4$  cm/s and  $V_m = 65.8$  cm/s [3]. Due to this characteristic of methane fuel, it is necessary to increase the angle of the electric spark. To obtain maximum efficiency from the combustion process (figure 1), the maximum pressure  $p_z$  is required to be 7÷15° after TDC (Top Dead Centre) [4-6]. Changing this angle through the action of a knock sensor is inapplicable because methane has an octane number of about RON 130 and is resistant to detonation burning. Most aftermarket advance processors that are used to change the ignition advance, can change the advance with a single fixed value for all engine operating modes with values typically of 3°, 6°, 9°, 12°, 15°, which under real operating conditions is a compromise option that improves performance of the engine but only in certain modes of operation [7-11]. However, there also exist advance processors that allow for changing the advance of ignition spark typically  $\pm 25^\circ$  depending on the crankshaft speed. The purpose of the present study is to determine the necessary increase in the ignition advance of a SI engine retrofitted for methane operation at all speed and load regimes.





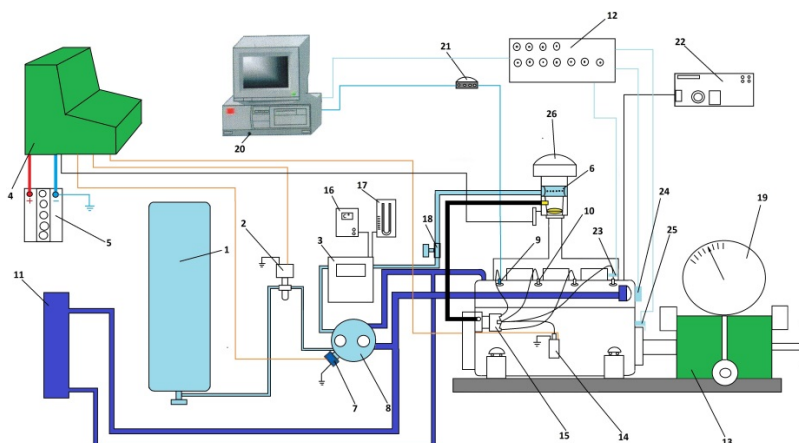
**Figure 1.** Base points of indicator diagram.

Figure 1 shows the main characteristics of the indicator diagram related to the influence on the combustion process. Point  $c$  is the moment where the electric spark is supplied. The period  $\varphi_1$  (from point  $c$  to point  $c'$ ) is the time for the formation of the pre-flame reaction into the cylinder of the engine. From point  $c'$  starts the combustion process in the cylinder. Point  $z$  is the top of the indicator chart corresponding to the maximum cylinder pressure. According to the theory of the internal combustion engine, there is maximum efficiency of the combustion process when  $p_z$  is obtained till  $15^\circ$  after Top Dead Centre (TDC) [5, 12, 13].

## 2. Experimental methodology

Experiments are made on SI engine with a volume of 1.275 liters, compression ratio  $\varepsilon = 9.75$  and nominal power  $46 \text{ kW}$  at  $5500 \text{ min}^{-1}$ .

The Methane fuel system is conventional with a reducer-evaporator, where it is easy to change the air-fuel ratio of the mixture. The engine is mounted on an electric DC current dynamometer. Many regulated characteristics have been made, from where the optimal parameters of air-fuel ratio and ignition advance, required for maximum efficiency of the combustion process are determined. Also, for each measured point, an indicator diagram was also recorded using a piezo-quartz sensor of the Kistler brand. A schematic diagram of the laboratory unit is shown in figure 2.



**Figure 2.** Experimental apparatus: 1 – methane bottle; 2 – magnetic valve; 3 – flow meter; 4 – control panel; 5 – battery; 6 – mixer; 7 – stop magnetic valve; 8 – reducer-evaporator; 9 – pressure sensor; 10 – spark plugs; 11 – cooling engine system; 12 – BNC adapter; 13 – dynamometer; 14 – ignition coil; 15 – distributor; 16 – thermometer; 17 – pressure gauge; 18 – gas regulator; 19 – brake force scale; 20 – PC system; 21 – amplifier; 22 – gas analyzer; 23 – ignition system sensor; 24 – hall effect sensor; 25 – hall effect sensor; 26 – air filter.

