ΠP periodica polytechnica

Transportation Engineering
41/1 (2013) 57–64
doi: 10.3311/PPtr.7100
http://periodicapolytechnica.org/tr

RESEARCH ARTICLE

Elaboration of a new method for developing a diagnostic procedure for motor vehicles based on a model

István Lakatos

Received 2012-11-08

Abstract

In diagnostic expert systems we utilize the professional knowledge accumulated in the given field. This is processed by an adequate software. Although, it causes problem that the regularities of the diagnostic systems cannot always be algorithmized. In the forthcoming section I analyse the connection between the elaboration of diagnostic procedures used for the operation of vehicles and vehicle systems and their modelling from a different perspective. It can provide an aid for the elaboration of a new diagnostic procedure if we apply models for the analysis of the behaviour of the phenomena we would like to study [10, 11].

Keywords
model · diagnostic procedure

István Lakatos
Department of Road and Railway Vehicle, Széchenyi István University, Egyetem tér 1., H-9026 Győr, Hungary
e-mail: lakatos@sze.hu

1 Internal combustion engine model for facilitating the elaboration of diagnostic procedures

1.1 Mathematical model of uncharged Otto-engine (simplified model)

Henceforth I introduce the lifecycle model of an own developed engine and its application [1], [2], [3], [4]. Applications with a model basis are often used in the vehicle industry. These methods are equally applicable onboard and off board (repair shop). For example we can use a four-stroke gasoline engine function model for diagnostic goals. The mathematical model was own-developed; its main characters are as follows:

Charge replace process:

- stationary model
- the stroke curves of the valves are created considering the dynamic conditions (Kurz method)
- accurate analytical creation of the opening cross-sections of the valves (Hardenberg method and Dong method)

Main work process model:

- compression process (polytrophic)
- combustion process (monozone combustion model; Vibe method)
- operation state dependant correction of the combustion parameters (Csallner method, Woschni method)
- reference combustion function identified on the basis of typical measured values
- expansion process (polytrophic)

$$\frac{1}{p_z} \cdot \frac{dp}{d\phi} = -\frac{\chi}{V_z} \cdot \frac{dv}{d\phi} = -\frac{\chi}{V_z} \cdot \frac{dV}{d\phi}$$

where:

V cylinder volume
p_z cylinder pressure [Pa],
V_z cylinder specific volume [kg/m^3],

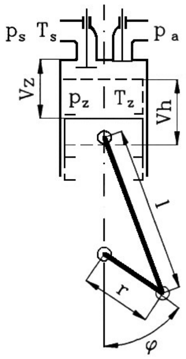


Fig. 1. In the charge-replace phase the cylinder pressure is obtained from the perfect gas law

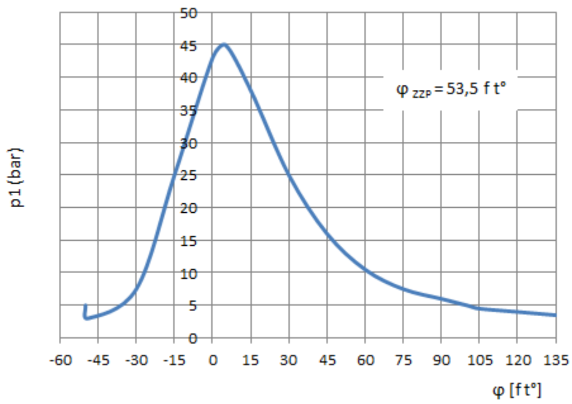


Fig. 2. Indicator diagram taken by measuring

χ adiabatic exponent,
ϕ crank angle [$^\circ$]

One common method of obtaining the mass fraction burned, x, is to use an empirically fit function of mass fraction burned versus crank angle, 0, such as the Wiebe function described, given as

$$x = 1 - e^{-6,908\cdot(\frac{t}{t_a})^{m+1}}$$

where:

x mass fraction burned,
t_z combustion duration,
m correlation parameter.

Naturally the model should be identified on a given work point of the pilot engine, on the basis of an indicator diagram taken by measuring (Figure 2.). Hereafter the model is able to create the indicated characters of the engine in the other points of the engine operational characteristic field by calculation.

The examined characteristics are:

- cylinder-pressure diagram,
- cylinder-temperature diagram,
- cylinder-charge diagram,
- residual gas diagram,
- indicated work (Figure 3.),
- indicated specific fuel-consumption.

Naturally the model should be identified on a given work point of the pilot engine, on the basis of an indicator diagram taken by measuring. Hereafter the model is able to create the indicated characters of the engine in the other points of the engine operational characteristic field by calculation.

The inlet characters of the model are given by the parameters and work point operational characteristics of the given engine. For example the revolution number of the engine, the suction pipe depression, and the pre-ignition value were determined by the roller bench test of the actual engine.

