THEORETICAL MODEL OF EXPLOITATION OF AUTOMOBILES OPERATED WITH BIOETHANOL-GASOLINE MIXTURE FUELS

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Abstract. With reduction of the energoresources in the world research in searching for different kinds of energoresources and their application becomes very topical. One of the kinds of renewable energoresources is biofuels that can be used in motor vehicles. Though, a great part of biofuels, if used in pure form or mixed in large percentage to fossil fuel, essentially change the automobile motor operation parameters and due to this also the automobile exploitation parameters. For comfortable determination and investigation of these parameters a mathematical model has been developed with which it is possible to model the influence of mixtures of different fossil fuels and bioethanol on the consumption of fuel, power and torque of automobiles. In the model original analytical calculation methods of the power determination coefficients arte applied. The model operation has been approbated and acknowledged as capable to operate.

Keywords: mathematical model, power, torque, fuel consumption.

Introduction

Exhaustion of fossil energoresources is observed in the world. Every year also the consumption of energoresources increases as the requirements of the inhabitants towards the quality of life become stricter and the number of people increases. The opinion exists that the increase of the inhabitants on the Earth can be characterized by exponential correlation. If the number of inhabitants continues to increase according to this correlation, the sources of fossil energy according to different development models will be enough only till 2050-2060. Due to this reason introduction of new energoresources based on renewable resources is topical.

In order to introduce new energoresources it is necessary to investigate them. The renewable energoresources include also bioethanol that can be used in motor vehicles as fuel.

The most essential parameters characterizing the operation of the Otto motors are the engine power, torque and consumption of fuel. Depending on what fuel is used – fossil gasoline, bioethanol or their mixtures – the values of the above mentioned motor parameters change essentially. In order to prognosticate the changes of the values of these parameters using one or the other fuel, it is necessary to develop the calculation methods by which it would be possible to determine the values of the engine power and torque and the character of their changes theoretically as well as to determine the changes in fuel consumption.

Materials and methods

The maximal theoretical consumption of fuel is in the moment when most fuel is injected. For automobiles with the electronic multy-point indirect injection system it will be at the maximal motor revolutions n_{max}.

The theoretical amount of air that can be fed in the cylinders in the atmospheric motors mainly depends on the operation volume of all cylinders of the motor V_l, that is also called motor capacity. One full cycle in which corresponding to V_l air is fed into the motor cylinders for a four stroke engine takes place in time of two crankshaft revolutions, but for a two stroke engine – during one crankshaft revolution. Due to this the amount of the air used by the motor can be calculated according to the following correlation:

$$Q_{g,t} = \frac{2 \cdot V_l \cdot n_{\max}}{\tau}, \tag{1}$$

where $Q_{g,t}$ – theoretical amount of air consumed in a unit of time, $l \cdot min^{-1}$;
V_l – motor operation capacity, l;
n_{max} – maximal motor crankshaft revolutions, min^{-1};
τ – number of motor strokes.

The values $2 \cdot n \cdot \tau^{-1}$ from the above correlation (1) determine the number of intake strokes per minute. In order to approach the theoretical consumed amount of air to the actual amount of air that is fed into the motor cylinders, the loading coefficient η_v is introduced into the correlation (1). The loading coefficient η_v characterizes the loading of the cylinder with fresh air depending on many factors. Mainly the loading coefficient depends on the air movement speed in the air tract and valve opening. The loss of pressure and worsening of loading related to it according to the laws of hydrodynamics is proportional to the square of the mixture movement speed. In order to increase the loading coefficient the number of inlet valves is increased in many engines of modern automobiles. The loading coefficient is influenced also by the engine warming degree. The more the incoming air is heated the more its density and also the cylinder loading decreases. Still, at correct design of the inlet tract using the incoming air flow in atmospheric motors the loading coefficient can be even higher than 1. Essential increase of the loading coefficient is caused by application of turbo compressors and compressors in automobiles.

