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VALVE MECHANISM WEAR IN GASOLINE INTERNAL COMBUSTION ENGINE DURING CONVERSION TO GAS

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Annotation. The main trends in automobile gasification are being considered. It is noted that a noticeable decrease in the valve mechanism durability when operating on gas is associated with the valve recession, which is proportional to the linear wear rate of the valve-seat pair and the length of the friction path, depending on various factors. Based on the data obtained, it was determined that converting a serial gasoline engine to gas without making changes to the valve mechanism design means an absolutely inevitable reduction in the valve-seat interface life. A methodology for calculating economic efficiency has been compiled and the characteristic boundaries and area of effective use of gas equipment in automobiles have been determined. It is shown that despite the large difference in prices between gas and gasoline, the total economic effect of converting a gasoline engine to non standard gas fuel for the entire period of the vehicle operation does not exceed 15-20% and, in general, has a number of serious limitations, not only economic, but and technical nature.

Keywords: internal combustion engine, gas fuel, gas equipment, valve recession.

Introduction. The transition of serial gasoline engines to gas motor fuel (liquefied propane-butane or compressed natural gas) has been considered as a promising one for various types of transport for a long time in many countries. The main advantages of such a conversion were previously denoted to be environmental benefits, including more complete combustion of the gas-air mixture, a significantly lower cost of gas and a longer durability of the cylinder-piston group.

However, serious problems may arise in the further operation of an engine converted to non-standard fuel. The advantages of gas in durability for the cylinder piston group are known. When gas is operating, there is no deterioration in lubrication due to the washing off oil by fuel from the cylinder surface and there is no carbon formation on the parts, as is known with gasoline. In such conditions, an engine oil lasts longer and is practically free from degradation when exposed to fuel. At the same time, when the engine is running on gas, accelerated wear of the valve mechanism is revealed in the form of the so-called valve recession, as it shown in Fig. 1. Moreover, accelerated wear is shown not only in the connection of the valve with the seat [1], but also the valve rod with the guide [2, 3].

The main reason lies in the breakage of the part lubrication during the complete combustion of the gas-air mixture, when the lubricant materials are absent in connection between parts (with gasoline it is carbon deposits and gasoline resins). In this case, the rotation and impact of the valve when landing on the seat, necessary with gasoline to remove carbon deposits and resins from the surface, on gas leads to dry friction and rapid wear due to impact loads. And since such wear of the "valve seat" pair, as practice shows, is a key factor in the transfer of an engine from gasoline to gas, the study should be based on the basic laws of this process.

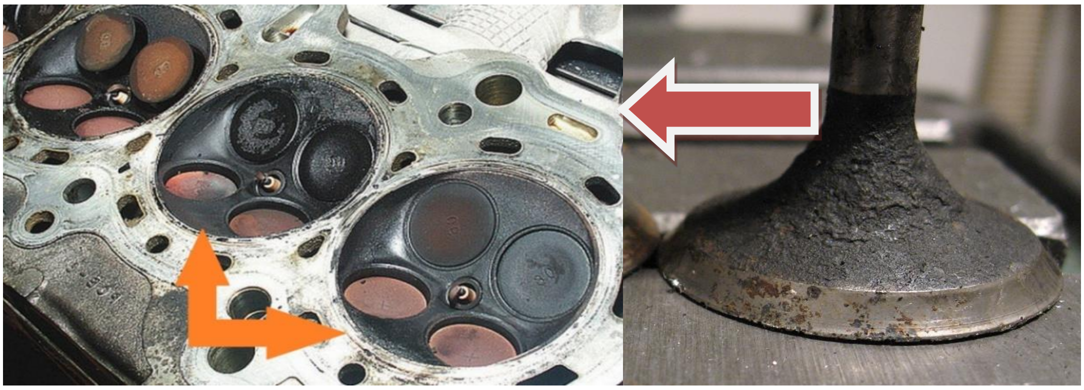

Fig. 1. Valve recessing during operation on gas (left) occurs due to intense wear of the seat and valve chamfer (right) [1, 3]

Aim. The purpose of the work is to develop a methodology and obtain quantitative data to assess the economic efficiency and technical feasibility of converting passenger car gasoline engines to natural gas fuel, taking into account various technical limitations and real economic costs.