We can perform the examinations at the same work points of the engine with mathematical model as well as with measurement (vehicle bench-test). The examined characteristics are shown in the Table 1.

Tab. 1. Characteristics analysed for the optimising examinations

N°	Mathematical model	Vehicle bench-test
1.	Indicated work	Wheel performance
2.	Indicated specific fuel consumption	Specific vehicle consumption
3.	Combustion top temperature	CO emission
4.	Factor of residual gas	HC emission

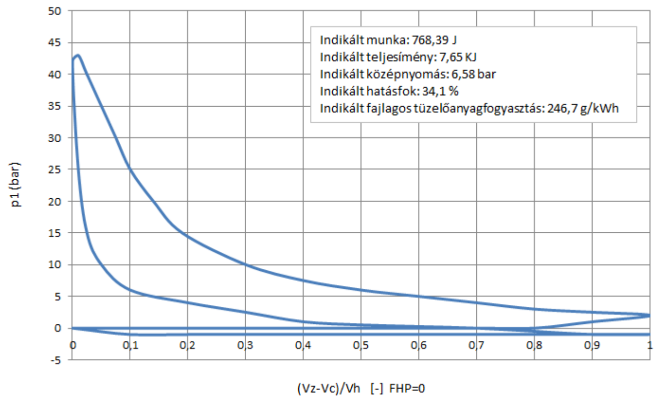


Fig. 3. Indicator diagram taken by model

Analising test results

In the example we can analyze the faults of valve timing. The characteristic curve of the pull (Figure 4) suits the indicated work function (Figure 5) in its tendency. The optimum place, however, shifts a bit because of the losses of the engine and the driving chain.

The parallelism of the hydrocarbon emission (Figure 6) and the part of residual gas (Figure 7) can be observed on the curves. The increasing amount of residual gas improves the HC emission (exhaust gas recirculation).

The effect of the phase shift on the specific fuel consumption is significant as well (Figure 8, 9).

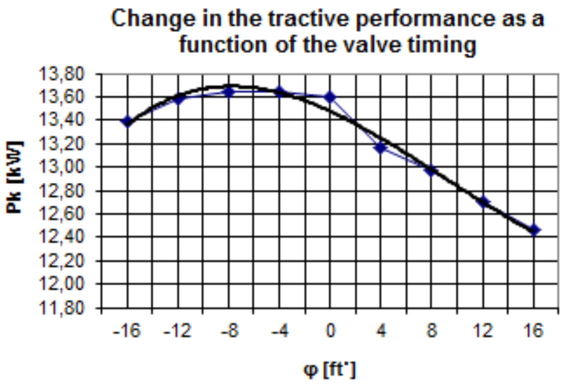


Fig. 4. Change in the tractive performance as a function of the valve timing

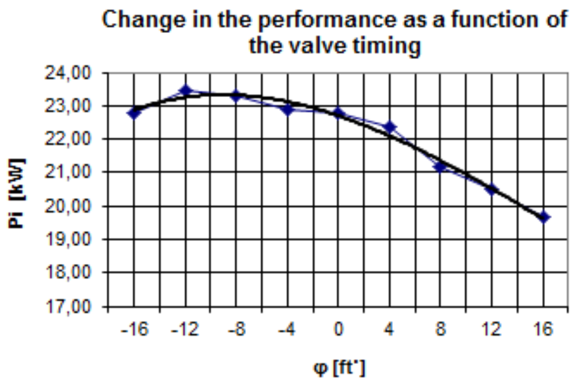


Fig. 5. Change in the performance as a function of the valve timing

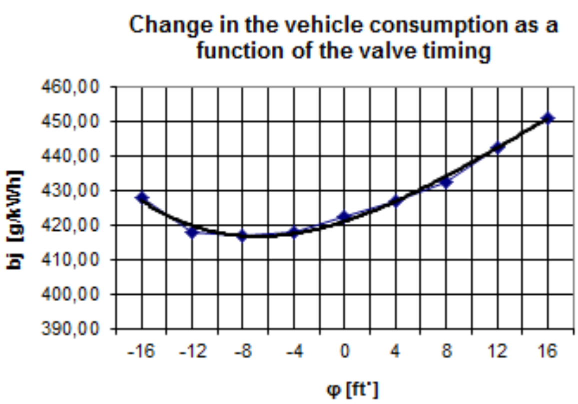


Fig. 6. Change in the vehicle consumption as a function of the valve timing

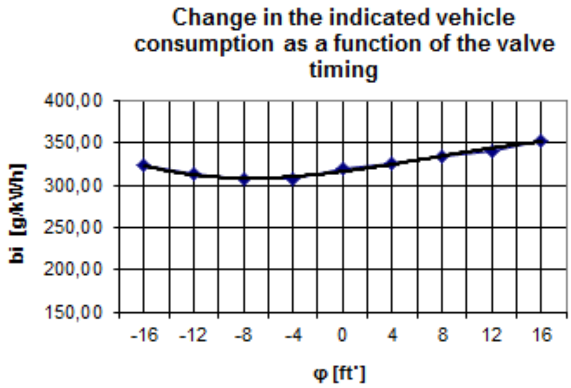


Fig. 7. Change in the indicated vehicle consumption as a function of the valve timing

