SIMULATION MODEL OF THE SINGLECYLINDER COMBUSTION ENGINE MZ125

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Summary: The use of one-dimensional CFD engine simulation is an essential tool to the engine development process. Engine design through simulation can drastically reduce time needed to perform engine experiments and prototyping, as most engine experiments can be simulated within the software.
Keywords: MZ125, combustion engine simulation, engine model, Ricardo wave

INTRODUCTION

The use of one-dimensional computation fluid dynamic (1D CFD) engine simulation software is widespread throughout the engine development industry. This simulation method allows for characterizing engine operation without the need for high-end processing and time-intensive computations.

There are two primary engine simulation software packages used in the industry today: Ricardo WAVE and GT-Power. Both software packages are similar in purpose and functionality. Cheaper software developed by Lotus, Lotus Engine Simulation is used at the universities.

The simulation work was part of the cooperation with Tommü Motor Tuning Company in the development of naturally aspirated 125 ccm motorcycle engine for use in autocross.

Source: Authors

Fig. 1 - Complete MZ125 engine ready for use in autocross

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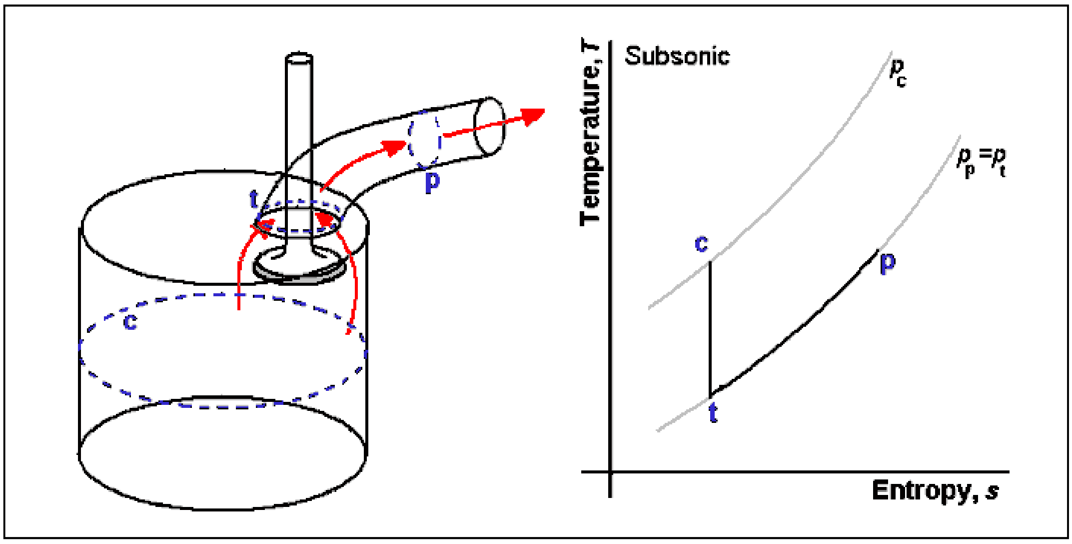
1. FLUID DYNAMIC SIMULATION OF THE COMBUSTION ENGINE

The basic operation of the WAVE code analyses flow networks composed of ducts, junctions, and orifices. Within this network of plumbing, engine cylinders, turbochargers, superchargers, compressors, and pumps can be inserted. WAVE can simulate internal combustion engines as well as the other compressible-fluid flow systems.

The simulation process can be divided into several steps. First step is pre-processing, next is solver and post-processor. Pre-processor of wave software is a part, which is called WaveBuild, is used for building of engine model and allows defining network of plumbing, its geometry and all features of the simulated engine. After the build a model and define parameters of engine, can be solving algorithm running. When the simulation ends, it's creating a large output file containing all data necessary to evaluate the simulation process. For the interpretation of simulation results is used post-processor WavePost. It allows the creation of time-dependent graphs, torque and power speed characteristics, animated diagrams and pressure maps for turbocharger and compressors.