Therefore, introducing the coefficient η_v in the correlation (1) and modifying it to obtain the amount of the used air $kg \cdot min^{-1}$ in the result the following correlation is obtained:

$$Q_g = \frac{V_l \cdot n_{\max} \cdot \eta_v \cdot \rho_g}{500 \cdot \tau}, \tag{2}$$

where Q_g – amount of the used air n a unit of time, $kg \cdot min^{-1}$;
V_l – motor capacity, l;
n_{max} – motor crankshaft revolutions, min^{-1};
η_v – loading coefficient;
ρ_g – air density, $kg \cdot m^{-3}$;
τ – number of motor strokes.

Knowing the amount of the used air in a unit of time and knowing the steheometric air-fuel proportion λ of the definite used fuel it is possible to determine the necessary amount of fuel.

The steheometric air-fuel proportion for every kind of fuel has already been approbated in theory and it is known. So, for instance, the fuel-air proportion for gasoline is 14.47 kg of air per one kilogram of fuel, in turn, for 100 % bioethanol (C_2H_5OH) this proportion is 9:1. The steheometric air-fuel proportion of different gasoline and bioethanol mixtures (E5, E10, E85 etc.) changes according to the linear correlation.

So, the necessary amount of fuel $Q_{d,m}$ in kilograms per minute is expressed by the following correlation:

$$Q_{d,m} = \frac{Q_g}{\lambda_x}, \tag{3}$$

where: $Q_{d,m}$ – necessary amouny of fuel per a unit of time, $kg \cdot min^{-1}$;
$Q_{g,}$ – amount of consumed air per a unit of time, $kg \cdot min^{-1}$;
λ_x – proportion of the amount of air necessary for burning of 1 kg of fuel.

Inserting the expression (3) in the correlation (2) we obtain:

$$Q_{d,m} = \frac{V_l \cdot n_{\max} \cdot \eta_v \cdot \rho_g}{500 \cdot \tau \cdot \lambda_x}, \tag{4}$$

The correlation (4) shows the maximally necessary consumption of fuel for a definite engine at maximal motor revolutions. The only value that in the present expression determines the changes of the fuel consumption depending on the kind of the fuel used is the fuel-air proportionality coefficient λ_x that is different for every kind of fuel. Knowing the maximally necessary fuel consumption it is possible to calculate different parameters of the engine fuel feeding system elements as, for instance, the necessary fuel pump capacity, capacity of the injectors as well as the maximal engine efficient power that we are interested in.

The efficient engine power is one of the most essential factors characterizing the engine capacity. The source of energy for every internal combustion engine is fuel. The potential of every fuel or energy is characterized by heating capacity. The heating capacity of gasoline and bioethanol is different, so it can be concluded that the efficient power of the motor using one or another fuel at the same amount of the fed fuel will be different. In ideal case the whole energy of the fuel would transfer into the mechanical energy of the motor, but in real life it does not happen. There are thermodynamic and mechanical energy losses that essentially reduce the coefficient of efficiency of the internal combustion engine.

So, if the heat capacity of the fuel and the consumed fuel in a unit of time are known it is possible to determine the maximally efficient power of the engine considering the energy losses:

$$N_{e,\max} = \frac{60}{3.6} \cdot Q_{z,s} \cdot Q_{d,m} \cdot \eta_e , \tag{5}$$

where: $N_{e,max}$ – maximal efficient motor power, kW;
$Q_{z,s}$ – lowest fuel heating capacity, MJ·kg^{-1};
$Q_{d,m}$ – necessary amount of fuel per unit of time, kg·min^{-1};
η_e – effective motor efficiency coefficient.

Knowing the maximal efficient power of the motor and motor revolutions at which this power is developed it is possible to determine the approximate shape of the motor power curve according to the empirical correlation [3]:

$$N_e = N_{e,\max} \cdot \left(a \cdot \frac{n_e}{n_{e,\max}} + b\left(\frac{n_e}{n_{e,\max}}\right)^2 - c\left(\frac{n_e}{n_{e,\max}}\right)^3 \right), \tag{6}$$

where: N_e – efficient motor power at the motor revolutions in quest, n_e, kW;
n_e – motor revolutions for any point in quest, min^{-1};
$N_{e,max}$ – motor maximal efficient power, kW;
$n_{e,max}$ – motor maximal revolutions, min^{-1};
a, *b*, *c* – empirical coefficients characterising the motor type.