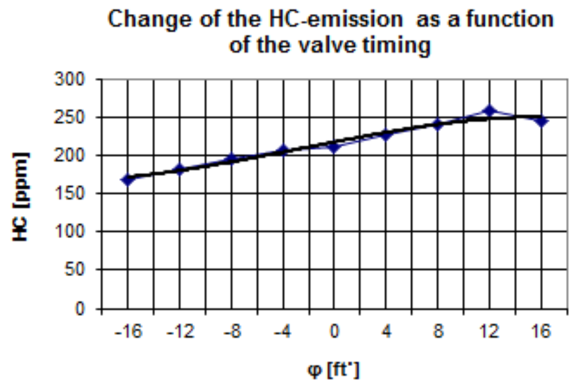


Fig. 8. Change of the HC-emission as a function of the valve timing

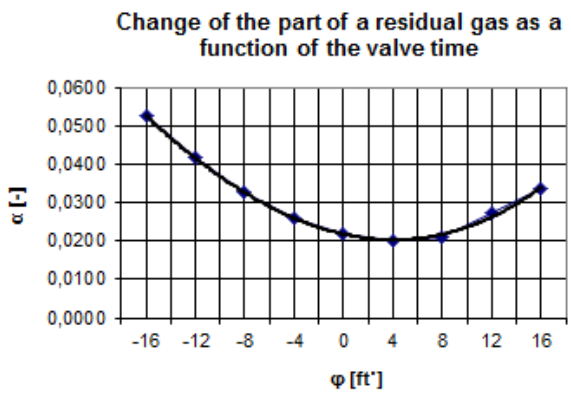


Fig. 9. Change of the part of a residual gas as a function of the valve time

However, the results given with the test and mathematical models certify that a significant improvement can be obtained at the operational point of the engine operational characteristic field also in our case.

The faults can be found by analyzing the mathematical model. The mathematical model presented in the article presents a possible example onto the mathematical description of the processes going on in the engine.

The parallelism of the hydrocarbon emission (Figure 6) and the part of residual gas (Figure 7) can be observed on the curves. The increasing amount of residual gas improves the HC emission (exhaust gas recirculation).

The effect of the phase shift on the specific fuel consumption is significant as well (Figure 8, 9).

However, the results given with the test and mathematical models certify that a significant improvement can be obtained at the operational point of the engine operational characteristic field also in our case.

The faults can be found by analyzing the mathematical model. The mathematical model presented in the article presents a possible example onto the mathematical description of the processes going on in the engine.

1.2 Modelling uncharged Otto-engine with GT Suite software

GT Suite is a professional modelling program. In the following I introduce its application with the help of some examples [6, 8, 9].

1.2.1 Suction-valve – cylinder-crank mechanism – exhaust valve model-unit

In GT Suite program the general structure and construction of the suction-valve – cylinder-crank mechanism – exhaust valve unit can be seen in Figure 10.

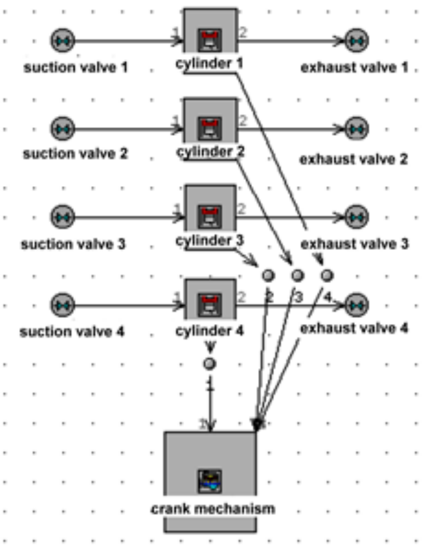


Fig. 10. GT Suite model unit

Each element is connected in the figure with arrows (linking elements) to one another according to their function, consequently the first suction valve to the first cylinder, then the latter to the first exhaust valve. All the cylinders are connected to the crank mechanism.

I indicate the data in connection with the change of the charge.

Valves

The valve data is provided in the program on the basis of groups:

Main:

- Valve Reference Diameter: (do not parallel with the real diameter in every case, the surface of flow must be taken into consideration)
- Valve Lash: (in case of engines with automatic valve lash compensator 0)
- Cam Timing Angle: crank shaft – camshaft timing angle

Advanced: In average case the parameters were not altered beyond the advanced menu point.

Scalars (coefficient): Diverse coefficients can be found here, the recommended settings are suitable here as well.

