

Keywords: combustion engine valves; operating damage; burnishing

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USE OF SURFACE WORKING FOR IMPROVING THE WORKING LIFE OF PISTON VALVES OF COMBUSTION ENGINES

Summary. This paper deals with the issue of operating damage of combustion engine valves. It presents an innovative way and construction of a tool for strengthening piston engine valves by way of surface working. It presents the concept of machines for comprehensive surface working and for profiling the faces of combustion engine valves. It also includes the discussion of the methodology of working.

1. INTRODUCTION

Piston combustion engines are commonly used in the drives of construction, road, agricultural, and mining machinery, especially in ore and rock mining. In the case of civil and military trucks and floating vessels, combustion engines are practically the only commonly used source of propulsion. These engines often work in very difficult operating conditions, with strongly variable loads, a wide range of ambient temperature changes, and in the presence of high levels of mineral dust in the air.

A steady construction tendency is observed in the scope of increasing the power of combustion engines and increasing the rotational speeds, while reducing the empty weight of propulsion units. Similar trends also apply to passenger car and delivery vehicle engines (the so-called downsizing) [12]. This results in the main components of combustion engines being exposed to very intense destructive processes. It is reflected in the increasing degree of strain and heat load on engine components. The above also applies to exhaust and suction valves of combustion engines, especially compression-ignition engines used in machinery used for work, exposed to strong thermal effects and a high variability of service loads. The operating conditions of combustion engine piston valves cause fatigue cracks and specific phenomena of thermal fatigue, material creep, and tribological wear.

Fatigue cracks in engine valves are the cause of sudden failures, often with a large negative technical and economic effect. Sometimes, they constitute a source of safety hazards. The emergence of valve fatigue cracks does not generate significant symptoms that could be detected by typical technical diagnostics methods. The number of cycles of load changes on the valves of combustion engines, directly related to the number of revolutions, causes the fact that the fatigue damage of the valves is most often definitely a high-cycle fatigue [1, 4, 7].

The fatigue cracking of valves is associated with extensive failures. Damage to pistons, heads, bending of connecting rods, and even damage to crankshafts and other timing gear components is very frequent. Therefore, removing the effects of engine failures resulting from the destruction of valves is usually very expensive and laborious. Therefore, effective new ways of improving the valve working life should be sought. Constructional, material, and technological optimization in the traditional scope, in view of many years of experience in the use of combustion engines, is approaching the limits of its usability. In this situation, it may be helpful to use strengthening through surface working methods and machines described in this paper.

2. FORMS OF OPERATING DAMAGE TO THE VALVES OF COMBUSTION ENGINES

The duty cycle of each engine valve is zero-pulsating, from zero load when the valve is open to a dynamic, almost impact load when it is closed under the action of valve springs. Valves with reciprocating motion and high accelerations and decelerations are additionally subjected to high mass forces, hence the efforts to minimize the weight of the valves result in an additional state of high effort of load-bearing cross-sections from variable loads. Valve fatigue cracks occur most often in the area of the valve lock, which is owing to the inevitable stress accumulation from the structural notch. Fatigue cracks are also observed in the zone of transition of the cylindrical valve shaft into the valve head (Fig. 1) [3] and much less often in the straight section of the shaft, especially when they are accompanied by signs of abrasion in the guides.



Fig. 1. Fatigue crack in the zone of transition of the cylindrical valve shaft into a valve head [15]

When the resistance to valve shaft movement owing to abrasion becomes greater than the force of the valve spring, the valve remains constantly open and the piston, hitting the head, causes permanent bending or breakage of the valve shaft and turns off the cylinder or the entire engine from work (Fig. 2).

