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[1.] Ilie DUMITRU, [2.] Ion BOGDAN, [3.] Mihnea CATANEANU, [4.] Alexandru OPRICA

USING TYPE IDENTIFICATION SYSTEMS TO TEST THE MATHEMATICAL MODEL FOR THE ECONOMIC POLE OF A DIESEL ENGINE

[1,3,4.] UNIVERSITY OF CRAIOVA, FACULTY OF MECHANICS, ROMANIA
[2.] NATIONAL COLLEGE "RADU NEGRU" OF FAGARAS, ROMANIA

ABSTRACT: *Optimizing power using diesel engines in automotive power systems (example: road train assembly or tractor and machine work system) requires determining the engine speed-actual torque function for which specific fuel consumption is minimum at each constant power level which gives the premises for the design and implementation of an information system for the management and control of optimal use of engine power. Experimental research is conducted mainly for collecting data required to develop and verify algorithms resulting from mathematical modeling of indirect determination of torque, optimum curve and hence the economic pole. For this purpose, the engine tested under laboratory conditions has been subjected to experimental measurements and corresponding parameters were measured: actual torque M_e and actual engine speed n_e at different constant values for exhaust temperature θ_{ge}. The solutions' validation requires the use of dedicated methods of which stands type identification method system. Checking the correlation coefficient between real data (measurements taken at the test track drive with the car brake) and theoretical relation established after mathematization. The main purpose of the track measurements was to verify the fidelity of mathematical modeling done by the author and data collection necessary to compare with the results obtained from stand.*
KEYWORDS: *mathematical model, optimizing power, economic pole, type identification method system*

REASONS FOR RESEARCH CONDUCTED

Phenomenas that take place during engine operation in different regimes are complex and mathematical models can be developed, generally only based on experimental results.

The procedures used are called system identification. In line with this type of procedure based on the analysis of experimental data and their processing can lead to theoretical formulations established into mathematical models that are searched.

To optimize performance engines in recent years there has been concerns for research in order to obtain mathematical models for the performance of diesel engine. These concerns are based on the advantages of analytical solutions in terms of testing compression ignition engines. So in the case of mathematical modeling to define an engine performance map, it involves reducing the number of measured points from 250 points (required for experimental lifting of the map) to 20 points (Figure 1).

In the study, the authors present sequences of using this method in research conducted to determine the economic pole.

Economic pole determination is based on the development of complex mathematical models that lead to obtaining the optimal engine operating map.

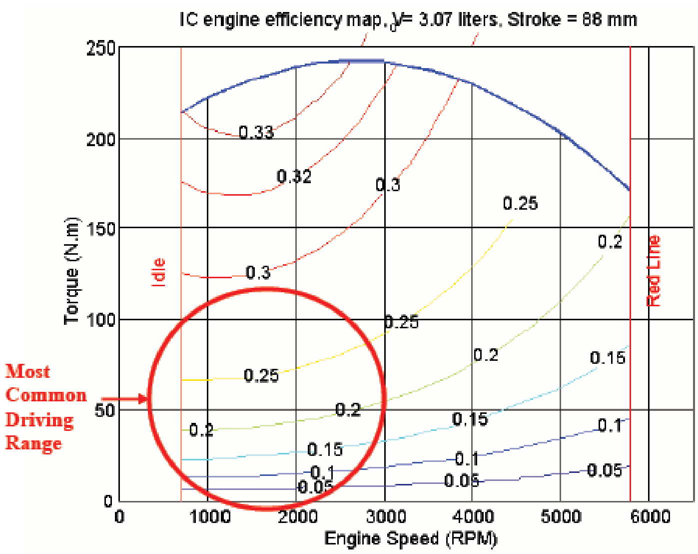

Figura 1. Efficiency Map of a Typical SI Engine (Guezennec, 2003)

To achieve an efficient system identification there are used data collected for this purpose from engine braking on stand (on schedule in Figure 2).

