RESEARCHES ON FRICTION FORCE BETWEEN VALVE MADE OF TIAL AND ITS GUIDE MADE OF PHOSPHOROUS BRONZE

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Abstract

A lightweight valve can be one made of steel but with a drilled stem. Another one can be made of TiAl alloys and its stem can be full or drilled. Lightweight valve can be also ceramic one made of Si3N4. Such valves can mate with guides made of cast iron or of phosphorous bronze in varying conditions in their common contact zone. The aim of researches has been to measure friction force in contact zone between valve stem made of TiAl alloy and its guide made of phosphorous bronze, in the absence of oil. The conditions of room temperature and of the atmosphere pressure have been used during experiment. Mentioned researches have been provided in tester, which design has been presented in the article. The loading of contact zone has varied periodically during serie. The displacement and acceleration of valve and the force during its impact into seat insert have been measured during tests. Additionally the sound level has been measured, either. Tests have been provided for different frequency of driving force. Obtained results of researches has been shown in the article. In all cases the measured sound level have been equal 94 dBA, when sound level of laboratory environment has been equal 40 dBA. Values for coefficient of friction between valve stem and its guide can change from 0.12 to 0.16 and decrease almost linearly with increasing of loading frequency. Values of dry friction coefficient between valve stem made of TiAl alloy and coated by chrome and its guide made of phosphorous bronze can be smaller up to 17% than values obtained in case of valve stem coated by nc-WC/a-C:H mating with a guide made of cast iron.

Keywords: *valvetrain, lightweight valve, friction force, TiAl alloy, phosphorous bronze*

1. Introduction

According to the current trend to reduce movable masses of valvetrain, lightweight valves are used in internal combustion engines. They can be made of light alloys of TiAl group or of ceramic materials such as silicon nitride. They are often coated with additional protective layers to reduce friction or the wear intensity. They may also be drilled steel valves, with the possible use of internal reinforcing ribs. Such valves can mate with guides made of cast iron or of phosphorous bronze in varying conditions in their common contact zone. The aim of present researches has been to measure the friction force in contact zone between valve stem made of TiAl alloy and its guide made of phosphorous bronze, in the absence of oil.

2. Methods for valves weight reduction

Weight reduction of 40% for the valve allows spring stiffness reduction by about 30%. In summary lightweight valves may occur as a hollow steel, alloy Ti-Al, or a ceramic.

2.1. Drilled valves

As it has been mentioned above, one way to reduce the weight of valves is the use of their drilled design. Valve stems are drilled, and micro-polished. Such drilling can be performed at 2/3 the upper part of the stem, where the stiffness is less of order than in the zone just above the valve head. After drilling, a hardened tip is welded at the top of the stem. As a result, it is obtained a valve lighter up to 20% than one of the full stem. The use of drilled valves in place of the full one can increase engine speed range of 300 -350 rpm, without having to modify the valvetrain [2].

Micropolishing reduces significantly the risk for the occurrence of indentations on the inner surface of the stem [3].

Drilling reduces the strength, so for the valves somewhat stronger alloys should be used. The durability of drilled valves used in naturally aspirated engines is not worse than one of full valves. However, they are generally used in the engines supercharged, turbocharged and used natural gas, due to the increased amount of generated heat in the engine. In engines more termally loaded, the drilled valves filled with sodium are used, particularly, as outlet one. The liquid molten sodium allows the heat transfer from the valve head to its stem during movement of the valve. The valve transfer through its stem up to 25 percent more heat than one with a full stem. This allows operation of the valve in stronger heat loading of its head [2].

Empty drilled valves are approximately 10% lighter than one filled with sodium [3].

The Mahle Ventiltrib Company has developed a drilled valve, filled with sodium, made of N06601 alloy containing 60% Ni, which has been 30-50% lighter than conventional valves. It can operate in temperatures up to 1230 K. Valve components have been made of steel with a thickness of 0.8 -1.8 mm, and welded by laser method [4].

Drilled valves can also be made of titanium alloys. [3]

Drilled steel valves have got chromed stems and seats with a hardness of 42 HRC [3].

Drilled titanium valves are available, either solely of drilled stems or a combination of drilled stems and heads. The use of only drilled stems reduces the valve weight by about 10 percent, and the drilling of valve head by additional 0.6 - 0.8 g depending on the valve size. The interior of the valve head can be strengthened, for example by ribs, to ensure adequate strength and stiffness [5].

