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DETERMINATION OF OPTIMUM OPERATING REGIMES OF ROAD VEHICLES BASED ON MINIMUM FUEL CONSUMPTION

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ABSTRACT

The paper deals with the mathematical calculation which allows the determination of the optimum conditions in operating the propulsion installations with internal combustion engines applied to road vehicles, in the conditions of minimum real fuel consumption, including the evaluation of the mechanical power and fuel consumption characteristics.

KEYWORDS: fuel consumption, optimum operating regimes

1. INTRODUCTION

The paper presents a mathematical model to determine the operating regimes with minimum fuel consumption based on the knowledge of power and fuel consumption characteristics. So that the desired speed of travel determines the optimum operating regime that is optimal gearbox ratio, load of engine, engine speed and minimum fuel consumption. Graphical results are presented as a case study.

2. MATHEMATICAL MODEL FOR DETERMINATION OF OPTIMUM OPERATING REGIMES FOR ROAD VEHICLES, BASED ON MINIMUM SPECIFIC FUEL CONSUMPTION

If we consider the working conditions quasisteady in operating the propulsion plants applied to road motor vehicles, it is possible to determine the optimum speed of car $V_{optimum}$, the optimum position of accelerator pedal $y_{koptimum}$ and the optimum ratio drive $i_{tr\ optimum}$ of transmission, in condition of realization of minimum real specific fuel consumption.

The mathematical model contains the following equations and consists in solving them:
- in case of propulsion installations with sparking plug engines [1], [2], [4]:

$$P_e(n,\theta obt)=\frac{P_R(\alpha,Gaut,V_x,condition\underline{\ }road)}{\eta tr(Pe,itr,n)} \quad (1)$$

$$c_e = c_e(n,\theta_{obt}) \quad (2)$$

$$\theta_{obt} = \theta_{obt}(y_k) \quad (3)$$

$$i_{tr} = \frac{n}{n_R};\ n_R = \frac{30}{\pi}\cdot\frac{V}{r_d} = ct \quad (4)$$

or

$$P_e(V,i_{tr},y_k)=\frac{P_R(\alpha,Gaut,V_x,condition\underline{\ }road)}{\eta tr(Pe,itr,y_k)} \quad (5)$$

$$c_e = c_e(V,i_{tr},y_k) \quad (6)$$

$$\frac{\partial c_e}{\partial i_{tr}}=0;\frac{\partial c_e}{\partial y_k}=0;\frac{\partial c_e}{\partial V}=0 \qquad (7)$$

-- in case of propulsion installations with diesel engine [1], [2], [4]:

$$P_e(n,h)=\frac{P_R(\alpha,Gaut,V_x,condition\_road)}{\eta tr(Pe,itr,n)} \qquad (8)$$

$$c_e=c_e(n,h);\quad h=h(n,y_k) \qquad (9)$$

$$i_{tr}=\frac{n}{n_R};n_R=\frac{30}{\pi}\cdot\frac{V}{r_d}=ct \qquad (10)$$

or

$$P_e(V,i_{tr},y_k)=\frac{P_R(\alpha,Gaut,V_x,condition\_road)}{\eta tr(Pe,itr,y_k)} \qquad (11)$$

$$c_e=c_e(V,i_{tr},y_k) \qquad (12)$$

and

$$\frac{\partial c_e}{\partial i_{tr}}=0;\frac{\partial c_e}{\partial y_k}=0;\frac{\partial c_e}{\partial V}=0 \qquad (13)$$

where [1], [4],

$$P_{R,rul}[kW]=\left(f\cdot cos\alpha+sign\cdot sin\alpha\right)\frac{V}{3600}\cdot G_{aut} \qquad (14)$$

$$P_{R,acc}[kW]=\left(sign\cdot\frac{G_{aut}}{g}\cdot\delta\cdot a\right)\frac{V}{3600} \qquad (15)$$

$$P_{R,air}[kW]=\left(\frac{k\cdot A\cdot V_x^2}{13}\right)\frac{V}{3600} \qquad (16)$$

$$P_R[kW]=P_{R,rul}+P_{R,acc}+P_{R,air} \qquad (17)$$

If we consider a=0 results:

$$P_R[kW]=P_{R,rul}+P_{R,air} \qquad (18)$$

where :

P_e,P_R -- the real power of the engine and the resistance power of the car; k - frontal aerodynamic coefficient; V_x[km/h] –resulting speed between vehicle speed and wind speed; V[km/h] – speed of the vehicle; a[m/s^2] – acceleration of vehicle;

