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## METHODOLOGY FOR THE REPAIR OF DENSO COMMON RAIL SOLENOID INJECTORS

### METODYKA NAPRAWY WTRYSKIWACZY ELEKTROMAGNETYCZNYCH UKŁADÓW ZASILANIA COMMON RAIL DENSO\*

*This paper presents the problems of Denso Common Rail solenoid injector verification and repair. Due to conscious policy of the manufacturer who does not offer spare parts or special tooling, their servicing comes down most frequently to external cleaning, internal rinsing by the thermo-chemical method, and testing on test benches. Based on the analysis of failures and malfunctions being most frequently observed, own methodology for the repair process have been presented, specifying the successive stages of disassembly and final assembly. A possibility of effective fuel metering correction has been demonstrated, which is presented on the example of injectors in a 2.2 HDI engine of Citroën Jumper II delivery van.*

**Keywords:** *compression-ignition engine, injectors, repair, adjustment.*

*W artykule przedstawiono problematykę weryfikacji i naprawy wtryskiwaczy elektromagnetycznych Common Rail firmy Denso. Ze względu na świadomą politykę producenta, który nie oferuje części zamiennych i specjalistycznego oprzyrządowania, ich obsługa sprowadza się najczęściej do czyszczenia zewnętrznego, płukania wewnętrznego metodą termochemiczną oraz testowania na stołach probierczych. W oparciu o analizę najczęściej spotykanych uszkodzeń i niesprawności, zaprezentowano własną metodykę procesu naprawy, z wyszczególnieniem kolejnych etapów demontażu oraz montażu końcowego. Wskazano na możliwość efektywnej korekty dawkowania, którą pokazano na przykładzie wtryskiwaczy silnika 2,2 HDI pojazdu Citroën Jumper II.*

**Słowa kluczowe:** *silnik o zapłonie samoczynnym, wtryskiwacze, naprawa, regulacja.*

#### 1. Introduction

The Common Rail injectors are the most sensitive, i.e. damageable, elements of the fuel delivery system of modern car engines [7, 8, 10]. This is chiefly due to exceptionally difficult operation conditions which may include, among others, high pressure and temperature, ballistic phenomena, turbulent fluid flow, etc. Defects appear as a result of the normal wear of needle and nozzle assemblies and actuators, occurring usually after the time of longer operation or use of considerable intensity. There are also defects being induced by erosion and cavitation, in particular in the vicinity of nozzle holes and control valve seat [1, 5, 6, 9, 12, 13]. In some cases, however, hugely accelerated processes take place, leading to premature damages. Failure wear, being also called pathological wear, may occur due to the use of fuels with inappropriate physicochemical properties (viscosity, density, water and sulphur content) and those being contaminated, for example, with the filings from faulty high-pressure pump [2, 5, 6, 7, 9, 12]. The external damages, resulting from the improper assembly and disassembly of injectors being performed inconsistently with the recommendations of manufacturer or without specialist tools, e.g. slide tampers, hydraulic instruments, bench vices, repair kits, torque wrenches, etc., are a separate group.

#### 2. Research objective

The Denso solenoid injectors are characterised by the design and the principle of operation being similar to the Bosch first-generation products which have been comprehensively discussed in the literature

[2, 3, 8, 10]. Therefore, the verification of respective parts is similar, focusing in particular on evaluation of the wear of: needle, nozzle tip, guide plunger, control unit (valve, body, mounting). Figure 1 also presents the elements which are taken into account when injector adjustment is needed, i.e. pressure spindle (full load fuel charge) and calibration and needle washers (pilot fuel charge and idle run fuel charge, respectively).

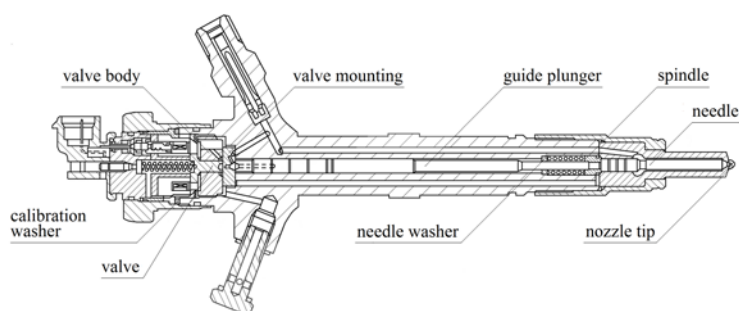


Fig. 1. A diagram showing Denso solenoid injector

The principal objective of this study was to provide a cognitive, factual evaluation of the reparability of Denso injectors, considering the given assumptions, i.e. lack of access to spare parts and necessity to determine guidelines for respective disassembly and assembly stages. These processes required an adapter to be prepared for unscrewing and screwing a nozzle nut which, due to wrench sizes, is not

(\*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie [www.ein.org.pl](http://www.ein.org.pl)

provided with the tooling being used when servicing injectors made by other manufactures. The second objective, of an utilitarian nature, was to make an attempt to determine a method for the correction of fuel charge, the value of which was not within acceptable limits during the tests being performed.

