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Hardening of Electrohydraulic Injectors Valve Units of Diesels at Repair

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Abstract: The analysis showed that most often in Russia and in the CIS countries the failure of the electrohydraulic nozzle is observed due to the loss of the hydraulic tightness of its shut-off valve. As a result of check valves experimental studies, it was found that one groove is formed in (40%) of cases and in the remaining two or more are formed. Studies confirm that the valve seat of the electrohydraulic injector is a 3D hardened part and has the same hardness at the entire depth. Lapping of the valve seat surface does not weaken the hardness in the contact area and therefore, cannot cause a decrease in the post-repair life. For the repair of valve seats, the repair technology of autotractor and combine electrohydraulic diesel engines Bosch with injector of common rail type by hardening of the shut-off valve seat is considered. Two methods of valve seat hardening: electric-spark hardening and the spraying of titanium nitride were compared. The first method is cost effective but the second method has advantages in hardness and surface quality and therefore has a greater operational life. The hardening of valve seats by electro-spark machining with VK8 electrode and spraying with titanium nitride increases the hardness by 2.2 and 2.7 times, respectively, compared with the new valve seats which may indicate a proportional increase in wear resistance in abrasion. In general, the studies have shown the possibility of using hardening operations when repairing electrohydraulic injectors.

Key words: Fuel delivery system, repaire technology, hardening technology, electrohydraulic injector, shutt-off value, grinding, precision element, hardness, hydro firmness

INTRODUCTION

The most common systems in automotive-tractor and combine diesels are battery powered Fuel Supply Systems (FSS) with electronic control of the Common Rail (CR) type (Gabitov *et al*., 2008; David *et al*., 2015; Sadegh and Worek, 2018). In operation, the issues of ensuring their efficiency are constantly arising due to the fact that modern fuel systems including CR are high-tech products in Russia and in Ukraine and Belarus there is no even a small-scale production of CR elements (Gabitov *et al*., 2008; Dingle and Lai, 2005). Small experience of operation is mostly due to the fact that mass production of such systems was established 10-15 years ago and the issues of repairing technologies, especially, Electro Hydraulic Injector (EHI) which is an important element of the CR system requires special attention. Our analysis showed that the most frequent failure of EGN happens because shut-off valve loses its hydraulic firmness. During experimental studies it was discovered that 40% of shut-off valves have one groove and the rest have two or more. The groove width is about 0.05, ..., 0.5 mm, the groove depth in 90% of cases does not exceed 0.03 mm (Gabitov and Negovora, 2016).

Taking into account the fact that the valve pair is one of the most expensive elements of Electro Hydraulic Injector (EGI) and the most complex to manufacture, it was proposed to introduce four additional operations into the

