SLIDING COUPLES FOR VALVE GUIDES AND VALVES OF PICTON COMBUSTION ENGINES

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Abstract

The article deals with the basic mechanisms of wear of the intake and exhaust guides of the valves and the valves themselves, which occurs during the operation of internal combustion engines. Particularly unfavorable conditions for friction pairs occur when operating engines with alternative fuels, such as natural gas, biogas or landfill gas, which may contain high amounts of sulfur. The article further describes modern materials and surface treatments of valves and valve guides. Furthermore, the article deals with non-destructive analysis of mechanical properties of guides, specifically the modulus of elasticity and strength. These properties are calculated by mathematical relationships that use the real and ultrasonic thickness of the material and, based on the change in thickness, express the mechanical properties.

Keywords: Valve guides, valves, sliding couple, tribology wear, non-destructive testing

1. INTRODUCTION

The valves of internal combustion engines precisely define the intake mode, the combustion of the flammable mixture and the exhaust of the flue gases. The performance stability and ecology of the engine operation depend on the precise valve guidance. The solution of a reliable valve-line pair is current for the design and material engineers of the development of engines for conventional, but especially alternative fuels. The developed materials, which are discussed in this paper, must ensure a guaranteed service life of fluid friction with minimum adhesive wear under deteriorating temperature and corrosion conditions.

2. ADHESICE WEAR FACTORS

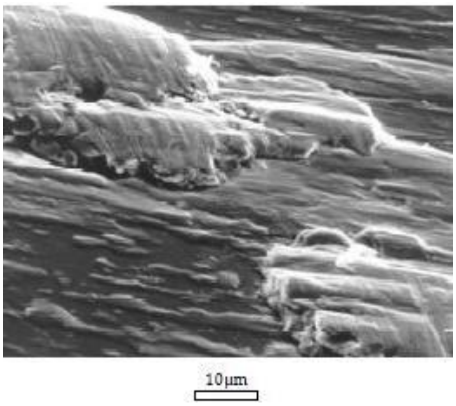

Figure 1 Fixed particle bond [1]

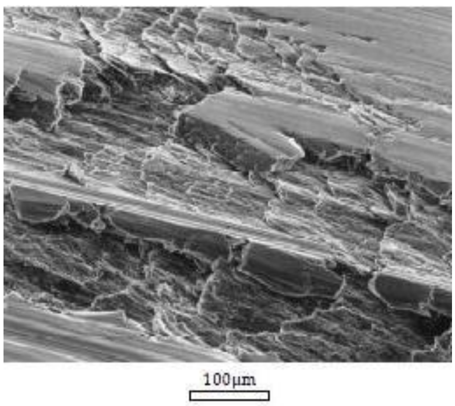

Figure 2 Extraction of particles from material [1]

The contact of the surfaces between the two components occurs on a large number of contact surfaces. Their formation is accompanied by plastic and elastic deformation of the tops of specific irregularities. Due to the adhesive forces, micro connections are formed on the exposed contact surfaces. Pulling and particle formation cause adhesive forces. The breakdown of micro connections is affected by a sharp increase in local temperature. This increases the diffusion and can form a firm connection between the torn particle and the surface of the second material (**Figure 1** and **Figure 2**). A prerequisite for blocking the transmission is provided by a sliding pair of "non-weldable" materials, thermally conductive materials, breaking of barrier layers from oxidation or other chemical reactions. E.g. the α-Fe2O3 coating is favorable for steels and acts as a protective layer and lubricant. Chemical reactions can also increase wear. Hard metal oxides are abrasive particles.

3. VALVE STEM

The sliding length of the valve stems in the subject area of the motors is galvanically chromium-plated. If the surface of the stem has a low roughness, a soft guide can be used. This limit value for chromium valves is Ra 0.04 µm, for others Ra 0.06 µm [1]. The chromium layer has a positive effect on the sliding properties in the guide and the resistance to corrosion and wear [2] The end of the valve stem must withstand high contact loads from the rocker arm, therefore it hardens inductively, surface or overall [3]. The valve material resists abrasion in heat, excels in dimensional stability, corrosion resistance, strength and fracture resistance [4]. Standard EN 10090 (42 0944) describes the suitability of steels and alloys for valves of internal combustion engines. The production of exhaust valves is common in the design, which is referred to as trimetallic = Co weld + head made of austenitic steel or Ni alloy + resistance or friction welded stem made of martensitic chrome steel with hardened shank, which is intended for contact with the rocker arm [4]. The shaft is made of hardened chrome steel [3]. Martensitic steel 17 115 was used in the Czech Republic.

