EDIA-PRO: PRACTICAL TIPS

1. Injection signal form – electromagnetic injectors

When analyzing injection signals with the EDIA-PRO device, you may encounter various signal forms. This document shows popular variants in Common Rail systems organized by injector manufacturer. Knowing the correct waveform makes it easier to detect potential faults, but it is important to remember that many factors influence the waveform. It is important to avoid quickly judging a particular waveform as incorrect if the same waveform is observed on all injectors and the engine is running relatively normally. Key factors influencing the observed waveform:

- The type of engine controller determines the method of injector supply (voltage levels, switching strategy).

- The electrical parameters of the injector and its circuit (resistance, inductance) influence

  the amplitude and slope of the signal edges.

- The engine operating conditions (e.g., RPM, transient power demand, temperature) affect

  the length and number of injection stages.

- The supply voltage in the electrical system (particularly lower during start-up) impacts the amplitude of signals and the way the controller switches.

When assessing the electrical performance of injectors and controller when comparing the waveforms, the pulse duration should mostly not be used as a guide. The length of the pulse should be closely linked to the doses and therefore it will depend on the transient power demand,

as well as on the coded injector performance and adaptive parameters.

For the assessment of electrical condition, the most critical factor is the shape of the initial part of the pulse, which should be very similar for all injectors (the probes should be attached to the injector wires evenly).

1. BOSCH System

Injectors from this manufacturer require standard control consisting of a high-voltage pulse (of the order of 60 V), typically lasting up to 100 microseconds, and a voltage pulse corresponding to the installation voltage, which is switched after the expected opening of the injector to reduce the current during the holding phase. Due to the similar electrical parameters of the injectors (resistance on the order of several tenths of an ohm) and the similar way of controlling, the presented variants exhibit minimal differences.
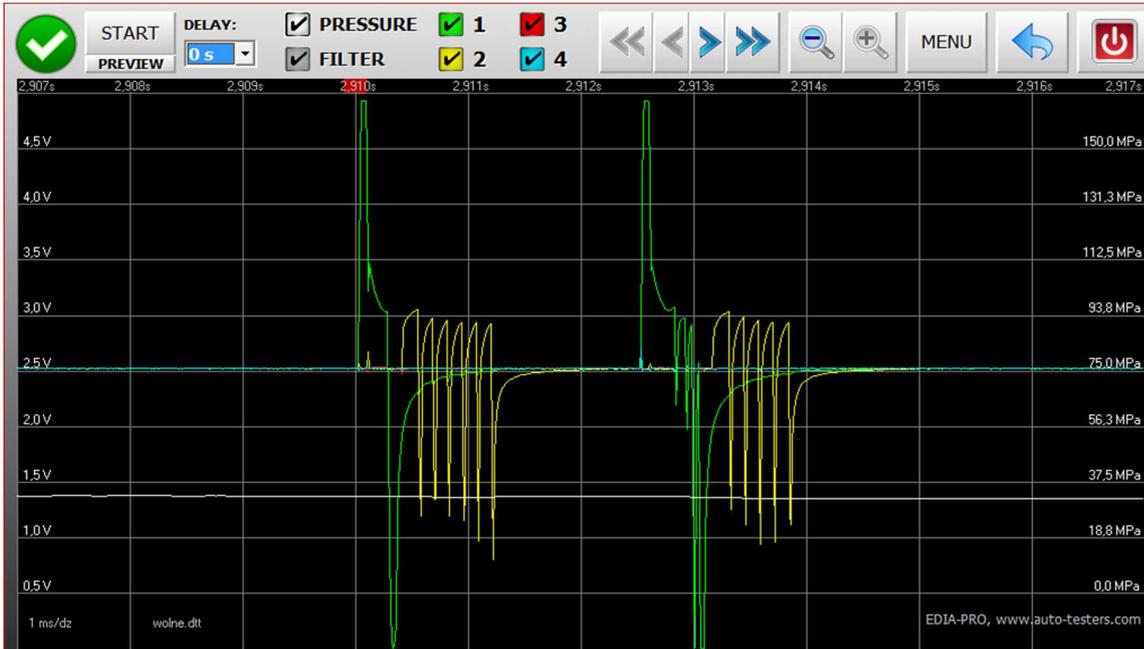
Variant I

Example: FIAT JTD 1.9 (CRI 1 injectors, EDC15 driver)