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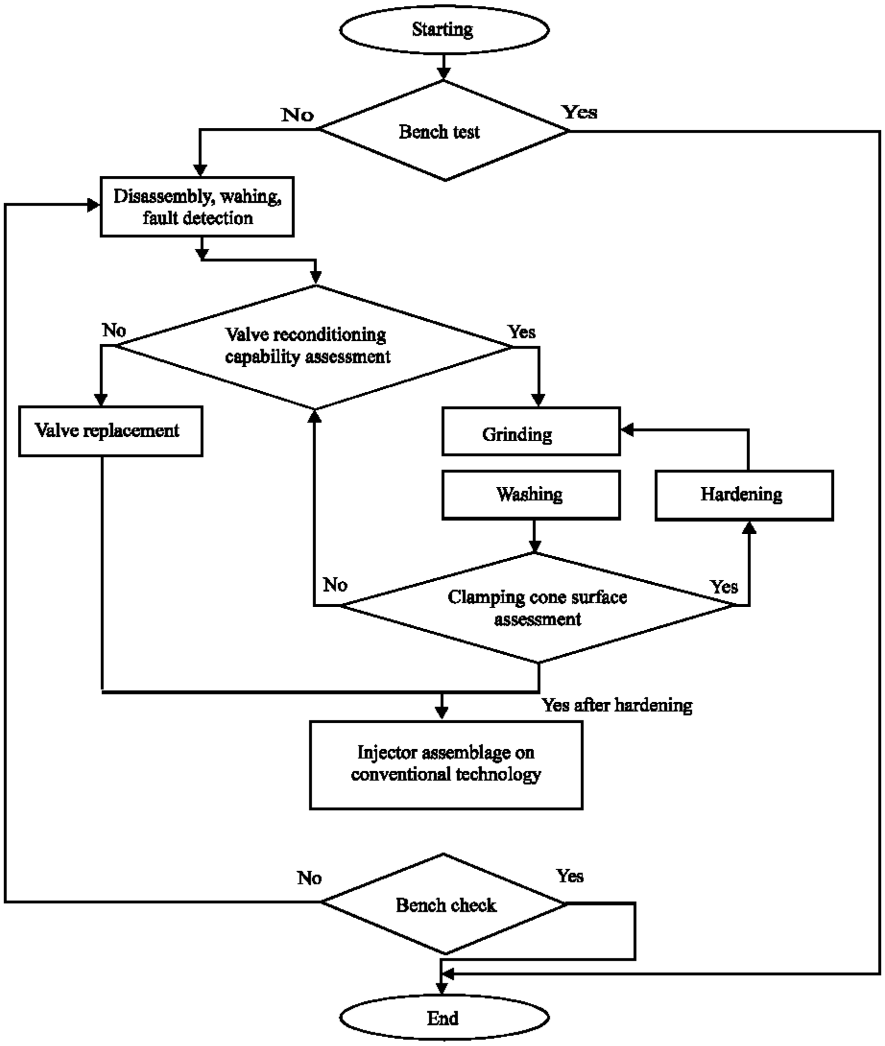

Fig. 1: Block scheme of common rail type injector repair technique

Bosch standard repair technology in shut-off valve performance restoration under the conditions of a specialized enterprise (Fig. 1): 5-lapping, 8-hardening, 6-washing and 7-surface quality assessment of the shut-off cone. It should be noted that this technology can be used for performance restoration if the wearing depth on the control valve is no more than 0.05 mm. The further process of EHI repairing (steps 9 and 10) is in accordance with the Bosch technology including all necessary adjustments (Vakhitov, 2013; Bosch, 1999; Reif, 2015). In this study, two types of the EHI valve seats hardening during repairing process are compared: electro-spark machining with tungsten carbide electrode and titanium nitride spraying (Ward, 2014). Electro-spark machining has been studied in great detail in articles (Burumkulov *et al*., 2009; Burkov *et al*., 2017; Tang, 2009), titanium nitride spraying is described in papers (Ward, 2014; Anonymous, 2017) while component overhaul of fuel injection equipment is thoroughly described in detail in papers (Gabitov and Negovora, 2016; Anan'in *et al*., 2015).

MATERIALS AND METHODS

The MBS-9 microscope was used to monitor the quality of the assembly and define the size of valve wear. Due to the fact that the sizes of worn places are very small and the geometric shape of the valve is complex, a calibrated gauge method was used to measure the width of the wear groove (a calibrated wire of 0.15 mm in diameter was used), followed by photography and scaling. The measurement of the valve seat worn place depth was carried out with the help of a special device and indicating gage.

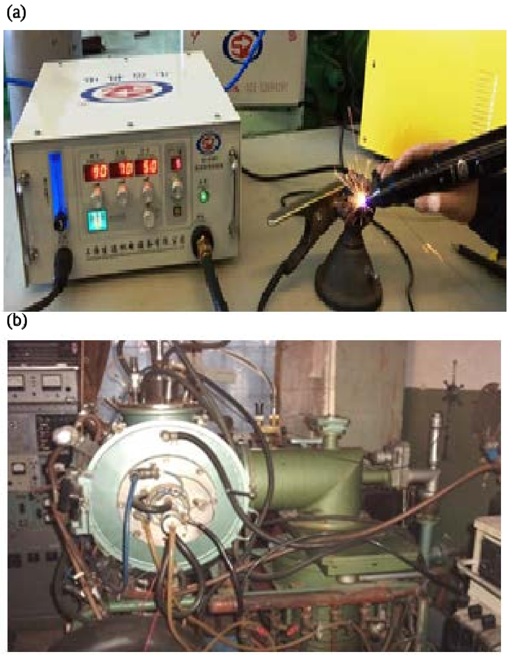

Fig. 2: a) The process of valve seat hardening on SZ-8100 device by tungsten carbide electrode and b) Bulat-9 device for titanium nitride spraying