To achieve this, it is necessary to analyze the main patterns of the effect of gas on the wear and durability of components and parts of gasoline engines, as well as to perform a comparative analysis of the technical and economic factors operating in the operation of vehicles of this type.

Materials and methods. To obtain quantitative estimates, it is necessary to consider what constitutes and on what the wear of the valve-seat interface depends. By definition, the linear wear rate W is the ratio of the wear value to the friction path along which this wear occurred, which can be written as [4]:

$$\boldsymbol{W} = \frac{\boldsymbol{\delta_\omega} + \boldsymbol{\delta_u}}{\boldsymbol{L}_\Sigma}, (\mathbf{1})$$

where $\boldsymbol{L}_\Sigma = \boldsymbol{L_\omega} + \boldsymbol{L_u}$ is the total friction path, δ_u is the amount of valve wear in one valve operation cycle during its linear movement when sliding on the seat at a speed u, δ_ω is the same when the valve rotates at an angular velocity ω.

When the wear of parts is expressed in a linear change in their dimensions, such wear can be represented in a complex way as valve recession [5] δ_Σ in the seat as a result of wear of both the valve itself and the seat:

$$\boldsymbol{\delta}_\Sigma = \boldsymbol{W}\boldsymbol{L}_\Sigma, (\mathbf{2})$$

whence it follows that the valve recession is proportional not only to the intensity of wear, but also to the path of friction, which is the greater, the greater the speed of rotation and seating of the valve into the seat (Fig. 2).

As a result, for the “valve-seat” pair under consideration obvious design measures follow to reduce wear when the engine is changed to non-standard fuel [6, 7]:

Decreasing the specific pressure of the valve on the seat [2, 6]. It is achieved mainly by a significant (several times) increase in the width of the working chamfer (Fig. 3),

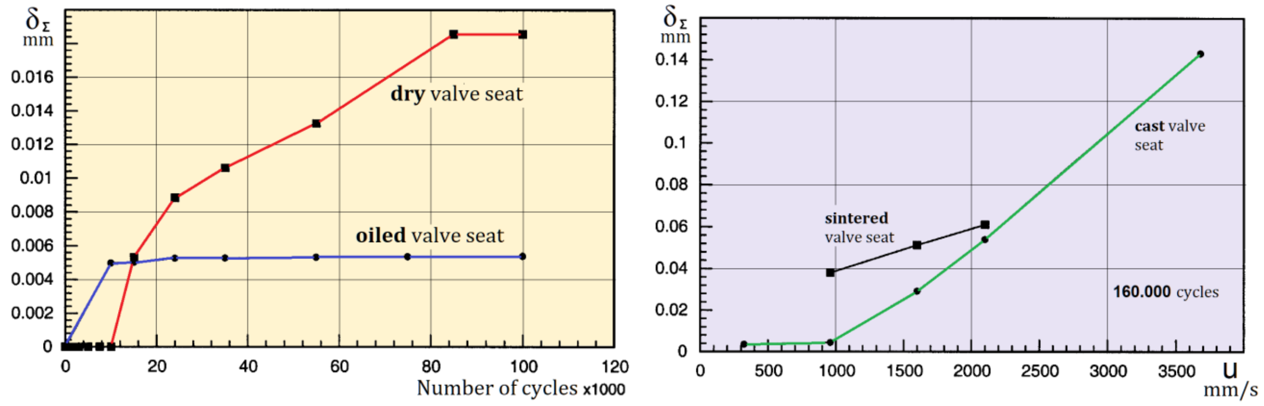

Fig. 2. Influence of valve impact and sliding in the seat on the valve recession (according to the data [5])

Reducing the friction path by eliminating sliding and preventing the rotation of the valve. It is achieved in 2 ways: using the design of a fixed fit of valve keepers and the valve stem in the spring retainer, and installing 2 concentric valve springs with the opposite winding direction (Fig. 3),

Reduction of valve impact speed during landing. It requires the use of other camshaft cam profiles with a smoother fit and, possibly, hydraulic compensators,

An increase in the hardness of the valve material. It is provided by applying a traditional wear-resistant chamfer coating with a special material such as Stellite [8].

Increasing the hardness and wear resistance of the seat. It also requires special materials with special properties [9, 10].