This variant of the BOSCH system is characterized by a series of short pulses on one injector immediately after the injection signal on another injector. These serve to charge the internal capacitor in the controller. The controller uses the inductance of the injector to obtain a higher voltage, which will then be used at the start of the next injection. These pulses are too short to open the injector.
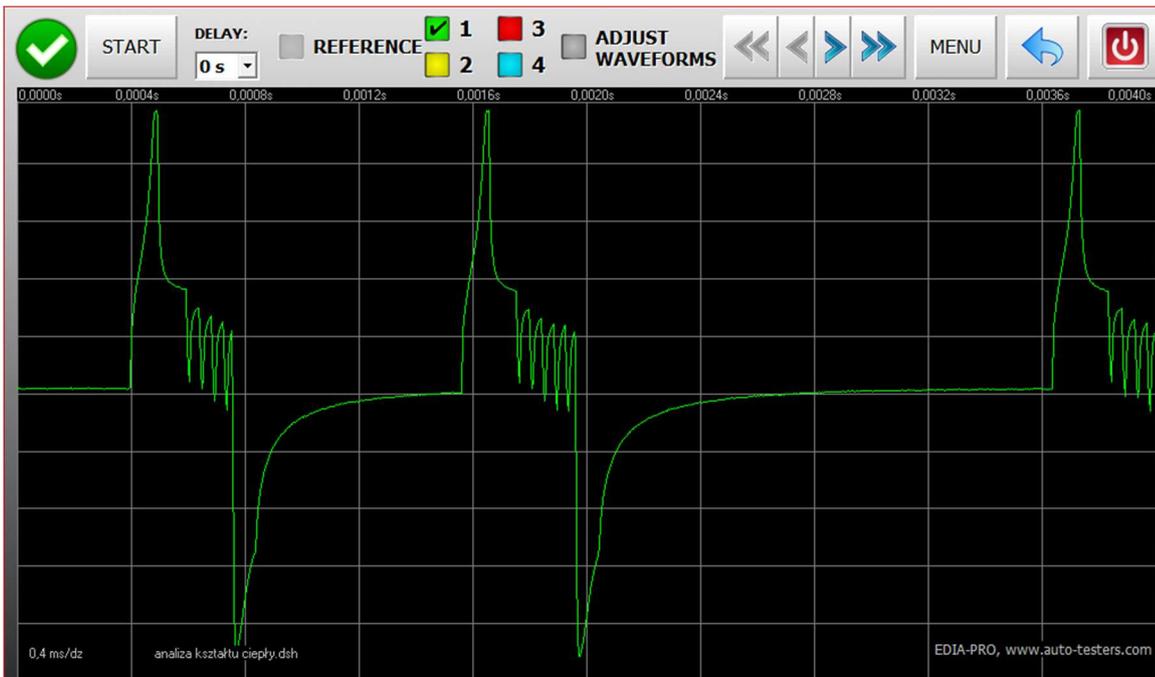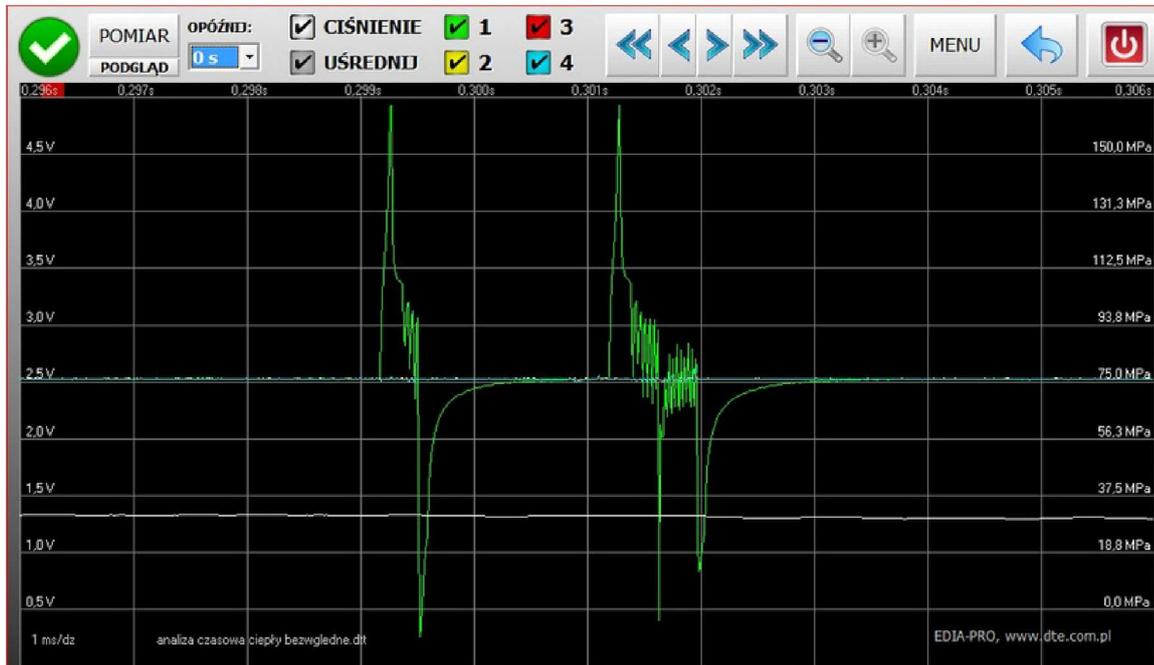
Waveform analysis:

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Timing analysis:

Variant II

Example: Mercedes W211 2.1 CDI (injectors CRI 2.1, EDC16 driver)

Waveform analysis:

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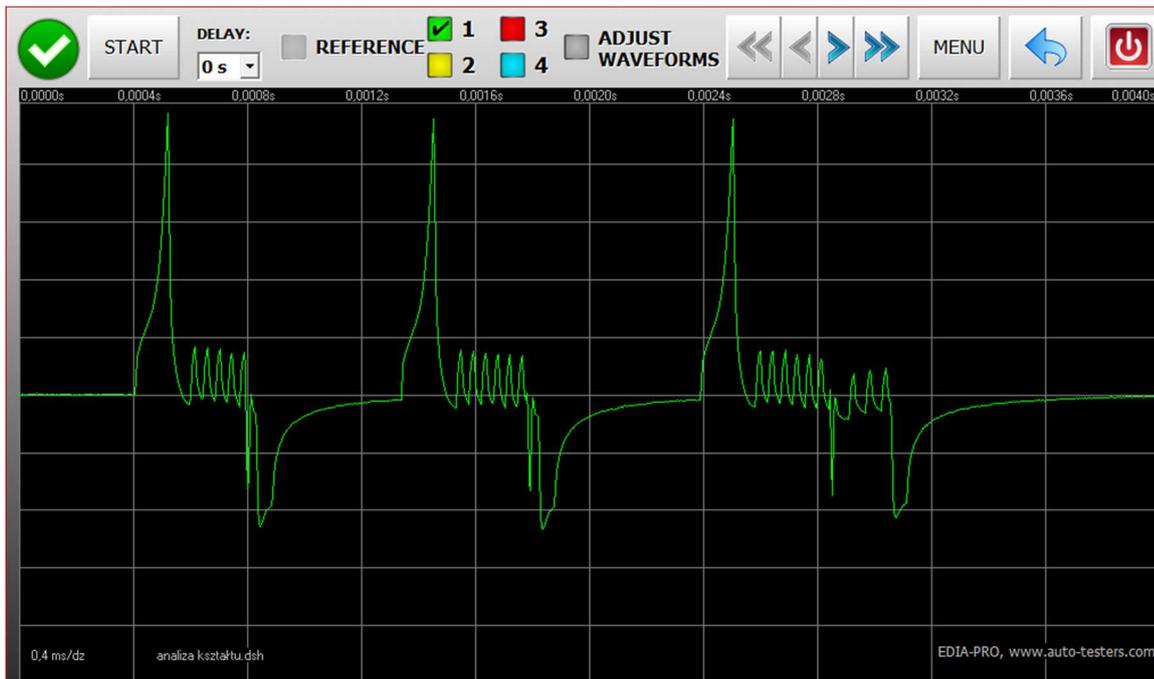
Timing analysis:

Variant III

Example: WV Tiguan 2.0 CDI (injectors: CRI 2, EDC17 driver)

Waveform analysis:

Timing analysis:

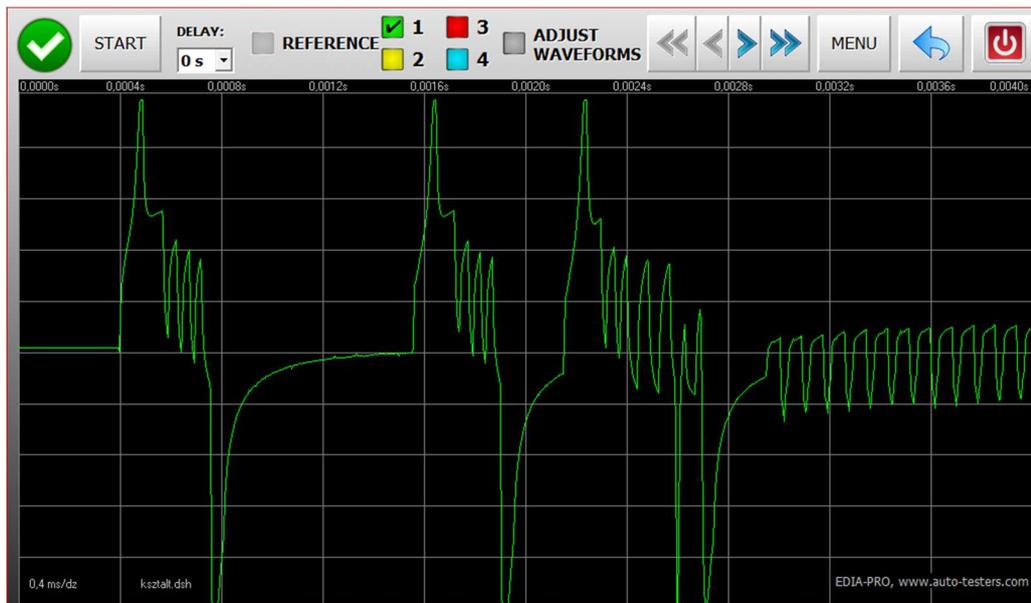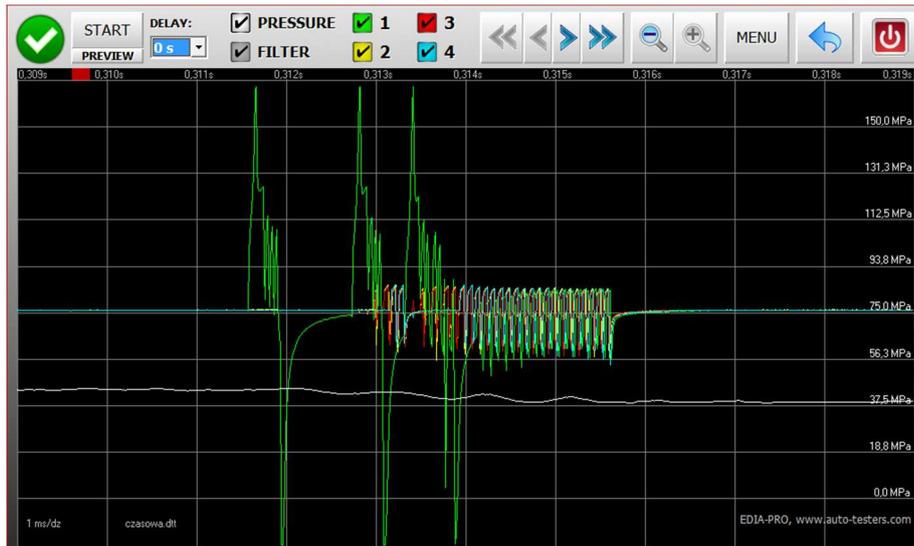*Variant IV*

Example: Fiat Linea 1.3JTD (injectors CRI 2.2, IAW 6F3 driver)

The timing analysis waveform shows a series of capacitor charging pulses in the controller – pulses are generated immediately after the injection in all injector circuits.

Waveform analysis:

Timing analysis:

2. DELPHI System

In contrast to other manufacturers, DELPHI used to supply the injector purely with the voltage of the vehicle's installation, without the use of additional voltage boost systems at the start of the opening. As a result, the initial current pulse is much broader than in other systems but with a much smaller amplitude. A coil with a resistance of typically 0.2-0.4 Ω is used to enable the appropriate power to be delivered to the injector control element. **Example: Renault Kangoo 1.5DCI (injectors DFI 1.3, DDCR driver)**

Waveform analysis:
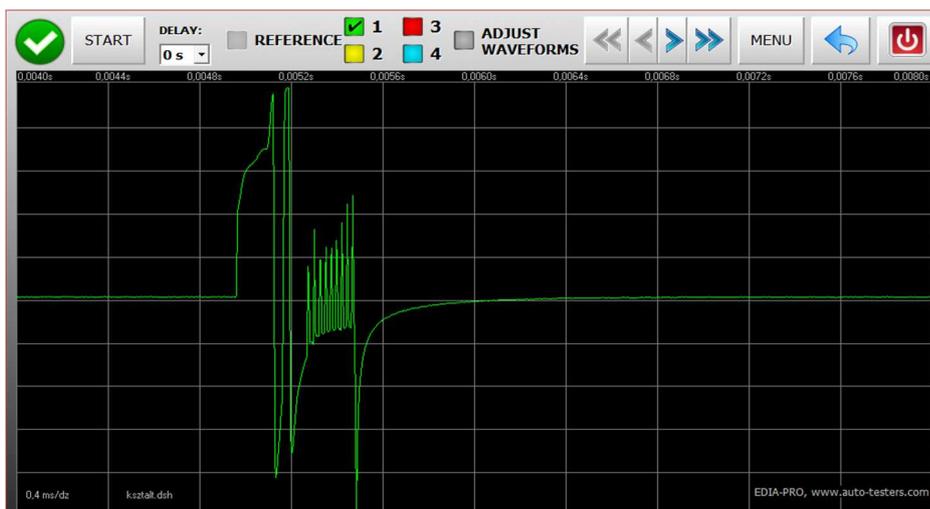
Timing analysis:

3. DENSO system

The DENSO system is characterized by relatively high injector resistance, which in some variants reaches several Ohms. A sufficiently high initial voltage is required to provide the appropriate mechanical energy to open the injector, while the holding current is lower than in other systems. Depending on the system variant, the waveforms differ significantly. The amplitude of the signals is significantly lower than in solutions from other manufacturers.

Variant I

The first signal variant of the DENSO system shown involves injectors with a resistance of approximately 1 Ω. The control signal includes the initial high-voltage pulse and keeps the injector open by pulsing the car's system voltage.