Hardening of the valve seat was carried out in two ways: by electro-spark method with VK-8 electrode and titanium nitride spraying. In the first case, the SZ-8100 device was used and in the second one Bulat-9 was used, Fig. 2. Electro-spark hardening was carried out on following operating regimes: U = 20, ..., 30 V, f = 250, ..., 300 Hz, η = 20, ..., 30%. Titanium nitride was spraying on the following modes: the voltage on the engine part was 240 ,..., 260 V, the pressure of the reaction gas was ~ 1.1. 10-1 Pa, the intensity current on the arc evaporator was 90 ,..., 110 A, the rotary velocity of the device was 5, ..., 8 rpm, the spraying time was calculated using the formula $T_0 = h_{\Pi}/V_0 = 35/50 = 0.7$h $\approx$42 min. (h_{Π} =35 µm-thickness of the settled coating, taken from the valve seat wear rate which was 30 µm and V_0 = 15 ,..., 50 is the plating rate, µm/h).

To grind valves at the "Automobiles and Machine-Tractor Complexes" department of Federal State Budgetary Educational Institution of Higher Education Bashkir State Agrarian University a grinding device was made. It is shown on Fig. 3. The device consists of: a housing (2), a nut (4), a guide space plate (5) and a lapping plate (6).

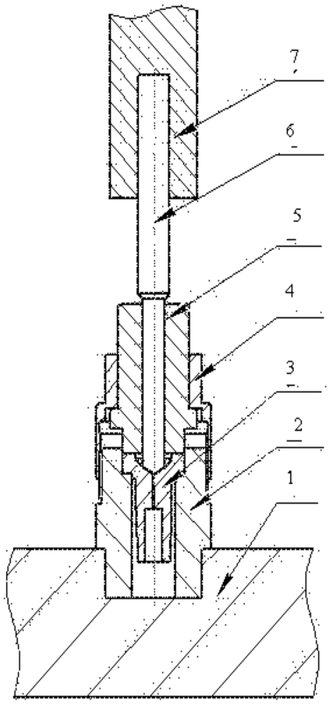

Fig. 3: Equipment for reconstruction the Bosch electrohydraulic injector shut-off valves; 1) Thrust plate; 2) Housing; 3) Valve seat; 4) Nut; 5) Guide space plate; 6) Lapping plate and 7) Chuck

The valve is installed in the housing 2 of the device and then the lapping compound is applied on cone for plunger pair lapping, after the valve the guide space plate 5 is installed and after that the valve with the space plate is tightened by the nut 4. The lapping plate itself is installed into the chuck 7 of the vertical drilling machine.

On the basis of BoschDieselService "Bashdizel", some experimental studies for rational regimes selection, developing and debugging of special equipment were conducted. For shut-off cone lapping it was recommended to use lapping compound with the size of abrasive particles no more than 3 µm, e.g., M3 lapping compound for plunger pair of JSC "Altai Precision Products Plant". The recovery cycle includes a periodic (15-20 times) pressing (with a force of 2-3 N) and brake-away of the lapping plate at a rotation speed of 2500-2600 rpm. The valve assembly is then washed in an ultrasonic bath, blown out with compressed air, after that a visual inspection of the lapping quality is performed using a microscope. When finding the matchmark on the shut-off surface, the lapping cycle is repeated. Then, the repairing process is continued in accordance with the standard technology (Fig. 4).