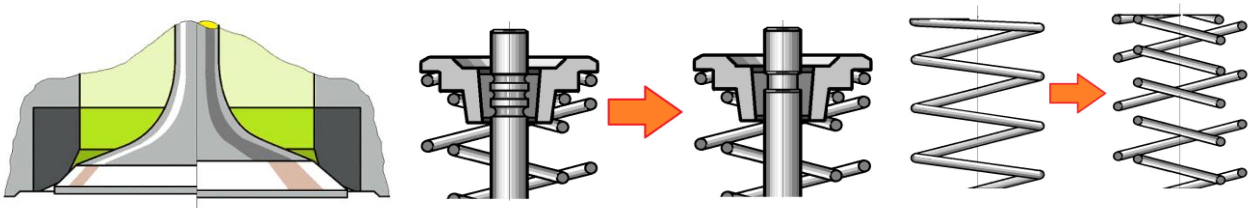

Fig. 3. Some design measures to reduce wear during the transition to gas fuel, which lie from the design models for the wear of "valve-seat" pairs: a wide valve working chamfer (left), valve keepers with a fixed fit (center), concentric springs with the winding opposite direction (right)

As shown in [2], the simultaneous and complete satisfaction of all these requirements makes the engine inoperable on gasoline, since the valve-seat interface loses its tightness due to a breakage of the self-cleaning of the working contact surface from resins and deposits [5].

At the same time, it is obvious that it is impossible to satisfy these requirements when converting a serial gasoline engine to non-standard gas fuel without making serious changes to the design of the valve mechanism. Even despite the fact that the very transfer of a gasoline engine to non-standard fuel is already a change in the design of the engine. This feature of the engine re-equipment turns out to be a key factor in operation, since it means an absolutely inevitable reduction in the life of the valve-to-seat interface.

If the data on the effect of gas on the life of the valve train is known (and if it is not known, the risk of a car owner suffering serious losses instead of saving may be unacceptably high), the economic efficiency of operating on gas compared to gasoline can be calculated.

For this purpose, it is necessary to set some parameters for the car and its engine, including: C_{LPG} is the cost of LPG equipment, its installation and certification, L_b is engine life on gasoline (km), G_b is gasoline consumption (liters / 100 km), C_b is the cost of 1 liter of gasoline.

In addition, it is necessary to set the gas mass flow coefficient g (taking into account the difference mainly in the density of gas and gasoline) and the price coefficient q_c for 1 liter of gas compared to gasoline. In addition, you should also set the relative repair cost q_{rep} of the engine (showing how many times the repair is more expensive than installing LPG) and the relative durability of the engine l_g on gas (showing how much times the engine mileage before repair on gas is less than on gasoline). These quantities can be written like this:

$$\boldsymbol{g = \frac{G_g}{G_b}, q_c = \frac{C_g}{C_b}, q_{rep} = \frac{C_{rep}}{C_{LPG}}, l_g = \frac{L_g}{L_b}. (3)}$$

Then the relative (concern to gasoline) cost of operating on gas for a service life corresponding to operating on gasoline can be written as:

$$\bar{C} = 100\frac{C_{LPG}}{L_b G_b C_b}\left(1 + \frac{q_{rep}}{l_g}\right) + q_c g. (4)$$

In formula (4), the second term corresponds to the theoretical economic efficiency of gasification of a gasoline engine without taking into account additional costs. The first term includes such costs; these are the initial costs for the LPG installation and the possible repair of the valve mechanism during operation. As practice shows, it is the first term that is often not taken into account, while it largely determines not only the real economic efficiency, but also the technical feasibility of switching the engine to non-standard fuel.

Results and discussion. When performing calculations according to formula (4), the following initial data were taken: gas mass flow rate compared to gasoline g=1,40, price coefficient of a liter of gas compared to gasoline q_c = 0,50, cost of LPG equipment, its installation and certification C_{LPG} = 600.00 USD, engine life on gasoline L_b =150.000 km, gasoline consumption G_b =10 l/100 km, cost of 1 liter of gasoline C_b =1,00 USD. The calculations were performed with several values of the relative cost of engine repair qrep in the range of 0,5-3,0 and relative (concern gasoline) engine service life l_g in the range of 0,25-1,0.

