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Repair methodology of a piezoelectric injector utilizing components obtained from selective decomposition

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The paper presents an example of regeneration of a common rail piezoelectric fuel injector, which was carried out with using used parts. The most important stages of maintenance activities are listed, as well as the types of diagnostic tests performed on separate test benches. The obtained results indicate that this process can be effectively carried out with existing technological problems and lack of support from the manufacturer. At the same time, it was shown that, contrary to popular belief, cannibalisation does not have to be limited only to minor elements, but also to key components important from the point of view of the satisfactory technical condition and correct working of the fuel injector during further operation.

Key words: *common rail system, piezoelectric fuel injector, selective decomposition, regeneration process*

1. Introduction

Selective decomposition consists in obtaining spare parts from damaged products, as well as their control for reuse [26]. This process is one of the forms of recovery being used to maintain or restore the original technical condition in a relatively short time. For this reason, it is successfully used in the automotive services sector, where the efficient satisfaction of customer needs and requirements plays a significant role [3, 25, 27, 32]. In addition, it enables the repair of selected assemblies or subassemblies when new spare parts are not available on the market [16]. With regard to the fuel equipment of compression-ignition engines, this is related to the conscious policy of manufacturers who limit the regenerative capabilities of common rail fuel injectors. This mainly applies to solutions with a stack of piezoelectric crystals, for which replacement of the actuating and controlling components is not provided [13, 18]. As a result, their maintenance was reduced to cleaning, testing and possible replacement of a worn plunger and barrel assembly (needle with nozzle) for selected reference numbers. This is the opposite of systems with a classic electromagnetic coil, because over the years as many as three stages of repair have been implemented for them [10, 22]. Since they were introduced gradually, cannibalization was used for small parts that were not offered for sale. Examples include retaining pins, valve and needle springs, adjusting shims from specific selection groups, etc. [24].

Recently, the regeneration capabilities of piezoelectric fuel injectors have significantly improved. This is primarily due to the availability of specialized measuring equipment, which allows for full diagnostics [21]. In this regard, the key issue is the software with the manufacturer's data, because the knowledge of the limit ranges eliminates the need to look for alternative tests, e.g. drawing up reference characteristic curves to assess the method of fuel dosing [23]. In addition, modern testers offer comprehensive control of electrical components, and test benches are equipped with stack revitalisation functions, i.e. removing short circuits between crystals, as well as assigning new codes after repair [8, 12, 29]. Essentially, the only unresolved problem is the lack of original spare parts, which makes it difficult to restore the full efficiency of fuel injectors from selected manufacturers. Nevertheless, such actions are being taken, as shown in the discussed example.

2. Methods

2.1. Test object

The tests were carried out on a Denso G2P piezoelectric fuel injector, which was removed from the 2.2 D-CAT (Diesel Clean Advanced Technology) engine of a Toyota Corolla Verso passenger car with a mileage of 322,000 km.

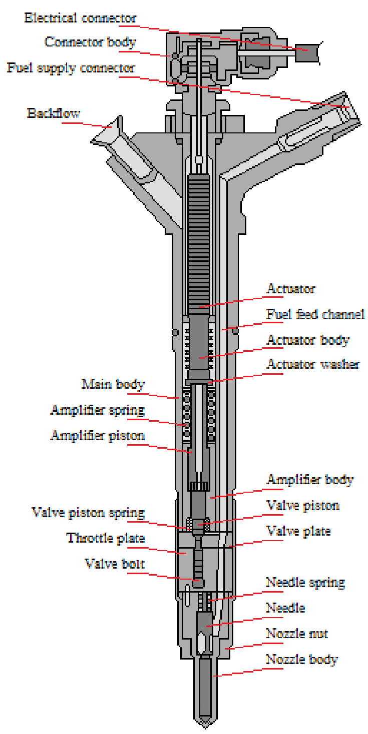

Fig. 1. Denso G2P fuel injector design: own study based on [7]