4. HARD CHROME LAYER

In general, chromium is resistant to chemicals, high temperatures, exceptional hardness and high abrasion resistance [2]. Hard chromium plating is one of the galvanic processes. These chromium coatings are deposited electrochemically. Chromium is precipitated from chromic acid by gradual reduction or is precipitated from chromic acid directly. In the chromium plating bath, the precipitation of chromium is determined by valence. When hard chromium plating is used, a coating with a thickness of 1 µm up to a few millimeters is deposited [5]. Excellent corrosion protection, for valves, is guaranteed by a chromium layer around 15 µm. The electrochemical deposition of these hard chromium coatings results in a high hardness [5]. This excluded chromium is a mixture of cubic centric and hexagonal allotropic structures. The deformation of the lattice, which determines the hardness, is caused mainly by the closure of oxygen-based chromium compounds. The hardness of chromium layers is determined by the content of chromium oxide. The compound content of this chromium layer is about 1%. Hydrogen only partially participates in the deformation. The forms of chromium differ from each other in both hydrogen content and crystalline form. Crystallization affects the hardness of the chromium layer. As the current intensity and temperature increase, the hardness first increases to a maximum and then decreases. This process is accompanied by increasing coarsening of the crystals, while the mutual cohesion decreases. Hardness also affects the composition of the electrolyte [6]. The optimum hardness at which the coatings are stable is approx. 860 HV. Coatings that are harder are unstable. Excellent friction values are obtained using a pair of hard chrome with perlitic cast iron, a composition or lead bronze. Good values are achieved for mild steel or hard steel with low roughness and sufficient lubrication. They show poor results when rubbing chromium against chromium or light alloys or phosphor bronze [6]. **Figures 3 and 4** show the structure of the tribological surfaces of the valve guides and valve stem.

The valve line dissipates 25% of the heat generated by the motor [2]. Standard ONA 30 2207 (invalid after accession to the EU) specifies the requirements of the guides for conventional piston engines. For cast iron guides, the matrix must be perlitic (max. 10% free ferrite F). The valve guide is pressed sub cooled into the cylinder heads and drilled in the head assembly into the final positions with the valve seats for precise valve guidance. The valve lines must therefore be easy to machine.

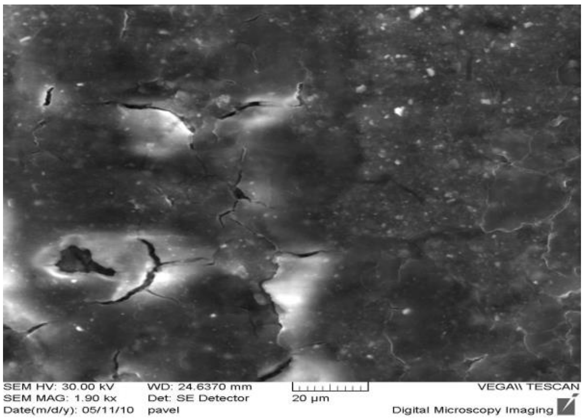

Figure 3 Operationally overloaded Cr layer of valve stem

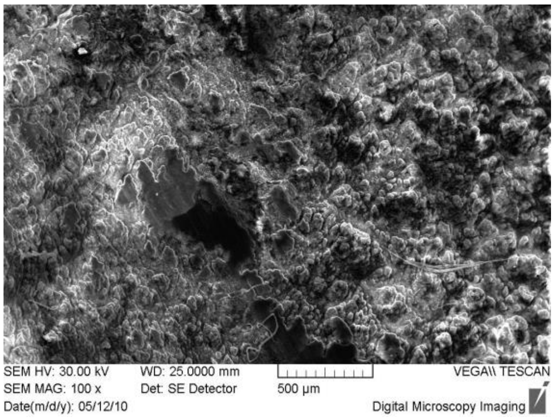

Figure 4 Operationally overloaded cast iron surface of valve guide

5. DEVELOPMENT OF GUIDE MATERIAL OVER TIME

The development of guide material has a history. Until 1993, the LIAZ engine guides were made of non-alloy cast iron with uniform flake graphite and perlitic matrix (quality ČSN 422425; casting ČSN 01 4470.4; hardness 190 to 240HB). Cast iron with flake graphite has the ability to dampen and thus reduce the level of vibrations. The structure of real castings used to be inhomogeneous with deliveries over time and within one semi-finished product; to a depth of 1.5 mm, the matrix is ferritic with perlitic cell boundaries. From 1.5 mm to 5 mm perlitic (70 to 85%), which is also of the highest quality. From 5mm to the center of the guide, there is super cooled graphite with 90% F bordered by perlite (40 to 60%). The critical parameter at this time was durability, not reliable hot operation. The perlitic matrix would be provided by Cu alloying. However, it was more efficient to introduce isothermal hardening of the line workpieces into a 350°C salt bath. Bainite (ausferite) excels in high resistance to wear, strength and hardness (260-300HB) with sufficient final machinability [7]. It was possible to harden castings from cheaper cast iron of quality 42 2415. The applicability of this cast iron is up to the temperature of isothermal hardening, then its properties can change (350 - 400°C). On the **Figure 5a** and **Figure 5b** there are sections through cast iron valve guide. **Figure 5c** shows valve with chrome-plated stem. It was used ordinary cast iron with flake graphite as a starting material for heat treatment based on ČSN 42 2420 For D up to 30mm R_m min 200MPa, HB170-220, E_{o}-110GPa, SE 0.93 to 0.99. In Table 1 and 2 are measured values, determined using a non-destructive ultrasonic method.