### 3. Experimental data and results

After processing and analysis of the collected experimental data, the best performance metrics for the methane engine are obtained with air-fuel ratio  $\alpha = 1.00 \div 1.1$ , which is due to the type of fuel. The following figures show part of the depicted flowcharts when running the methane engine at different crankshaft speeds. Characteristic points used in the processing of the experimental tests are noted on the diagrams. The first channel of the oscillograms shows the variation of the cylinder pressure, the second channel shows the position of the TDC, the third and the fourth ones indicate spark ignition time information. Figure 3 shows an indicator diagram at  $3540 \text{ min}^{-1}$ , air-fuel ratio  $\alpha = 1.00$ , fully open throttle, whereby the maximum pressure value is obtained at about  $5^\circ$  after TDC. Figure 4 shows an indicator diagram at  $4530 \text{ min}^{-1}$ , air-fuel ratio  $\alpha = 1.10$ , a fully open throttle, wherein the angle of supply of the electric spark is about  $50^\circ$  before the TDC.

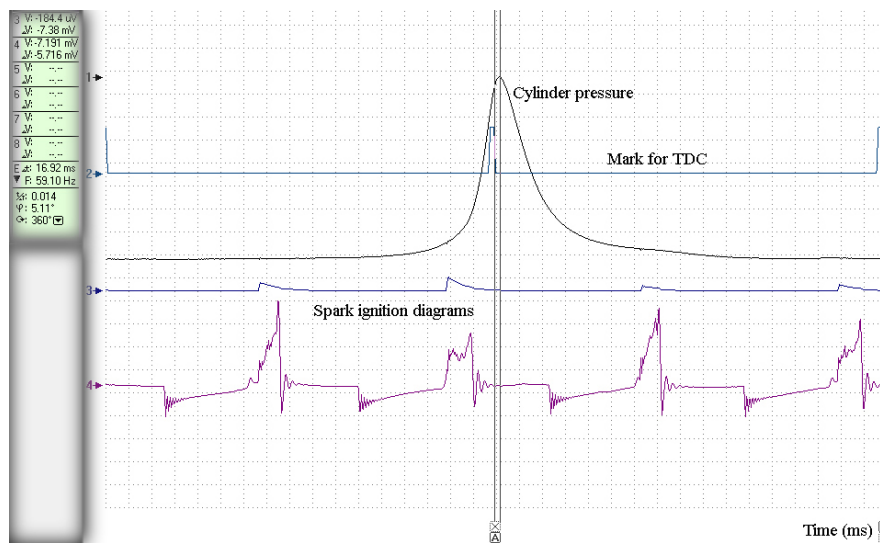


Figure 3. Indicator diagram at 3540 rpm.

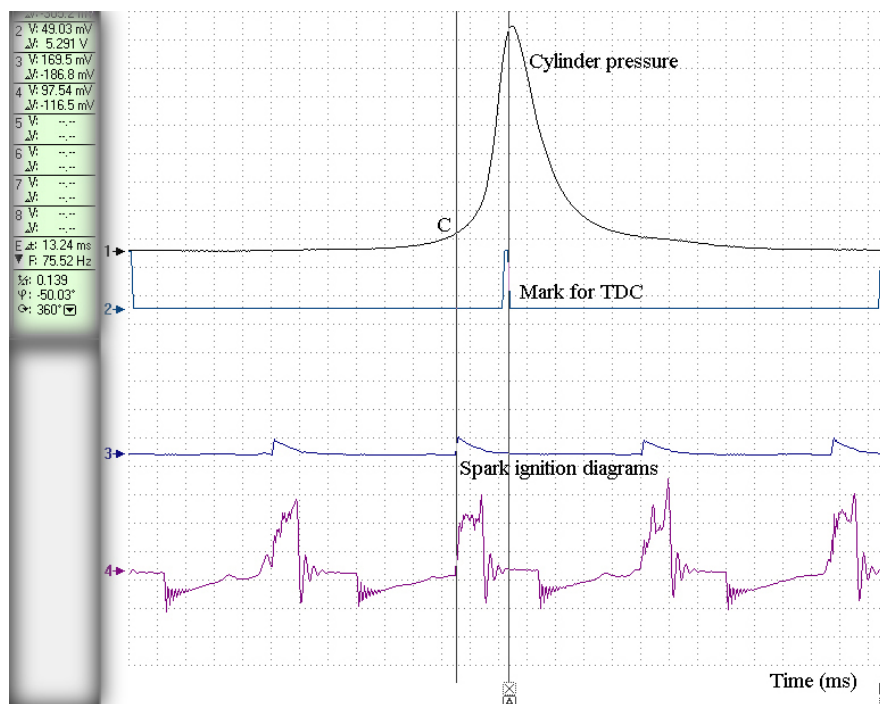
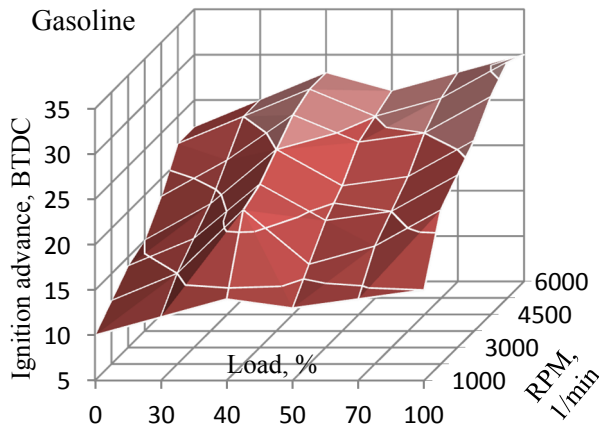
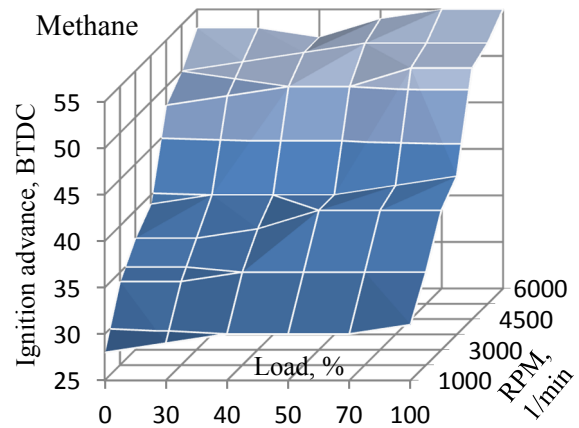