Fuel injectors of this type are the second generation of common rail systems (CRS), working at maximum operating pressures up to 180 MPa [5, 15]. Figure 1 shows the internal structure, detailing the elements of the hydraulic booster, control valve and nozzle. The listed components are analogous to the solutions from Bosch [1, 20]. A characteristic feature, however, is the movable part of the control valve, which in the form of an elongated plunger (screw) performs an additional sealing function. Unfortunately, laboratory and workshop practice shows that damage to its working surfaces is diagnosed relatively often, which results in an increased amount of fuel going to the fuel return overflow. In addition, the construction of the fuel injector practically did not take into account the adjusting shims, eliminating the possibility of additional correction of fuel dosing, which the manufacturer provided for solutions with an electromagnetically controlled valve [11, 14].

2.2. Test beds

The following equipment and instrumentation were used in the regeneration of the tested fuel injector:
– 12PSB test bench with a Stardex test kit,
– Mega Tester V3 piezoelectric actuator tester,
– Yizhan 13MP HDMI VGA microscope camera,
– Polsonic Sonic 9 ultrasonic cleaner,
– Facom E.316A200S electric torque wrench,
– vices, grips and workshop tools.

Fig. 2. 12PSB test bench with a Stardex test kit

The Stardex test kit included the Nova Ultima simulator, the Stream flow meter and the Prima cooling, filtering and damping module. The system was complemented by a PC computer with the Ubuntu Linux system, equipped with the necessary peripheral devices (Fig. 2). Its connection to the 12PSB test bench allowed for a comprehensive fuel injector check in automatic mode. Other control, repair and maintenance activities, including additional calculations, were carried out at separate laboratory stations.

2.3. Research plan

Figure 3 shows the test plan, the course of which is analogous to the standard procedures used in the maintenance of fuel injectors. Differences may result from the access to specific diagnostic equipment, as well as the type of irregularities found. For example, electrical tests are usually conducted on the main test bench [17]. However, their isolation makes it possible to detect damage to the crystal stack already at the initial stage, which makes further actions pointless. In the absence of a dedicated tester, a universal multimeter with a capacitance measurement function can be used [2, 4]. In turn, the suspicion of the presence of metal filings entering the fuel injector from a faulty pump will result in an earlier microscopic examination. In this way, they will not be removed during cleaning in an ultrasonic cleaner.

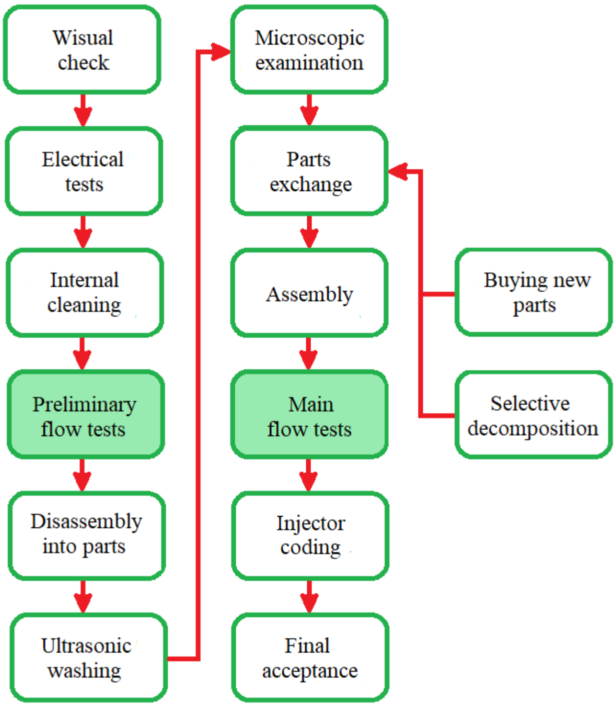

Fig. 3. The research plan for Denso fuel injector

3. Analysis results and discussion

3.1. Preliminary tests

During the external inspection, no external defects or missing components of the fuel injector were detected.

