

## CREATION AND CALIBRATION OF COMPUTATIONAL MODEL OF THE HISTORIC RACE ENGINE

Pavel Dresler<sup>1</sup>, Pavel Šperlich<sup>2</sup>

---

---

*Summary: Using a CFD simulation in the development of internal combustion engines, with 1-D approach, can significantly reduce the time and costs associated with experiments and prototyping. With commercial software we can use 1-D computational models to optimize the parameters of manufactured engines and observe hardly measurable values. This article describes the basic principle of creating and calibration of computational model.*

*Key words: Škoda 100, the internal combustion engine, the engine computational model, Ricardo Wave, 1-D simulation*

### INTRODUCTION

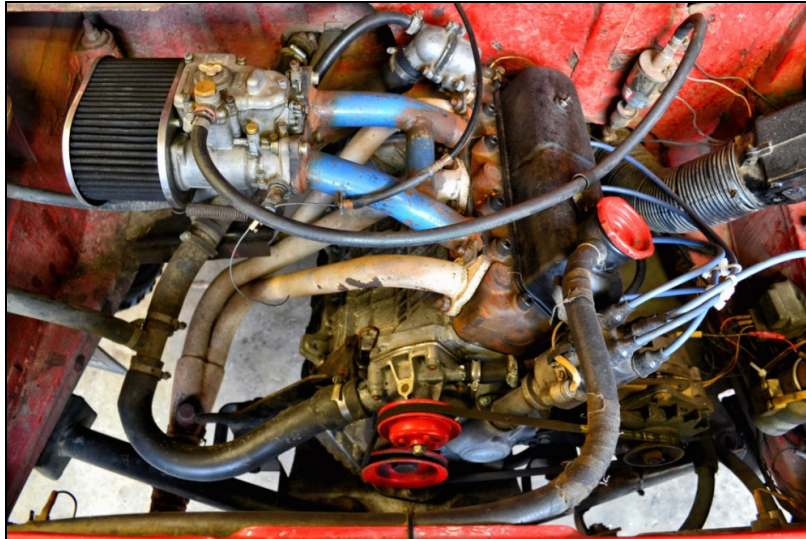
Internal combustion engine has undergone a long development, which is still continuing. This is related with developed methods that are using in this time. It is no longer possible to use complex analytical calculations. The complexity and lengthiness is unthinkable to use for the progressive development of internal combustion engines. The trend in the development of internal combustion engines is to use of the computing and simulation software, which are with comparison of the analytical calculation very efficient and accurate. In this time is for simulation in engine development exclusively used Ricardo Wave, GT - Power or AVL Boost.

For the purposes of the racing team was created a simulation model for racing engine of historic Škoda 100 developed in 1973 (Fig. 1). Is the engine based on the basic version, modified according to the rules defining the permitted changes to the engine according to the class to which the car belong.

---

<sup>1</sup> Ing. Pavel Dresler, VŠB – Technical University of Ostrava, Faculty of Mechanical Engineering, Institute of Transport, 17. listopadu 15/2172, 708 33, Ostrava - Poruba, Tel.: +420 597 324 375,  
E-mail: [pavel.dresler@vsb.cz](mailto:pavel.dresler@vsb.cz)

<sup>2</sup> Ing.. Pavel Šperlich, VŠB – Technical University of Ostrava, Faculty of Mechanical Engineering, Institute of Transport, 17. listopadu 15/2172, 708 33, Ostrava - Poruba, Tel.: +420 775 319 515,  
E-mail: [pavel.sperlich@hella.com](mailto:pavel.sperlich@hella.com)