1.1 Modelling the gas exchange process

To simulate the working cycle internal combustion engine is necessary in each step of calculating to determine mass of the mixture, that enters into the cylinder and out of the cylinder through the control areas, which are indicated by dashed line in Figure 2.



Source: (4)

Fig. 2 - Control areas of cylinder (left) and T-s Diagram for subsonic flow through a valve (right) [4]

The final equation for calculating the mass flow according to (4):

$$\dot{m} = A_{ef} \cdot \sqrt{2 \cdot p_c.\rho_c} \cdot \sqrt{\frac{\kappa}{\kappa-1} \cdot \left[\left(\frac{p_k}{p_c}\right)^{\frac{2}{\kappa}} - \left(\frac{p_k}{p_c}\right)^{\frac{\kappa+1}{\kappa}}\right]} \quad (1)$$

Where: p_c, p_t … pressures in specific areas [Pa]

ρ … density $[kg \cdot m^{-3}]$

κ … Poisson constant [-]

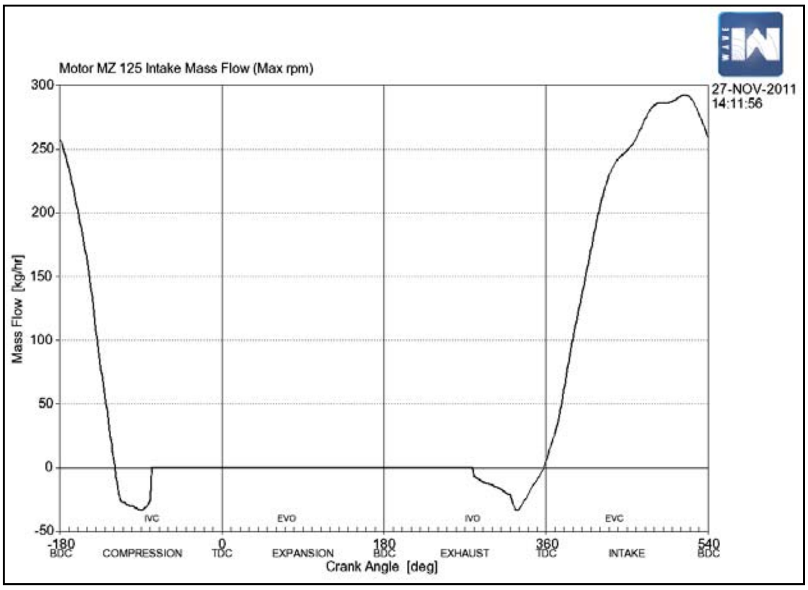
A_{ef} … effective area, which is calculated:

$$A_{ef} = C_f \cdot A_{ref} \tag{2}$$

Where: C_f … flow coefficients for valves are used in order to represent the results of a steady-flow test instead of stating directly the values of the valve effective area.

A_{ref} … represents a reference area. Define a limiting geometric area which is a function of valve lift.

In the following diagrams (figure 3) are shown the results of simulations for the intake and exhaust mass flow rate at maximum engine speed