Another form of valve damage, especially concerning suction valves, is the phenomenon of heat fatigue. Alternating thermal cycles of cooling – heating of the surface layer of the element result in its core in a steady state adopting an approximately constant, generally elevated temperature. During heating, the surface layer is subject to compression due to thermal expansion phenomena and when cooling below the core temperature, the surface layer is subject to stretching [6, 8]. These variable stress cycles generated by thermal cycles can lead to the formation of a characteristic mesh of numerous cracks with a multi-directional pattern, often resembling “snake skin” [13] (Fig. 3). These cracks, although generally shallow, are strong stress concentrators, and if the element experiences additional variable external loads, even shallow cracks from thermal fatigue develop into transverse cracks, typical of mechanical fatigue. This is the case with engine valves, and especially suction valves. When the air is sucked in, especially low temperature air, the surface layer rapidly cools, and then, as a result of fuel dose combustion, a rapid increase in valve temperature occurs, especially in the zone of the valve head and the transition of the shaft into the head.

Alternating cycles of opening-closing of the cracks caused by thermal fatigue additionally contribute to the intensification of the development of transverse fatigue cracks as a result of the wedging action of surfactants (the so-called Rebinder effect) [4]. In this case, the role of active centers is played by fuel particles and its combustion products. Their activity in relation to strongly chemically

activated fatigue crack zones is considerable, even if they do not show significant activity toward steel under other conditions. Thermal fatigue plays a certain role in the observed fatigue cracks of the valve heads, especially when manufacturing deviations are present, resulting in uneven lining of the valve faces into the sockets. This is facilitated by frequent abandoning of valve grinding operations for economic reasons. In the case of exhaust valves, a similar destructive process is observed, intensified during overloads of combustion engines, especially gas-powered ones. The result is a loss of valve tightness owing to burning of the face.



Fig. 2. Permanent bending of the valve shaft [15]



Fig. 3. View of a fragment of the abraded valve shaft [15]

Friction between the valve shafts and the guides is the cause of tribological wear of this node. This type of damage is often a result of work in an environment heavy with mineral dust, a deteriorated efficiency of air filters, and irregularities in the machining of valve shafts. During grinding, the surfaces of shafts often receive inclusions of hard grains broken from incorrectly selected grinding wheels. The wear of valve shafts and guides results in the loss of tightness and in engine oil getting into the cylinders. Then, the engine oil burns and strongly pollutes the atmosphere with harmful chemical compounds.

A significant improvement in the scope of the described mechanisms of valve damage can be achieved by using cold surface strengthening treatments.

3. THE MACHINE FOR COMPREHENSIVE SURFACE WORKING OF COMBUSTION ENGINE VALVES

Surface working, although known for many years and despite the development of a number of solutions for its implementation, is still used to a negligible extent, despite the number of beneficial

effects it allows to achieve – provided that it is used correctly [2, 9-11, 14]. It seems that this results from, among other things, insufficient knowledge among engineering staff regarding the possibilities that can be achieved in this respect with relatively low expenses.

The concept of a machine that can enable comprehensive strengthening of engine valves in all of the described critical zones is illustrated in Figure 4 [16].

The machine is equipped with a set of burnishing rollers (1) swivel-mounted in cranes (2), which are pivotally supported in stands (3) and on pins (4). The burnishing rollers are pressed against the machined valve shaft (5) with springs (6) with a voltage regulated by nuts (7). The shaft of the machined valve is slid through the tubular guide (8) and supported by a spring (9). The valve face (10) of the machined valve head is burnished with a set of conical rollers (11), additionally mounted in the housing (12) which has the ability to travel in a longitudinal manner without the ability to rotate around the axis. Rotation around the housing axis is prevented by sliding inlet connections (13).

The burnishing of the valve surface is made possible by the rotary head (14), owing to vertical movement and after coupling with the valve head. The coupling of the rotary head with the machined valve takes place through an incision (23a) made for the purposes of grinding of the valves in the engine head and/or through a liner (23) made of a high-friction material.

The housing (12) is fixed in extreme positions by a lever (15) meshing with the grooves (16) and (17) of the housing (20). The vessel (18) formed by the housing, connected to the base (19) and sealed with a rubber gasket (24), is filled with a cooling lubricant (21), where the entire burnishing process of the critical zones of the valves takes place.