Fig. 4. Testing of the electrical parameters of the fuel injector

In the next step, electrical measurements were started, which were carried out using the Mega Tester V3 tester (Fig. 4). There was no breakdown of insulation between the actuator and the main body ($R_i = \infty$). In addition, almost exemplary results were obtained for the remaining parameters, as shown in Fig. 4. The capacitance of the crystal stack was C = 3.00 μF, and its resistance R = 1.01 MΩ, which is characteristic only for piezoelectric fuel injectors from this manufacturer. This value remained unchanged in the continuous R_C load test.

Then, flow tests were carried out on the 12PSB test bench with a Stardex test kit, the results of which are summarized in Table 1. It can be seen that the amount of fuel going to the overflow is definitely too high, which clearly indicates incorrect operation of the valve group [31]. In addition, incorrect values of the idling and pilot doses were obtained, taken in the range of the lowest operating pressures and activation times. The probable cause is the deterioration of the cooperation of the plunger and barrel assembly, i.e. grinding of the needle in the nozzle, and thus the failure very often encountered at high mileage [30].

Table 1. Results of the preliminary fuel injector flow test

Test number	Injection pressure p_{inj} [MPa]	Nozzle opening time t [μs]	Injection dosage d [ml/min]	
			Nominal range	Result
1	180	600	79.1±10.0	74.4
2	180	277	27.5±6.0	27.1
3	180	194	8.7±4.0	7.9
4	140	700	76.3±11.3	68.3
5	140	317	29.3±6.0	29.8
6	140	178	6.7±4.0	4.2
7	80	696	48.3±7.0	43.7
8	80	180	4.5±3.2	1.1
9	35	693	22.5±4.5	17.1
10	35	300	5.4±4.0	1.3
Test number	Injection pressure, p_{inj} [MPa]	Nozzle opening time t [μs]	Back flow r [ml/min]	
11	160	800	35.0±25.0	66.8

a)

b)

Fig. 5. Examples of assemblies after disassembly: a) hydraulic booster, valve, nozzle, b) piezoelectric actuator

Figure 5 shows the view of exemplary fuel injector components after disassembly. At this stage, it is possible to inspect the individual components in detail, as well as to carry out simple tests, e.g. checking the patency of the nozzle openings. The easiest way is to use the WD-40 multipurpose spray directly (Fig. 6). This test should be regarded as optional, usually performed when the nozzle tip is heavily coked or contaminated.

Fig. 6. Checking the patency of the nozzle openings

Fig. 7. Microscopic examination of the valve plunger

Before microscopic examination, all parts, except for the piezoelectric actuator, were subjected to baths in an ultrasonic cleaner and dried. The examination under high magnification confirmed the previous assumptions. The edges of the valve plunger exhibited distinct signs of abrasive wear, similar to its working surfaces (Fig. 7). In turn, numerous longitudinal scratches were observed on the needle, which indicates the progressing process of its scuffing (Fig. 8). In addition, corrosion was found on some parts in contact with the fuel, such as the body of the hydraulic booster, throttle and valve plates. As a result, a decision was made to replace the actuating and controlling units, omitting the efficient piezoelectric actuator.

At present, the commercial offer includes only the nozzle group, produced, for example, by Warszawskie Zaklady Mechaniczne "PZL-WZM" [27]. The remaining components were obtained through selective decomposition of a low mileage injector, in which the non-replaceable stack of piezoelectric crystals suffered permanent damage.