$P_{R,rul}$ -- the resistance power during the horizontal and in slope running;

$P_{R,air}$ -- the resistance power due to the friction with air resistance;

$P_{R,acc}$ -- the resistance power when accelerating;

δ -- coefficient of reduced mass;

n,n_R -- the revolutiom of engine and the revolution of power wheels;

f -- the resistance coefficient for the rollling of wheels;

G_{aut} -- the weight of the car;

A -- the maximum transversal surface of the car;

i_{tr} – gear ratio of power transmission;

r_d -- the dynamic radius of wheels;

y_k -- throttle position;

c_e -- the real specific fuel consumption ;

θ_{obt}, h – air flap position for spark ignition engine, respectively the actuator position of the injection pump for diesel engine;

α -- the angle of the road measured by the horizontal surface;

η_{tr} -- the efficiency of power transmission;

sign = + 1 for the road in rising slope;

sign = - 1 for the road in downhill slope;

In a general case, can be written the following restrictions for the car speed $V_{min}< V < V_{max}$ or $V <= V_{max}$ or $V = V_{imposed}$, relations which must written with the previous relations, (7) and (13). With the help of spline functions of one, two or three variables we can estimate the static functioning mechanical characteristics for the internal combustion engines, power transmission and consumer [3], [5].

The stages of the calculation mode which lies at the basis of the program running on the computer for the determination of optimum values are:

a) -- we state a value for the speed V = ct; in accordance with (4), (10) it results engine rotation 'n';

-- using relation (17) we calculate $P_R= P_R(V)$ = ct for speed V ;

-- it is known the transmission characteristic:

$$\eta_{tr}=\eta_{tr}\left(P_e,n,i_{tr}\right) \qquad (19)$$

where for sparking plug engine:

$$P_e=P_e(n,\theta_{obt}),i_{tr}=i_{tr}(n)\Rightarrow\eta_{tr}=\eta_{tr}(\theta_{obt},n) \qquad (20)$$

for Diesel engine:

$$P_e=P_e(n,h),i_{tr}=i_{tr}(n)\Rightarrow\eta_{tr}=\eta_{tr}(n,h) \qquad (21)$$

-- we calculate the ratio:

$$\frac{P_R(V)}{\eta_{tr}(P_e,i_{tr},n)}=\frac{P_R(V)}{\eta_{tr}(\theta_{obt}(or,h),n)} \qquad (22)$$

which results with θ_{obt}, n , respectively h, n variables.

--there are known the mechanical power characteristics $P_e = P_e(n,\theta_{obt})$ respectively $P_e = P_e(n,h)$ for the engine, interpolate using [3] for the same values of 'θ_{obt}' and n , respectively 'h' and 'n' with calculated the ratio above.

The aim of these arithmetical operations is to solve the equation (1) respectively (8).

$$P_e(n,\theta_{obt}), P_e(n,y_k) = \\ = \frac{P_R(\alpha, V_x, G_{aut}, condition\_road)}{\eta_{tr}(P_e, n, i_{tr})} \quad (23)$$

After we compared the values of both members of equation (1) or (8) we will keep the values of 'θ_{obt}' , 'n' respectively 'h' , 'n', and observe the error established in the solution of the equation .

--there are known the characteristics $c_e=c_e($ n,$\theta_{obt})$, respectively $c_e=c_e($ n,h) interpolate using [3], [5] for the same values of θ_{obt}, n respectively h, n calculated before, at the previous arithmetical operation .

-- for the V=ct established , we obtain c_{emin} and determine n , θ_{obt} respectively n , y_k in case of diesel with governor.

b) – we repeat the previous arithmetical operations for another values of speed V=ct.

c) -- At the end, from all the values c_{emin} we obtained from different V=ct, we will establish $c_{eminmin}$, the value of $V_{optimum}$, $n_{optimum}$, $\theta_{optimum}$, respectively, $n_{optimum}$, $h_{optimum}$ in connection with $c_{eminmin}$ that is equivalent with working conditions in operating with a minimum real specific consumption.

-- we used (4) to determine n_{Roptim}, $i_{tr\ optim}$; we used (3) respectively (10) to determine y_{koptim} in connection with $c_{eminmin}$.

3. GRAPHIC RESULTS FOR A CASE STUDY

Using the mathematical model of computation it was created a computer program that allows for optimum operating regimes of a car, in the sense specified in the paper. Numerical results are presented in the following table and diagrams.