2.2. Utilization of TiAl alloys

Currently, there are several methods for obtaining titanium valves. One of them is a powder metallurgy. Powder metallurgy allows to produce titanium rods for hot forging. Other titanium outlet valves are made by casting and rolling the Ti6Al2Sn4Zr2MoSi alloy. To increase the wear resistance of these valves the plasma carburizing is used [6].

Many titanium valves are produced by the initial forging and machining to final shape. Some design forms are met as two partially treated segments joined together by friction welding, and then machined to the final shape [5].

To ensure hard cup for valve stem it is used currently three methods: hardened steel cap, cap with ceramic coating, thin film coating by PVD technology [5].

Since titanium is a relatively soft material, the additive hardened caps are usually used. For the valve stem of diameter less than 7 mm, it is used hard coating for the stem tip to avoid impacts of friction nature in contact zone between the cup and the valve stem tip [5].

In the case of titanium valves with Stellite tip friction welded, such tip can be ground during the repair, but up to a maximum 0.015 - 0.020 mm [5].

2.3. Ceramic valves

Using the ceramic valve in place of the steel one it can be obtained the reduction of the valve weight up to 56% and of the valve spring loading up to 20% [6].

Ceramic valves made of Si_3N_4 were intensively investigated for applications in both light and heavy duty engines. In light duty engines it has been appeared the improvement of fuel economy, the reduction of emissions and of engine noise. In heavy duty engines, a serious problem is the durability and reliability, due to the much longer time of use and greater powers in comparison to light duty engines. Ceramic valves are made of brittle material that may fail due to a defect [7].

There is a region for the greatest loading of valve in a thin subsurface layer. In such region, there may be internal defects such as porosity and voids, and external damage remaining after treatment [8].

Ceramic valves can be grinded by diamond [8].

3. Research stand

The researches have been made on the stand presented in the Fig. 1. It has been measured the values for impact force for valve impacting its seat insert (by sensor C7), for friction force between valve and its guide (by sensor C3), for displacement (by sensor C1) and acceleration (by sensor C2) of valve. Additionally the sound level has been measured by the sonometer C6 [9]. The temperature (from sensors C4 and C5) has been the room one. Measured values have been transmitted by control cassette C8 into computer C9 drive and registered there.

The method of calibration for measuring circuits has been described in [9].

Values of friction coefficient μ have been estimated from equation (1) [9]:

$$\mu = \begin{cases} \dfrac{T}{R} = \dfrac{T}{(m_v + m_a)\cdot g \cdot \dfrac{h_v}{h_v - (h_G + x)}} & (for\, case\, a), \\ \dfrac{T}{R_1 + R_2} = \dfrac{T}{(m_v + m_a)\cdot g \cdot \dfrac{h_g + 2(h_G + x)}{h_g}} & (for\, case\, b), \end{cases} \quad (1)$$

where:

- T – measured value of friction force between valve stem and its guide,
- R, R_1, R_2 – reaction between valve stem and its guide, depending on the case (Fig. 2),
- $g = 9.81$ m/s^2 – gravitational acceleration,
- $x = (0 - 5)$ mm – valve displacement,
- $m_v = 19.7$ g – valve mass,
- $m_a = 0.4$ kg – added mass,
- $h_v = 90$ mm – valve length,
- $h_g = 45$ mm – guide length,
- $h_G = 35$ mm – dimension between valve guide and weight centre of the valve – added mass assembly (Fig. 2).

