INFLUENCE OF WORKING REGIMES ON DOUBLE VIBE FUNCTION PARAMETERS FOR DIESEL ENGINES

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INTRODUCTION

More the one century in vehicle are dominating two basic groups of engines:

- petrol engines, and
- diesel engines.

Diesel engine is always considered to be more economical. Therefore it can be said that the diesel engine is widely used in today's vehicles.

From the time of inception to the present day, the diesel engine is largely changed, and always will exist in the future need to develop new and improving existing engines.

When developing new and improving existing engines, it is necessary to do many studies, including the study about combustion process in engine cylinder. Off course indispensable part of every research is experiment. However, the performance of the experiment requires equipment and time. Specifically, the performance of the experiment can be very expensive and long. Today are very often used mathematical models. The main reason for the growth in engine modelling activities arises from the economic benefits; by using computer models, large savings are possible in expensive experimental work when engine modifications are being considered. Models cannot replace real engine testing but they are able to provide good estimates of performance changes resulting from possible engine modifications and thus can help in selecting the best options for further development, reducing the amount of hardware development required [1]. In this paper is described the methodology of modelling combustion process, with purpose to see how the working regimes affect on double Vibe parameters.

One of the most famous equations or functions that are used for modelling the combustion process in IC engines is Vibe function. Author of function is Ivan Ivanovitch Wiebe (1902-1969) [2].

1. COMBUSTION PROCESS MODELING BY DOUBLE VIBE FUNCTION

The Vibe function is often used to approximate the actual heat release characteristics of an engine:

$$\frac{dx}{d\left(\frac{\phi}{\phi_z}\right)} = \frac{a}{\phi_z}(m+1)\left(\frac{\phi}{\phi_z}\right)e^{-a\left(\phi/\phi_z\right)^{m+1}} \tag{1}$$

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The integral of the Vibe function gives the fraction of the fuel mass that has been burned since the start of combustion:

$$x = 1 - e^{-a\left(\phi / \phi_z\right)^{m+1}} \tag{2}$$

$$\begin{aligned} x_1 &= \sigma_g \cdot x = \sigma_g \cdot \left[1 - e^{-a\left(\phi_1 / \phi_{z1}\right)^{m_1+1}}\right] \\ \frac{dx_1}{d\left(\dfrac{\phi_1}{\phi_{z1}}\right)} &= \sigma_g \cdot \frac{a}{\phi_{z1}}\left(m_1+1\right)\left(\frac{\phi_1}{\phi_{z1}}\right) e^{-a\left(\phi_1 / \phi_{z1}\right)^{m_1+1}} \end{aligned} \tag{3}$$

For modelling combustion process in diesel engines with direct injection is used double Vibe function. Relations (3) are used to describe the first part of the double Vibe function, and relations (4) to describe the second part.

$$\begin{aligned} x_2 &= \left(1-\sigma_g\right) \cdot x = \left(1-\sigma_g\right) \cdot \left[1 - e^{-a\left(\phi_2 / \phi_{z2}\right)^{m_2+1}}\right] \\ \frac{dx_2}{d\left(\dfrac{\phi_2}{\phi_{z2}}\right)} &= \left(1-\sigma_g\right) \cdot \frac{a}{\phi_{z2}}\left(m_2+1\right)\left(\frac{\phi_2}{\phi_{z2}}\right) e^{-a\left(\phi_2 / \phi_{z2}\right)^{m_2+1}} \end{aligned} \tag{4}$$

Double Vibe function is expressed as the sum of the first and second part of the Vibe function:

$$\begin{aligned} x &= x_1 + x_2 \\ \frac{dx}{d\varphi} &= \frac{dx_1}{d\varphi} + \frac{dx_2}{d\varphi} \end{aligned} \tag{5}$$

where:

- x - is cumulative normalized heat released (mass fraction burned),
- ϕ - is angle between initial and current time of the simple Vibe function,
- ϕ_z - is duration angle of the simple Vibe function (duration of the heat release),
- m - is Vibe function shape parameter,
- a - is Vibe function parameter, $a = 6.908$, and
- σ_g - is the share of fuel mass burnt as describe by the first Vibe function.

The appearance of a double Vibe function is shown in Figure 1.