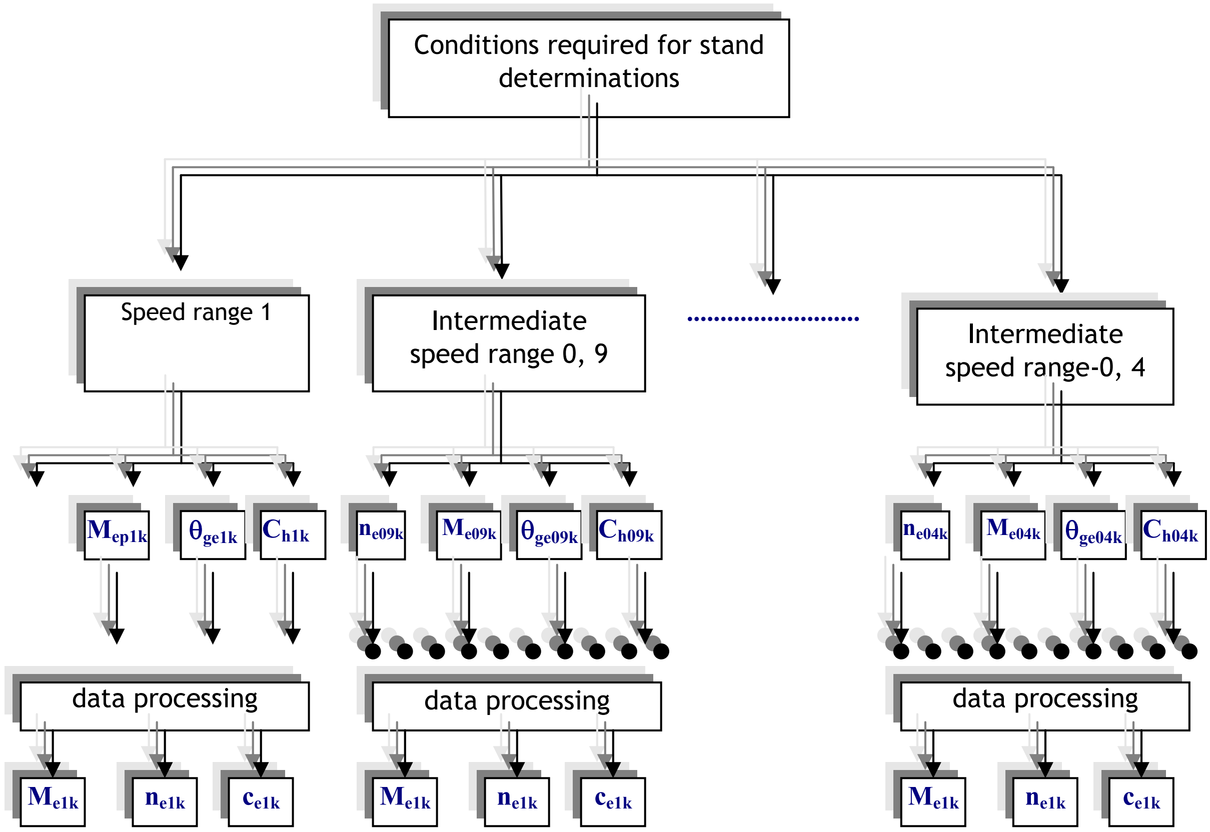

Figure 2. The experimental measurements schedule in the laboratory (stand)