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Example: Toyota Avensis 2.0 D-4D 2005 (injector 23670-0G010)

Waveform analysis:

Timing analysis:

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Variant II

The second variant shown differs slightly in the shape of the pulses, the electrical parameters of the injector are similar to Variant I. The timing analysis diagram shows four injection stages.

Example: Mazda 6 2.0 CDTI 2002 (injector RF5C13H50A)

Waveform analysis:

Timing analysis:

Variant III

The third example of the DENSO system is significantly different from the others. In this case, the injectors have a resistance of 3.5 Ω, which clearly limits the amplitude of the signals. The supply phase of the higher voltage is necessary to provide the power required to open the injector.

Example: Toyota Previa 2.0 d-4d 2001 (injector 23670-27030)

Waveform analysis:

Timing analysis:

2. Injection signal shape – Piezoelectric injectors

Although injectors based on piezo technology have been on the market for a long time, recent years have seen an increase in the share of this technology in Common Rail direct injection. This is primarily due to their main advantage – the ability of this type of actuator to achieve a fast response. This makes it possible to realise a great number of injection stages and thus control combustion more precisely.

The control method differs significantly from electromagnetic injectors. In this case, the actuating element is a piezoelectric stack, which deforms by charging it to a suitable voltage (electrically, the piezo stack resembles a capacitor with a capacity of single µF). While maintaining an electromagnetic injector in the open position requires a continuous flow of sustaining current, in the case of piezoelectric injectors, the open position is associated with only minimal current flow. Obtaining the appropriate stack deformation and therefore the necessary valve lift of the injector requires high voltages, in the order of a hundred or more volts. The control current occurs at the time of opening (the need to charge the stack) and closing (discharge).

The charging and discharging processes should not proceed too quickly – doing so would shorten the stack's lifespan. Therefore, controllers include mechanisms for controlling the stack charging current. Due to structural differences in control modules, the waveforms obtained with the EDIAPRO device vary significantly across different piezo systems.

At this point, it should be reminded to avoid hastily judging a given waveform as faulty if the same shape is observed on all injectors and the engine runs relatively normally.

The high voltage required for control is obtained by a dedicated converter in the controller. Therefore, in the case of piezo injectors, the system voltage does not have a significant influence on the waveform (as long as an adequate minimum is provided). It is worth noting that due to the requirement of very short injection times (e.g 200 us) with comparably long charging and discharging times, these two stages often overlap. In extreme cases, the charging stage may be shortened and go straight into discharge.

The EDIA-PRO waveforms shown below indicate the start and end times of charging/discharging.

1. SIEMENS System

The Siemens system is characterized by the use of output that gently shape the current during both charging and discharging. These stages are quite similar, the difference being the opposite direction of the current changes seen on the graph.

Variant I

The first variant is characterized by particularly smooth current changes – due to the use of inductive components, the current changes slowly and the waveforms of the charging and discharging pulses are distinctly rounded. The amplitude is relatively small.

Example: Peugeot 407 2.0 HDI (9647247280 injectors , SID803 driver)

Waveform analysis:

Timing analysis:
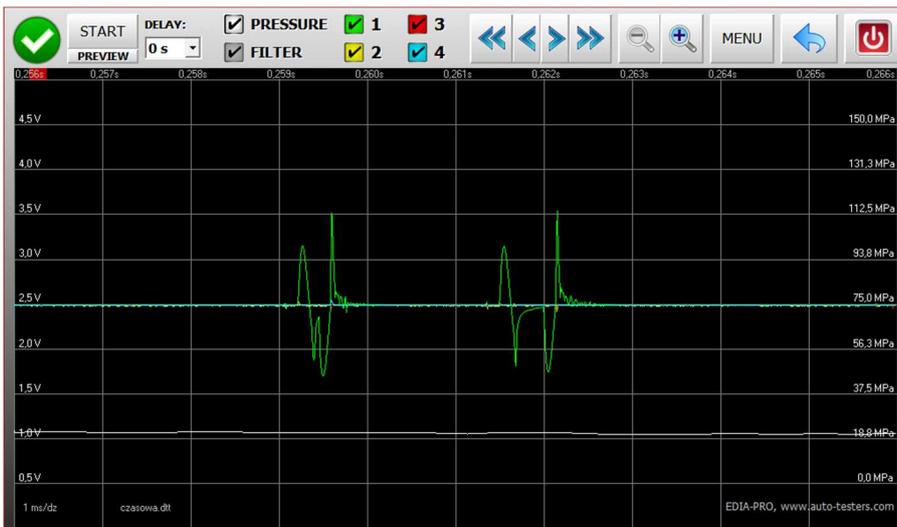
Variant II

The second variant is characterized by more jagged waveforms, which at first glance may appear somewhat irregular. Nevertheless, the current waveforms are smoothed enough that the waveforms have a small amplitude.

Example: Citroen Jumper 2.2 HDI (BK2Q-9K546-AG injectors, SID208 driver)

Waveform analysis:

Timing analysis:
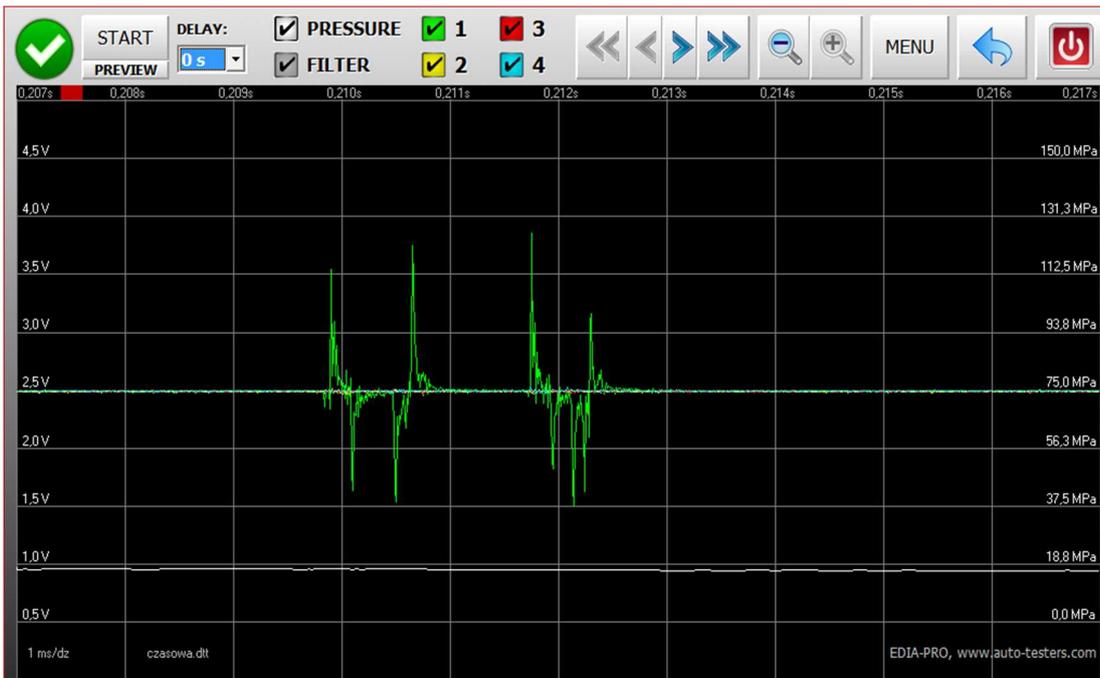
2. BOSCH System

This manufacturer's controllers differ from the previous examples in terms of their output circuits. In this case, the regulation of the charging and discharging current of the piezo stack is done by keying at high frequency. The average current is correspondingly low (similar to that in other systems), but the output waveform is not as smooth as, for example, in the case of controllers working with Siemens injectors. Significant fluctuations in the instantaneous current value are visible on the EDIA-PRO graph as high amplitude pulses.

Example: Audi Q7 3.0 TDI (0445116022 injectors, EDC17 driver)

Waveform analysis:

Timing analysis:

3. Pressure control valve diagnostics

The most common symptom of pressure control valve issues observable with the EDIAPRO device is characteristic pressure fluctuation, as well as engine shutdown in cases where the required rail pressure cannot be achieved. Of course, such a fault may also prevent the engine from starting at all, in which case a recording of the start-up attempt should reveal insufficient pressure and extreme control values being applied to the valve. These problems may be constant, but it is more typical for them to occur only under specific conditions – usually with a cold engine.

Example: Peugeot Boxer II 2.2 HDI 88kW

Reported symptoms include idle speed fluctuations when the engine is cold and occasional engine shutdown shortly after starting.

The first measurement in timing analysis mode was taken at idle speed.

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The automatic analysis window is especially useful for quickly assessing the situation.

Firing order: ● 1 -> 3 -> 4 -> 2 ○ 1 -> 2 -> 4 -> 3 ○ 1 -> 2 -> 3 -> 4	**1**	**3**	**4**	**2**
No. of injections detected:	65/65	65/65	64/64	65/65
Average inj. signal duration:	1583 us	1579 us	1610 us	1593 us
Average pressure drop/ms:	0,55 MPa	0,43 MPa	0,54 MPa	0,43 MPa
Average fuel expense: P	19,4	15,1	19,1	15,0
Cycle deviation:	-109 us	-28 us	+164 us	-27 us

The number of detected injections is small – results can be inacurate.

900obr/m   41MPa

0,0s   10,1s

Avg. RPM:	RPM change:	Pressure pulsation:	DTE DeltaTech Electronics	📷	🔍	Recalc	Print	↩
771 /min	120 /min	14,8 MPa						

The small graph at the bottom of the window is very helpful for diagnosing the pressure control valve. In this case, it can be seen that along with the observed engine speed fluctuations, there is a noticeable oscillation

 in the pressure value. The period of these fluctuations is about 0.7 seconds, and this type of pressure fluctuation, significantly slower than the engine and pump is a typical symptom of a sticking control valve.

Pressure and speed fluctuations are not always this clear, they often occur only occasionally, for example after a sudden change in rail pressure, and then disappear on their own after a while.

At the same time, the measurement table shows some uneven engine operation (cycle time deviation). However, at this stage, we refrain from assessing the injectors, as the observed phenomena clearly disrupt the operation of the entire system. Additionally, the measurement was taken with a cold engine. In order to reliably assess the injectors performance, the main fault must first be resolved.

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To confirm the malfunction, a measurement was carried out in timing analysis mode with the pressure control valve connected:

The measurement showed that the pressure fluctuations were also accompanied by fluctuations in the control value

of the control value – in the graph, in addition to the pressure (white), the duty cycle of the valve control signal (green) is also visible. In this case, the control valve clearly qualifies for replacement.

After the repair, a repeat measurement was performed in timing analysis pressure mode at idle speed:
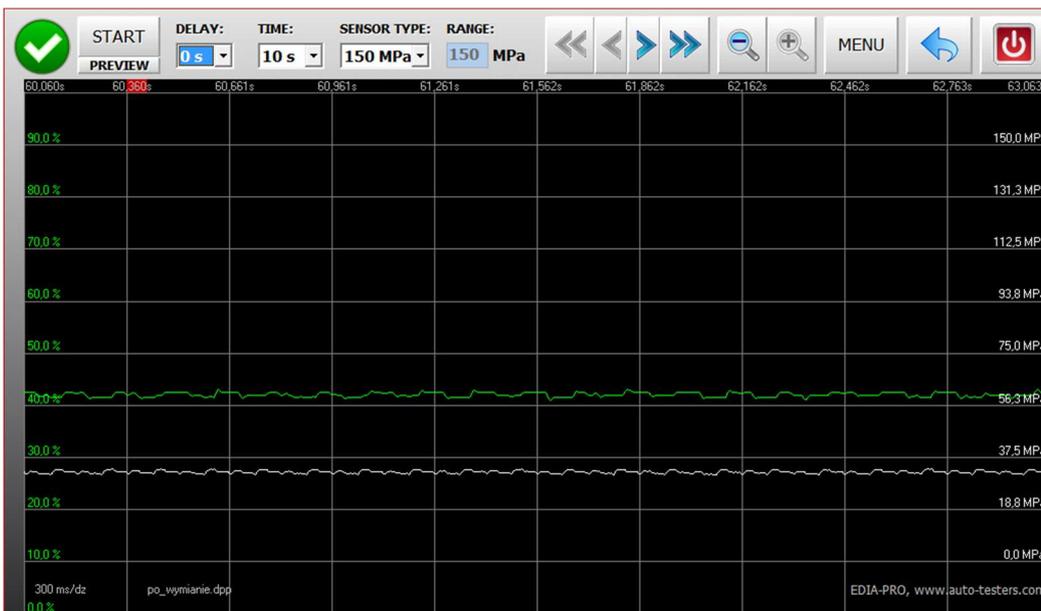
As can be seen in the graph above, the pressure fluctuations have stopped, and the control valve signal is stable.