### 3. Test object and test bed

The test object were Denso solenoid injectors which had been removed from a 2.2 HDI (*High Pressure Direct Injection*) engine of Citroën Jumper II delivery van with the mileage of 148 thousand km. It is a four-cylinder, 16-valve compression-ignition engine with a maximum power of 88 kW, with Common Rail direct fuel injection system. The repair of injectors was conducted on laboratory stands at VASCO Co. Ltd in Mierzyn near Szczecin, co-operating with the Department of Automotive Engineering of the West Pomeranian University of Technology (ZUT) in Szczecin. The following tests were used in this process:

- test benches (Diesel Bench CRU 2 Zapp, Diesel Tech DS2 Zapp),
- FL150/70 microscope with a camera for recording digital images on a PC-class computer,
- MIC-40700 LCR meter,
- Flexbar IP54 digital micrometer,
- ultrasonic cleaners (Elma Elmasonic S 10 H, Carbon Tech Ultrasonic Bath S15/C2),
- GRS Tools POWER HONE diamond grinder,
- vices and injector disassembly and assembly kits,
- torque wrenches.

### 4. Test scope and methodology

Tests were conducted according to an own methodology adopted which included three successive implementation stages (Fig. 2).

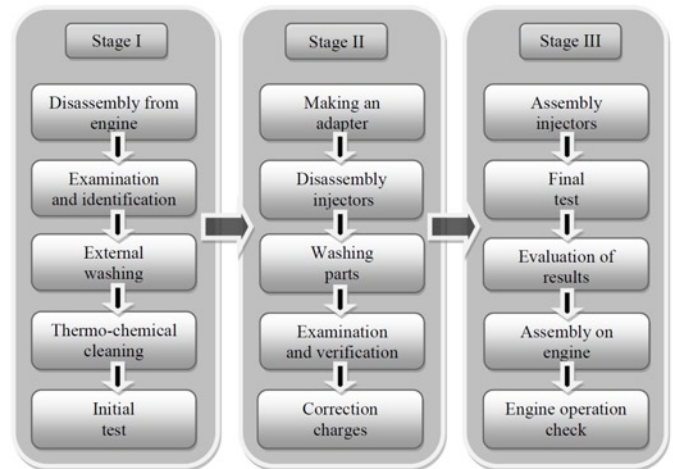


Fig. 2. Methodology for the repair of injectors being analysed

The steps included in respective stages match the standard Bosch procedures. The basic difference is the third step of repair introduced by the manufacturer, basing on the equipment and instrumentation dedicated solely for own products. A distinctive feature of the current technology in operation is earlier adjustment of injectors in order to obtain correct results on a test bench. The methodology being pre-

Table 1. Examples of the most frequent external damages of Denso injectors

Type of part	Type of defect	Possible causes
Main body	Cracking	Incorrect assembly on or disassembly from engine (too strong tightening of the mounting yoke, no lubricant, wrong tools selected)
	Deformation of shape	Incorrect assembly on or disassembly from engine; grinding of the surface is required to aid injector mounting
	Contamination, coking	Long-term operation of engine; fuelling with poor quality fuels or those with high level of vegetable component; combustion of lubricating oil due to scavenge phenomena
High pressure connector	Deformation of shape	Incorrect assembly on or disassembly from engine (tightening the injection pipe nut with too high torque, strong impact)
	Thread damage	
Control solenoid valve	Damages to plastic housing	Incorrect assembly on or disassembly from engine
	Damage to nut	Incorrect assembly or disassembly (tightening with too high torque, wrong tools selected)
	Damage to electrical connection	Incorrect assembly or disassembly of feeder cable plug
	Damage to overflow pipe and connector	Incorrect assembly or disassembly
Nozzle	Nozzle tip damage	Overheating; unauthorised cleaning
	Contamination, coking	Long-term operation of engine; fuelling with poor quality fuels or those with high level of vegetable component; combustion of lubricating oil due to scavenge phenomena
	Nozzle tip burning	Long-term and intensive operation of engine, fuelling with poor quality fuels
	Deformation of holes	Long-term operation of engine; fuelling with poor quality fuels; high combustion temperatures; erosion and cavitation processes

