IMPACT ANALYSIS OF DYNAMIC SUPERCHARGING ON ENGINE PROPERTIES

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Summary. This paper presents the results of research work into the influence of dynamic supercharging on the course of torque curve and matching of engine characteristics to the driving conditions of the vehicle. Some tests results concerning dynamic supercharging of SW-680 engine were obtained, particularly concerning its influence on the torque curve. Methodology, suggested by the author, of simulation tests concerning adjustment of engine working point to the conditions of driving, was explained.

Key words: dynamic supercharging, driving conditions, torque curve.

INTRODUCTION

One of the most essential factors determining the functional properties of traction engines is the value and shape of torque curve, which is of much importance for the engine working on external characteristics with violent changes of vehicle resistance to motion [2]. In such cases, the engine is required to have self-regulation properties. This means that the engine intrinsically adjusts to the changing load during its operation. This self-acting adjustment of the engine to the load is conditioned by a proper course of the torque curve on the engine external characteristics. In the area, where the torque curve goes down along with the increase of rotational speed, a condition of constant equilibrium between engine torque and the torque resulting from resistances to motion is possible, and a change in load leads to self-acting establishment of a new condition equilibrium, with simultaneous reduction of rotational speed of the engine crankshaft. The steeper the torque curve, in the area in question, goes down, the faster the condition of equilibrium occurs. This means that the rotational speed range of changes, required for the achievement of a new condition of equilibrium, will be lesser. The discussed phenomenon of self-adjustment is referred to as engine elasticity [2]. As can be seen, the course of torque essentially influences the dynamic properties of the engine, thus influencing the traction properties of the vehicle (ability to accelerate, gradeability) [12]. Hence, the possibility of having an influence on the course of engine torque curve is a very important issue. In order to achieve good dynamic properties and high elasticity of the engine, its maximum torque area should occur at possibly lowest rotational speeds of the crankshaft.

High value of nominal power and proper shape of engine external characteristics has a favourable influence on the vehicle acceleration and gradeability at full load without the necessity of changing the transmission ratio. However, it should be stressed that a traction engine is operated in such conditions extremely rarely. Most of the total working time falls on low and medium engine loads. This determines the directions for optimization of design and regulation parameters of the engine, which combines engine properties with the ways of operation [3,6,7,17]. Such action leads to reduction of fuel consumption and toxic compound emission by the engine in average operating conditions through the increase of engine efficiency in the areas of the characteristics, where it is operated most of the time.

The increase of torque value in the area of low rotational speeds on the full power characteristics, together with adequate change of transmission ratio, cause that the engine working point is shifted towards the higher overall efficiency. Engine work at lower rotational speed in the area of lower unit fuel consumption has an effect on reduction of fuel consumption in average operating conditions.

Engine operating conditions can be expressed as a distribution of engine relative operating time in conditions defined by torque values Mo and rotational speed values n, limited by the area of general characteristic. These can be obtained by performing road tests of a specific vehicle in real operating conditions. The thus obtained collection of pairs of values Mo and n is referred to as Time Density Characteristic [3], which combines engine properties with its way of operation (Fig. 1).

The results of these tests, after taking into account the characteristics of drive system and the way of driving the vehicle, make a proper collection of data regarding engine conditions and enable the plotting of the wanted characteristic.



Fig. 1. Engine relative operating time in specific ranges of torque in urban traffic.

The most effective way of achieving an increase of engine torque, without increasing its size, is the increase of the mean effective pressure p_e. The achievement of increase of the mean effective pressure value requires that air with higher density should be fed to the engine. This is obtained by initial compression of air as a result of supercharging.

TESTING

One of the supercharging systems, which does not require using of any additional supercharging equipment, is a dynamic supercharging, which uses oscillations of air column in intake pipe, hence, the basic problem is to define the frequency of free oscillations of the medium in the inlet system. Understanding the phenomena occurring in the intake system will enable their usage for the improvement of filling.

A typical intake system consists of intake pipes, valves and intake manifold (Fig. 2). Intake pipe is a system, which is closed at one end by the intake valve. At the other end, the intake pipe is connected to the intake manifold, which can be considered as environment. Diagram of dynamic supercharging system is shown in Fig. 2.



Fig. 2. Diagram of dynamic supercharging system [10] 1- intake manifold, 2- intake pipe, 3- intake duct, 4- exhaust duct, 5- exhaust manifold

The author's former tests show that the dynamic supercharging only increases the torque in a small range, however its basic advantage is the possibility of changing the rotational speed at which this torque occurs [9,10,11]. The truck engine most often works in the range of medium rotational speeds and loads. Therefore, it will be advantageous to get the dynamic supercharging effect in this range. A special feature of dynamic supercharging is that the effect of supercharging occurs in a certain, rather narrow range of rotational speed [5,13,16,18]. Therefore, the geometrical parameters of the intake system, particularly the length of the intake pipes, should be selected so that the effect of supercharging occurs in the desired range. As a result of the preliminary tests [9] of the intake system, during which performance of SW-680 engine with dynamic supercharging system were compared at different lengths of intake pipes, the intake pipes length was determined at which the supercharging effect should occur at lower rotational speed than in the case of a standard engine. The best results were achieved for the length of $L_d=843$ mm. These results are shown in Fig. 3 as an external characteristic.