Cuts of the valve seat were manufactured with abundant cooling. The cuts were filled with epoxy adhesive and after drying, the samples were ground,

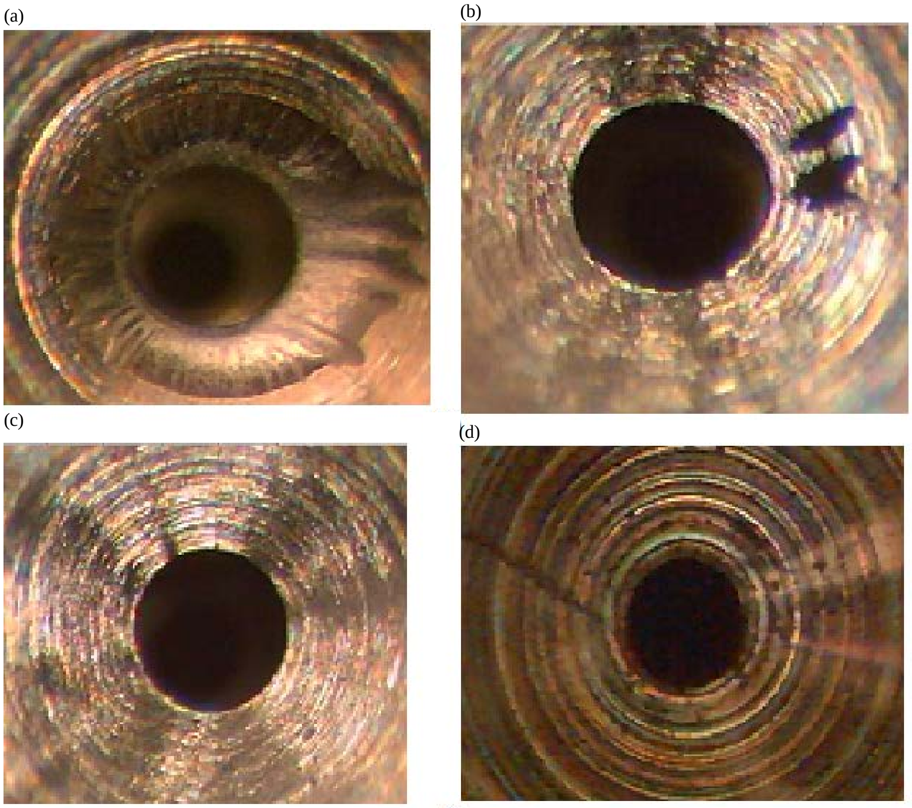

Fig. 4: Valve seat surface: a) Worn out valve seat before lapping; b) After the 1st stage of lapping; c) After the 2D stage of lapping and d) A new valve seat

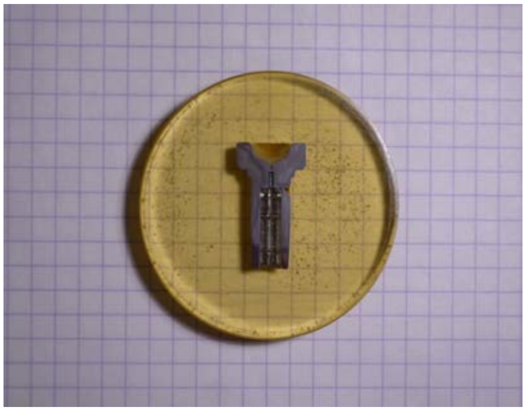

Fig. 5: Shut-off valve section

polished and several valve seats were pickled with a 5% solution of nitric acid in ethylic alcohol, Fig. 5.

Microhardness was measured with PMT-3 device with a load of 50 grams. The measured microhardness was converted into hardness units according to the Rockwell method.

RESULTS AND DISCUSSION

After hardening the valve seats by two methods with the subsequent grinding of the hardened layer, their surface looked as in Fig. 6. It is not possible to harden the whole surface of the cone of the valve seat as the diameter of the check ball is only 1.45 mm. The figure shows that after the electro-spark hardening, the surface of the valve seat is rough with relatively deep pores on it (Fig. 6a) as compared to the titanium nitride spraying (Fig. 6d). Subsequent lapping of the surface, after electro-spark hardening, removes fins (Fig. 6b, c). The surface coating structure after hardening is shown on Fig. 7.