Minor fluctuations indicate that the regulation system is functioning correctly.

4. The impact of incorrect injector coding

One of the key changes introduced in subsequent generations of Common Rail systems is the injector coding mechanism, which is designed to introduce information about their initial efficiency to the controller. This is related to a more advanced mechanism for determining fuel doses necessary to meet increasingly stringent emission standards. Of course, during operation, the injectors gradually wear out, and their parameters significantly differ from the initial ones, but thanks to adaptation mechanism, the controller adapts to the new parameters. It is important that such changes occur slowly and the controller is designed to handle them.

Sudden, abrupt changes in parameters do not occur under normal conditions. From the controller's perspective, such a sudden shift in parameters would be the result of replacing injectors without entering new codes. Naturally, the tolerance of the system to such a situation will vary depending on the type and generation of the injection system, but it can always be a source of problems.

It is important to take into account such an eventuality when observing incorrect operation of the injection system using EDIA-PRO, especially in the case when the injectors were replaced.

Example: Toyota IQ 1.4 D-4D 66kW
The following symptoms are present: irregular engine operation, and clearly audible metallic knocking. The problems only occur when the engine is cold, and disappear after warming up. The injectors (BOSCH piezoelectric) were replaced in the vehicle, but the engine still works incorrectly. The measurement was performed in timing analysis mode on a cold engine (when the symptoms were clearly visible).

Below is a screenshot of the recorded injector operation parameters:
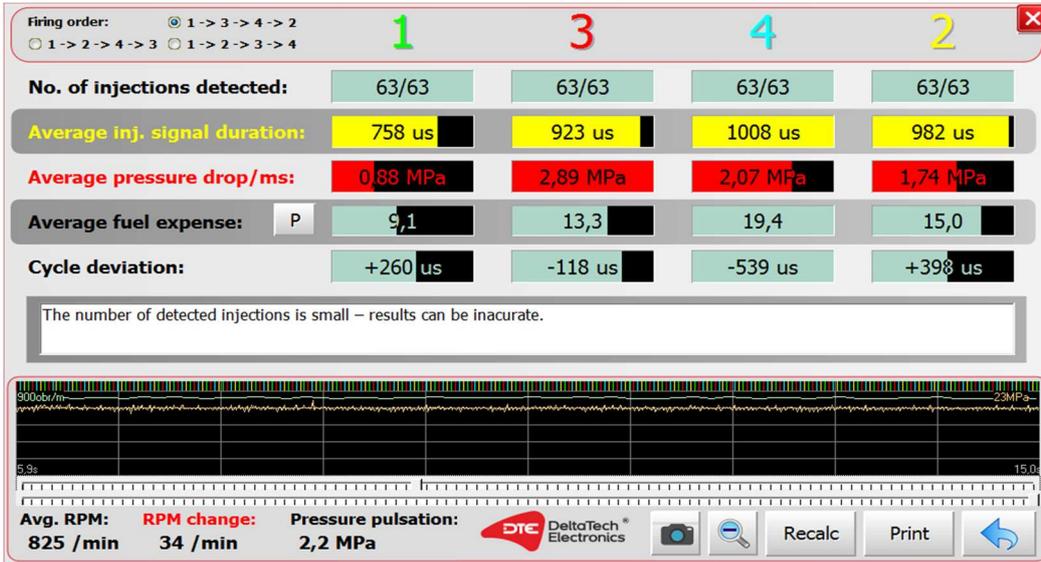
At first glance, there is a significant irregularity in the timing of the signals controlling the injectors.

At the same time, there are significant differences in engine running consistency. The operation

of cylinders 1 and 2 is clearly weaker (positive parameter „cycle time deviation").

The next measurement was taken with the engine warmed up:
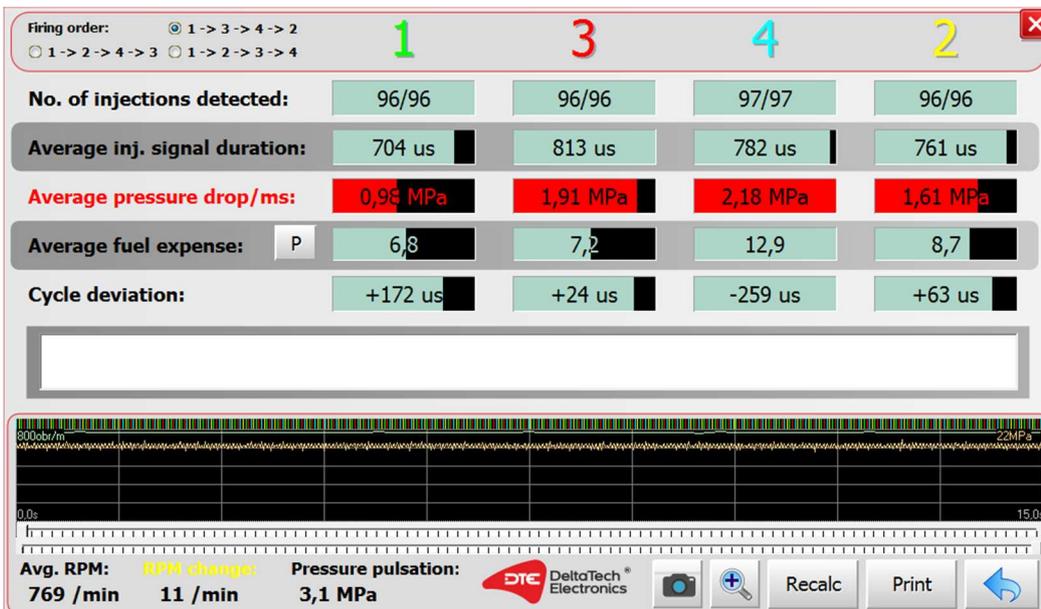
As can be seen, even after the engine warms up, its operation remains incorrect, despite the apparent

improvement observed.