An oil-water emulsion used in metal machining processes can be used as a cooling lubricant.

Figure 4 presents the location of the machine components before starting the comprehensive valve machining process. The complete machining cycle is described below. After inserting the valve shaft tip (5) into the tubular guide (8), the rotary head (14) rotates and moves to contact and couple with the valve head. As a result of the rotation of the valve caused by the rotary head, the valve shaft lock groove is burnished. After the assumed number of resolutions, the rotational head moves downward, as a result of which the burnishing rollers (1) successively work the entire cylindrical surface of the valve shaft. The housing (12) moves downward, and then the conical rollers (11) cooperate with the valve head face, causing its burnishing. When the housing reaches the lower end position, it pushes the protrusion (2a) of the lever (2) through the flexible element (2b), which gradually releases the burnishing load of the rollers (1) onto the valve shaft. The gradual release of the load on the burnishing rollers allows for a smooth transition of the reinforced zone of the shaft into the valve head arch, which eliminates the formation of an unfavorable structural notch in this valve zone.

In the final stage of movement, the housing rests on the ring (25) through the protrusion (2a) and the flexible element made of polymer (2b). Then, the surface of the face is burnished fully, with the final burnishing force regulated by the pressure force on the rotary head (14). In this phase of the treatment, the housing (12) is locked in the lower extreme position as a result of cooperation of the lever (15) with the groove (17), and the head is lifted to the starting position.

The whole machined valve is lifted up by the spring (9) and can be removed from the machine. After removing the machined valve, it is possible to place another valve in the guide (8). After releasing the lever (15), the housing (12) returns to the upper extreme position owing to the action of the spring (22).

Replaceable rollers (1) and (11) should be made of high hardness steel or cemented carbide. The working surfaces of the rollers should preferably be made with high smoothness with the final polishing procedure, which allows for obtaining a high smoothness of the shafts and faces.

The use of three evenly spaced burnishing rollers (1) and conical rollers (11) operating in one plane allows for a full internal balance of forces during the procedure, and thus eliminates the possibility of bending of the valve shafts during working. The rotary motion and advance of the rotary head (14) can be achieved by means of a bench drill, pillar drill, or vertical milling machine.

The result of machining in the described machine is strengthening in the notch area associated with the valve lock, the entire cylindrical portion of the shaft, the zone of transition of the shaft into the valve head, and the surface of the valve face in one continuous machining cycle.