Lift array (values): the lift array values are summarized in a table in this case. It can be done depending on the angular displacement of main shaft or camshaft. It is an important requirement for the values in monotonous form to fall between -360 and +720 degrees. The angular values cannot be repeated in the columns. These values were recorded with inductive route and angle signalling device installed on the cylinder head.

Flow arrays (factors): the flow factors have to be recorded.

The flow cross section of the valve is smaller than the geometric opening cross section (A_G). In case of maximum valve opening ($h \approx 0.25 \cdot D$) the flow cross section is 60-80% of the geometric cross section.

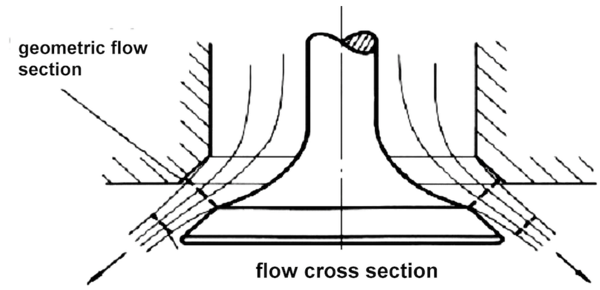


Fig. 11. Media flow through the valve

The geometric cross section has to be altered with the μ contraction coefficient according to the actual flow conditions .

$$A_{actual} = \mu \cdot A_G$$

The μ function is displayed in Figure 12 in accordance with the valve opening.

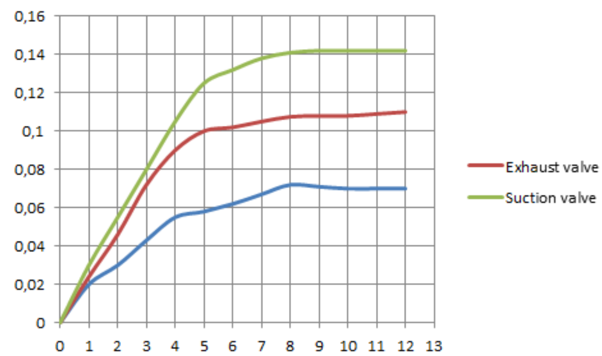


Fig. 12. Contraction coefficients

Cylinder

In case of cylinder object the data should be provided in two groups, from which in the first case accurately defined data are needed, while in the second case we can generally take the data recommended by the program. Later on, these data are corrected to be more precise.

In this case we need the following vital data:

- Mixture Composition:

- Wall Temperature Object
  - Cylinder Head Temperature: 575 K
  - Piston Temperature: (575 K)
  - Cylinder Temperature: 400 K
- Heat Transfer Object: heat transfer model WoschniGT
- Geometric data
  - Cylinder Head (gas side) / Cylinder bore Area Ratio
  - Piston/Cylinder bore Area Ratio
  - Piston Cup Object

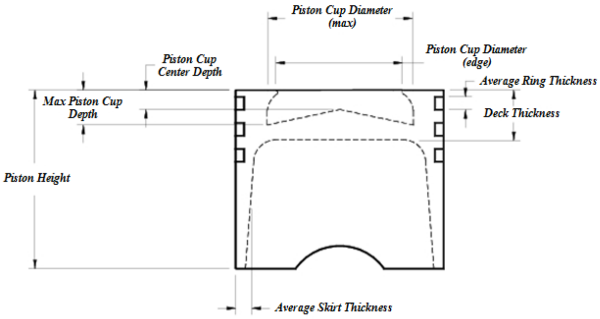


Fig. 13. Piston geometrical dimensions

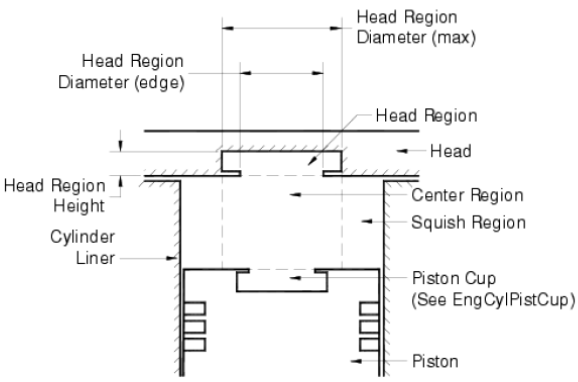


Fig. 14. Piston and combustion chamber dimensions

For the modelling it is necessary to know the elements of the intake and exhaust system details. Hereinafter we show the method of the measuring process.

1.3 Defining the valve-lift chart

We measured the valve moving chart with disassembled cylinder – head. For this measuring we use inductive way and angle signalling device. With this measuring technique we get the chart which is based on camshaft rotation.