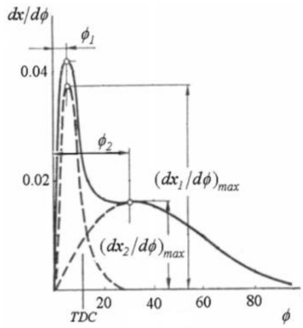

Figure 1 Double Vibe function [2]

2. EXPERIMENTAL RESARCH

One of the most frequently used ways to obtain necessary information about the working process is recording of the cylinder pressure. Even without any calculation, the cylinder pressure record provides some information about combustion in engine cylinder, for example: peak pressure and its position, the rate of pressure rise… Information can be obtained by analysing indicator diagram.

Pressure recording was performed in the Laboratory for IC engines of the Faculty of Engineering in Kragujevac. Test engine is shown on Figure 2, and measuring chain used for measurement of cylinder pressure on Figure 3.

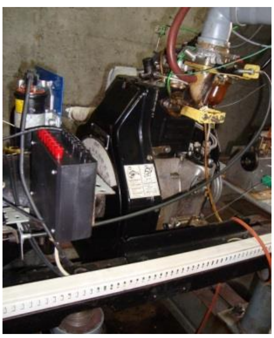

Figure 2 Test engine

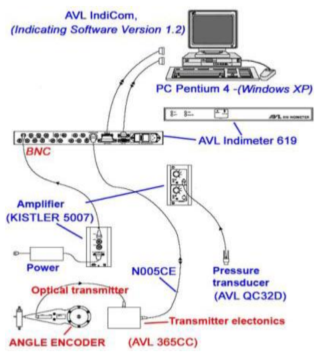

Figure 3 AVL Indicating system diagram [1]

The 450 was used in experiment. It is mono-cylindrical, air-cooled DI-diesel engine. Compression ratio of this engine is 17.5. Injection timing was fixed at 18.5 °CA at all regimes. Engine is loaded by hydraulic brake, SCHENK U116/2, Figure 4.

Figure 4 Engine brake SCHENK U116/2

Recording pressure was performed on 13 working regimes (Figure 5), and for every regime was obtained indicator diagram (Figure 6).

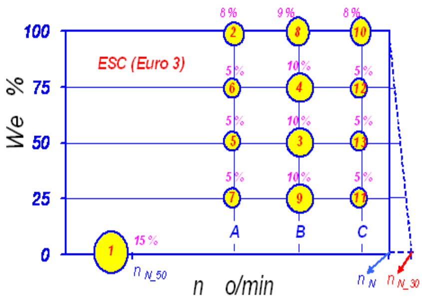

Figure 5 Working regimes [4]

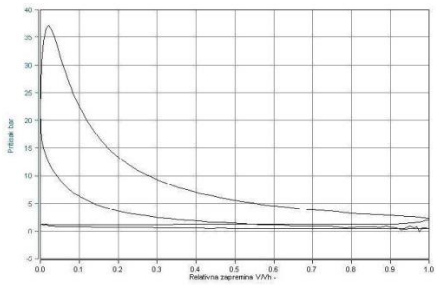

Figure 6 Indicator diagram for one of the regimes

Based on the data of pressure values that are obtained from the indicator diagrams for each working regime is modelled combustion law using Vibe function, and using software are obtained values for Vibe function parameters.

3. INFLUENCE OF WORKING REGIMES ON DOUBLE VIBE FUNCTION PARAMETERS

Figure 7 shows the influence of engine speed and engine load on the first Vibe function shape parameter. It may be concluded that engine load and engine speed do not have significant influence on the first Vibe function shape parameter. The smallest value of the first Vibe function shape parameter is recorded at $n = 2687$ rpm and highest value at $n = 2325$ rpm.

Figure 8 shows the influence of engine speed and engine load on the second Vibe function shape parameter. In this case, the second Vibe function shape parameter have the biggest values on the smallest values of the engine load and conversely.

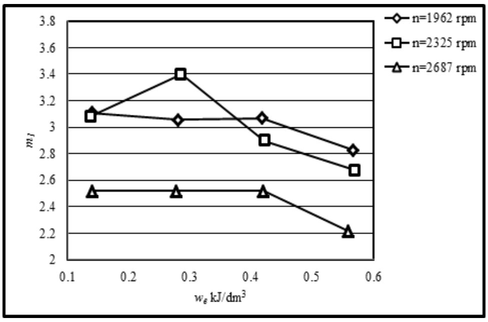

Figure 7 Influence of working regimes on the first Vibe function shape parameter

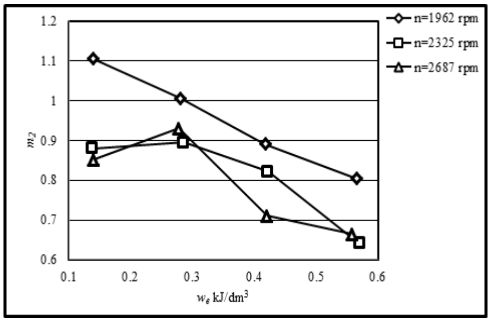

Figure 8 Influence of working regimes on the second Vibe function shape parameter