The next stage of the research was experiments on the structure integrity assessment and hardness of the reconstructed shut-off valve surfaces. Figure 8 shows the section of the EHI valve at different magnifications whereas the boundary layer characterizing the surface hardening of the new valve seat is not found.

Then the microhardness of the valve seat surface coating to a depth of 0.5 mm was tested. Figure 9 shows the section of the EHI valve after measuring the microhardness in depth at various magnifications.

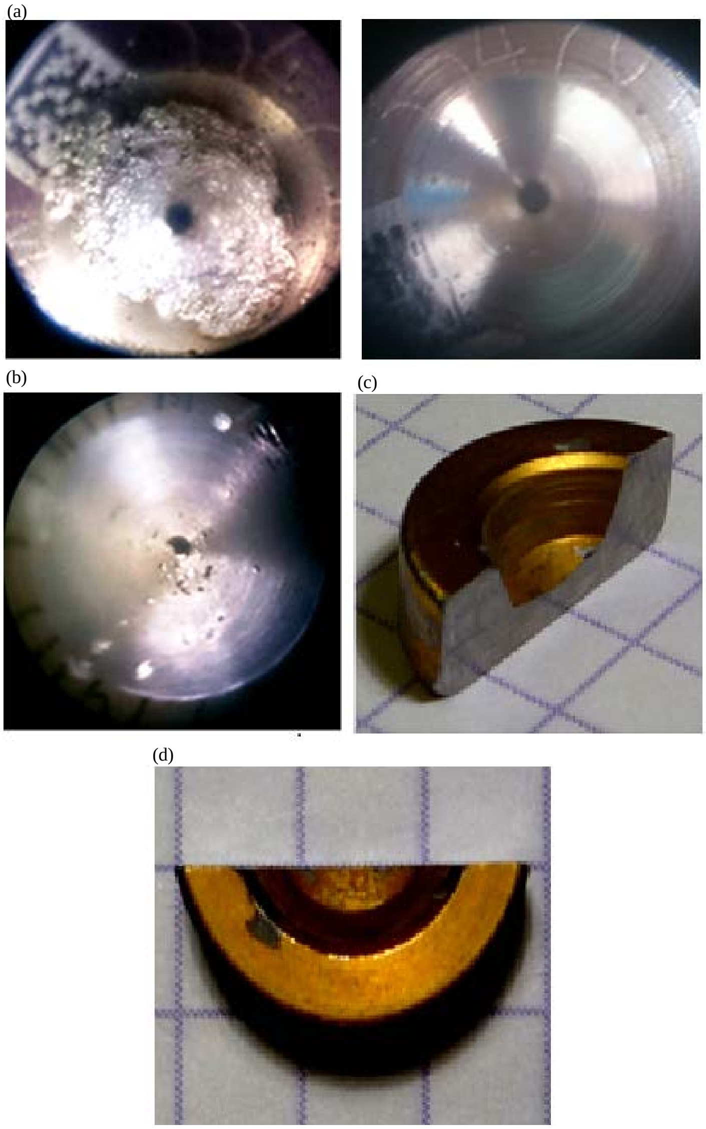

Fig. 6: The image of the valve seat after different types of hardening: a) After the electro-spark hardening; b) After the first stage of lapping the surface, after the electro-spark hardening; c) After the second stage of lapping the surface, after the electro-spark hardening and d) The valve seat surface after the nitride titanium spraying (the surface is flat, so, lapping is not required)

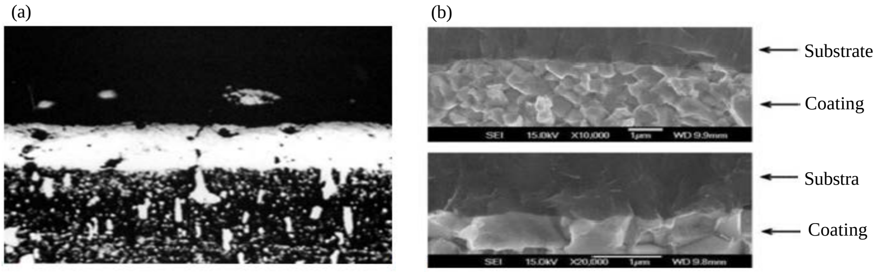

Fig. 7: Surface coating structure after hardening: a) After electro-spark hardening and b) After the titanium nitride spraying