Source: Author

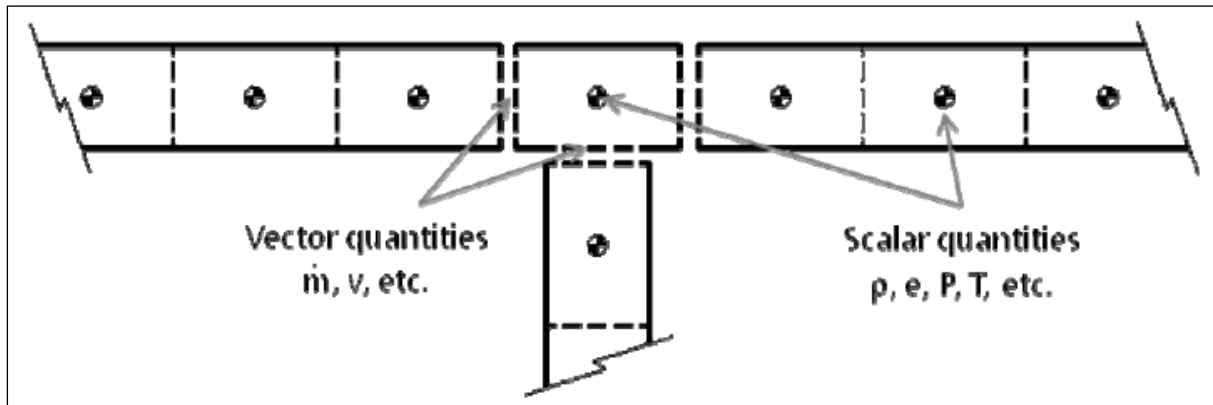
Fig 1 - Modeled engine of historic racing car

## 1. COMPUTING MODEL OF ENGINE

The fundamental principle in a 1-D modeling in software Ricardo Wave is analysis of flow in the grid, which consists of a duct, crossing or junction and 0-D model of thermodynamic cycle in engine cylinder. 1-D modeling is actually solving a system of general differential equations based on the law of conservation of mass, energy and momentum, which includes friction, pressure and momentum forces. For the solvability of equation system is used the ideal gas state equation in differential form.

### 1.1 Fluid Dynamics Governing Equations

The flow model involves the solution of the Navier-Stokes equations, namely the conservation of continuity, momentum and energy equations. These equations are solved in one dimension, which means that all quantities are averages across the flow direction. The whole system is discretized into many volumes, where each flowsplit is represented by a single volume, and every pipe is divided into one or more volumes. These volumes are connected by boundaries (Fig. 2). The scalar variables (pressure, temperature, density, internal energy, enthalpy, species concentrations, etc.) are assumed to be uniform over each volume. The vector variables (mass flux, velocity, mass fraction fluxes, etc.) are calculated for each boundary. This type of discretization is called to as a staggered grid. (6)



Source: (6)

Fig 2 - Schematic of staggered grid approach: scalars calculated at centroid, vector quantities at boundaries

Continuity:

$$\frac{dm}{dt} = \sum_{\text{boundaries}} \dot{m} \quad (1)$$

Energy:

$$\frac{d(me)}{dt} = p \frac{dV}{dt} + \sum_{\text{boundaries}} (\dot{m}H) - hA_s(T_{\text{fluid}} - T_{\text{wall}}) \quad (2)$$

Momentum:

$$\frac{d(mu)}{dt} = \frac{dpA + \sum_{\text{boundaries}} (\dot{m}u) - 4C_f \frac{\rho u |u| dx A}{2D} - C_p \left( \frac{1}{2} \rho u |u| \right) A}{dx} \quad (3)$$

Where:

- $\dot{m}$  boundary mass flux into volume
- $m$  mass of the volume
- $V$  volume
- $p$  pressure
- $\rho$  density
- $A$  flow area (cross-sectional)
- $A_s$  heat transfer surface area
- $e$  total internal energy (internal energy plus kinetic energy) per unit mass
- $H$  total enthalpy
- $h$  heat transfer coefficient
- $T_{\text{fluid}}$  fluid temperature
- $T_{\text{wall}}$  wall temperature
- $u$  velocity at the boundary
- $C_f$  skin friction coefficient

- $C_p$  pressure loss coefficient
- $D$  equivalent diameter
- $dx$  length of mass element in the flow direction (discretization length)
- $dp$  pressure differential acting across  $dx$