$n = 1962$ rpm $$m_1 = -2{,}335 \cdot w_e^2 + 1{,}0584 \cdot w_e + 2{,}9895 \quad (6)$$

$n = 2687$ rpm $$m_1 = -3{,}875 \cdot w_e^2 + 2{,}0592 \cdot w_e + 2{,}2914 \quad (7)$$

$n = 1962$ rpm $$m_2 = 0{,}2401 \cdot w_e^2 - 0{,}8874 \cdot w_e + 1{,}2271 \quad (8)$$

$n = 2325$ rpm $$m_2 = -2{,}3356 \cdot w_e^2 + 1{,}1042 \cdot w_e + 0{,}7711 \quad (9)$$

Relations from (6) to (9) describe the dependence of the parameters function shape of engine load.

Figure 9 shows the influence of engine speed and engine load on the relative duration of the first Vibe function. It may be concluded that engine load and engine speed do not have significant influence on the relative duration of the first Vibe function.

Figure 10 shows the influence of engine speed and engine load on the share of fuel mass burned as described by the first Vibe function. The values of this parameter are droping while engine load is rising.

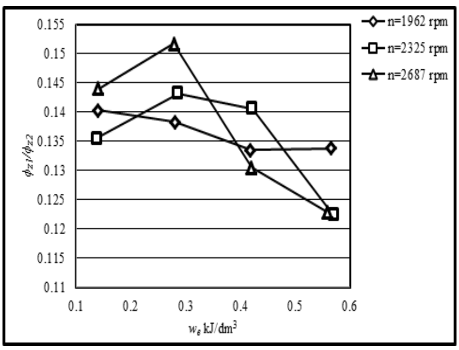

Figure 9 Influence of working regimes on duration of the first Vibe function

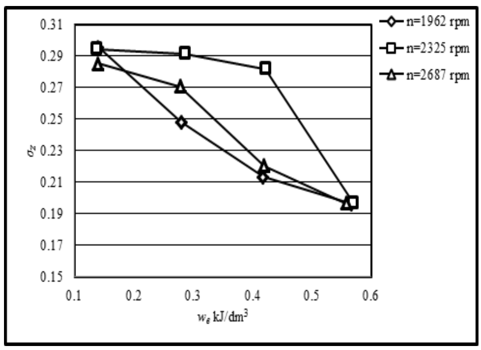

Figure 10 Influence of working regimes on the share of fuel mass burned during the first Vibe function

$n = 1962$ rpm $$\varphi_{z1}/\varphi_{z2} = 0{,}0302 \cdot w_e^2 - 0{,}0383 \cdot w_e + 0{,}1455 \qquad (10)$$

$n = 2325$ rpm $$\varphi_{z1}/\varphi_{z2} = -0{,}3076 \cdot w_e^2 + 0{,}1885 \cdot w_e + 0{,}1151 \qquad (11)$$

$n = 1962$ rpm $$\sigma_Z = 0{,}4032 \cdot w_e^2 - 0{,}5194 \cdot w_e + 0.3608 \qquad (12)$$

$n = 2325$ rpm $$\sigma_Z = -0{,}9806 \cdot w_e^2 + 0{,}4821 \cdot w_e + 0.2434 \qquad (13)$$

$n = 2687$ rpm $$\sigma_Z = -0{,}1229 \cdot w_e^2 - 0{,}1407 \cdot w_e + 0.3102 \qquad (14)$$

Relations from (10) to (14) describe the dependence of the duration of the first Vibe function and share of fuel mass burned during the first Vibe function of engine load.

CONCLUSIONS

In this paper is established that can define dependence between engine load and next parameters:

- shape parameter of first Vibe function m_2, and
- the share of fuel mass burned during the first Vibe function σ_z.

However some of the parameters cannot be defined by the equations, because of insufficient number of working regimes:

- shape parameter of first Vibe function m_1, and
- duration of the first Vibe function ϕ_{z1}/ϕ_{z2}.

The experiment is realized only on mono-cylindrical, air-cooled DI-diesel engine. Applicability of presented results on other diesel engines just is needed to check.

In the future can be going considered influence of other factors on double Vibe function parameters. For example: compression ratio, fuel characteristics…

Also in the case for diesel engines with modern injection systems, combustion process can be described with sum of more Vibe functions.

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