For a car with maximum power $P_{e,max}$=125 [Kw] at 6250 [rpm], maximum speed V_{max}=200 [km/h] and maximum continuous rating $P_{e,MCR}$=100[kW] at 5750 [rpm] using the known characteristics for power and fuel consumption (stand characteristics determined experimentally) using spline interpolation functions [3], [5] are obtained extended graphics features mentioned in Fig.1 and Fig. 2.

Using these extended mechanical characteristics, and the computer program performed with MATLAB software were determined for different speeds of movement of the vehicle, the speed and ratio of gearbox movement providing minimum fuel consumption of all possible alternatives for each speed considered.

Numerical results are presented in Table 1, respectively graphical charts Fig.3, Fig. 4 and Fig. 5.

Tab 1. Engine rotation, ratio of transmission in gearbox, minimum fuel consumption at diferent speeds

Car Speed [km/h]	Engine Rotation [rot/min]	Ratio of transmission in gearbox	Minimum fuel consumption [g/kWeh]
30.00	1230	1.8033	297.6144
40.00	1050	1.1545	265.5091
60.00	1170	0.8577	264.2626
80.00	1350	0.7422	262.6804
90.00	1650	0.8063	272.8741
100.00	1590	0.6993	260.7871
120.00	1950	0.7147	257.5121
140.00	2550	0.8011	252.0421
160.00	3210	0.8824	247.0696
180.00	4350	1.0062	236.5977
190.00	4350	1.0070	241.9400
200.00	5070	1.1150	230.8621