## 1.2 Thermodynamic combustion model

The default function describing the burning process in the cylinder of internal combustion engines is the semi-empirically derived equation which was derived by Wiebe. In the software Ricardo Wave is for modeling of the combustion used Wiebe function (equation 4). However, it is necessary to appropriately set parameters of this function.

$$x = 1 - e^{a y^{m+1}} \quad (4)$$

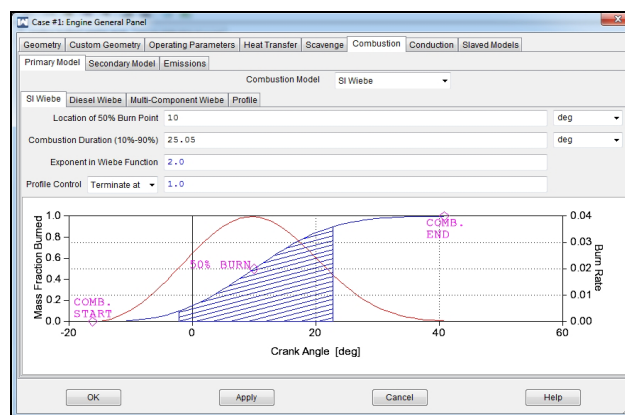
$$y = \left( \frac{\varphi}{\varphi_B} \right) \quad (5)$$

$$a = -\ln(1 - \eta_{ch}) \quad (6)$$

Where:

- $a$  coefficient of Wiebe function
- $m$  shape parameter of function
- $\varphi$  current angle from the beginning of combustion
- $\varphi_b$  the total angle of combustion
- $\eta_{ch}$  chemical efficiency

Burning time is significantly affected by the type of used fuel. For this model is necessary to specify start and end of the combustion. Is very difficult to measure beginning and end of combustion, for this reason is used angle of the crankshaft in the range 10-90% burned mixture.