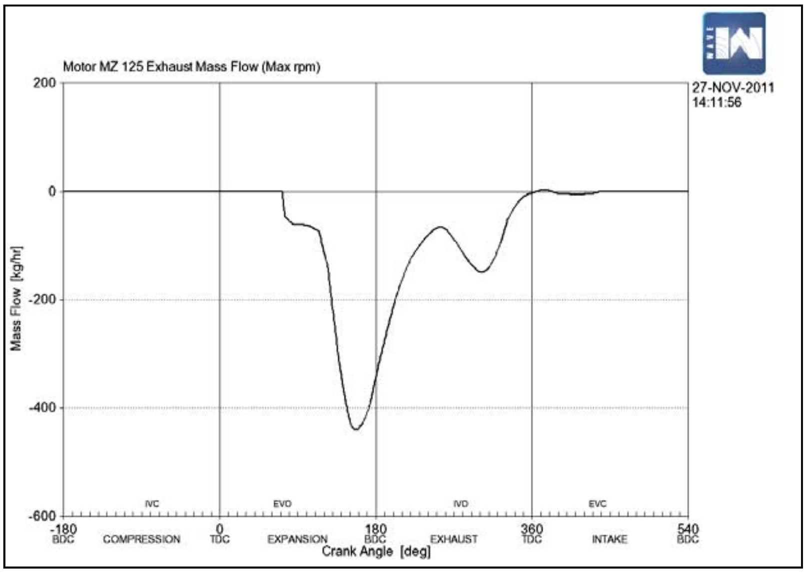


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Fig. 3 - Intake (up) and exhaust (down) mass flow

1.2 Thermodynamic model of combustion

The model of combustion is concerned with heat release process in engine cylinder. This process is influenced by the method of mixture preparation, fuel type and conditions in the cylinder during combustion. In an ideal combustion cycle is all heat released in an infinitely short time at the top dead centre of piston. In the real combustion cycle of engine, this heat is releasing gradually and unevenly. Inserting the model of combustion to the complex mathematical simulation model of the combustion engine leads to precise results and saves time in the engine development.

Currently, there are not generally valid mathematical-physics equation that would allow a matching precision to determine combustion process on the basis of the design and operating parameters of the engine (2). Still effective is use of simplified models of combustion, or analogies. The default formula for calculating the combustion in the cylinder of internal combustion engine is the equation, which was deduced by Wiebe.

The Wiebe function is widely used to describe the rate of fuel mass burned in thermodynamic calculations. This relationship allows the independent input of shape function parameters and of burn duration. It is known to represent quite well the experimentally observed trends of premixed spark ignition combustion.

The Wiebe function define the mass fraction burned as

$$W = 1 - e^{-ay^{m+1}} \quad (3)$$

$$y = \left(\frac{\varphi}{\varphi_b}\right) \quad (4)$$

where: a … coefficient in Wiebe equation [-]

m … coefficient in Wiebe equation [-]

φ … actual burn angle (after start of combustion) [deg]

φ_b … total burn angle (10-90% burn duration) [deg]

derivation of W by dy gives the intensity of burning:

$$\frac{dW}{dy} = a \cdot (m+1) \cdot y^m \cdot e^{-ay^{m+1}} \quad (5)$$

Experimentally were detected values of coefficients of Wiebe function, which are listed below in table 1. These coefficient values can be regarded as normal and depend mainly on used fuel in engine (4).

Tab. 1: Experimentally determined values of the Wiebeho function coefficients

fuel	coefficient a	coefficient m
gasoline	10	2
diesel	6,9	0,5
methane	5	2,2
methanol	10	2

To find suitable shape of Wiebe function is necessary to define combustion duration and ignition timing. The burn profile in the input panel can be used to observe the effects of varying the input parameters. Varying the 50% burn point simply shifts the entire curve forward or backward. Varying the 10%-90% duration will extend the total combustion duration, making the profile extend longer or compress shorter. Varying the Wiebe exponent will shift the curve to burn mass earlier or later. These values are entered into the simulation program, which then renders curve of Wiebe function. On figure 4 is the curve of Wiebe function for engine MZ125.