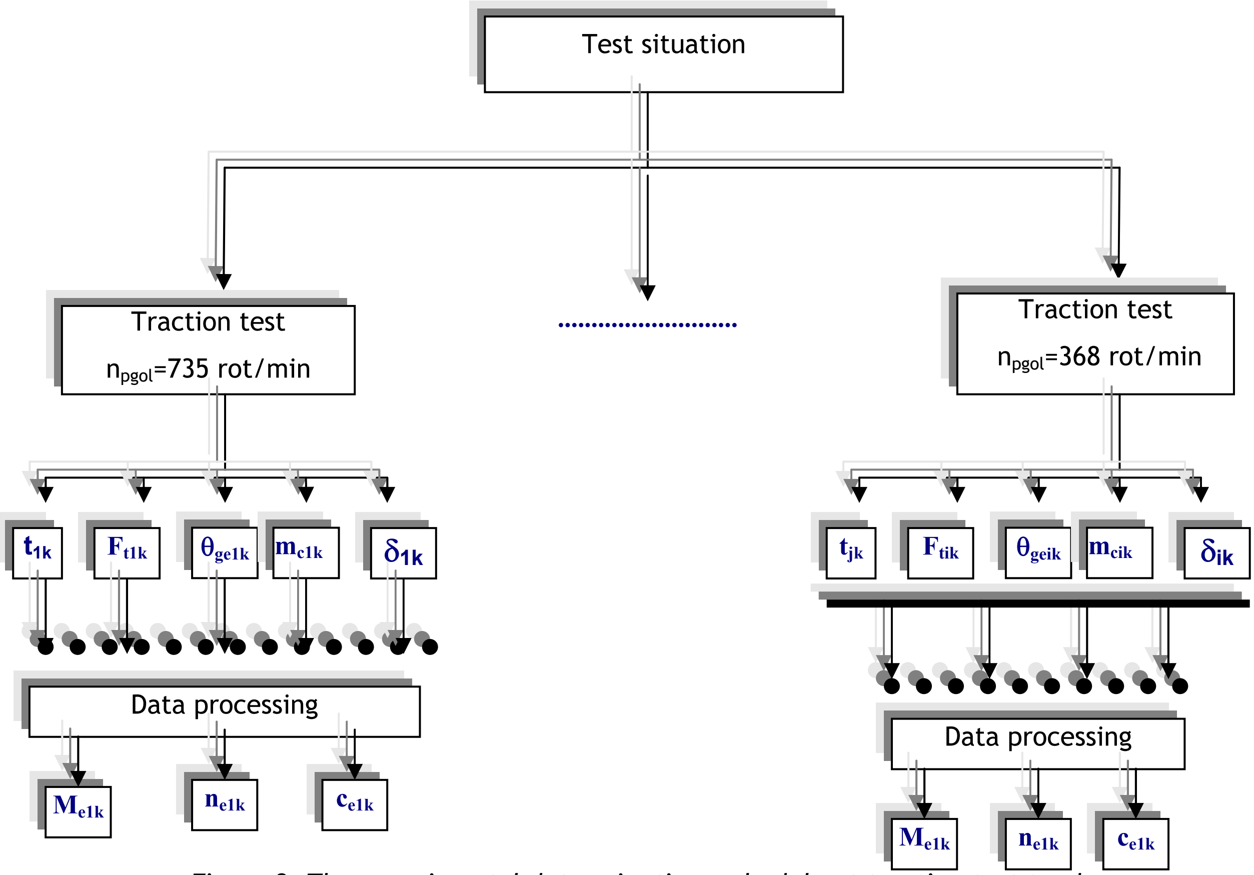

Figure 3. The experimental determinations schedule at traction test track

Subsequently, the validation of mathematical models is made using processed data obtained from the test track determinations (according to schedule in Figure 3).

For this purpose, the engine has undergone appropriate experimental measurements using the brake system through the PTO.

Parameters that were measured are: actual torque M_e and actual engine speed n_e at different constant values corresponding to the exhaust temperature t_{ge}.

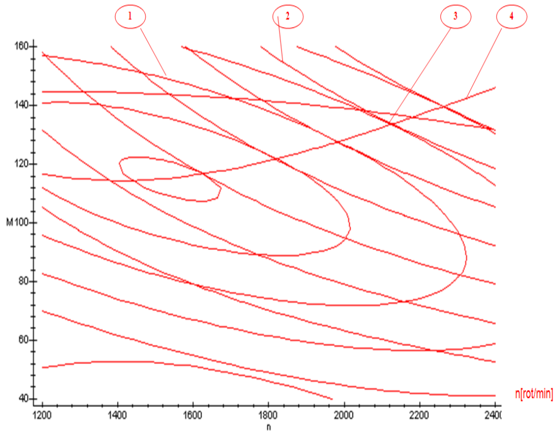

Figure 4. Model of optimal functioning map for the engine in test

STAGES OF MATHEMATICAL MODELING

☐ *Algorithm necessary to obtain the izo-consumption curves*

There were performed h experimental determinations in which the specific fuel consumption c_e [g / kWh] was followed for different values of engine speed n_e [rot/min] and effective torque M_e [Nm], the specific fuel consumption being considered a polynomial function of time and speed:

$$c = \sum_{i=0}^{p} \sum_{j=0}^{s} a_{ij} \cdot M^{i} \cdot n^{j} \tag{1}$$

To determine the coefficients a_{ij}, it is used the method of the least squares:

Having determined the coefficients, their values are entered in the specific fuel consumption relationship:

$$c = a_{00} + a_{10} \cdot M + a_{01} \cdot n + a_{11} \cdot M \cdot n + a_{20} \cdot M^{2} + a_{02} \cdot n^{2} \tag{2}$$

And thus obtain the final form of dependencies c_e (M_{ek}, n_{ek}):

One can notice that the dependence c_e (M_{ek}, n_{ek}) is an equation that defines an ellipse. To represent the izo-consumption curves (Figure 5), the same program is used.