The results of calculations using formula (4) are shown in the diagram (Figure 5), where you can see the following characteristic boundaries and areas:

1) The lower limit of economic efficiency at $\bar{C}$ = 0,70 corresponds to the maximum theoretical efficiency of the engine running on gas without taking into account costs. Then $\bar{C}$ = 0,30 (30%) is the fuel savings that the consumer would receive if his initial costs are zero (psychological level $\bar{C}$ = 0,50, i.e. 50% savings that the consumer can see at a filling station in a direct comparison of gas and gasoline prices is not shown because it is not real).

2) The upper limit $\bar{C}$ = 1.0 is the payback limit corresponding to zero economic efficiency. Higher, the transition to gas generally loses its economic meaning, since it physically means a loss (additional, in comparison with gasoline, the cost of operating on gas). In fact, the payback limit is somewhat lower and amounts to $\bar{C}$ = 0.90-0.95, since the calculations did not take into account the loss of time and

possible moral damage from an increase in the number of repairs and their cost.

In addition, the area of economic efficiency of converting to gas will be limited on the right - by the inevitable reduction of the valve mechanism durability of any gasoline engine running on gas. There is also a limit on the left in terms of the number of repairs or replacements of the cylinder head. For example, if the number of repairs is more than three during the life of the car, we can talk about the technical inexpediency of gasification of this car. As a result, the area of economic efficiency of gasification of a particular car can be shown as an oval (Fig. 4).

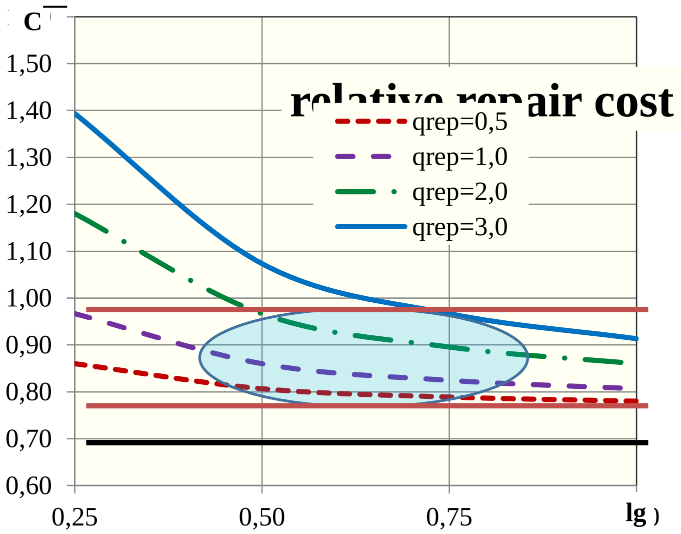

Fig. 4. The approximate area of economic efficiency of switching the engine to gas fuel at the various values of the relative durability and the relative cost of intermediate repairs.

the existing operating experience and data on the wear pattern of the valve It is easy to see that even a not very expensive version of LPG makes the maximum possible efficiency of switching a car to gas obviously higher than $\bar{C}$ = 0.80. That is, the greatest savings will be only 20% and, at best, will be half as much as follows from a simple comparison of gas and gasoline prices at gas stations. With the growth of the cost of inevitable repairs, the transfer of the engine to non-standard fuel becomes less and less profitable. For example, if the cost of repairs is twice the cost of the installed LPG, it will already be economically inefficient even with a slight decrease in durability.

For a number of car models, especially high-end ones, the apparent benefit from operating on gas can lead to serious losses, which are determined by excessively high repair costs in cases of a noticeable decrease in the life of the engine valve mechanism when operating on non-standard fuel.

Conclusions. According to the results obtained, there are 2 main limitations for unauthorized converting a gasoline engine to gas fuel: the engine durability on gas (no more than 2 times less than gasoline) and the relative cost of engine repairs (no more than 2 times higher than the cost of LPG installation).

As a result of the combined action of all factors, the area of permissible, from the conditions of economic efficiency, the use of gas-cylinder equipment can be significantly narrowed to inexpensive cars of a small class, as well as common car models for which non-original and / or inexpensive cylinder heads exist and are supplied as spare parts. The final conclusion about the economic efficiency (or inefficiency) of converting a specific car model to gas fuel is possible by only taking into account mechanism of a particular engine.

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