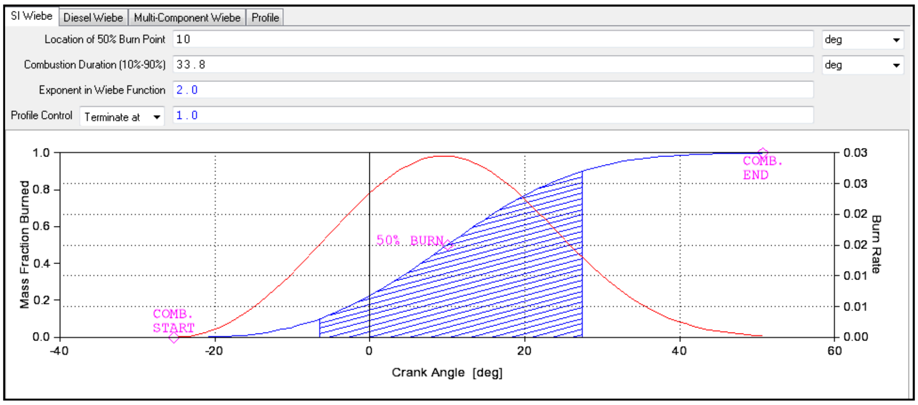

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Fig. 4 - Wiebe function for engine MZ125

1.3 Equations of gas flow

The conditions (state variables, velocity) within pipe elements are calculated at each time step (calculation crank angle) by solving a set of conservation equations for mass, momentum and energy.

Suppose that the flow of compressible fluid flows through the elementary part of the pipe (control volume). The control volume is formed of pipe walls and surfaces that are perpendicular to the axis of flow and pipe diameter is changing. Velocity u is in the general case unequal, but the distribution of velocity along the space flow, we consider constant.

Then we can write the general equation of continuity for the one-dimensional flow as follows (4):

$$\frac{\partial(\rho \cdot S)}{\partial t} + \frac{\partial(\rho \cdot u \cdot S)}{\partial x} = 0 \qquad (6)$$

Where: ρ … density $[kg \cdot m^{-3}]$

S … surface [m^2]

u … velocity [ms^{-1}]

p … pressure [Pa]

t … time [s]

x … displacement [m]

In the flowing fluid is normal stress created by fluid pressure and tangential stress due to friction forces. On the fluid are reflected forces from own motion of molecule. The following equation represents Momentum equation.

$$\frac{\partial(\rho \cdot u \cdot S)}{\partial t} + \frac{\partial(\rho \cdot u^2 + \mathrm{p})}{\partial x} - \mathrm{p} \cdot \frac{dS}{dx} + \frac{1}{2}\rho \cdot u^2 \cdot \mathrm{f} \cdot \pi \cdot D_h = 0 \qquad (7)$$

Where: f … coefficient of friction between the fluid and pipe wall [-]
D_h … hydraulic diameter of the pipe [m]

On the following graph (figure 5) are showed the results of simulations flow velocity in intake and exhaust port at maximum engine speed.