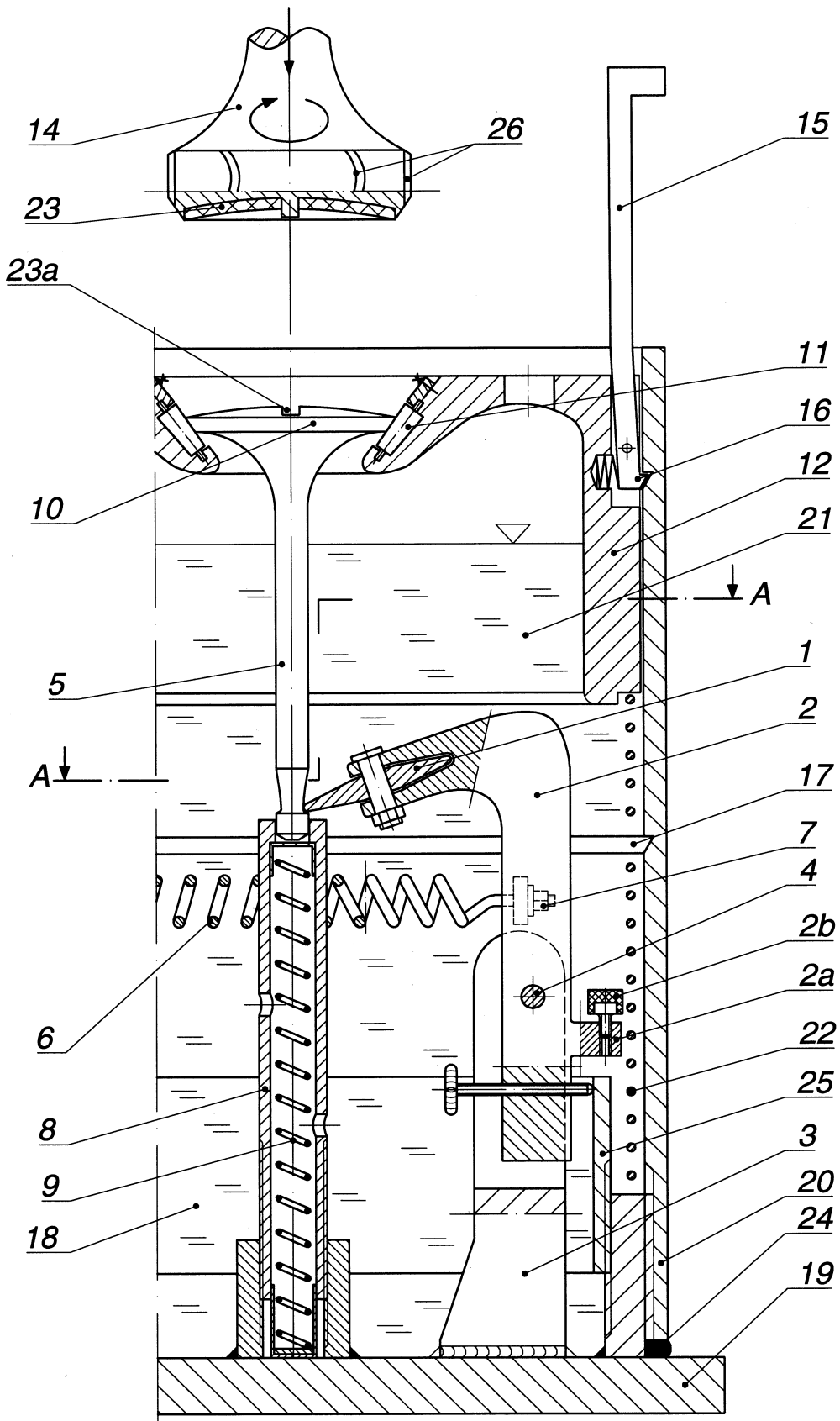


Fig. 4. Machine for comprehensive burnishing of combustion engine valves [16]

The improvement of fatigue cracking resistance is obtained by forming a favorable permanent state of compressive residual stress [13] in the surface layer of the valves. In addition, burnishing of all valve zones increases the hardness of the surface layer, thus increasing the resistance to abrasive wear. Burnishing causes possible spalling and removal of hard grains embedded during grinding from the valve surface. This minimizes the wear of valve guides. The surface texture created during burnishing causes the formation of many lubricating micro pockets which improve lubrication conditions. It also promotes better sealing of the shaft – guide connection as a result of the formation of a multi-stage labyrinth seal.

4. A MACHINE FOR PROFILING THE FACES OF THE COMBUSTION ENGINE VALVES BY SURFACE WORKING

The faces of combustion engine valves are exposed to particularly intense working conditions. They are exposed to surface wear from large variable contact pressure at high working temperatures. These zones are exposed to the phenomenon of heat fatigue, which leads to loss of tightness, and often to the breakage or spalling of valve head parts. With even small performance deviations regarding coaxiality and skew of the valve seat axes, there is a strong edge effect, leading to damages to the valve or valve seat. Significant improvement in this respect can be achieved by using appropriate profiling of the valve face combined with strengthening by surface working. This can be achieved with the machine presented in Figure 5 [17]. It consists of two main assemblies, a rotary burnishing and profiling head and a vessel with a cooling lubricant with a filtration and liquid mixing system.