Fig. 3. External characteristic of SW-680 engine with dynamic supercharging system, for intake pipe length of 843 mm.

The characteristic shows that the maximum torque occurred at the rotational speed somewhat over 1200 r.p.m. while in the case of a standard engine the maximum torque was achieved at 1400 r.p.m. The value of torque increased insignificantly, practically within the limits of measuring error.



Fig. 4. Universal characteristics of SW-680 engine with dynamic supercharging system, for intake pipe length of 843 mm.

As already mentioned, in traction uses the engine is operated extremely rarely within the area of external characteristic, therefore the author thinks it is advisable to define engine working parameters corresponding to any possible operating conditions. Therefore, it is necessary to have a set of rotational speed characteristics, determined at different settings of injection pump, or load characteristics determined for the whole range of obtainable rotational speeds of the engine. Much more convenient than using a set of partial or load characteristics is using a universal characteristic, which shows, on a single curve, the operating capabilities of an engine and defines its unit fuel consumption in any operating conditions [1]. The universal characteristic of the tested engine, defined on the basis of a set of load characteristics, is shown in Fig. 4.

The universal characteristics shows that the contour line of relatively low unit fuel consumption (220 g/kWh) occupies a significant area of the rotational speed and load range. It should be also noted that this area includes the range of low and medium rotational speeds and medium loads, thus overlapping with the area where the truck engine works most frequently [3]. Therefore, it is highly probable that the engine operating point will be present exactly in this area of the characteristics, preferably due to high efficiency.

On the universal characteristics (Fig. 4), lines of torques under which the engine is put are present, corresponding to basic resistances to the truck motion. These lines were defined for the fifth and sixth gears using the following relation [2,8]:

$$M_{op} = \frac{\left(W_{t} + W_{p}\right) \cdot r_{d}}{i_{c}} = \frac{\left[f_{t}^{0}\left(1 + 0,0005 \cdot v^{2}\right) \cdot G_{c} + 0,613 \cdot c_{x} \cdot F \cdot v^{2}\right] \cdot r_{d}}{i_{c}}$$

where: W_t - rolling resistance [N],

W_n – rolling resistance [N],

 r_d – wheel dynamic radius [m],

 $i_c = i_b i_g i_{zw}$ – total ratio as product of gearbox ratios, final drive ratio and wheel reduction gear ratio,

 f_t^0 – rolling resistance basic factor

v - vehicle speed [m/s],

- c_x non-dimensional air resistance factor (shape factor)
- G_c vehicle total weight [N],
- $F end face [m^2].$

These lines are marked with the symbols M_0 5th gear and M_0 6th gear in the drawing. As can be seen, the anti-torque line for the 5th gear is located in the area of the characteristics where the unit fuel consumption is higher than 260 g/kWh, while the anti-torque line for the 6th gear is located in the contour lines of unit fuel consumption of 260 g/kWh, 250 g/kWh, 240 g/kWh and 230 g/kWh. These are the above-mentioned lines determined for the values of total ratios in the drive system of a standard quality engine. In this quality the truck engine will never operate in the most effective manner, particularly in 5th gear, that is at low unit fuel consumption and high efficiency.

The next lines, marked in the drawing as M_o ' 5th gear and M_o ' 6th gear, show anti-torque values corresponding to basic resistances to motion for the ratio whose value is lower than the standard factory value. In the presented simulation, the value of final drive ratio was reduced from 1.96 to 1.5.

As can be seen, the course of these lines is much more advantageous, especially for the 6th gear. With this ratio, the anti-torque line runs in a considerable part through the area of minimum fuel consumption. The engine is therefore operated with the highest efficiency.

CONCLUSIONS

On the basis of the presented tests and simulations it can be stated that the dynamic supercharging does not have a substantial effect on the value of maximum torque of the engine, but instead it has quite a significant effect on the value of rotational speed at which the maximum torque occurs. Such shifting results in an increase of the rotational speed elasticity (rotational speed span), and consequently there is an increase of elasticity factor, which is a product of torque span and rotational speed span. The increase of elasticity factor of the torque and shifting its maximum to the area of lower rotational speeds significantly influences the improvement of engine traction properties. This allows for the reduction of the number of ratios in the gearbox and change of the final drive ratio of the vehicle. This can therefore be an effective method of adjusting the engine characteristics to the distribution of loads occurring in the engine operating conditions.

As a result of reduction of rotational speed value at which the maximum torque occurs, an effective operation of the engine is possible in the area of medium and low rotational speeds and loads, that is in the area of universal characteristics in which the engine is operated most frequently. The achieved value of the area of the lowest unit fuel consumption allows to suppose that in the real conditions of driving there is a high probability of being in this operating point of the engine.

When using dynamic supercharging, one should perform a simulation of the course of antitorque lines corresponding to the basic resistances to truck motion for the specific values of the ratios. In the presented analysis, a reduction of final drive ratio was carried out, as a result of which the anti-torque line for the 6th gear is located, in its significant part, in the area of low unit fuel consumption. Probably a more advantageous solution would be a change of gearbox ratios since the reduction of the final drive ratio value will influence the total ratio for all gears, which will reduce the gradeability at the reduced value of ratio.

Therefore, it can be seen that the use of supercharging should also cause changes in the truck drive system in order to adjust the engine to the most frequently occurring conditions of driving.

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