Table 2. Preset test parameters when measuring injector delivery rate

Type of fuel charge	Injection Pressure [MPa]	Injection time [ $\mu$ s]	Set value of injection fuel charge [mg/skok]	Set value of return fuel charge [mg/skok]
Full load	160	910	$47,74 \pm 6,93$	$32,90 \pm 32,90$
Emission (half-load)	80	720	$18,28 \pm 4,20$	$25,00 \pm 25,00$
Idle run	25	710	$3,90 \pm 1,84$	$15,00 \pm 15,00$
Pilot	80	320	$1,84 \pm 1,22$	$15,00 \pm 15,00$

sented is a classic approach based on the long-standing workshop and laboratory practice but being possible to use in a much broader scope. It assumes a correction of fuel charges only after the results of initial test stage have been obtained. Furthermore, successive stages may be modified as required, enabling the repair of solenoid injectors of different types and manufactures. In the case of the Denso products, it was necessary to make an adapter for nozzle nut.

#### 4.1. Stage I

First of all, the injectors were prepared to initial test. After their removal from the engine, the injectors were evaluated by visual assessment and completeness check of components. Examples of external damages, detectable in this stage, are summarised in Table 1. Next, theirs were identified, reading the numbers on the main body

and entering them into the memory of test benches in order to carry out the measuring stage.

The washing of injectors in ultrasonic cleaners was carried out so that control solenoid valves were not immersed in the cleaning fluid. This is because the plastic housing may soften and insulation may be damaged. Duration of this process did not exceed 30 min. Next, the injectors were dried and purged with compressed air.

The procedure of initial test was started checking the solenoid coil resistance and inductance and its fault to frame. This testing should be treated as a supplementary (additional) one because inspection of injectors on test benches includes within its scope basic electrical measurements. It should also be noted that defects of the element under discussion in Denso products have been occasionally encountered during several years of practice, which does not find confirmation in

Table 3. Examples of the most frequent internal damages of Denso injectors

Type of part	Type of defect	Possible causes
Control valve unit	Scratching or deformation of valve seat	Too large half-ball travel; poor fuel quality and fuel contamination; improper filtration; presence of solids (faulty pump); erosion and cavitation processes
	Scratching of valve spindle surface	Poor fuel quality (lubricating ability) and fuel contamination; improper filtration; presence of solids (faulty pump)
	Damages to the surface of valve body and mounting	Poor fuel quality and fuel contamination; improper filtration; presence of solids (faulty pump); erosion and cavitation processes
	Corrosion of the surface of valve body and mounting	Poor fuel quality (sulphur and water)
Guide plunger	Surface scratching or seizure	Poor fuel quality (lubricating ability) and fuel contamination; improper filtration; presence of solids (faulty pump)
	Surface corrosion	Poor fuel quality (sulphur and water)
Nozzle	Seat deformation	Poor fuel quality and fuel contamination; improper filtration; presence of solids (faulty pump)
	Worsening of the needle and nozzle assembly cooperation	Abrasive wear as a result of natural processes
	Surface scratching or seizure	Poor fuel quality (lubricating ability) and fuel contamination; improper filtration; presence of solids (faulty pump)
	Pressure face corroding	Poor fuel quality (sulphur and water)
	Contact zone overheating	Long-term and intensive operation of engine; too high temperature of operation
Needle	Worsening of the needle and nozzle assembly cooperation	Abrasive wear as a result of natural processes
	Damage to needle cone	Poor fuel quality (lubricating ability) and fuel contamination; improper filtration; presence of solids (faulty pump)
	Surface scratching or seizure	
	Surface corroding	Poor fuel quality (sulphur and water)
	Contact zone overheating	Long-term and intensive operation of engine; too high temperature of operation

the assessment being presented in the paper by Kuszewski and Usztrzycki [11].

In injector measurements made on testers, the following initial tests were carried out:

- electrical test „eRLC” (*Resistance, Inductance, Capacitance*), except the capacitance being checked for the products with piezoelectric elements,
- leakage test „LKT” (*Static Leak Test*),
- nozzle opening pressure test „NOP” (*Nozzle Opening Pressure*),
- volume test „iVM” (*Injector Volume Metering*) for respective fuel charges, the parameters of which are summarised in Table 2.