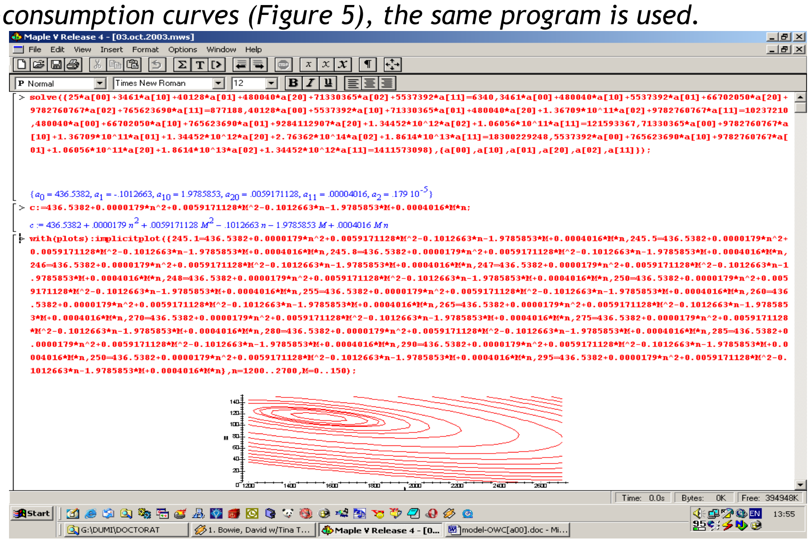

Figure 5. The topograma of fuel specific consumption fields for engine D 115

☐ *Mathematical modeling for determining the curve of optimal operation of the studied engine*

To determine the optimal operating curve of an engine, it is considered that this is the locus of optimal points. These points are defined from the condition that the slopes curves M = f (n) at constant power (P_e = const) and specific consumption constant (c_e = const) are equal, using the theorem of "equal slope".

$$\left(\frac{\partial M}{\partial n}\right)_{P=ct} = \left(\frac{\partial M}{\partial n}\right)_{c=ct} \tag{3}$$

Using the mathematical and grouping terms it is obtained the economic operation optimum of the engine during operation via the "optimal engine operation curve" defined by the following function:

$$2a_{20} \cdot M^{2} + a_{10} \cdot M - 2a_{02} \cdot n^{2} - a_{01} \cdot n = 0 \tag{4}$$

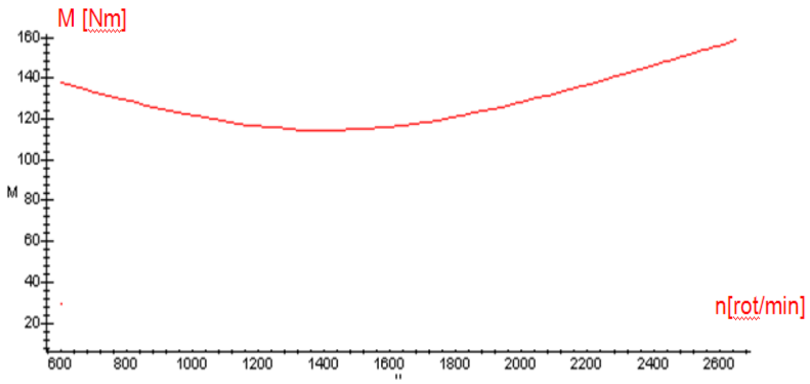

Figure 6. Optimal engine operation curve for D 115

- *The graphical determination of the torque evolution of the speed characteristic at full load*

Using the software MAPLE on the polynomial function found experimentally it is obtained the following graphical representation for a sequence (Figure 7) with(plots):

implicitplot ({ M = 131.7104177 + .2195173611e-1*n - .9146556711e-5*n^2 } , n=100..2400, M=0..150);