The valve under strengthening (8) is set head downward on a high-friction solid liner (11) to the seat formed by the retaining ring (9), which is based on the spring (10). Then the burnishing head (2) equipped with burnishing rollers (1), held in the correct position by the rings (3) and (4), is lowered. The even distribution of the rollers along the head circumference is ensured by the separator (5). After rotating the burnishing head, the process of burnishing the valve face with force P takes place. The burnishing operation is carried out in complete immersion of the burnishing zone in the cooling lubricant (7) filling the vessels formed from the housing (12) and the base (13) sealed with a rubber gasket (14). The fluid level must always be set above the inlet (15) of the fluid circulation pump. As a result of the rotation of the burnishing head, on which the fan of the centrifugal pump (6) is mounted, the liquid sucked through the holes (15) is filtered through a filter (16) that retains solid particles. Additionally, magnets (18) are mounted in the filter, capturing metallic wear products created during machining from the cooling lubricant stream. As a result of the liquid flow, e.g. oil-water emulsion, intensive cooling of the burnishing zone and lubrication of the worked surface occurs, which ensures high smoothness of the burnished surface. In Figure 5, arrows indicate the liquid circulation. It is advisable to use three burnishing rollers spaced every 120° , thus achieving total internal balance of forces.

To ensure cooperation of the burnishing rollers with the machined valve in rolling conditions without slippage, it is advantageous to maintain the relation $r/d = R/D$ (Fig. 6). It is substantiated to apply burnishing and profiling of the face with an increasing load in several cycles of several dozen or several hundred rotations of the head, with periodic pressure release.

After performing the valve working, the burnishing head is lifted up and its rotation is switched off to eliminate the splashing of the liquid outside the machine. After the removal of the machined valve, another valve can be inserted immediately and the machining cycle is repeated from the beginning for the new valve.

The selection of burnishing force and working time is set during tests, depending on the valve size, material, and type of previous workings. The burnishing force and rotary motor of the head can be implemented using typical machine tools with a vertical spindle system, i.e. milling machines, drills, and boring machines. The centering pin (20) helps to achieve the alignment of the machine on the table. When changing the size of the valve to be machined, replace the base (19) with the high-friction lining (11), as well as the ring (9) and spring (10).