#### 4.2. Stage II

To unscrew nozzle nuts, a special adapter was made, using a 30 mm hexagonal iron (Fig. 3). This was a necessary condition to carry out disassembly because adapters for injectors of other manufacturers have different dimensions.

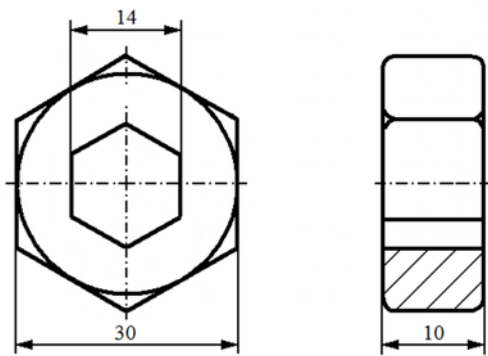


Fig. 3. An adapter enabling nozzle nut to be unscrewed

When unscrewing the nut, a torque of 150 Nm should not be exceeded because the sealing surface may be permanently damaged and the pins locating nozzle position against a fuel feed hole may be shorn. After this step, an access to the following elements was gained: needle, lower spring, needle washer, spindle and guide plunger. It should be noted that any resistance occurring when removing the latter from the main body is evidence of permanent seizure and impossibility to repair the injector.

Before disassembling the upper part, scribing markings were made, locating the original position of control solenoid valve against a high pressure connector. The unscrewing of nut enabled the following elements to be removed: valve shim and spring washer, upper spring, and half-ball valve. Access to the body and mounting, co-operating with the latter, required a special triple-bit wrench to be applied.

All parts, except solenoid valve, were rinsed in ultrasonic cleaners and then dried and purged with compressed air. Their evaluation and verification was done by the visual method (organoleptic assessment), as well as at high magnification of laboratory microscope. A summary of the most frequent internal defects, detectable in this stage, is presented in Table 3. Possible correction of fuel charges should take place after last stage, before assembling the injectors and carrying out the main tests.

#### 4.3. Stage III

In the first instance, upper parts of the injectors were assembled, preserving the reverse order to disassembly. The tightening torque for the valve body should not exceed 75 Nm. The mounting of half-ball is important so that its flat surface is outside the seat. It must also be remembered that the original position of solenoid valve coil against a high pressure connector is to be preserved. Threads for solenoid valve and nozzle nuts should be lubricated with white mineral oil and their

tightening should be done with torques amounting to 10–15 Nm and 45 Nm.

Inspection of the injectors on test benches was carried out in a similar way to that for the initial test. Owing to that, a comparison of the test results from before and after the repair was possible. Next, the injectors were assembled on the engine, the operation of which was assessed during a test drive.

## 5. Results and discussion

Evaluation of the injectors did not show any external defects or missing components. After the preparation stage, initial tests were performed, the results of which are summarised in Table 4 and Figures 4 and 5. Electrical measurements excluded a failure solenoid coils, while no fault to frame in them was found in the supplementary test (outside test bench) These findings were consistent with the guidelines being presented by other authors [8, 9]. In the leakage tests, no fuel leaks on injector tips were found, while fuel overflow delivery rates were minimal. Also the nozzle opening pressure was positively evaluated. Any failures in this respect would induce an immediate termination of the test stage, disqualifying a given injector from further tests.

Table 4. Results of the initial tests for the Denso injectors being analysed

Injector number	Electrical test „eRLC”		Leakage test „LKT” [MPa]	Nozzle opening pressure test „NOP” [MPa]
	Coil resistance [Ω]	Coil inductance [μH]		
1	0,54	181	81,80	16,00
2	0,72	184	82,70	18,50
3	0,55	179	90,30	15,50
4	0,72	179	86,80	16,00

The analysis of fuel delivery rate in the „iVM” test showed that idle run fuel charges for injector 2 and 4 were too small, amounting to 1.78 mg/stroke and 1.94 mg/stroke, respectively. The results pointed to the worsening of the needle and nozzle assembly co-operation, which became apparent only when setting low pressure on a tester. Malfunction of this type is one of the most frequently detectable defects, being also encountered in the products of other manufacturers, but it is usually observed in the injectors of engines with a relatively low operational mileage. In such cases, a change in the initial stress of lower spring is required, which reduces the lift of needle at low pressure and in consequence the charge of injected fuel. The correction of fuel charge is conducted by reducing needle washer thickness.