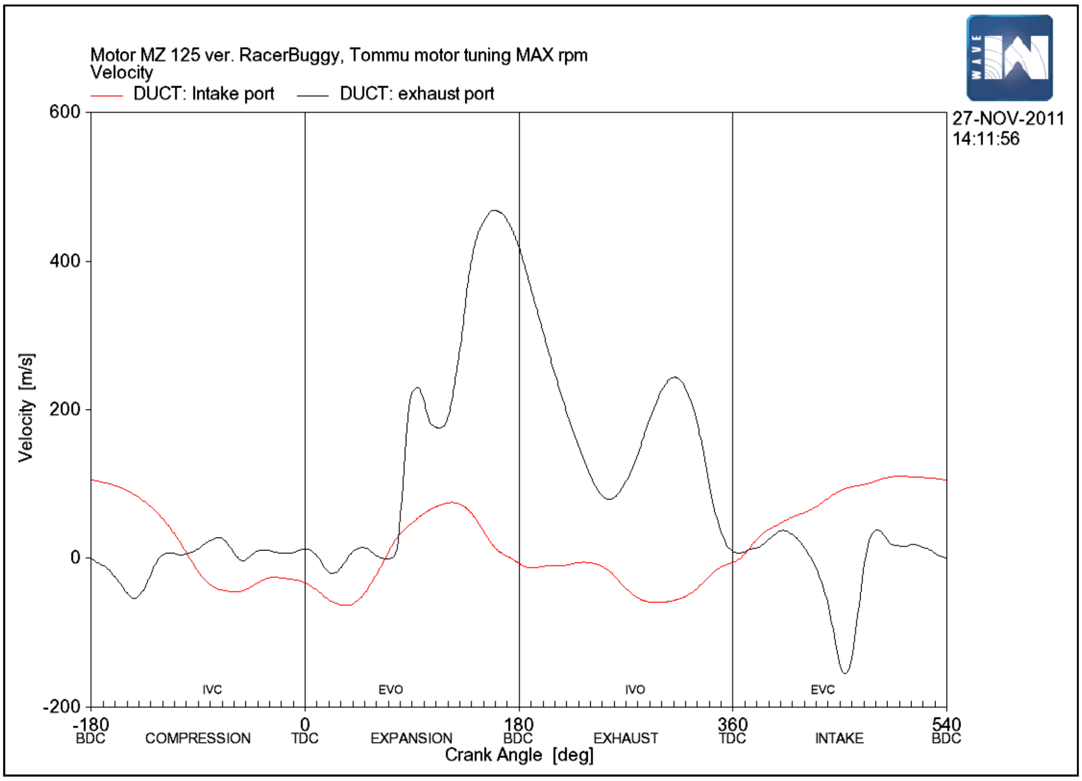

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Fig. 5 - Flow velocity in intake and exhaust port

2. DESIGN AND SETUP OF MODEL

Visualization of engine in Ricardo Wave software is composed of the creation and definition geometry of cylindrical unit (engine cylinder and engine head). Then the cylindrical unit in the direction from intake to exhaust is connected and defined the geometry of the intake and exhaust pipe with accessories (throttle, mufflers, etc.) Figure 6.

After the setup of basic input parameters, other parameters, which define the gas exchange process and the combustion must be set. They are especially the port flow coefficients, valve lift per crankshaft rotation, and combustion modelling.

The aim of calculation cycles of real internal combustion engines is to determine changes in state variables during the engine working cycle. From the state variables are calculated following values, as mean indicated pressure, indicated efficiency, mechanical and thermal loads. The program uses calculations based on the equation (6), (7), law of conservation of energy and mass.

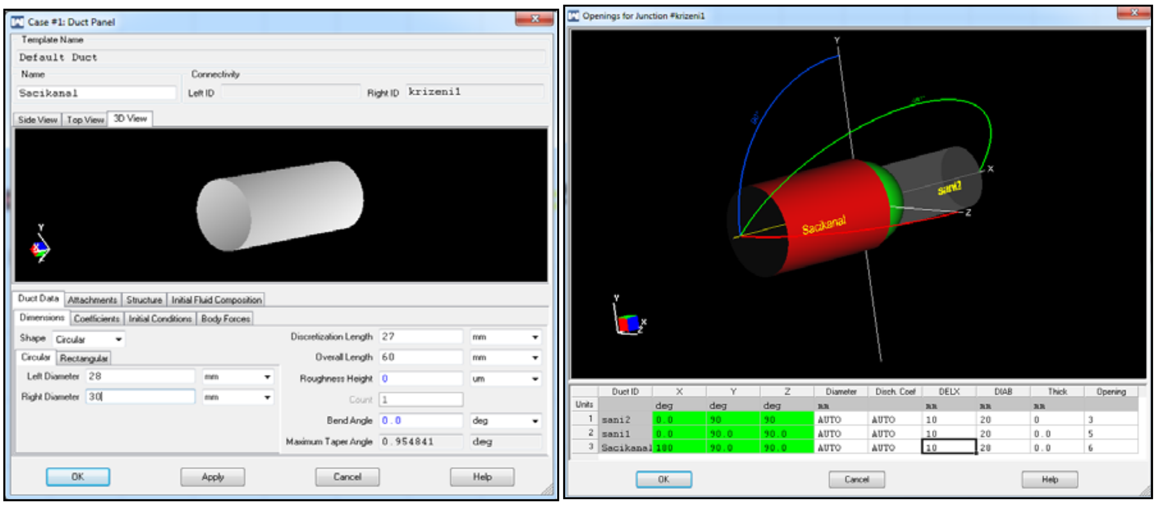

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Fig. 6 - The dialog box for defining the geometry of piperine