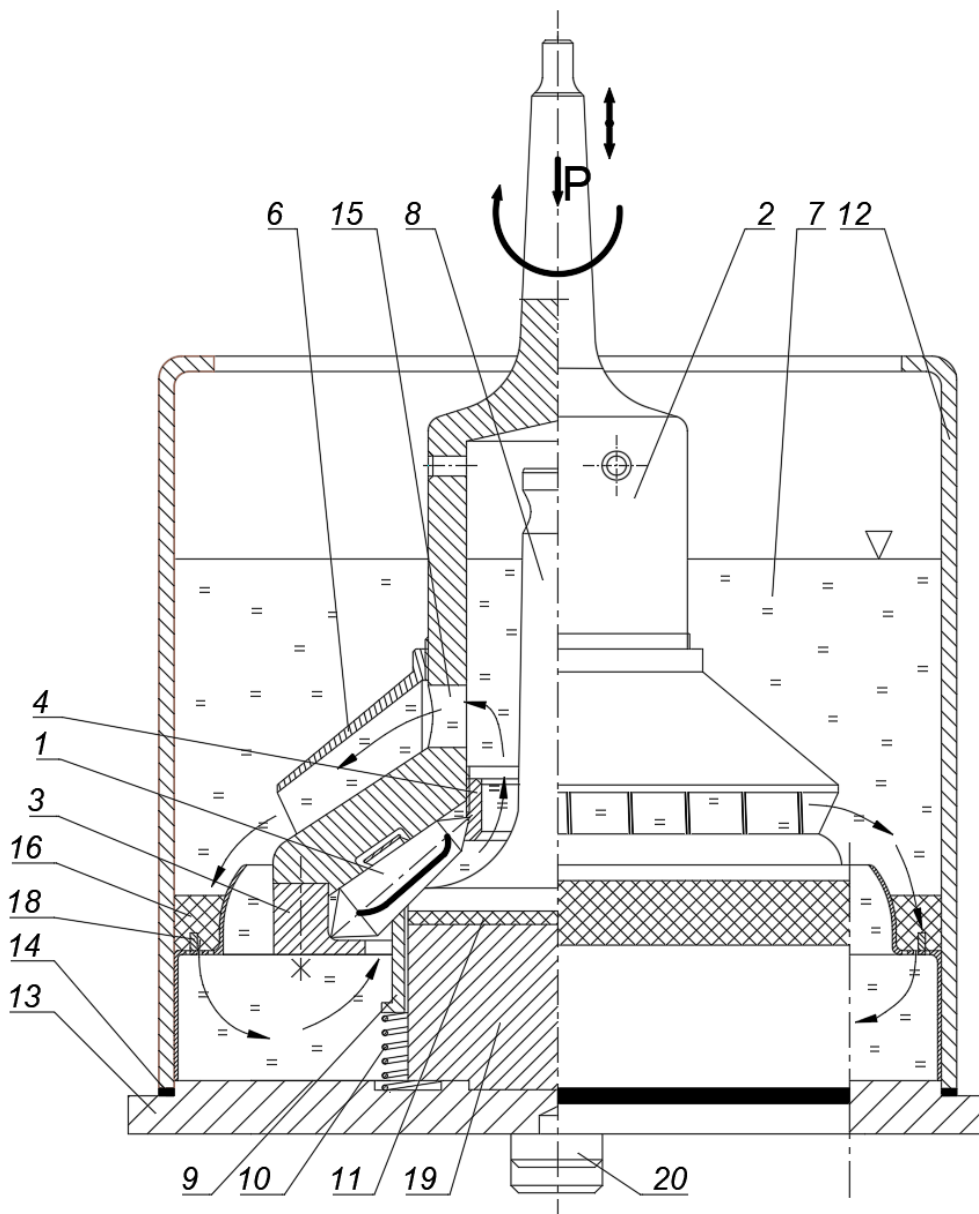


Fig. 5. Machine for profiling the faces of combustion engine valves [17]

The machine can be used during the production of new engine valves and in the process of valve regeneration after a specified period of operation. This allows to increase the time of efficient use of combustion engines.

When using rollers with a modification of the longitudinal profile of the working part, it is possible to obtain an additional profiling effect on the valve face.

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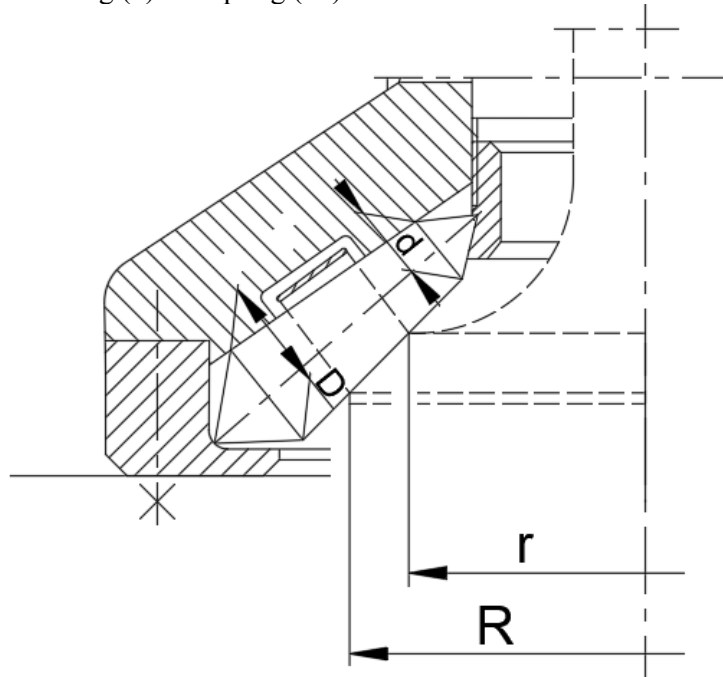


Fig. 6. Fixing burnishing and profiling rollers [17]

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Figure 7 illustrates examples of types of face profiling, where view 7a is a conical profile without profiling and view 7b and 7c are examples of applied modifications. In the figure, the size of the modification has been strongly highlighted; the actual size of the modification should not exceed hundredth parts of a mm.