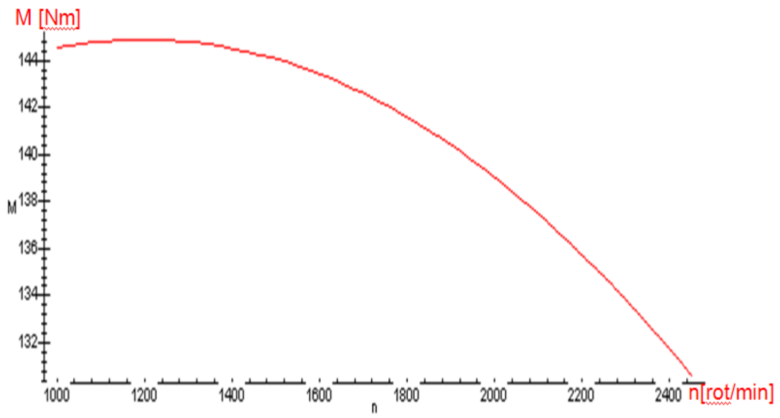

Figure 7. Graphical representation in MAPLE of the torque variation for the studied engine

CORRELATIONS STUDY ON IDENTIFYING SYSTEM TYPE THEORY

The correlation coefficient (R) is an indicator that measures the intensity of the relationship between two variables x and y. In practice it is used the formula:

$$R = \frac{n \cdot \sum x_i \cdot y_i - \sum x_i \cdot \sum y_i}{\sqrt{\left[n \cdot \sum x_i^2 - \left(\sum x_i\right)^2\right] \cdot \left[n \cdot \sum y_i^2 - \left(\sum y_i\right)^2\right]}} \quad (5)$$

where: n is the number of measurement points, and x_i and y_i are the values of pairs of points.

Closer values to 1 means a stronger correlation between variables x and y. If R = 0 there are independent or uncorrelated variables, and for R = 1 it results functional dependence between the two variables

Not to work with radicals, usually it is calculated the square of the correlation coefficient noted with R^2.

In practice it is considered that if:

$0<$	$R^2 <$	0,2	*there is not a significant relationship;*
$0,2<$	$R^2 <$	0,5	*there is a weak connection;*
$0,5<$	$R^2 <$	0,75	*there is a medium intensity connection;*
$0,75<$	$R^2 <$	0,95	*there is a strong link*
$0,95<$	$R^2 <$	1,00	*can say that the relationship is relatively deterministic*

- *Correlation for the algorithm of effective torque - exhaust gas temperature - engine speed*

In order to assess mathematical modeling, the authors used the Statistical module in Microsoft Excel.

The first step to determine theoretical torque depending on the exhaust gas temperature and speed is creating a MAPLE program with the following structure:

```
ne: array(1...k,[n1..nk];
tge :array(1...k,[tge 1..ntge k];
for i from 1 to i do ;Mteor[i]:= -58.80756705 + .2917930092*tge[i] - .5774045918e-5*tge[i] ^2 + (.2531481953 - .3583852919e-3*tge[i] + .6951621429e-8*tge[i] ^2)*n[i] + (-.1087378640e-3 + .1565572144e-6*tge[i] - .1936656122e-11*tge[i] ^2)*n[i]^2, print(Mteor[i]); od:;
```

With data thus obtained and using the software presented, it is determined the correlation coefficient (Figure 8). Its value is 0.968671165 thus resulting a relatively deterministic relationship

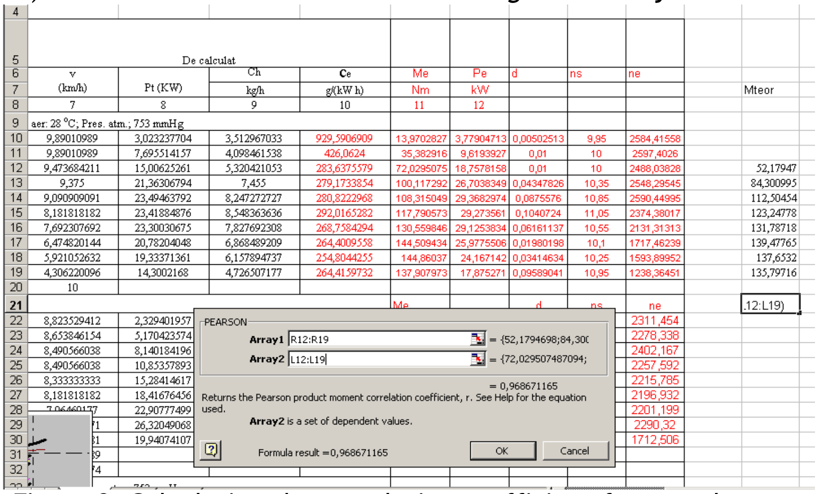

Figure 8. Calculating the correlation coefficient for actual torque

- *Correlation for the theoretical function established for specific fuel consumption*

Going through the same steps it is obtained (Figure 9.) a value of 0.934975777. Experimental data were taken from the test for intermediate speed range (0.9) taking into account the speed range between maximum torque speed and rated speed.