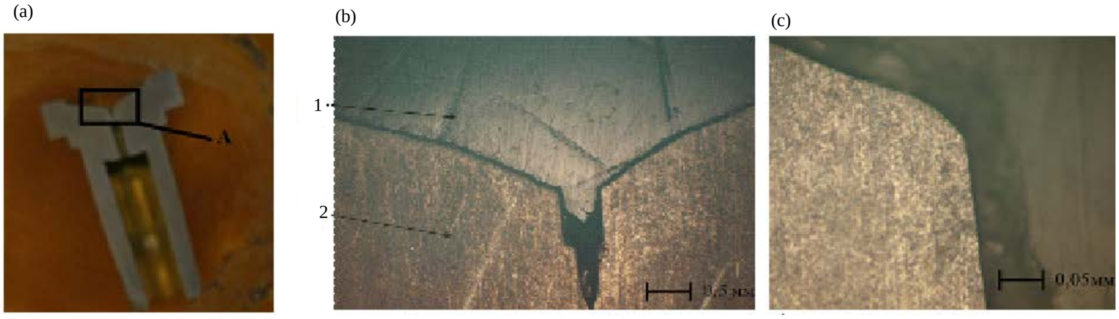

Fig. 8: Section of the EHI valve: a) After etching (actual size); b) Zone A at 30 times magnification (1-epoxy adhesive, 2-valve section) and c) Zone A at 300X magnification

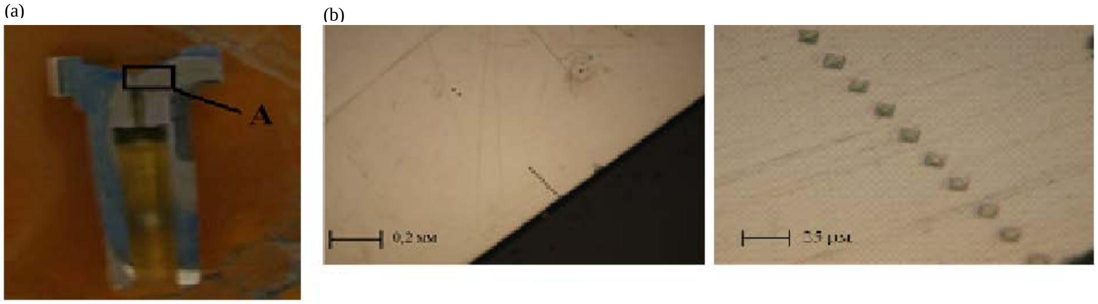

Fig. 9: EHI valve section: a) Filled in epoxy adhesive with subsequent grinding and polishing (actual size) and b) Diamond pyramid traces after microhardening was tested

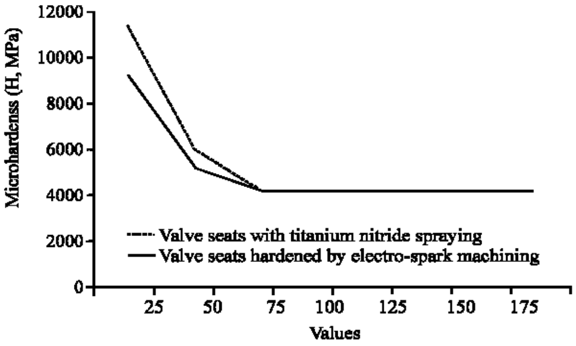

Fig. 10: Microhardness distribution in depth of valve seat

When measuring the microhardness, it is established that the trace sizes are the same on the entire surface of the valve section (Fig. 8b). Vickers hardness was HV650 units when converted into Rockwell units it was HRC58. It was also found that the hardness of new Bosch valves is about HRC40, ..., 42 while the valves hardness of 2009 ,..., 2012 production years was HRC57, ..., 59.