Figure 4. Indicator diagram at 4530 rpm.

After processing of the experimental results, values have been obtained for the necessary angle change of the electric spark over the entire operating speed and load range of the engine. Figures 5 and 6 show 3-dimensional diagrams for the ignition advance depending on the load and the crankshaft speed of the engine with petrol and methane respectively.



**Figure 5.** 3D diagram when the engine works with gasoline.



**Figure 6.** 3D diagram when engine works with methane.

When the engine works with gasoline, at 1000 rpm, the ignition advance changes from 10 to 15° before TDC, respectively, at a load from 0 to 100%. At 3500 rpm (maximum effective torque), the ignition advance changes from 15 to 26 degrees before TDC, respectively, at a load of 0 to 100%. At high rpm above 5000 min<sup>-1</sup>, the ignition advance changes from 22 to 31° before TDC, respectively, at a load of 0 to 100%.

When the engine works with methane, at 1000 rpm, the ignition advance changes from 25 to 30° before TDC, respectively, at a load from 0 to 100%. At 3500 rpm (maximum effective torque), the ignition advance changes from 39 to 45° before TDC, respectively, at a load of 0 to 100%. At high rpm above 5000 min<sup>-1</sup>, the ignition advance changes from 48 to 55° before TDC, respectively, at a load of 0 to 100%.

After analysing and processing the resulting 3D diagrams, a table (matrix 11×7) is produced giving the numerical values of coefficients with which it is necessary to increase the ignition advance of the electric spark during retrofitting and operation of a SI engine on methane. The values obtained are shown in table 1, where, depending on the crankshaft speed and the engine load, the coefficients for increasing the engine preload are given.

**Table 1.** Increase of ignition advance in degrees.

RPM/Load	0	10	20	30	40	50	60	70	80	90	100
1000	15	15	15	15	15	15	15	15	15	15	15
2000	20	20	20	20	20	20	20	20	15	15	15
3000	20	20	20	20	20	20	20	20	15	15	15
3500	25	25	25	25	25	20	20	20	20	20	20
4000	25	25	25	25	25	25	25	25	25	25	25
5000	30	30	30	30	30	30	30	30	25	25	25
6000	30	30	30	30	30	30	30	30	25	25	25

With a crankshaft rotation speed of 1000 min<sup>-1</sup>, the required advance extension is 15° for the entire load range. With a crankshaft rotation speed of between 2000 to 4000 rpm, the required extension in advance is between 20÷25°, with the increase in engine load the coefficients decrease by 5°, due to

better mixing conditions and improved thermo-dynamic engine parameters. At high crankshaft speeds, the coefficients take maximum values of up to  $30^\circ$  due to the reduced time for one duty cycle, and with a load of 80÷100% the ignition advance again has lower values.

#### 4. Conclusion

The resulting  $11 \times 7$  matrix allows us to use the engine with maximum efficiency over its entire speed and load range when the engine works with methane fuel.

The data obtained represent important and necessary information for adjusting and tuning the methane system to obtain maximum efficiency when converting a gasoline engine to work with methane.

The theory of maximizing engine efficiency makes it possible to obtain the values for the ignition advance coefficients at  $5^\circ$  without affecting the efficient engine performance.

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