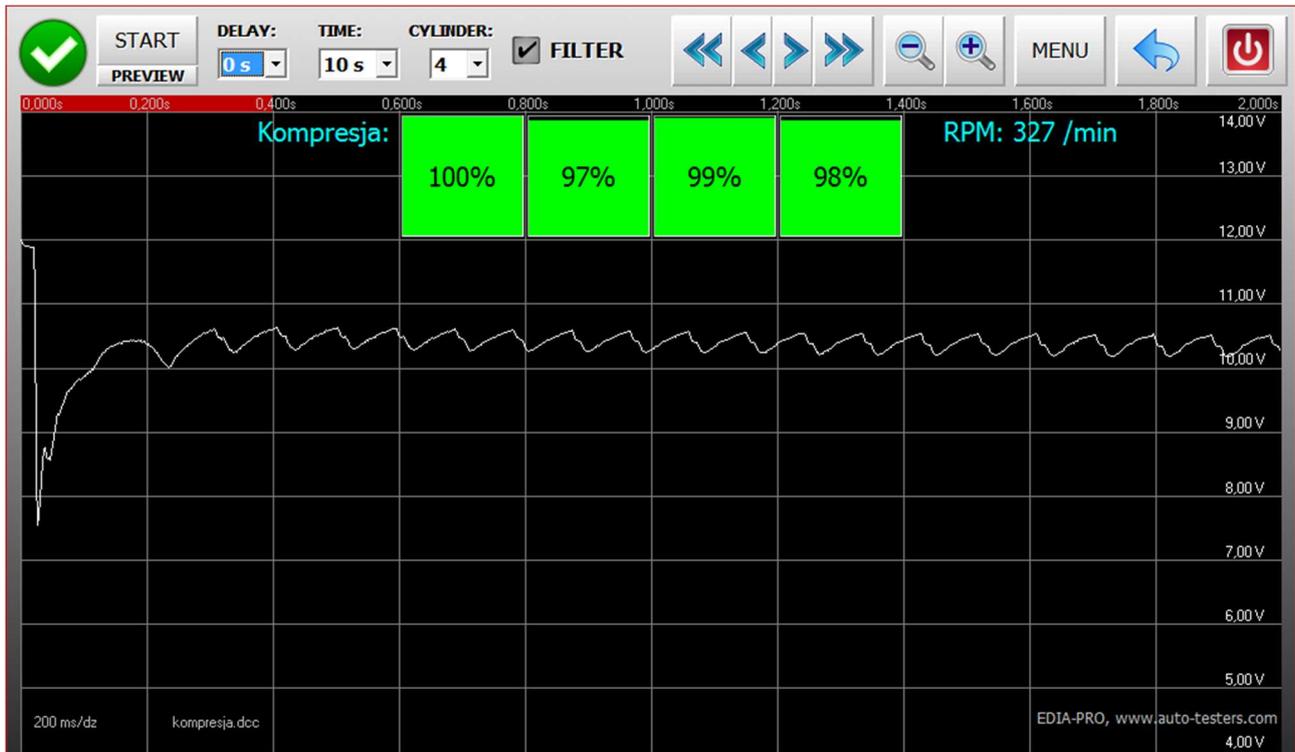To assess the engine's condition, an automatic compression measurement was performed using the indirect method **in the „Compression pressure analysis" mode:**

The measurement showed that the compression differences between individual cylinders were minimal, so they would not affect the engine running consistency.

The tests performed so far seemingly indicate a possible problem with the injectors. However, a close look at the parameters reveals a certain problem. The previously shown differences in injector control signals do not correspond to the observed cycle time deviations (engine speed fluctuations).

For example, cylinder no. 1 has a longer cycle time, meaning the engine slows down. The work of this cylinder is lower than average. At the same time, the injection signal duration is the shortest of all. Therefore, the computer, by applying such control, led to this state. The natural reaction to such a case would be to increase the dose, and therefore the duration of the control signals.

Why didn't that happen? Because although the injectors were replaced with new ones, they were not properly coded. As a result, the controller retains the data and adaptations for the previous injectors, and the new components are being controlled as if they were worn.

It's important to remember, that the last letter in the code of BOSCH piezoelectric injectors is the so-called ISA code, a letter designation of the voltage required to open the injector. Therefore, in this case, the code affects not only the duration of the pulses given to the injector, but also the voltage to which the piezo stack is charged.

In this case, resolving the fault involved simply entering the correct injector data into the controller, and resetting the adaptation parameters. After this procedure, engine operation returned to normal.

Firing order: ⊙ 1 -> 3 -> 4 -> 2 ◯ 1 -> 2 -> 4 -> 3 ◯ 1 -> 2 -> 3 -> 4	**1**	**3**	**4**	**2**
No. of injections detected:	66/66	66/66	66/66	66/66
Average inj. signal duration:	946 us	934 us	914 us	991 us
Average pressure drop/ms:	1,19 MPa	1,37 MPa	1,56 MPa	1,31 MPa
Average fuel expense: P	14,6	15,9	15,9	15,6
Cycle deviation:	+12 us	+17 us	-55 us	+26 us

800obr/m ... 21MPa

0,0s ... 10,0s

| Avg. RPM:	RPM change:	Pressure pulsation:	DTE DeltaTech Electronics	📷	🔍	Recalc	Print	↩
790 /min	14 /min	2,0 MPa						

5. Incorrect operation under load

A common phenomenon in the case of problems with injectors is their incorrect operation only in specific conditions of temperature, pressure and control signal, outside of which the element functions normally. In some cases, this can lead to a situation where the injector successfully passes tests on the test bench, but performs incorrectly when installed in the engine. EDIA-PRO measurement proves to be extremely useful in such situations thanks to the possibility of assessing components in real working conditions. In such a situation, it is crucial to record the waveforms precisely at the moment the problem appears.
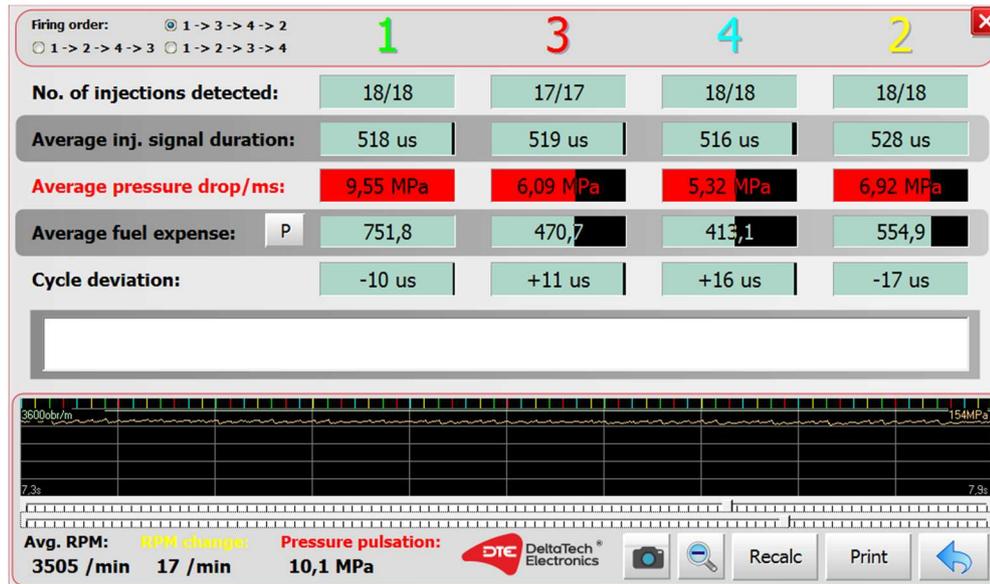
Example: Citroen Jumper 2.8 Hdi