According to the data of the present theories the values of the empirical coefficients of Otto motors are correspondingly: $a = 1$, $b = 1$ and $c = 1$. In general calculations when the characteristic curves of the definite motor are not known, for instance, working with another kind of fuel, usually it is assumed that $a = b = c = 1$. These coefficient values determine the outer character of the power characteristic curves.

In motors, especially in their newest models where electronic injection of fuel is practiced, alteration of the motor characteristic curves is possible according to special fuel or motor operation maps. Such alterations are done in order to adapt the motor to definite exploitation conditions, achieve the maximal power and torque at other motor revolutions than it is in the standard version. In this case correction of the coefficients a, b and c is needed solving the system of equations.

Expressing *a* from the correlation (6) we obtain:

$$a = \frac{n_{e,\max} \cdot N_e}{n_e \cdot N_{e,\max}} - b\frac{n_e}{n_{e,\max}} + c\frac{n^2{}_e}{n^2{}_{e,\max}} \tag{7}$$

If necessary, also *b* or *c* can be expressed depending on which variable we wish to obtain:

$$b = \frac{n^2{}_{e,\max} \cdot N_e}{n^2{}_e \cdot N_{e,\max}} - a \cdot \frac{n_{e,\max}}{n_e} + c\frac{n_e}{n_{e,\max}} \tag{8}$$

$$c = a \cdot \frac{n^2{}_{e,\max}}{n^2{}_e} + b\frac{n_{e,\max}}{n_e} - \frac{n^3{}_{e,\max} \cdot N_e}{n^3{}_e \cdot N_{e,\max}} \tag{9}$$

The torque is calculated according to the correlation [2]:

$$M_e = 1000\frac{N_e}{w_e}, \tag{10}$$

where: w_e – motor rotation angular speed, rad·s^{-1}.

From equation (10) expressing N_e and considering that:

$$w_e = \frac{\pi n_e}{30} = 0.10472 n_e, \tag{11}$$

Correlation (12) is obtained:

$$N_e = \frac{M_e \cdot n_e}{9549} \tag{12}$$

For calculation of the torque the power at different motor rotation frequencies calculated according to the correlation 6 is used.

For calculation of the coefficients the system of equations including the correlation 7 and equations relating all three variables *a, b* and *c* has to be solved [3]:

$$\begin{cases} a = \dfrac{n_{e,\max} \cdot N_e}{n_e \cdot N_{e,\max}} - b\dfrac{n_e}{n_{e,\max}} + c\dfrac{n^2{}_e}{n^2{}_{e,\max}} \\ 1 = a + b - c \end{cases} \tag{13}$$

As the system (13) has three unknown quantities and only two equations, indefinitely many solutions are possible. Therefore, for solution the variables *a, b* are expressed with the variable *c*. Analogical solution can be expressed also for other variables.

From the system of equations (13) using elementary modifications the solution of the system (14) can be obtained that is expressed by the variable *c*:

$$\begin{cases} a = \dfrac{(n^2_{e,\max} \cdot N_e - n^2_e \cdot N_{e,\max})n_{e,\max}}{n_{e,\max} - n_e} - c\dfrac{n_e}{n_{e,\max}} \\ b = 1 - \dfrac{(n^2_{e,\max} \cdot N_e - n^2_e \cdot N_{e,\max})n_{e,\max}}{n_{e,\max} - n_e} + c(1 + \dfrac{n_e}{n_{e,\max}}) \end{cases} \tag{14}$$

Choosing the values of *c* the corresponding values of *a* and *b* can be obtained. The coefficients are found with the iterative or gradual approach method. In this case the value of *c* is assumed, then the value of *a* is calculated and after that the value of *b* according to the second correlation. This way by help of this method the power curve for a definite motor is calculated. For automation of calculations it is useful to apply the Microsoft Excel table where calculation is performed according to the equation system 14 drawing the curve in the graph.