The process of disassembly was carried out for all products being analysed, mainly to wash and carefully verify their components. It can, however, be simplified in the situation when only idle run fuel charge adjustment is assumed, which requires the nozzle itself to be unscrewed and taken to pieces. Due to the fact that needle washer replacement is not possible, its butting face was ground off on a GRS Tools POWER HONE grinder. An assumption was made, like in the case of Bosch injectors, that thickness reduction by 0.1 mm would allow obtaining an increase in fuel delivery rate by about 1,5 mg/stroke. The size of fuel charges in the products being positively evaluated was also taken into account in order to obtain relatively similar injection parameters. Therefore, the thickness of needle washers in injectors 2 and 4 was reduced from 1.33 mm to 1.27 mm. Before assembling, evaluation of all parts was made in a microscopic examination, focusing in particular on the needle and nozzle assembly and actuators. No internal damages were detected.

The findings of main tests show that adjustment of the injectors being repaired produced advantageous results (Figs 6 and 7). An increase in idle run fuel charges by a predicted value of 0.75 and

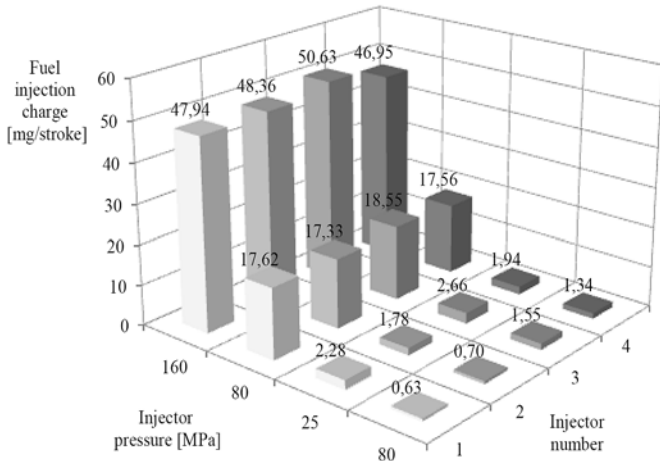


Fig. 4. Results for injected fuel delivery rate according to injection pressure obtained from the initial test for the injectors being analysed

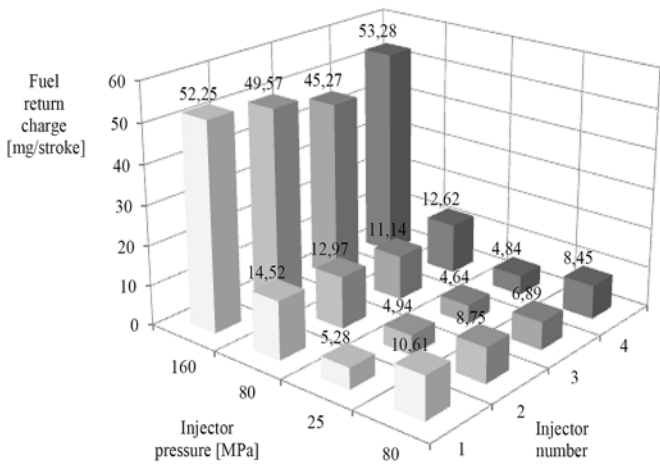


Fig. 5. Results for fuel return charge according to injection pressure obtained from the initial test for the injectors being analysed

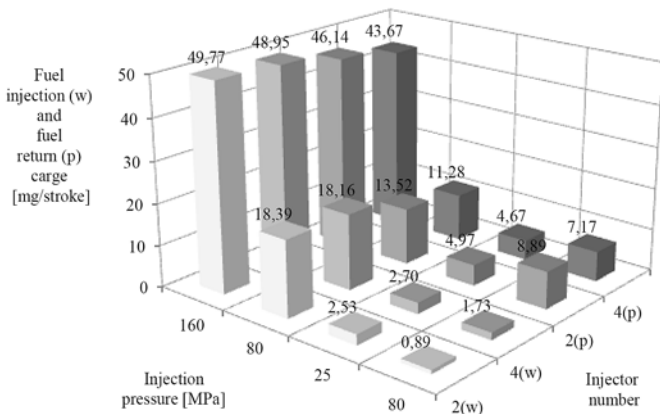


Fig. 6. Results for fuel injection and fuel return charge according to injection pressure obtained from the initial test for the analysed injectors after repair

0.76 mg/stroke. This means an improvement in the co-operation of needle and nozzle assemblies because needles in both products stopped to be blocked when setting low pressure. As a result, more fuel will go to given cylinders of the drive unit, while the rotational speed will not be lowered.