To define the operation of the cylinder head, the valve lift per incremental camshaft rotation had to be defined (Figure 7). The MZ125 cylinder head is dual-overhead cam (DOHC) format, meaning that there is a separate camshaft for the intake and exhaust valves.

The final simulation model (Figure 8) is a four-stroke single-cylinder gasoline engine MZ125.

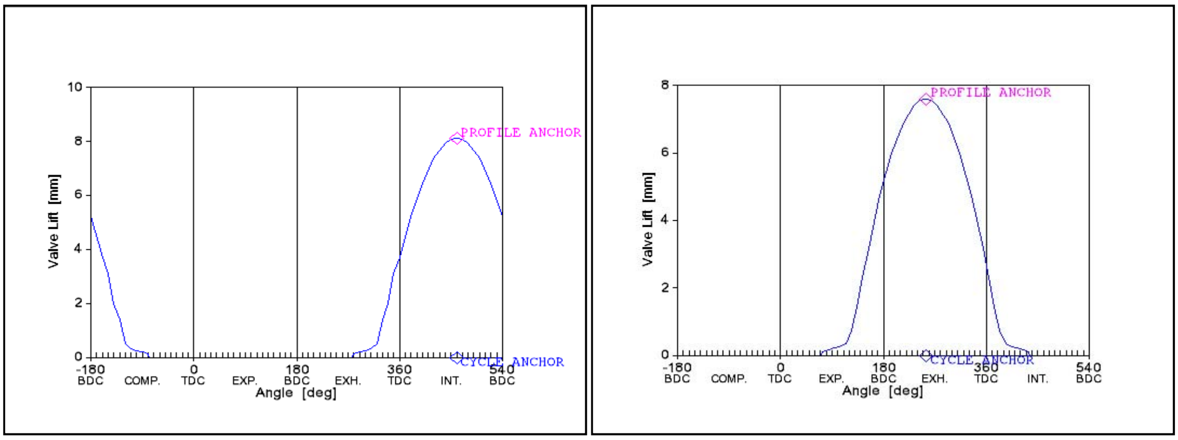

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Fig. 7 - Valve lift curve for exhaust (left) and intake (right) valve

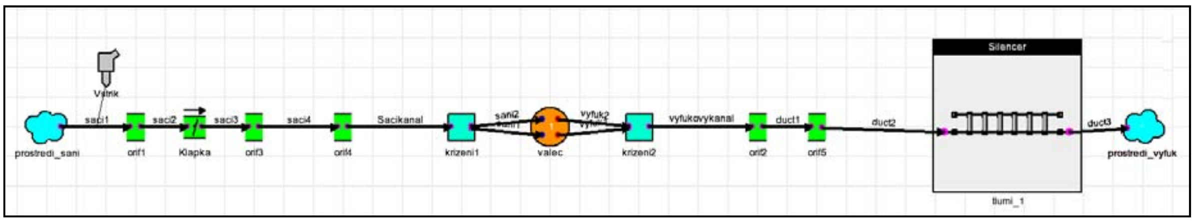

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Fig. 8 - Complete simulation model of MZ125 engine

2.1 Simulation results

Ricardo Wave displays the calculation results for the individual steps in real time. In the post-processor WavePost we can see all the simulation results. We can display flow velocity in any section of pipe, the pressure in the pipeline, but also in the cylinder and all performance parameters. The result of this simulation in the development of engine is torque and power characteristics depending on engine speed (figure 9).