Results and discussion

For practical testing of the theoretical calculations the theoretically obtained power curve and the power curve obtained in the experiments (for automobile VW Passat with 1.8 l motor) are graphically compared (See Figure 1). The same graph shows also the power curve without correction when $a = b = c = 1$. Changing the coefficient *c* in the range from 0.4 to 0.05 a curve maximally approached to the experimental results is obtained. In this case using extrapolation it is possible to obtain also the parts of the power curve that are difficult to be obtained in experiments, for instance, at the maximal and idle revolutions of the motor.

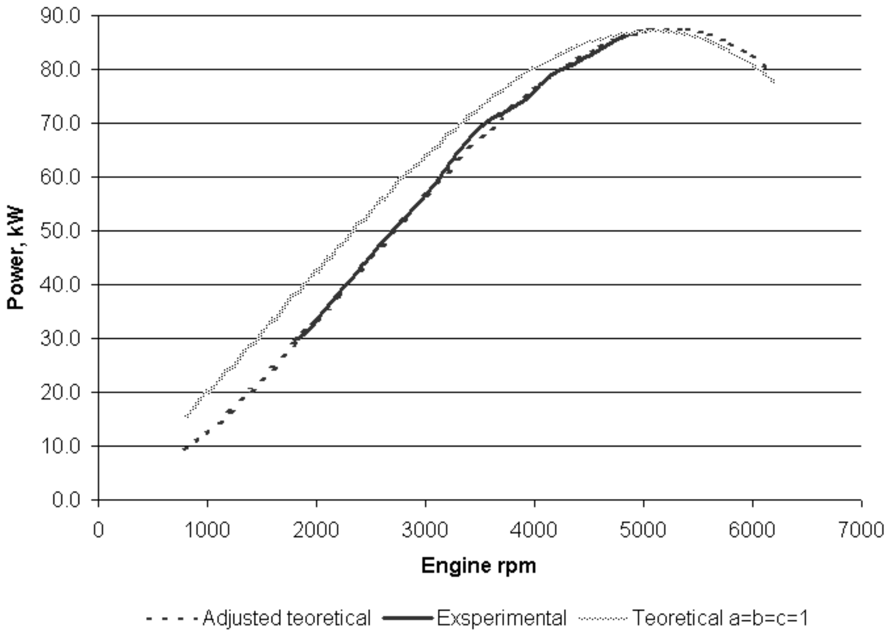

Fig. 1. **Motor power curves**

In Figure 1 it can be seen that constructing the power curves with the Otto motor empirical coefficients $a = b = c = 1$ assumed by now, they do not correspond to the actual character of today's Otto motor power curve. In order to obtain a theoretically calculated power curve that in its character is close to the experimentally obtained curve it is necessary to correct the coefficients *a, b* and *c*.

Applying the given methods it is possible to determine power curves of motors with different capacity, compare the theoretical and experimental curves in order to determine the specific improvements of the motor.