Microstructure analysis and microhardness testing in the depth of the EHI valve seat show that this part is 3 D hardened, therefore, the constructively incorporated wear resistance parameters for lapping the worn (not strengthened) valve remain.

The microhardness of valve seats hardened with titanium nitride spraying is 1.2 times higher than that of hardened by electro-spark machining with a tungsten carbide electrode (VK-8) (Fig. 10) and 2.7 times higher than in new ones which may indicate a proportional increase in abrasion wear. To compare the work of hardened and ground (not strengthened) EHI valves, comparative experimental studies were conducted.

Comparative studies on the efficiency assessment of valve pairs reconditioning were carried out for the Bosch EHI Model 0 445 110 376. The main diagnostic parameters were determined in accordance with the manufacturer's test plans (idle running check, at full load, pre-injection and hydro-firmness check), before and after repair (lapping) (Table 1) for comparison, data on testing of three new injectors are also given. According to the test data, fuel consumption for the control of all three new EHI before lapping the shut-off valves at full load exceeded the permissible limits for the Bosch test plan.

To test the working efficiency of the hardened valves, 4 Bosch injectors (EHI) of the Gazelle Next vehicle (Cummins ISF 2.8 engine) with different wear rates were selected. Number of the injector is 0445110376. The data on injector’s condition are shown in Table 2.

As can be seen from Table 2, all 4 injectors do not fit into the test plan. The key moment is the consumption

Table 1: Data on Bosch model 0445110376 repaired injectors on Bosch EPS 708 bench without valve seat hardening

Step of the test	Leak test	Full load	Idle running	Pre-injection
Electromagnetic pulse run time (µc)	0	800	700	295
Pressure in rail (MPa)	160	160	30	60
Cycle feeding (mm^3/cycle)				
According to plan	Not measured	64.8±8	5±3	1.8±1.5
Actual				
Before repairing				
No. 1	78.3	7.8	0.9	
No. 2	65.9	5.6	0.5	
No. 3	80.2	4.1	0.7	
After repairing (grinding)				
No. 1	61.0	5.2	1.4	
No. 2	59.4	4.8	1.6	
No. 3	58.7	4.6	1.7	
New one				
No. 1	62.3	5.1	2.3	
No. 2	63.2	5.2	2.5	
No. 3	64.5	5.4	2.3	
Control consumption mm^3/cycle				
According to plan	35±35	44±26		
Actual				
Before repairing				
No. 1	37.4	98.0	Not measured	
No. 2	82.3	208.2		
No. 3	20.2	86.6		
After repairing (grinding)				
No. 1	20.3	40.6		
No. 2	22.9	41.4		
No. 3	21.6	42.3		
New one				
No. 1	11.0	34.9		
No. 2	17.9	37.3		
No. 3	27.5	30.5		

Table 2: Data on Bosch model 0445110376 worn injectors testing on Bosch EPS 708 bench

	Standard 500 61000 MKC		VL1600 6ap800 MKC		
Injector codes	Feeding 28±3 (mm^3 /cycle)	Consumption control 14±6 (mm3/cycle)	Feeding64, 8±8 (mm^3/cycle)	Consumption control 44±26 (mm^3/cycle)	Armature stroke pilot-type valve 0.041±0.004 (mm)
C2A7CSC	36	160	-	-	0.050
ET3SNSI	28	90	78	220	0.045
AI1WGI8	29	40	68	100	0.042
ASHK4W4	28	20	62	75	0.048

Table 3: Strokes of armature groups and hardened layer thickness

Injector code	Initial armature stroke of control valve 0,041±0,004 MM	Armature stroke of control valve after the first stage of lapping	Armature stroke of control valve after initial lapping and running 10000 cycles	Armature stroke of control valve after surfacing (welding)	Armature stroke of control valve after final lapping	Hardened layer thickness
C2A7CSC	0.050	0.074	0.075	0.052	0.052	0.023
ET3SNSI	0.045	0.059	0.060	0.039	0.039	0.021
AI1WGI8	0.042	0.051	0.051	0.020	0.041	0.010
ASHK4W4	0.048	0.066	0.068	0.035	0.056	0.012

control which also includes leak of all micrometric elements in the injector. According to Bosch's complete test plan, the injector test should be performed in the following modes: VL- full load, EM-medium load, LL idle running, VE-pre-injection.