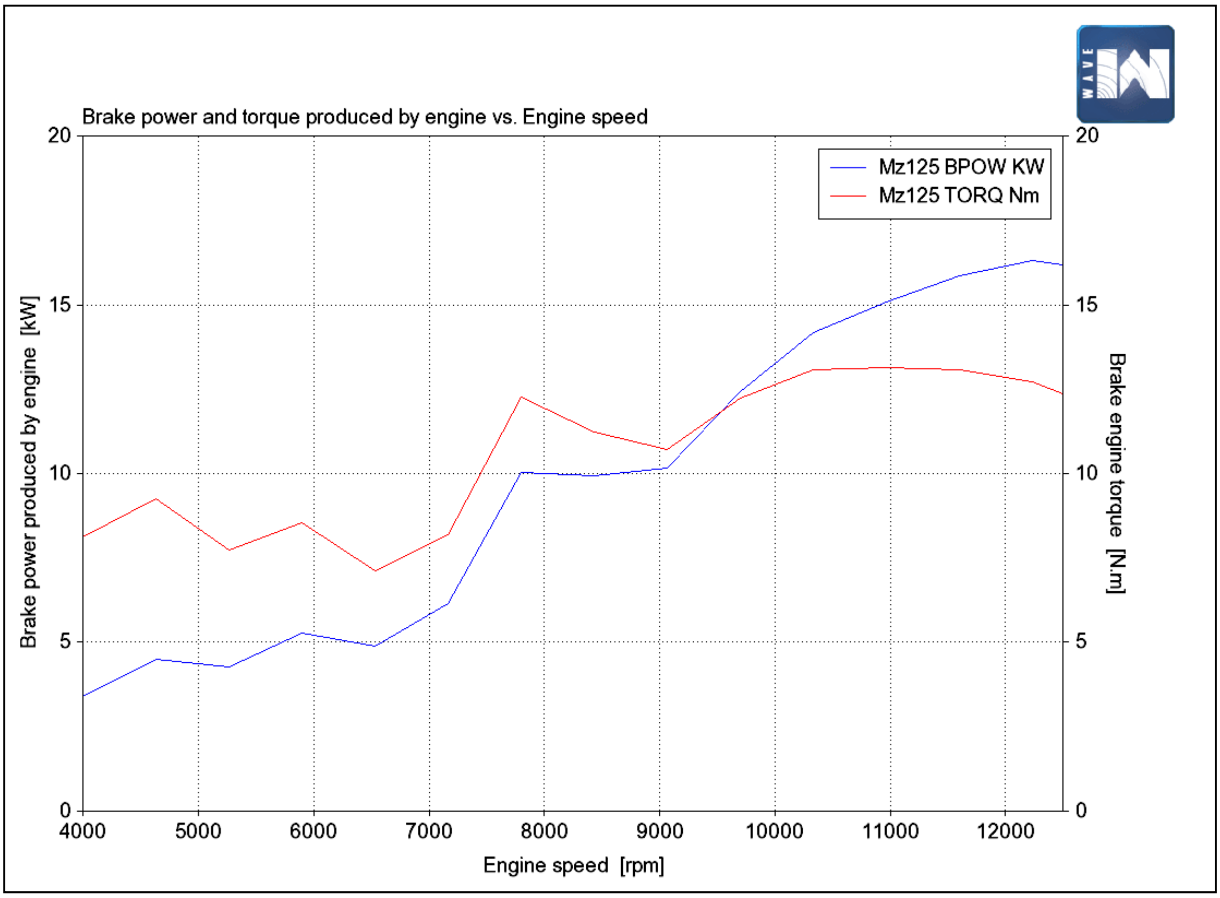

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Fig. 9 - Brake power and torque [author]

CONCLUSION

This simulation model was used to estimate the parameters and performance of engine MZ125. Results were the characteristics of torque and engine power, depending on engine speed before real performing construction modifications of engine. After construction change of engine are the engine simulation results characteristics compared with experimental measurements on a bench.

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