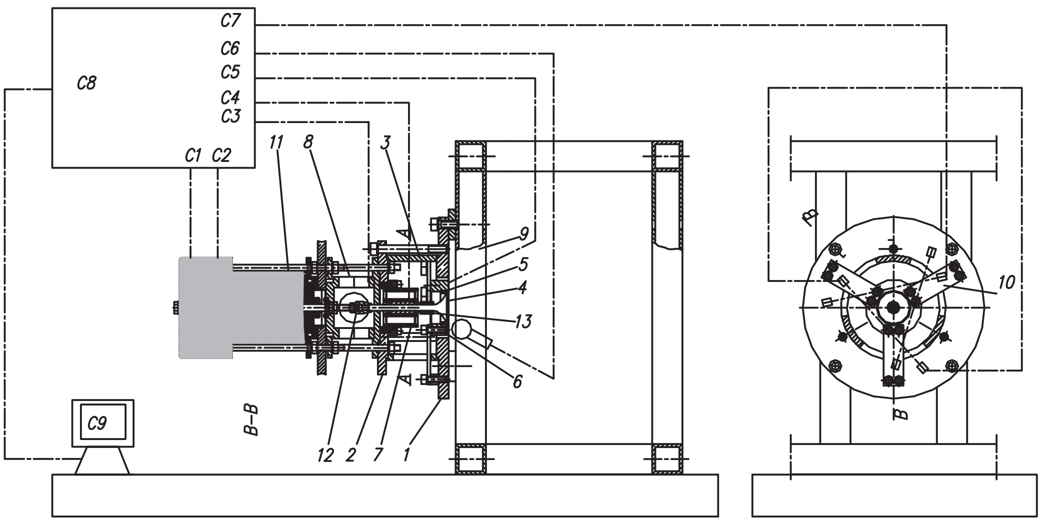

Fig. 1. The scheme of the research stand. 1 – base, 2 – cover, 3 – case sleeve, 4 – valve, 5 – seat insert, 6 – sleeve of seat insert, 7 - valve guide assembly, 8 – cantilever, 9 – frame, 10 – flat spring, 11 – driving assembly, 12 – connector, 13 – added mass, C1 – valve lift sensor, C2 – valve acceleration sensor, C3 – sensor of friction force between valve and valve guide, C4 – valve guide temperature sensor, C5 – seat insert temperature sensor, C6 – sound level meter, C7 – impact force sensor for valve impacting seat insert, C8 – control cassette, C9 – computer

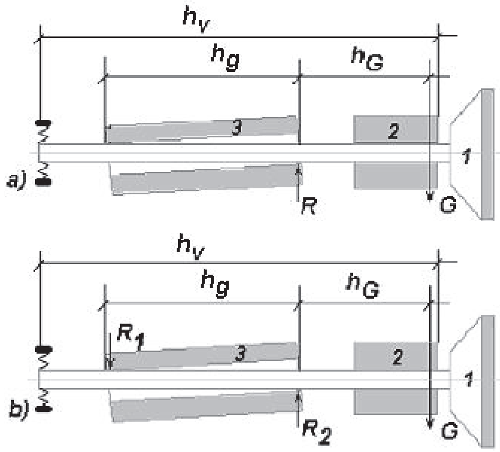

Fig. 2. The scheme of loading for the valve – added mass – guide assembly; 1 – valve, 2 – added mass, 3 – valve guide, $G = (m_v + m_a) \cdot g$ - loading force; a) loading case, when reaction R between valve stem and its guide has existed in only one place, b) loading case, when reactions R1 and R2 between valve stem and its guide have existed in two places

4. Results of calculations

Obtained results of researches have been presented in the Fig. 3-8. Measured values of valve displacement vs. time have been shown in the Fig. 3. Valve lift has been equal 5 mm. Observed changes of valve position, during valve contact with its seat insert have resulted from the stiffness of the measuring set. Measured values of valve acceleration vs. time have been shown in the Fig. 4. The maximum value equal 480 m/s^2 has been obtained during valve impact into its seat insert. Measured values of impact force between valve and its seat insert vs. time have been presented in the Fig. 5. After the impact, the valve have been pushed into its seat insert by the force, which value has been equal 50 N. Measured values of friction force have been presented in the Fig. 6. Values, pointed T_{max}, obtained during rising and setting of valve have been slightly different. Observed changes in friction force values have been resulted from the stiffness of the measuring set.

Values of friction coefficient, calculated from equation (1) vs. time have been presented in the Fig. 7. They have been obtained for loading frequency f = 16 Hz, and maximal valve lift h_{max} = 5 mm and they have been equal from 0.12 to 0.16. Such values vs. loading frequency have been shown in the Fig. 8. They have decreased with frequency increasing, almost linearly. Obtained values of the friction coefficient between the researched valve stem and its guide have been smaller than values obtained for the case of valve stem coated by nc-WC/a-C:H mating with a guide made of cast iron, when values have changed from 0.135 to 0.23 [9].

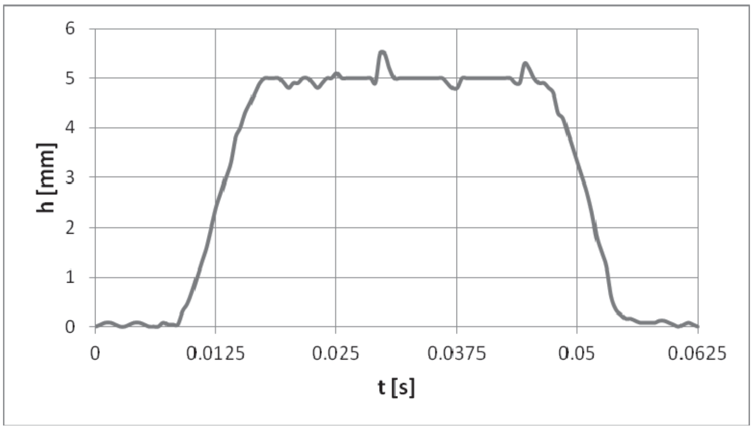

Fig. 3. Measured valve displacement h vs. time t: loading frequency f = 16 Hz, maximum valve lift h_{max} = 5 mm