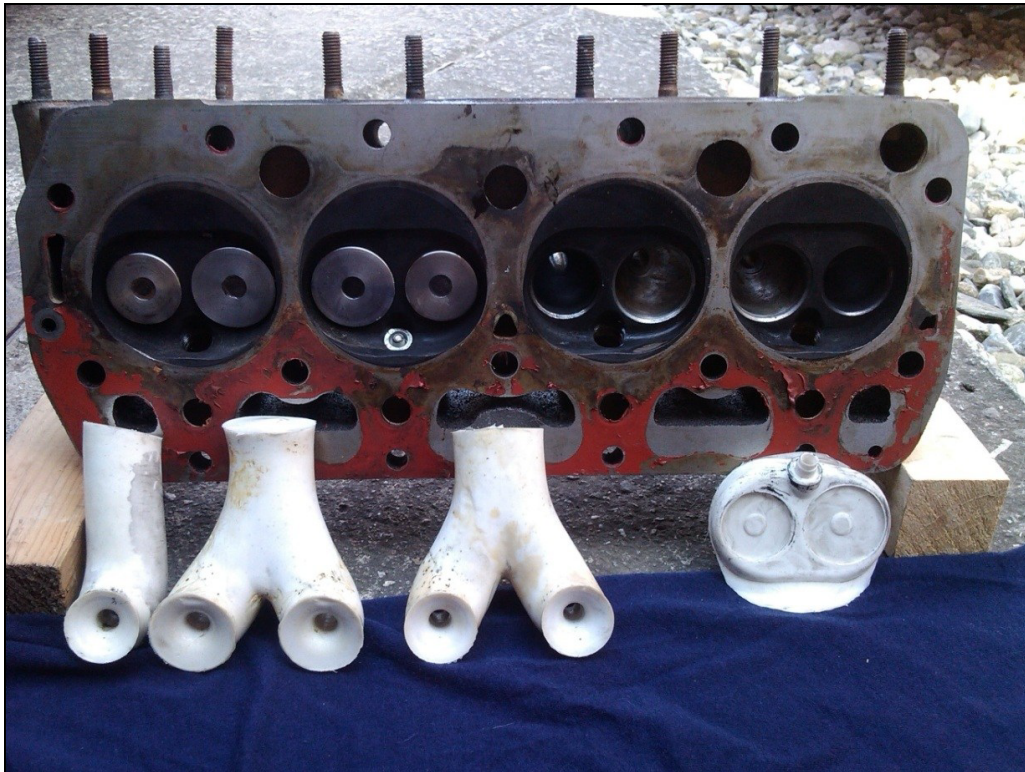
Source: Author

Fig. 3 - Graphical view of the wiebe function in Ricardo Wave software

## 2. CREATION OF MODEL OF ENGINE ŠKODA 100

When we are creating a model is necessary to observe some procedure. Before the creation of engine model have to be entered the basic input data. First is necessary to set duration of simulation, system of basic units in which are entered the input parameters. Next step is to define the basic geometry of the pipe lengths, diameters, wall heat transfer model, friction loss and this all with respecting the convention for model creation - building of model with the direction of gas flow. Is important to accurately set the engine cylinder unit, where are entered the basic parameters of the engine - basic geometry, operating parameters, transfers the heat from combustion and other advanced parameters. These parameters are known to us either from measurements on a specific engine, or are known from measurements of engines of similar construction.

For obtaining accurate geometrical dimensions of the intake and exhaust ports is highly advantageous to make a cast of ports and combustion chamber (Fig. 4). This cast is also possible to use for scanning and creating 3D CAD models for CFD investigation of flow coefficient in ports.

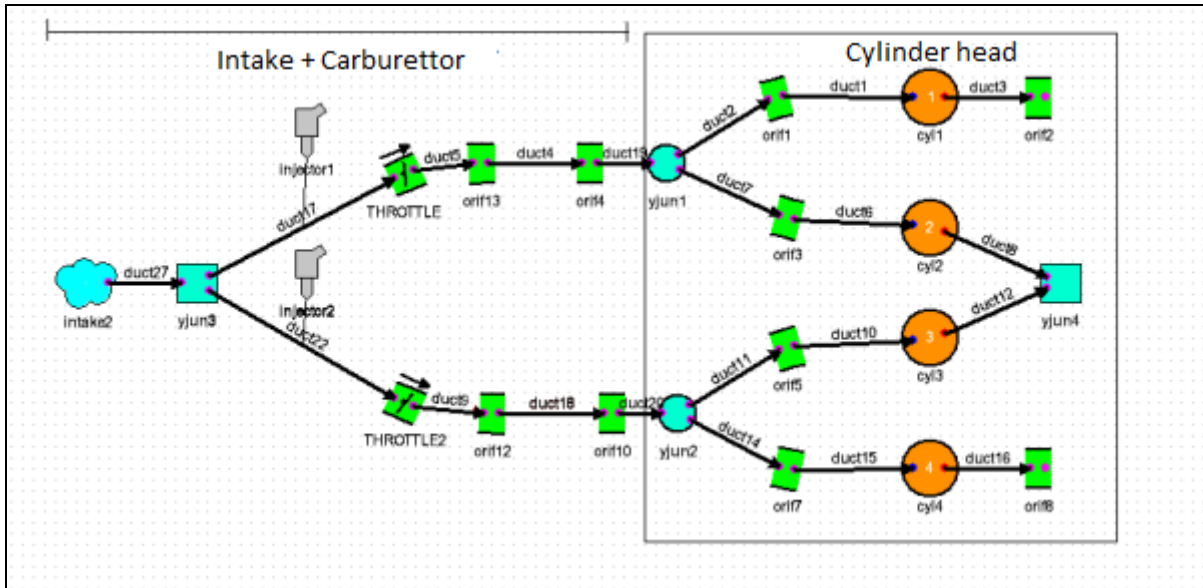


Source: Author

Fig. 4 - Complete models of inlet and exhaust ports

### 2.1 Intake and carburettor

Figure 5 shows the intake and the cylinder head of our engine in software Ricardo Wave. The marked section represents individual cylinders, intake and exhaust ports. Exact geometry of ports was measured on cast from resin. For all elements from software database is necessary to define geometry from measurements on real engine.