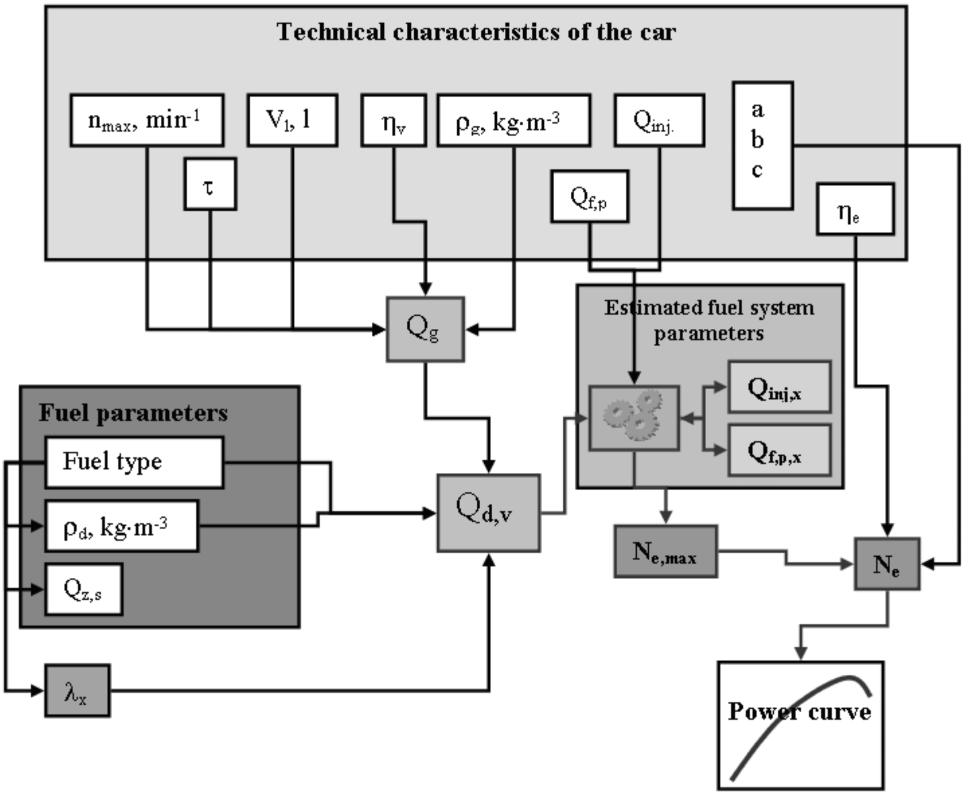

Fig. 2. **Block scheme of power characteristic curve construction**

The correlations described in the part about the methods allow for correlation of definite characteristic values of automobiles with different fuels. In the result it is possible to evaluate how the fuel consumption and the power of the automobile change depending on the fact if pure gasoline, E85 or gasoline and bioethanol mixture in another proportion are used. Besides determination of the above mentioned parameters enlarging the calculation methods it is possible also to determine whether the capacity of the automobile injectors is large enough to be used for operation with bioethanol - gasoline mixtures. It is possible to calculate the capacity of the injectors to be installed for operation of standard gasoline automobiles with E85 or gasoline – bioethanol fuel of other proportion.

In the result of the calculation methodology also a detailed block system has been developed that shows the correlations of the motor feeding system elements of different automobiles with the qualities of the used fuel and their influence on the consumption of fuel as well as the motor power characteristic curve (See Figure 2).

Conclusions

1. Original methods have been developed for determination of the motor maximal power using gasoline and bioethanol mixtures of different compositions
2. The methods for construction of the internal combustion engine power curves used by now are not adequate to the power curves of today's motors that are obtained in experimental research; due to this reason methods for determination of corrected power curve calculation coefficients should be elaborated.
3. For correction of the power curves at different motor rotation frequencies three coefficients are used – *a, b* and *c*. After determination of these coefficients for a definite motor it is possible to obtain power curves that differ from the experimentally obtained not more than by 3 %.
4. For determination of the coefficients the calculation methods have been developed by means of which it is possible to determine the coefficients using the iterative or gradual approach method. Altering the coefficient *c* other coefficients are calculated.
5. The corrected coefficients can be used for determination of the operation parameters of a definite motor also with other fuels as well as with bioethanol and fossil fuel mixtures of different compositions.
6. Using the power alteration curves it has been envisaged to develop in future an algorithm for determination of the automobile dynamic factor, run-up acceleration and run-up time.

References

1. Automotive Handbook. 7th Edition. Robert Bosch GmbH, July 2007. 1196 p.
2. Pommers J., Liberts G., Theory of Ground Motor Vehicle. Riga: Zvaigzne, 1985. 248 p. (In Latvian).
3. Blīvis J. Gulbis V., Kažoks J. Constructions, theory and calculation of motors of tractors and ground motor vehicles. Riga: Zvaigzne, 1980. 375 p. (In Latvian).