As follows:

n:=array(1..26,[729.6,802.56,875.52,948.48,1021.44,1094.4,1167.36,1240.32,1313.28,1386.24,1459.2,1532.16,1605.12,1678.08,1751.04,1824,1896.96,1969.92,2042.88,2115.84,2188.8,2261.76,2334.72]);
M:=array(1..26,[125.2696,130.0558,135,138.7717,141.124,144.1248,144.414,144.214,144.215,144.321,144.472,143.345,143.234,143,141.845,141.241,140.218,139.254,138.654,137.454,135.854,72.9,38.92]);
> for i from 1 to 23 do Cteor[i]:=436.5382+0.0000179*n[i]^2+0.0059171128*M[i]^2-0.1012663*n[i]-1.9785853*M[i]+0.0004016*M[i]*n[i]; print(Cteor[i]); od:;

253.8852235
251.4719674
249.7960679
248.8293596
248.2862980
248.2426431
248.0881684
248.0301329
248.2025363
248.5955381
249.1997131
249.5682009
250.4370086
251.4422592
252.2485945
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254.5768188
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259.0379629
260.4706585
252.4904551
266.1299794

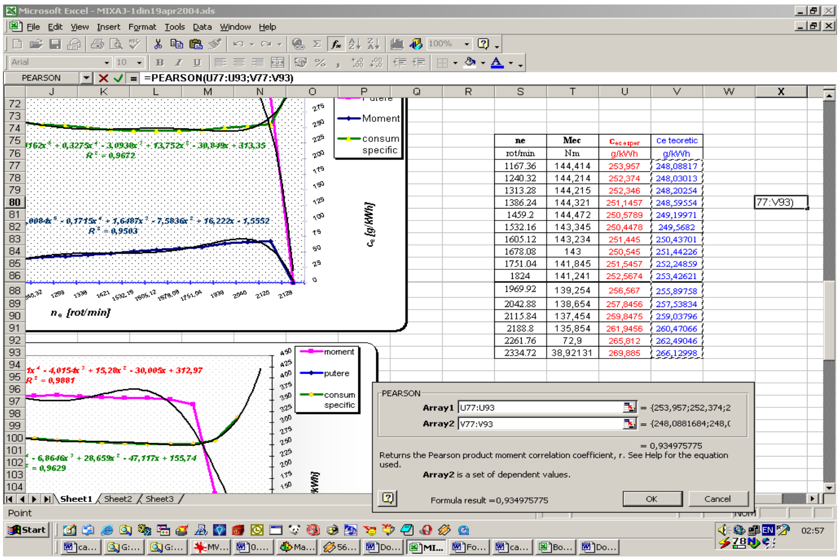

Figure 9. Calculating the correlation coefficient for the specific fuel consumption

CONCLUSIONS

Phenomena that take place during engine operation in different regimes are complex and mathematical models can be developed, generally only based on experimental results.

The procedures used so are called system identification. In line with this type of procedure based on the analysis of experimental data and their processing can lead to theoretical formulations established into mathematical models that are searched.

To optimize performance engines in recent years there has been made research to develop mathematical models of diesel engine performance. These concerns are based on the advantages of analytical solutions in terms of testing compression-ignition engines. So in the case of mathematical modeling to define an engine performance map, it involves reducing the number of measured points from 250 points (required for experimental lifting of the map) to 20 points.

To achieve efficient identification system there data collected for this purpose from engine braking stand are used.

Subsequently, the validation of mathematical models is made by processing data obtained from determinations on the test track.

To obtain optimum engine operation it is required the development of:

- *Algorithm necessary to obtain izo-consumption curves*
- *Mathematical modeling to determine optimal operation curve for the studied engine*
- *Evolution of the torque and engine speed characteristic at full load*

Validation of one mathematical model requires the use of the indicator R^2 (multiple correlation coefficient).

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