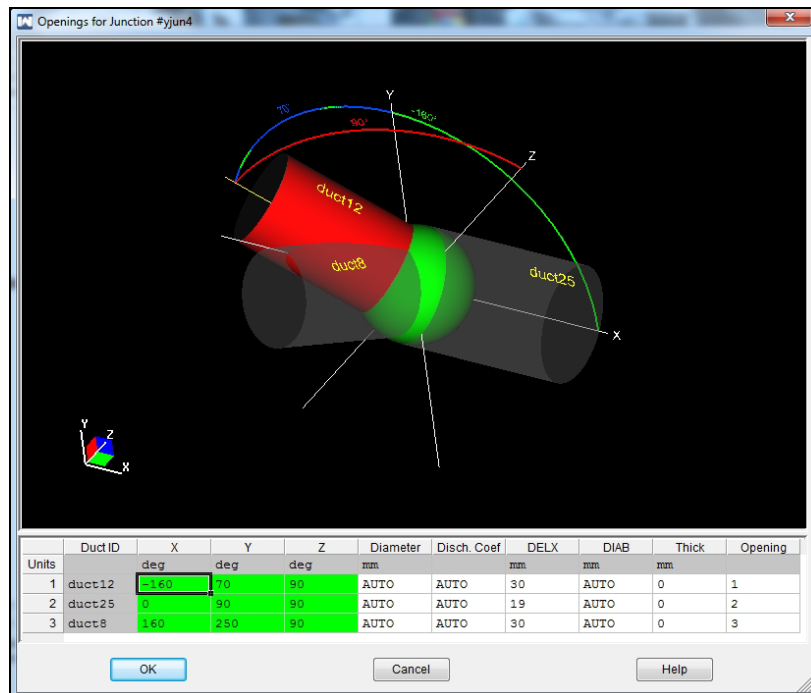


Source: Author

Fig. 5 – The cylinder head, intake ports and carburettor

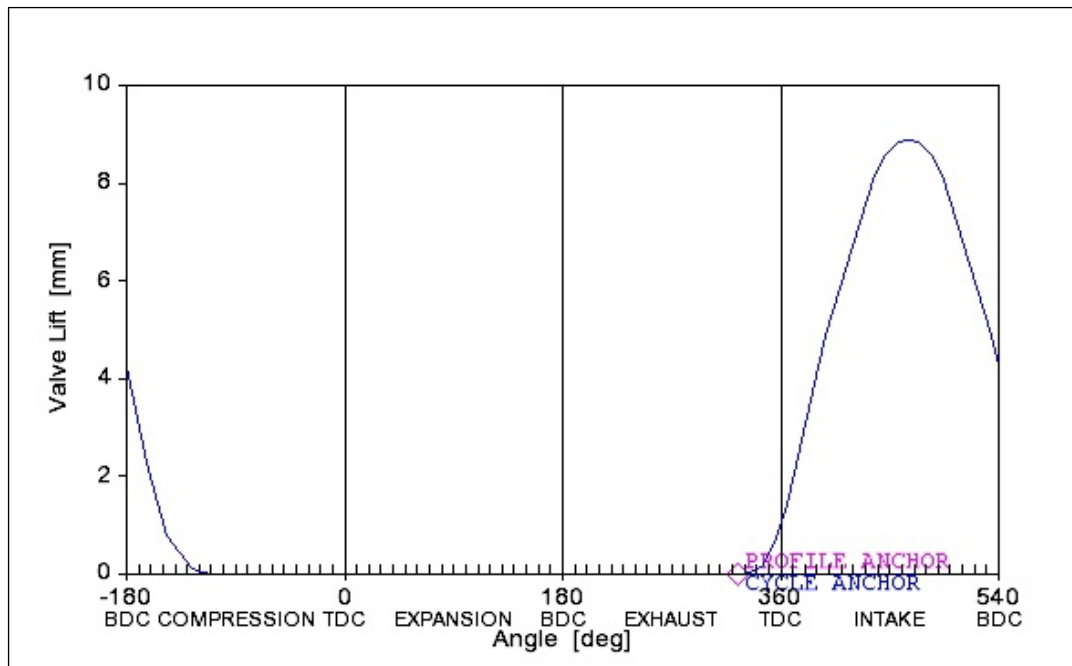
## 2.2 Crossing the intake ports and valve lift settings