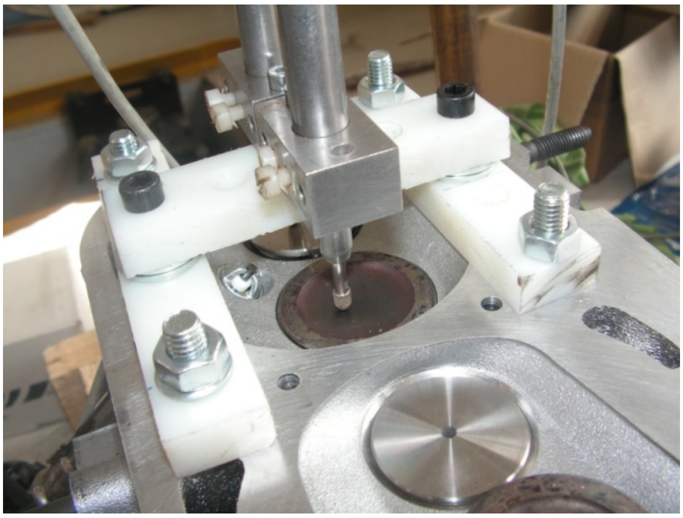


Fig. 15. Measuring the valve movement chart (movement measure)

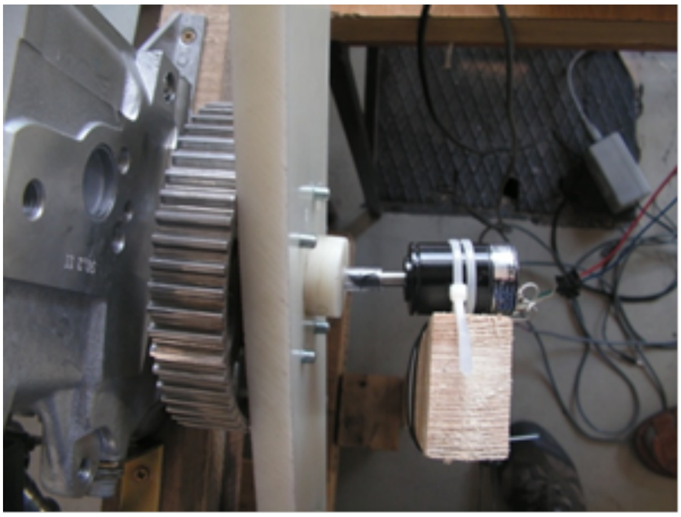


Fig. 16. Measuring the valve movement chart (angle signalling device)

Definition of the mass data of the crank gear

Intake system

With the computer tomography we can control the outside and inside geometries with high level exactitude. The exterious profile can be measured with ATOS optical measuring system, the 3D digitalizing system creating a polygon-mesh with high resolution. The system converts these data to CAD data using reverse engineering method. The steps of this process:

1 cloud-model

2 STL file(*.stl) only the surface is described with the help of 923.196 triangle elements

3 Making the 3D model using the computer tomography geometries of lower part of the intake system (Fig. 18)

4 Fitting the guideline to intake system and defining the length of the axis and the angle between the two connecting surfaces

5 Using the guideline we can measure the diameter of the intake system (Fig. 19)

2 Model operations for facilitating the elaboration of diagnostic procedures

2.1 Analysing the relations of the pressure and the temperature of the exhaust system

The exhaust pipes which are derived from particular cylinders gather to a common piping after the influx. Depending on the

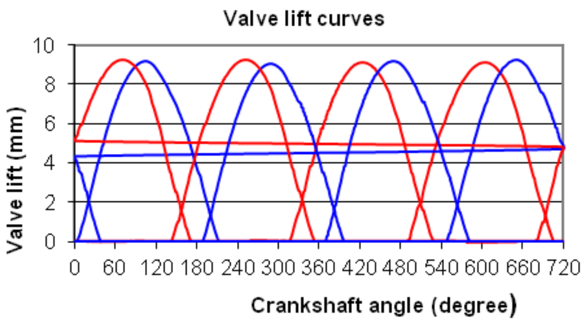


Fig. 17. Lower intake system

Fig. 18. Lower intake system

ignition time of the cylinders, these connections are constructed in a way to let exhaust fumes arrive into the piping at different times. In the next diagram those pressure values are visible which are measured after the joining of exhaust piping of the first and fourth cylinders:

If we compare this with the second and third cylinder pressure values measured after the joining of exhaust piping, then it can be seen that the pressure waves weaken each other [9].

This can be very well detected with pressure measurement, as a diagnostic procedure. The burning processes of each cylinder are the shortcomings of this pressure procedure. The analysis of the processes related to the diagnostic procedure can be resolved with the help of the model.

The formation of temperature relations

The program indicates the calculated data of the temperature of the exhaust system with a colourful figure.