After testing the working efficiency of worn out injectors, they were disassembled, cleaned and checked for defects. The sprays were washed in an ultrasonic bath. The valve seats were hardened with the two above mentioned methods. The valve ball and the sealing fluoroplastic washer were replaced with new ones.

Armature valve stroke is also one of the key moments when adjusting the EHI as it is necessary for further measurement of the hardened layer. The armature stroke is measured with the help of a special device and electronic indicator. Table 3 gives data on the travel of armature groups with different methods of hardening. The valve seats No. 1 and 2 were sprayed with titanium nitride and No. 3 and 4 were treated with electro-spark machining. After electro-spark hardening, the seat of the shut-off cone has lost its hydraulic firmness that's why the valves were re-ground and then the injector was again assembled and the armature strokes were tested.

Table 4: Data on repaired Bosch model 0445110376 injectors testing on Bosch EPS 708 bench after hardening the valve seats

Test run step	Leak test	Full load	Idle load	Pre-injection
Electromagnetic pulse run time (μc)	0	800	700	295
Pressure in rail (МПа)	160	160	30	60
Cycle feeding mm^3/cycle				
According to plan	Not measured	64.8±8	5±3	1.8±1.5
Actual				
Before repairing				
No. 1		Н.Д	Н.Д	Н.Д
No. 2		78.0	5.6	0.3
No. 3		68.2	7.8	0.1
No. 4		62.1	6.3	0.7
After spraying valve seat with titanium nitride				
No. 1		62.3	5.2	1.7
No. 2		59.4	4.8	1.8
After hardening valve seat with electro-spark machining				
No. 3		62.3	5.1	1.6
No. 4		63.2	5.2	1.9
Control consumption mm^3/cycle				
According to plan	35±35	44±26	Not measured	
Actual				
Before repairing				
No. 1	450	Н.Д		
No. 2	82	220		
No. 3	48	100		
No. 4	51	75		
After spraying valve seat with titanium nitride				
No. 1	20.3	40.6		
No. 2	22.9	41.4		
After hardening valve seat with electro-spark machining				
No. 3	20.0	44.9		
No. 4	17.9	37.3		

Table 3 shows that the hardened layer thickness of No. 3 and 4 valves is 0.011 mm and of No. 1 and 2 valves is 0.022 mm. When spraying titanium nitride, the surface is flat and no final grinding is required. After electro-spark welding, the layer becomes thicker, about 0.031-0.033 mm but the surface is not even and requires final grinding, however in this process, about 0.020 mm of the hardened coating is removed.

After the valves restoration with hardening of the seats all injectors within the tolerance limits the diagnostic parameters during testing at the EPS 708 bench were included (Table 4).

As can be seen from Table 4 injectors with valves and after the titanium nitride spraying and after electric spark treatment hardening are included in the permissible parameters for all indicators of the manufacturer's test plan. Then all 4 injectors were installed on a car and now have more than 20,000 km of run.

The comparative cost value of three different types of repair of the EHI valve shows: repair without hardening (only grinding) -1 conv. unit, repair of the valve seat with electro-spark hardening -1, 2 conv. units, repair with hardening of the valve seat by titanium nitride spraying 1.5 conv. units.

CONCLUSION

These studies prove that the EHI valve seat is a 3D-hardened part and has the same hardness at the entire depth. Lapping the surface of the valve seat does not weaken the hardness in the contact area and, therefore, cannot cause a decrease in the post-repair life. The hardening of valve seats by electro-spark machining with VK-8 electrode and the spraying of titanium nitride increases the hardness by 2.2 and 2.7 times, respectively in comparison with the new valve seats which may indicate a proportional increase of wear resistance in abrasion. In general, the studies have shown the possibility of using hardening operations when repairing electrohydraulic injectors.

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