Figure 4 shows that some of the intake and exhaust ports are connected into a common duct of greater diameter. This case is solved in Ricardo Wave by the Y-junctions. Location where occurs crossing of ports is replaced by an imaginary spherical volume which is generated after entering the desired diameter. For modeling the connection of two pipelines, it is necessary to set the orientation of the pipe in space. In Ricardo software is it by using coordinates. It is also necessary to specify the distance between the connections. (Fig. 6) Intake and exhaust valves are set by using valve lift curves. As is shown in Figure 7 and 8



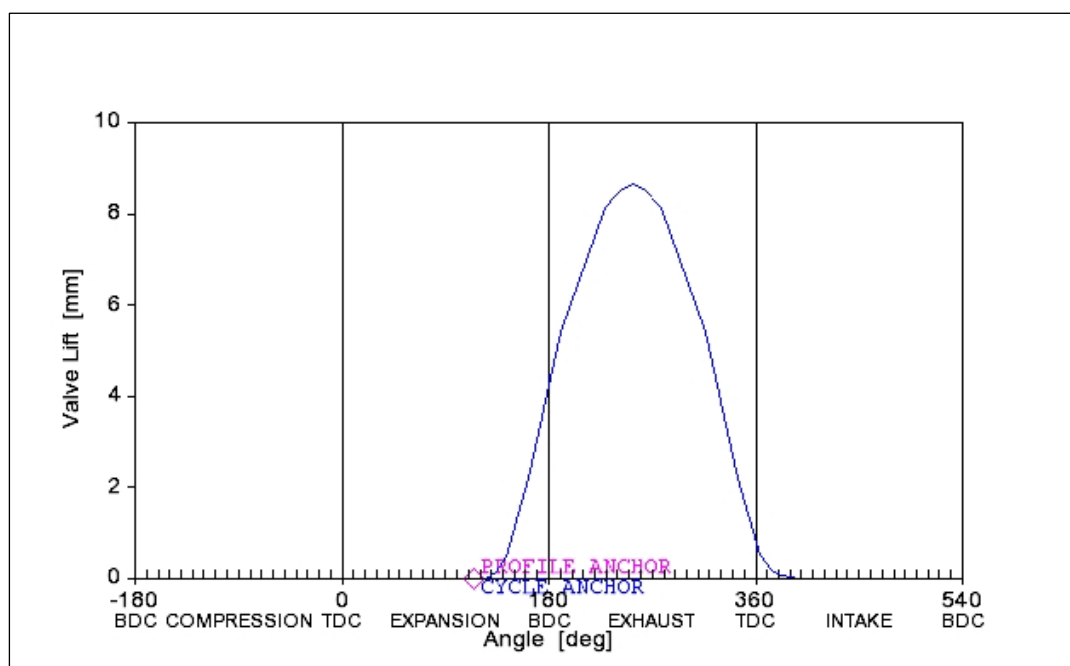
Source: Author

Fig. 6 – Crossing the intake ports



Source: Author

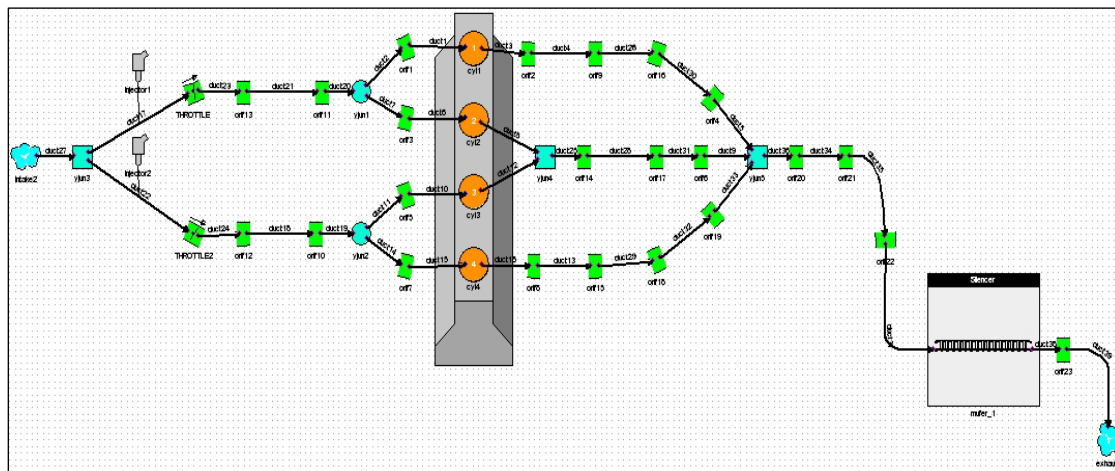
Fig. 7 – Valve lift curve for intake valve



Source: Author

Fig. 8 – Valve lift curve for exhaust valve

### 3. COMPLETE ENGINE MODEL AND SIMULATION RESULTS



Source: Author

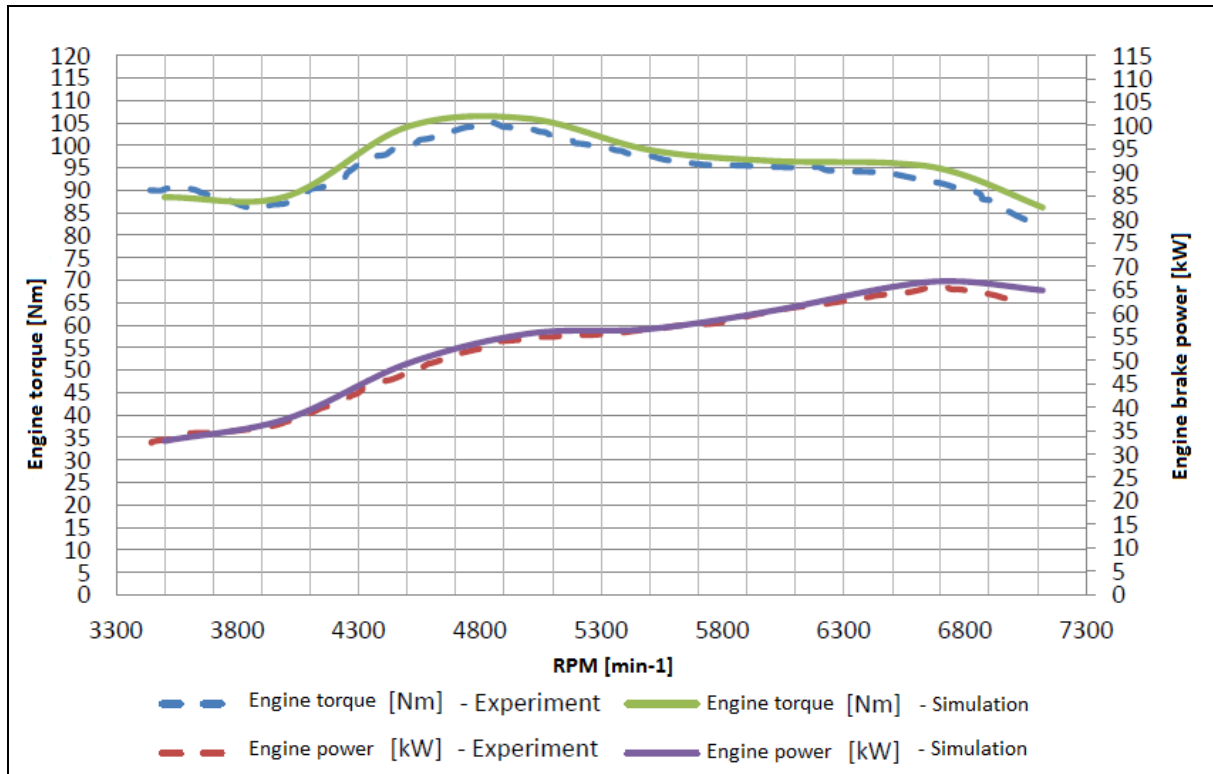
Fig. 9 – Complete Škoda 100 engine model