The different colours display different temperature data. The meaning of each colour can be interpreted with the help of the scale on the left hand side. The temperature data of the following page belong to an operating point with the revolution number 7000 1/min:

These test values can be utilized for the evaluation of diagnostic measurements, for elaborating tests, which can be conducted with the help of e.g.: a thermal imaging camera.

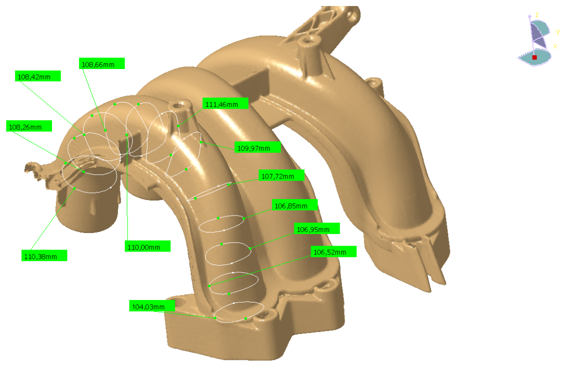


Fig. 19. Lower intake system dimensions

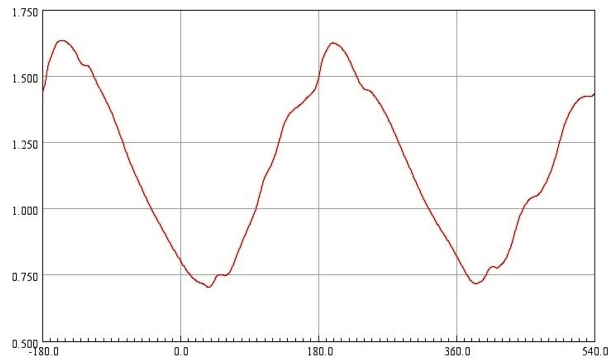


Fig. 20. 1. and 4.cylinder pressure values measured after the joining of exhaust piping according to the crankshaft rotation

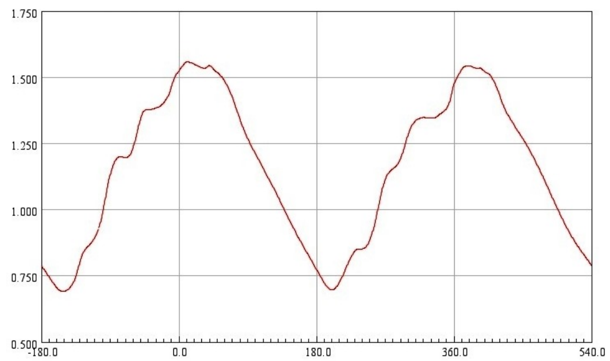


Fig. 21. 2. and 3.cylinder pressure values measured after the joining of exhaust piping according to the crankshaft rotation

The significance of the new procedure is that it is applicable in case of diagnosing any vehicle (old, modern, modern internal combustion, hybrid, electric).

Fault diagnostic software can be developed for the system. In the following part I am showing an example of its principle:

The software loads a photo taken with the thermal imaging camera about the vehicle to be diagnosed namely about its suitable part.

By choosing a pixel from the area to be analysed we can determine which zone we would like to study

The program displays graphically in which areas the pixels are located in the chosen zone.

By activating the switch in the program we can even choose the inverse of the temperatures in our chosen zone, therefore

Fig. 22. Temperature relations in the exhaust system (total load, n = 7000 rev/min). Part 1.

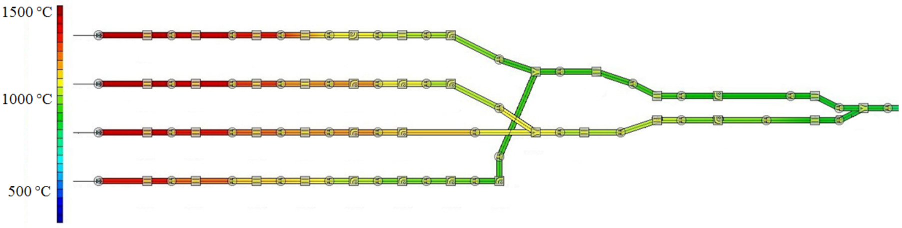
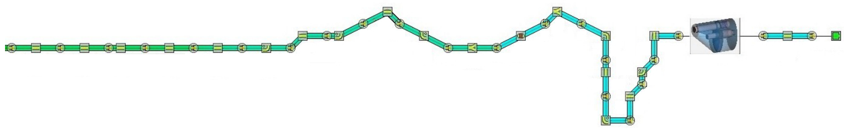


Fig. 23. Temperature relations in the exhaust system (total load, n = 7000 rev/min). Part 2.