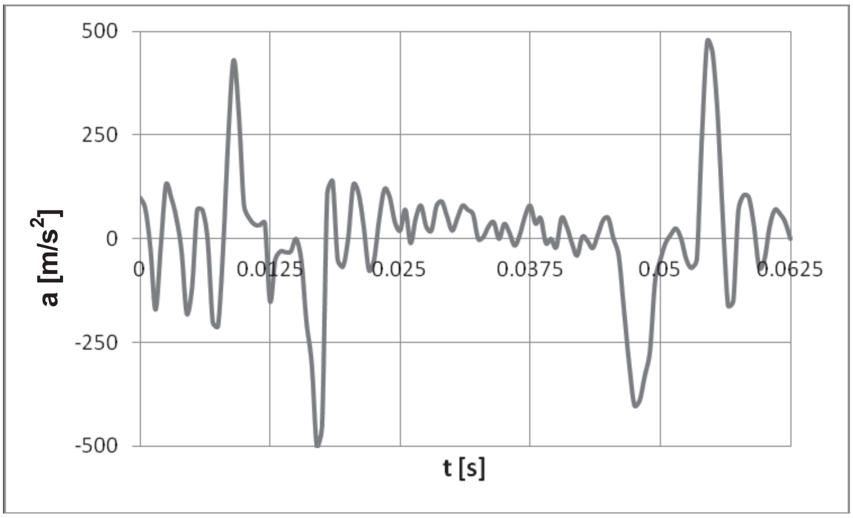

Fig. 4. Measured valve acceleration a vs. time t: loading frequency f = 16 Hz, maximum valve lift hmax = 5 mm

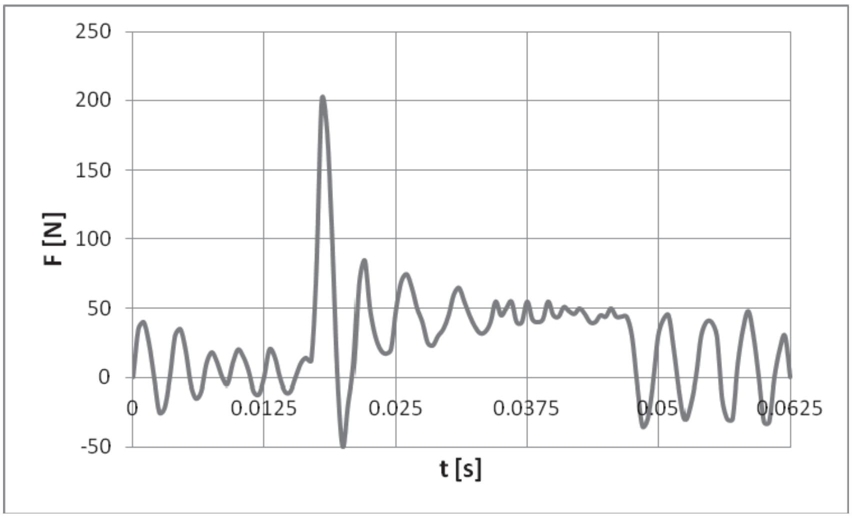

Fig. 5. Measured impact force F between valve and its seat insert vs. time t: loading frequency f = 16 Hz, maximum valve lift hmax = 5 mm