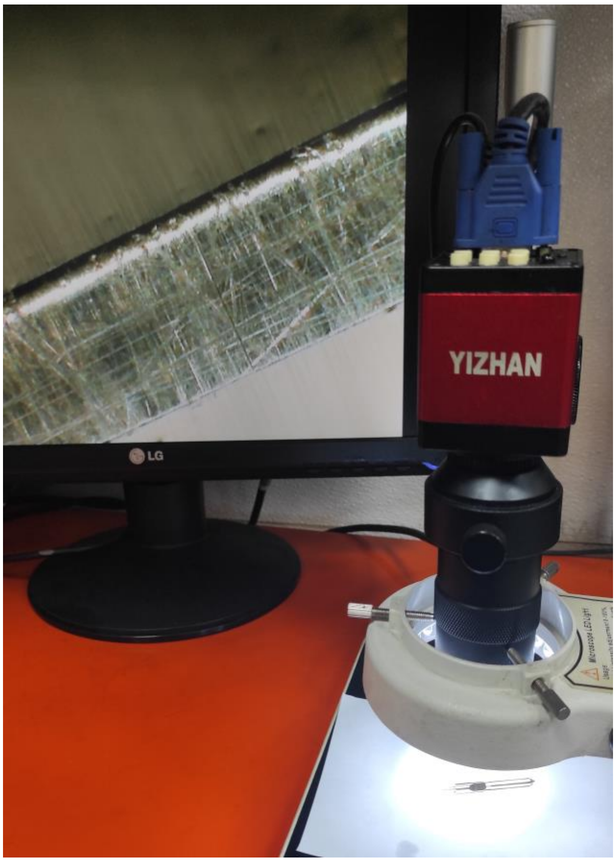

Fig. 8. Microscopic examination of the needle

Next, the assembly process was carried out. It should be noted that the assembly of the piezoelectric actuator must be carried out in the presence of diesel oil, as in the solutions of Bosch [9]. In this way, the possibility of falsifying test results in flow tests on the test bench is eliminated.

3.2. Main tests

Table 2 presents the results of flow tests of the fuel injector after regeneration. This process should be assessed positively, as the values of all doses were within the limit ranges specified by the manufacturer. In addition, a small amount of fuel going to the overflow indicates that the valve group and the hydraulic booster are working perfectly fine.

It is worth noting that during the repair the fuel injector receives new IMA (German: Injektor-Mengen-Abgleich) dosing correction codes. However, unlike solutions from other manufacturers, it is not enough to enter them into the engine control module (ECM), as the so-called zero dose calibration is also required. In this process, the system performs self-diagnosis, which consists in checking the method of fuel supply at various operating pressures and activation times. Essentially, only this stage ends the regeneration procedure, although it is not directly related to it.

Table 2. Results of the main fuel injector flow test

Test number	Injection pressure p_{inj} [MPa]	Nozzle opening time t [μs]	Injection dosage d [ml/min]	
			Nominal range	Result
1	180	600	79.1±10.0	77.1
2	180	277	27.5±6.0	31.3
3	180	194	8.7±4.0	10.4
4	140	700	76.3±11.3	73.2
5	140	317	29.3±6.0	33.6
6	140	178	6.7±4.0	6.5
7	80	696	48.3±7.0	53.1
8	80	180	4.5±3.2	3.3
9	35	693	22.5±4.5	25.0
10	35	300	5.4±4.0	4.4
Test number	Injection pressure p_{inj} [MPa]	Nozzle opening time t [μs]	Back flow r [ml/min]	
11	160	800	35.0±25.0	11.5

4. Conclusions

The presented example indicates that selective decomposition does not have to be limited solely to small components. This is because the complete main components, which are crucial for proper operation, have been replaced. At present, this is essentially the only way to regenerate Denso fuel injectors, assuming that the piezoelectric actuator has not been damaged. For the above reasons, service companies that repair fuel equipment do not sell used parts, nor do they return them to the manufacturer. The added value is participation in the chain of their acquisition and reuse, which is part of the term reverse logistics [6, 19].

Acquiring used parts can be done in various ways. Many of them come from injectors that have not been qualified for flow testing, for example due to incompleteness, lack of sealing, damage to the crystal stack, etc. They can be left by customers themselves, provided by friendly car workshops, or finally purchased on the secondary market. However, it should be emphasized that a necessary condition for their reuse is a good technical condition. This means that the main components of the executive and control assemblies must be completely free of corrosion and any mechanical damage (cracks, material defects, traces of rubbing, etc.) that could have a negative impact on the functionality of the injector. Therefore, before reuse, they should undergo procedures such as cleaning in ultrasonic cleaners, drying, and detailed microscopic inspections.

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