Certificate: Quality 42 2420; 198-204HB;

R_m* 244.5-252 MPa; C 3.51%, Si 2.22%; P 0.23%. (*Calculated according to equation (1; 2) from [8].)

$$E = \left(\frac{K*L}{Lu}\right)^2 \quad (1)$$

where:

E – Young´s modulus [GPa]

K – Value of K, can be calculated from the results of acoustic measures on slender bars [9] *[-]*

L – Real thickness [mm]

Lu – Ultrasonic thickness [mm]

$$R_m = 7.211 * \frac{L}{Lu}^{2.278} * HB^{0.75} \quad (2)$$

where:

R_m – Tensile strength [MPa]

L – Real thickness [mm]

Lu – Ultrasonic thickness [mm]

HB – Brinell hardness [-]

The certificate already states S_E 0.93-0.94.

Figure 5a Quality sliding surface

Figure 5b Worn by heat adhesion and corrosion

Figure 5c Valve with chrome-plated stem

Table 1 Mechanical properties of valve guides LIAZ

Hardness HB	L_u	L	E_o [GPa]	R_m [MPa]
207	332.7	263.3	128.64	252

L_u – *Ultrasonic thickness [mm]*

L – *Real thickness [mm]*

Table 2 Mechanical properties of valve guides LIAZ depending on measuring position

	HB10	L_u	L mm	E_o [GPa]	R_m [MPa]
inflow	187	21.9	17.2	126	222
the end	213	22.5	18.8	143	299

Table 3 Metallurgical composition of LIAZ valve guides

	Graphite	Matrix	Phosphorus. eutectic
Inlet to the casting	GIA – 4/5	Perlite 92%, P1, Pd1	Individual departments
Beginning	GIA - 5	Perlite 95%, P1, Pd0,5	Individual departments

Table 2 and **Table 3** show properties of LIAZ valve guides. In **Table 3** in column Matrix means P1 – Lamellar perlite; Pd factor – Dispersion of lamellas [μm]

For cast irons, the maximum service life without TZ is guaranteed by a guide with the composition: C 3.2 - 3.5; Si 1.8 - 2.2; Mn 0.6 - 0.8; P 0.65 - 0.9; S max 0.12; Cr max 0.2 [%]. The resistance of this alloy is up to 600 °C. However, the composition results in difficult machinability. The use of alternative fuels (e.g. biogas) leads to a high corrosion temperature load of the parts adjacent to the combustion chamber. Cast iron guides do not comply (**Figure 5b**). Special CuAlFe bronzes have been developed for these applications.

Measurement method: XRF. The structure does not resemble the classic Al bronzes. The hardness and strength of these Cu alloys can be modified within wide limits by curing and other heat treatment processes [6]. For sliding applications, a hardness of around 300HV is recommended. At the turn of the millennium, the most heat-intensive engines (such as gas in the "stechio" combustion mode) used expensive "exotic" alloys based on Ni, Ag and other metals, or cheaper ones such as Ni Cr13Mo2Bi5Sn4Fe2. Their metallurgy and heat treatment are not easy and they are covered by industrial legal protection.

6. CONCLUSION

Valve lines made of isothermally hardened cast iron with flake graphite are suitable (standard in TEDOM) for standard operating conditions of gas and diesel small series engines. Valve lines with small diameters (up to 7 mm) are proven to be made of complex alloy brass. Extremely stressed lines (corrosion, temperatures) were used from Al bronzes and expensive complex alloyed Cu alloys. Phosphorous cast iron castings with flake graphite are still suitable for large-scale production conditions under normal line conditions. However, most valve guide suppliers have switched to products made of a mixture of steel powder and bronze made by powder metallurgy technology with additional pressing to remove residual porosity. Residual porosity does not seem to reduce the service life of the line, because the currently applied variants of the line material are always porous. Although the porous guide prepared by PM has a significant minimum of stiffness and hardness and a limiting high roughness of the bore in the middle of the length. Pure steel-bronze lines were enriched with variants with increased content of P and Mo + S. The lines examined in 2020 are only a combination of alloy steel and Mo + S ("lubricates" the hot end to the highest temperatures).

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