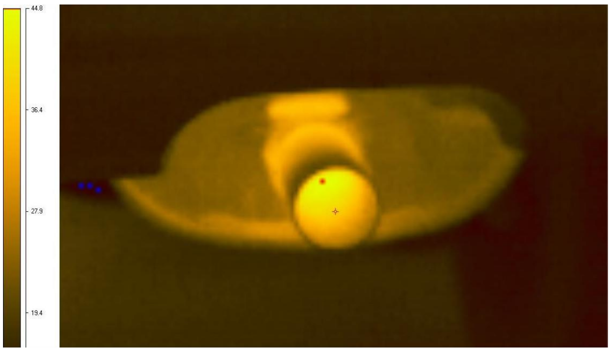


Fig. 24. Photo taken with a thermal imaging camera

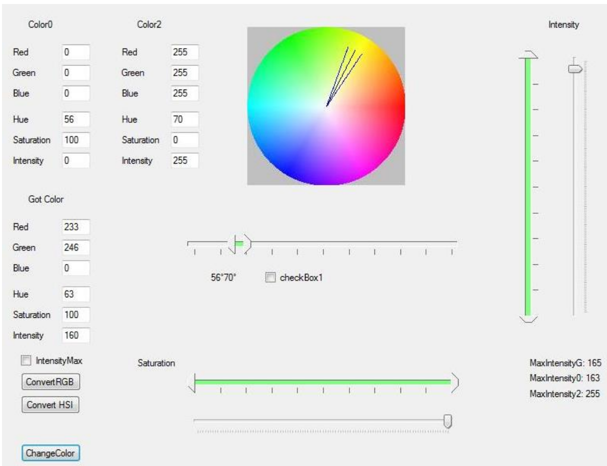


Fig. 25. Studied zone

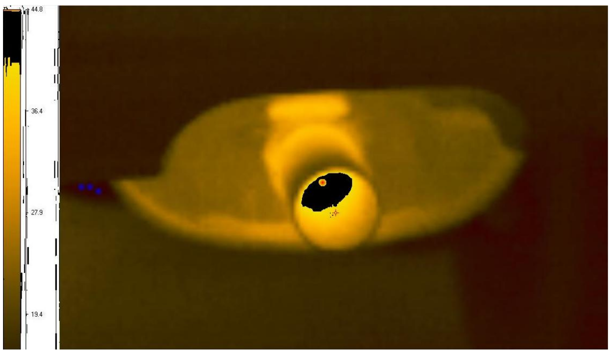


Fig. 26. Pixels located in the chosen zone

only the zone of our interest will be visible. It provides a significant aid to evaluate the components of vehicles.

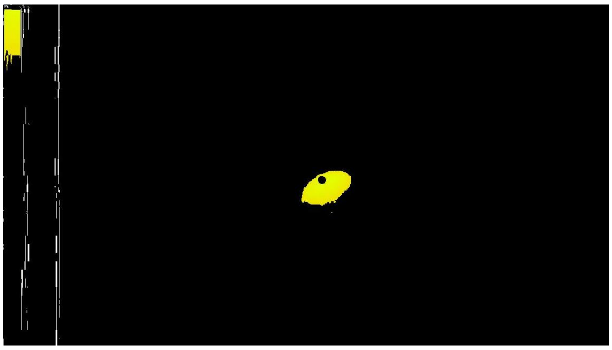


Fig. 27. The studied zone of our interest

Vehicle diagnostics with thermal imaging camera can be applied in various fields:

- Status study of the pipe network of vehicles in case of both liquid and gas networks.
- Analysing various parts of undercarriage.
- Trouble-shooting of brakes.
- Measuring the gearbox of vehicles with automatic transmission.
- Analysing electric and hybrid vehicles

2.2 Diagnostic analysis of the pressure conditions in the cylinder

We get useful information for diagnostics by using the pressure curve indicated while we are running the model with simulated faults.

During the diagnostics with indicated plug the deviations deriving from fault simulation can be utilized well for the evaluation.