The performance of profiling and burnishing of the valve face is conducive to improving the working life of valves owing to the fact that the profiled surface of the face improves valve tightness, whereas burnishing improves the hardness and contact stiffness of the face surface layer. The state of compressive residual stress in the face surface layer, obtained during the burnishing, results in the variability of stress caused by thermal cycles being transferred to the compression range, approaching the zero-pulsating course on the compression side. The static and fatigue strength of steel under compression is definitely higher than its tensile strength.

The surface compressive residual stress is balanced by an appropriate state of tensile stress located at greater depths. However, they are definitely less harmful, as they concern larger cross-sections, no notch influence, and are located in zones with no destructive impact of the working environment. Focal points of fatigue cracks, however, are practically always located in the surface layer or on the surface of machine elements.

5. CONCLUSION

Modern piston combustion engines are very loaded constructions, which means that their components are exposed to intensive destructive processes. One of such components are valves, the damage of which can lead to a serious failure of virtually the entire engine (crank-piston system, head, timing system elements, and even the engine block).

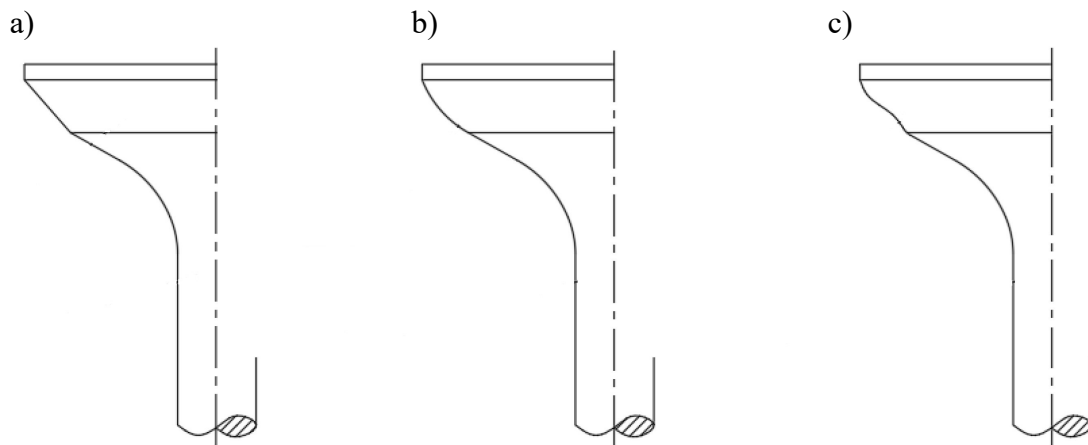


Fig. 7. Examples of modification forms of face surface shapes of combustion engine piston valves: (a) initial profile, conical before modification, and (b, c) examples of the shape modifications of the valve face surfaces

Fatigue cracks on valves are the most common ones; therefore, new methods should be sought to increase their working life.

This paper demonstrates that the application of surface working with the machines described in this study can be used for the following:

- profiling of the faces of combustion engine valves and
- comprehensive burnishing of combustion engine valves.

Profiling, which consists in modifying the shape of the valve face using the machine described in this paper, allows to obtain valves with more favorable utility properties, significantly improving the valve tightness. The machine for comprehensive surface working of valves enables the machining of all critical valve zones in one continuous machining cycle.

Burnishing improves the hardness and contact stiffness of the valve face and valve shaft, ultimately increasing its working life. In addition, a surface texture is created (lubrication micro pockets), which improves lubrication conditions and results in a better sealing of the shaft – guide connection.

By using surface working, a significant improvement in the working life of the piston valves of combustion engines can be achieved. The use of described machines in practice will allow for achieving large technical and economic effects as well as improving the safety of using combustion engines in machinery.

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Received 27.04.2019; accepted in revised form 28.08.2020