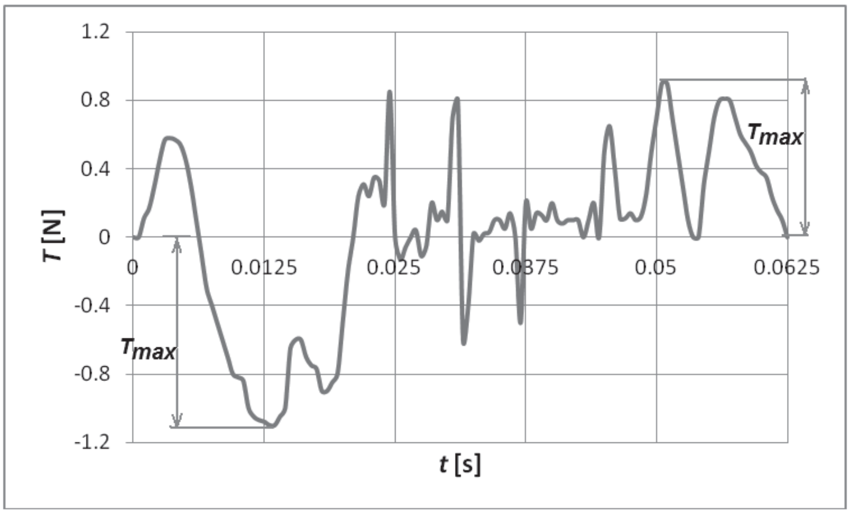

Fig. 6. Measured values of friction force T between valve and its guide vs. time t: loading frequency f = 16 Hz, maximum valve lift hmax = 5 mm, Tmax – maximum friction force during valve displacement against its guide

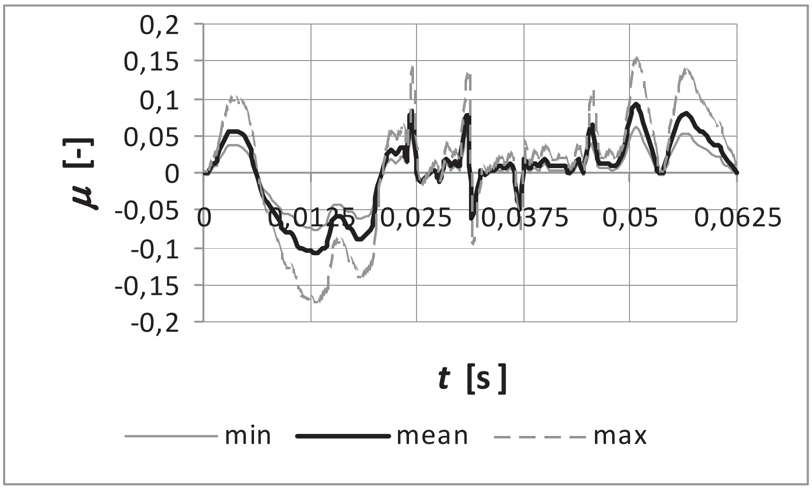

Fig. 7. Calculated values of friction coefficient μ between valve and its guide vs. time t: loading frequency f = 16 Hz, maximum valve lift hmax = 5 mm

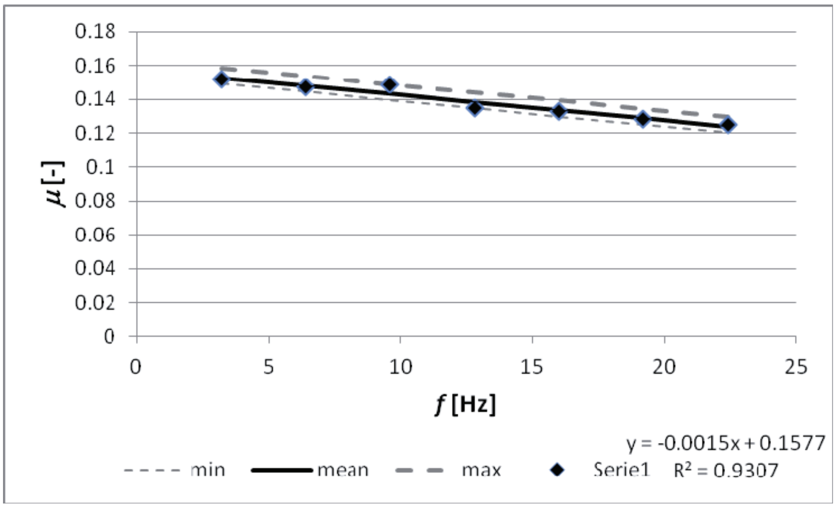

Fig. 8. Calculated values of friction coefficient μ between valve and its guide vs. loading frequency f; maximum valve lift hmax = 5 mm

In all cases the measured sound level have been equal 94 dBA, when sound level of laboratory environment has been equal 40 dBA

5. Conclusions

1. Calculated values for coefficient of friction between valve stem and its guide can change from 0.12 to 0.16, depending on the reactions set Fig. 2).
2. Values of dry friction coefficient between valve stem made of TiAl alloy and coated by chrome and its guide made of phosphorous bronze can be smaller up to 17% than values for the case of valve stem coated by nc-WC/a-C:H mating with a guide made of cast iron.
3. Friction coefficient values have decreased almost linearly with loading frequency increasing.

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