After successful end of the simulation run it is possible to show results in post-processor environment. There we can see results in text form or graphic representation. In the post-processor we can find a large number of characteristics which we can compare with experimental data. More of characteristics we can set before the simulation for each part of model, especially thermodynamics and flow characteristic for working cycle.

After the first simulation is the power and torque of the engine relatively distanced from actual results of experimental measurements. These inaccuracies are from incorrectly setting of combustion (parameters of wiebe function), which we are not able with our measurements set correctly. We are only able to estimate an approximate value. Another factor that significantly affects the results of the initial simulation is the absence of setting of frictional losses.

Because that modeled engine is based on the engine from 1973 and in racing car working on limit rpm, we can expect high losses associated with friction. For second calibration of engine was available data for combustion and friction losses from engine of similar construction. Therefore it was possible to change settings of the Wiebe model of combustion and also set the friction losses. These were set by FMEP (Friction Mean Effective Pressure). In Fig. 10 is completely calibrated engine model of Škoda 100 compared with results of experimental measurements on dynamometer. On this model we can make optimization of several parameters and watching dependencies on power or torque.





Source: Author

Fig. 10 – Comparison of the simulation and experimental results

## CONCLUSION

As was written, engine simulation software has a great potential for the development of new engines and optimization of engines. Simulation results are a part of prediction of the characteristics and parameters the engine before it will be actually manufactured. The second part is the modeling of the real existing engine as it was described in this article. In this way is then possible to make further calibration of the model based on data obtained from experimental measurements, which allows you to get a fairly accurate model of the engine with considering to real operating characteristics. In calibrated model is the big advantage that we can simulate structural changes on engine. The simulation results are after the appropriate changes to the model very accurate.

## REFERENCES

- (1) ŠPERLICH, Pavel. Výpočetní simulační model spalovacího motoru historického závodního automobilu a jeho experimentální ověření. Ostrava, 2013. 92 s. Diplomová práce. VŠB-Technická univerzita Ostrava.
- (2) SVÍDA, David. Analýza vnitřní termodynamiky spalovacího motoru. In Výzkumné centrum spalovacích motorů a automobilů Josefa Božka II [online]. Brno: Vysoké učení technické, 2010 [cit. 2011-05-20]. Dostupné z WWW: <[http://www3.fs.cvut.cz/web/fileadmin/documents/12241-BOZEK/publikace/2006/2006\\_002\\_01.pdf](http://www3.fs.cvut.cz/web/fileadmin/documents/12241-BOZEK/publikace/2006/2006_002_01.pdf)>.
- (3) CORDON, Dan, Charles DEAN, Judith STECIAK a Steven BEYERLEIN. <i>One-Dimensional engine modeling and validation: Using Ricardo Wave</i>. University of Idaho, 2007. Dostupné z: <[http://www.webpages.uidaho.edu/niatt/research/Final\\_Reports/KLK434b%20N07-09.pdf](http://www.webpages.uidaho.edu/niatt/research/Final_Reports/KLK434b%20N07-09.pdf)>
- (4) PÍŠTĚK, Václav a Josef ŠTĚTINA. Výpočetní metody ve stavbě spalovacích motorů: Určeno pro posl. fak. strojní. Vyd. 1. Brno: VUT, 1991. Učební texty vysokých škol. ISBN 80-214-0368-3.
- (5) Wave Build 8.0.1: Help. 2013.
- (6) GT- Power 7.2.1 Manual.