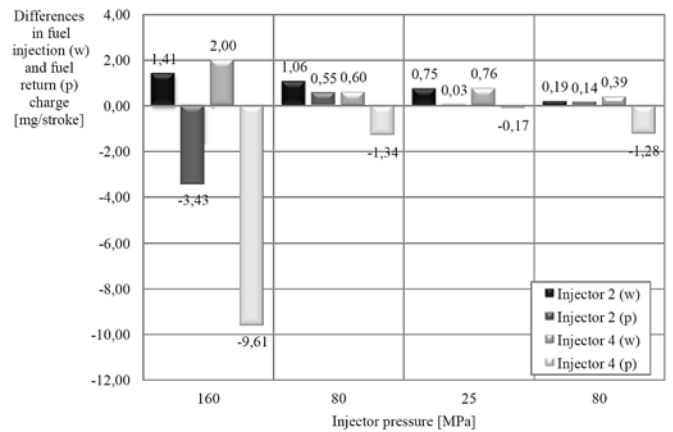


Fig. 7. Differences in fuel injection and fuel return charge according to injection pressure in the injectors being repaired

An intermediate effect on other fuel delivery rates was observed, in particular reduction of the fuel amount on most overflows. In injector 2, this effect occurred only with the full load, while for other fuel charges (emission, idle run and pilot fuel charges) the increase was negligibly small. In this respect, the repair process should be also positively assessed because excessive amount of fuel on the return might manifest in difficulties in starting the engine, its spontaneous stoppage, and observable loss of power at different load ranges. In the products being analysed, these problems should not be found. The test results being obtained on test benches and the verification of parts, in which other causes were excluded, e.g. damages to valve unit, loss of internal leak-tightness, nozzle hole plugging, is evidence of this.

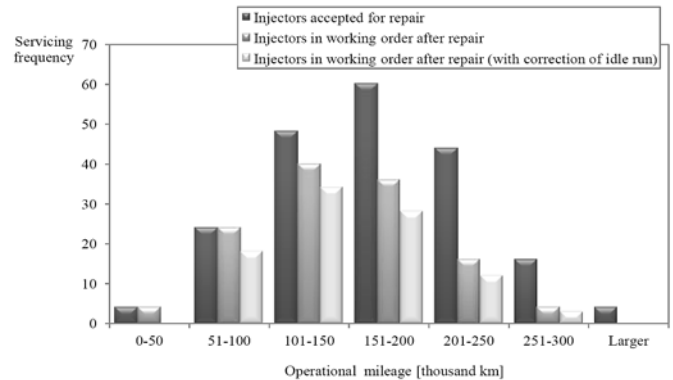


Fig. 8. Histogram of Denso solenoid injector repairs

Figure 8 presents the histogram of Denso solenoid injector repairs in VASCO Co. Ltd which were performed in the time period of October 2012 – February 2013. The data referring to the products being acknowledged operational represent the unimodal distribution, being characterised by a moderate right-side asymmetry. The obtained results indicate a high efficiency of this process with mileage to 200 thousand km but in most cases a correction of idle run fuel charge was necessary. Considerably less observations are grouped within the ranges being found at the end of the series. This is because the repairs become groundless with no spare parts, while the cleaning itself and adjustment brought selective benefits only. As a consequence, it was decided to limit acceptance of the injectors from motor-car engines with high operational mileage for repair.

## 6. Conclusions

The results of own study show that the repair of Denso Common Rail injectors may be conducted but its efficient depends on many factors. A crucial issue is the initial condition, and more specifically the type of malfunction being found, which - with lack of spare parts - may exclude a given product. This refers in particular to the needle and nozzle assembly and actuators, including control valve unit and guide plunger. The workshop practice shows that application of the substitute parts being found on the market is not indicated because, in respect of their quality, they decidedly fall behind the original elements, leading to accelerated (pathological) wear. A relatively numerous group is also external damages, developing frequently when disassembling or assembling the injectors which is performed without the tooling required or not observing the servicing procedures.

The proposed procedure methodology specifies the scope of activities to which attention should be paid during the repair process. Also, an adapter of own design has been presented, the making of which allowed disassembling the nozzle unit. The obtained results have broaden the scope of Denso solenoid injector servicing, which is usually reduced to external washing, internal cleaning and testing on test benches. However, it is noteworthy that, out of consideration for the aforesaid limitations, correction of respective fuel charges is possible for motor-car engines with a relatively low mileage, so for those with no serious internal damages.

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