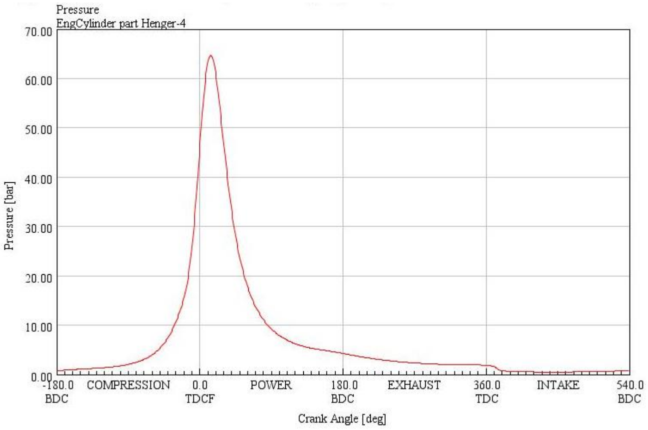


Fig. 28. Indicated pressure diagram

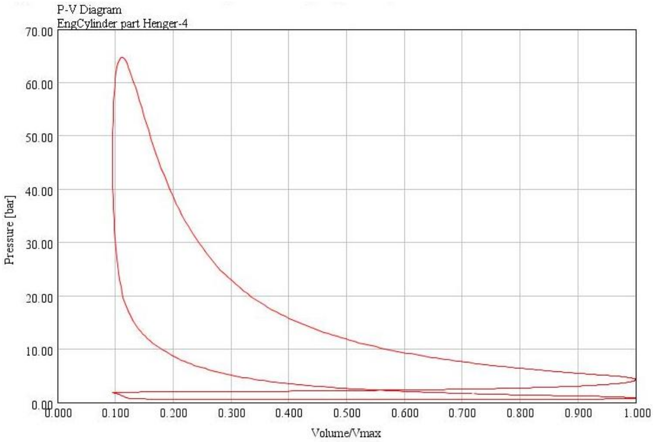


Fig. 29. Indicator diagram

With the help of the adequately validated model the effective performance can also be calculated, which can provide an aid for several other diagnostic analyses, as well.

3 Summary

Computational modelling of motor vehicles and motorcycles do not only facilitate the development work. It provides strong bases for elaborating new diagnostic procedures. In the article I indicated an example about it. Naturally besides the introduced case several other possibilities exist. The advantage of the elaboration of the diagnostic procedure supported with a model is its cheapness: there is no need for measurements taken on vehicles; however, easily usable results can be achieved fast.

References

1 **Lakatos I**, *Töltetcsere időzítés hatása a négyütemű, feltöltetlen Otto-motorok üzemére (Effect of timing of the charge exchange on the operation of four stroke uncharged Otto-engines)*, Ph.D. thesis, BME; Budapest, 2003.

2 **Stein B, Niggemann O, Balzer H**, *Diagnosis in Automotive Applications,A Case Study with the Model Compilation Approach*, Third Monet-Workshop on Model-Based Systems (MBS 06), (Wotawa), In:, University of Trento; Trento, Italy, 2006, pp. 34–40.

3 **Struss P, Price C**, *Model-based systems in the automotive industry*, AI Magazine, **24**(4), (2004), 17–34.

4 **Lakatos I**, *Töltetcsere-időzítés hatása a négyütemű feltöltetlen Otto-motorok üzemére (Effect of timing of the charge exchange on the operation of four stroke uncharged Otto-engines)*, Ph.D. Thesis, BME, 2002 (Hungarian).

5 **Lakatos I**, *Mobilitás és környezet: Járműipari, energetikai és környezeti kutatások a Közép- és Nyugat-Dunántúli Régióban projekt*: *Gépjármű hajtáslánc modellezése és szimulációja, hajtáslánc optimális irányítása K+F project (Mobility and the environment: Automotive industrial, energetic and environmental researches in the Middle and Western Transdanubia Region project motor vehicle drive train modelling and simulation, optimal operation of drive train of K+F project)*, TAMOP, 2011, Report No.:TAMOP-4.2.1/B-09/1/KONV-2010-0003 (Hungarian).

6 **Mohiuddin AKM, Rahamn A, Dzaidin M**, *Optimal design of automobile exhaust system using GT-Power*, International Journal of Mechanical and Materials Engineering (IJMME), **2**(1), (2007), 40–47.

7 **Kramer U**, *Potentialanalyse des Direktstarts für den Einsatz in einem Stopp-Start-System an einem Ottomotor mit strahlgeführter Benzin-Direkteinspritzung unter besonderer Berücksichtigung des Motorauslaufvorgangs*, dissertation, Universität, Duisburg–Essen, 2005.

8 **Bos M**, *Validation Gt-Power Model Cyclops Heavy Duty Diesel Engine*, MSc. Thesis, 2007.

9 **Lakatos I**, *Gépjármű hajtáslánc modellezése és szimulációja, hajtáslánc optimális irányítása (Motor vehicle drive train and simulation, optimal operation of drive train), Mobilitás és környezet: Járműipari, energetikai és környezeti kutatások a Közép- és Nyugat-Dunántúli Régióban (Mobility and environment: Automotive industrial, energetic and environmental researches in the Middle and Western Transdanubia Region)*, TÁMOP 4.2.1/B-09/1/KONV-2010-0003 Workshop, (Győr, 2011-06-27), In:, University of Trento; Trento, Italy, 2011, pp. 34–40 (Hungarian).

10 **Németh B, Gáspár P**, *Vehicle modeling for integrated control design*, Periodica Polytechnica Transportation Engineering, **38**(1), (2010), 45–51, DOI 10.3311/pp.tr.2010-1.08.

11 **Varga I, Bokor J**, *A new approach in urban traffic control systems*, Periodica Polytechnica Transportation Engineering, **35**(1–2), (2007), 3–13.