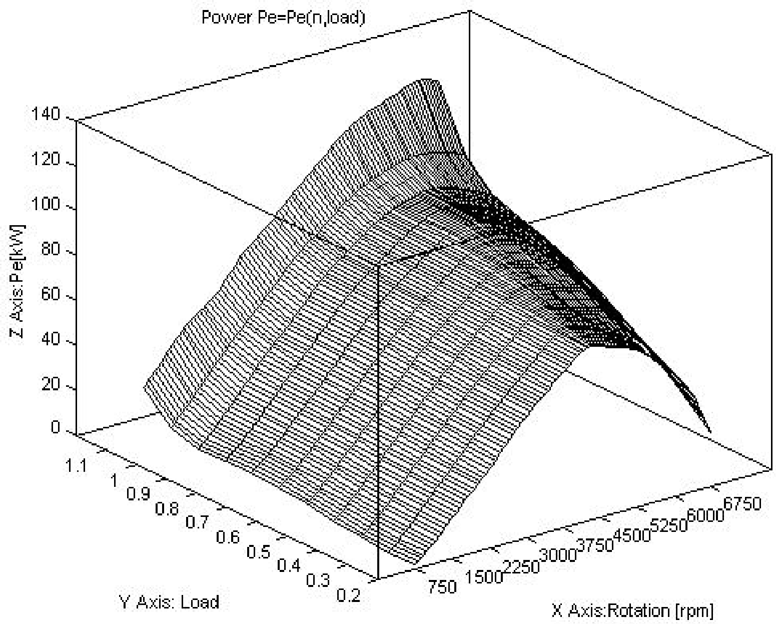

Fig. 1 Power depending on rotation engine and load

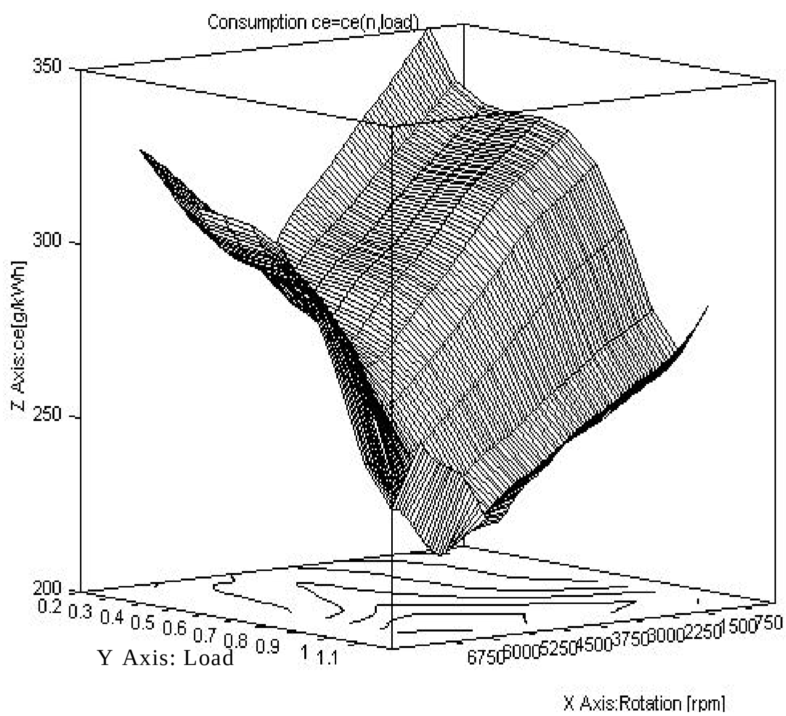

Fig. 2 Fuel consumption depending on rotation engine and load

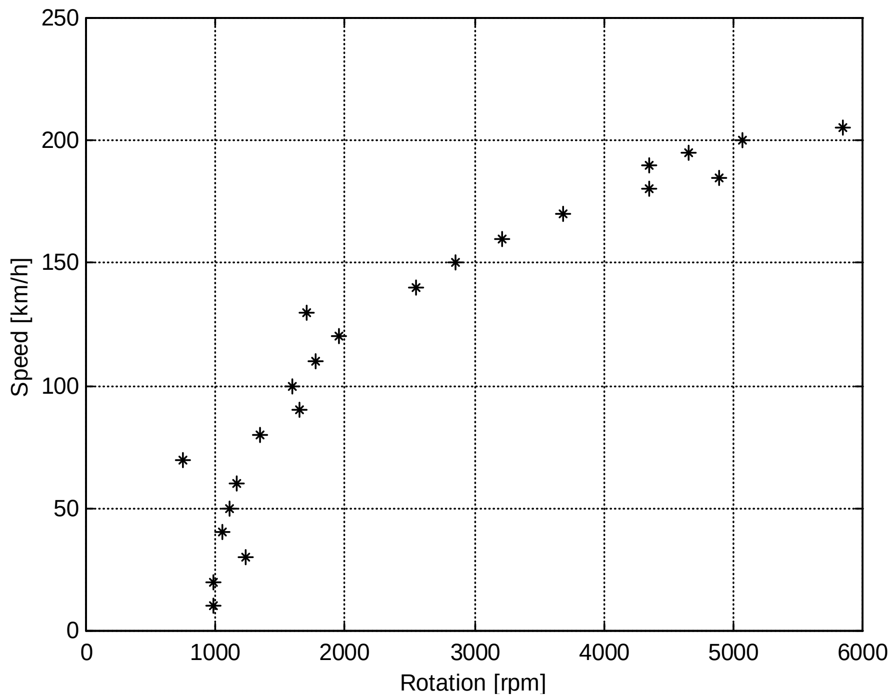

Fig. 3 Speed according to engine rotation for minimum fuel consumption regimes

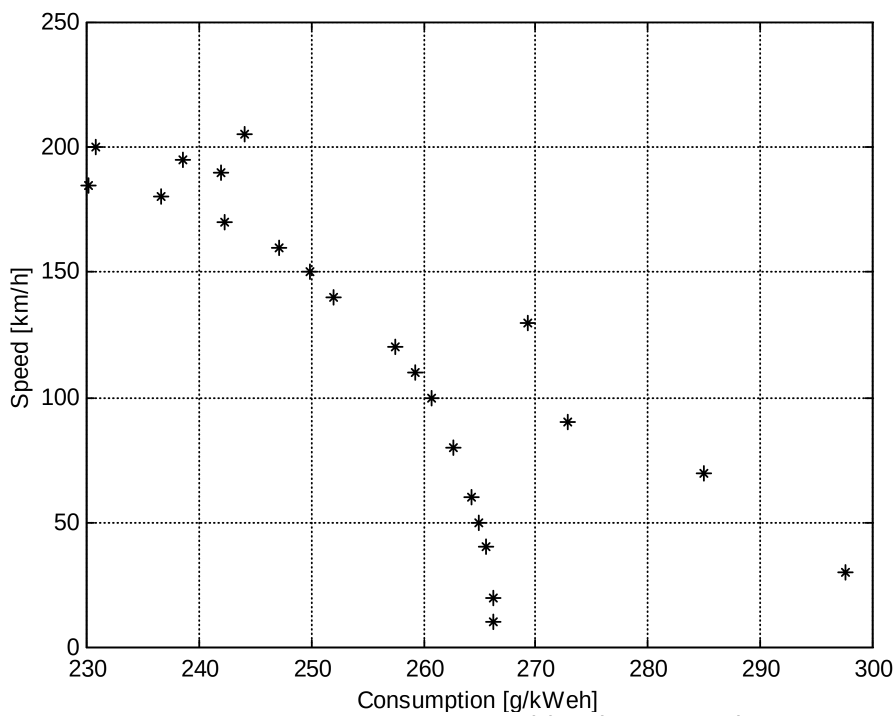

Fig. 4 Minimum consumption of fuel for speeds of the car

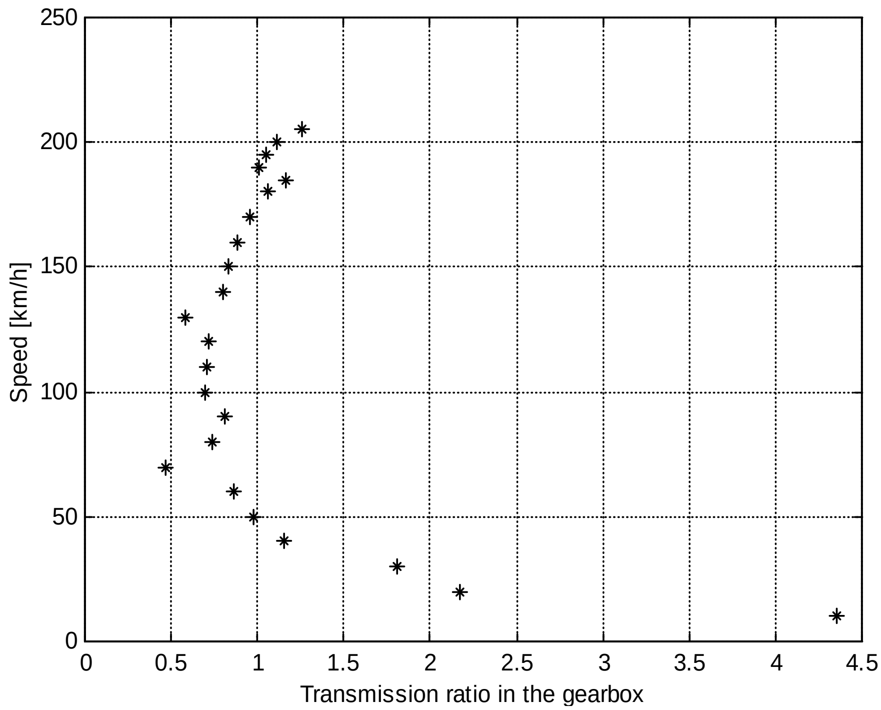

Fig. 5 Transmission ratio gearbox, which ensures minimum fuel consumption for speeds

4. CONCLUSIONS

Determining working conditions in operating the propulsion plants with internal combustion engines applied to road motor vehicles, in order to establish the conditions in operating with minimum real fuel consumption characterized by y_{koptim}, V_{optim}, $i_{tr\ optim}$, n_{optim} for the conditions and restrictions imposed, leads to the realization of important fuel economy, using at maximum the performance of propulsion installations.

The determination of optimum positions of automatically controlling systems is solved using the mechanical functioning characteristics known for the constituent parts, and the interpolation with the help of spline functions (in case of two or three variables) and solve the unlinear equation. The result is the best economic working condition and also the optimum conditions in operating for different speeds of the car. In this way, depending on operating working conditions and external conditions, can produce an automatic control system that is able to command actuators that act upon the throttle position, air flap position for spark ignition engine, respectively the injection pump for diesel engine and gear ratio on the optimum positions, for optimal operating regimes with low fuel consumption.

REFERENCES

[1] **Burciu, M.,** *Systems with Internal Combustion Engines for Propulsion*, Bren Publishing, Bucharest 2003.

[2] **Burciu, M.,** *Internal Combustion Piston Engines – Thermodynamic Processes, Turbocharger, Operating Characteristics and Engine Installations*, Europlus Publishing, Galati 2006.

[3] **Dumitru, Gh., Burciu, M.,** *Program for the approximation of functions with two or three independent variables using Spline functions*, The scientific session in University " Dunarea de Jos " , Galati 1993.

[4] **Potincu,Gh., Tabacu,I.,***Cars*, Pedagogical Publishing Bucharest 1980.

[5] **Reklaites, G.V., Revindran, A., Ragsdell, K. M. ,** *Engineering optimization, Methods and Applications*, John Wiley and Sons , New York, Chinchester , Toronto , Singapore , 1983.