The reported symptom concerns very loud engine operation during driving, but only under heavy engine load. The problem does not occur at idle or during gentle driving conditions. Previously, the engine underwent a major overhaul and was thoroughly checked from the mechanical side. The injectors were reconditioned and checked on the test bench. The controller does not log any error codes, even when problems occur.

The first measurement in the *Timing analysis* mode was performed at idle speed, on a warmed-up engine:

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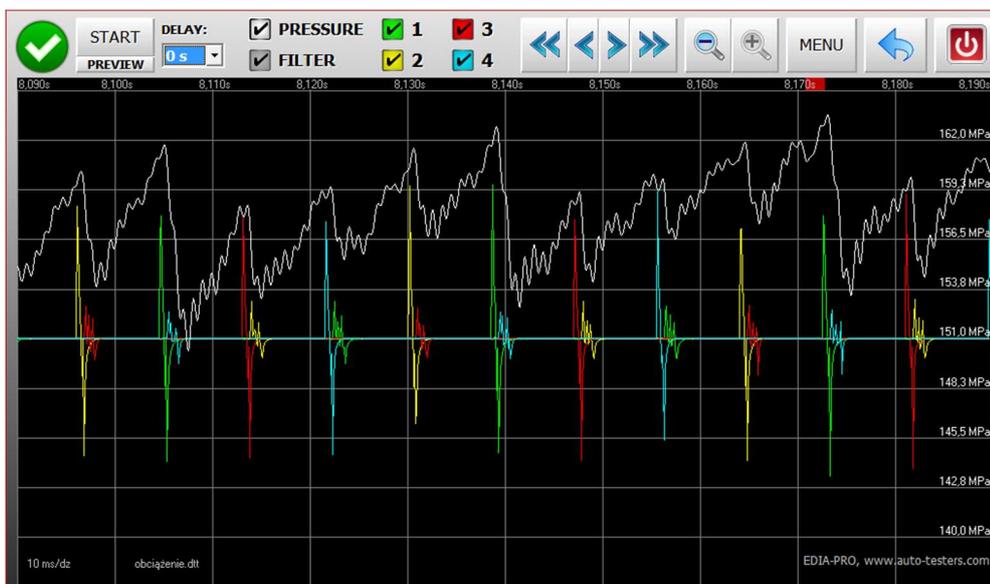
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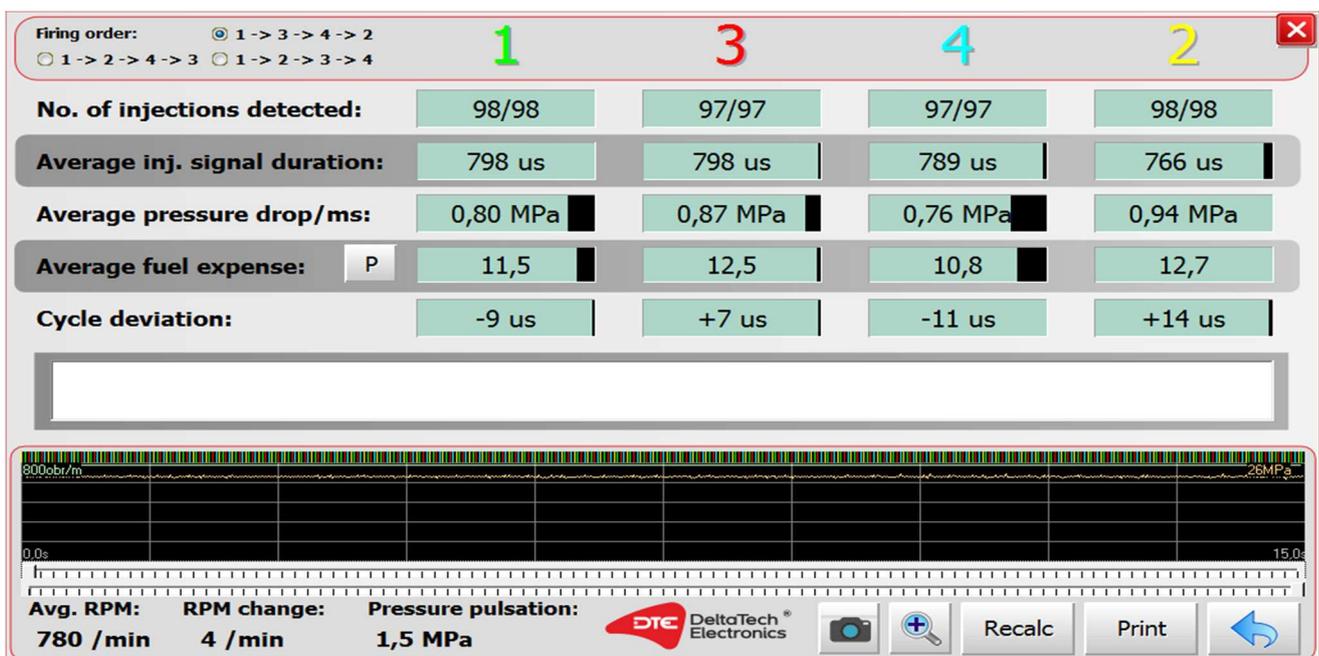
The idle speed is almost perfect, the measured parameter deviations are small. The pressure and RPM values are very stable.

In this situation, it was necessary to perform the measurement at the time the problem occurred. The next check therefore involved properly securing the EDIA-PRO device in the vehicle and performing the measurement under high engine load conditions.

Firing order: ◉ 1 -> 3 -> 4 -> 2 ◯ 1 -> 2 -> 4 -> 3 ◯ 1 -> 2 -> 3 -> 4	**1**	**3**	**4**	**2**
No. of injections detected:	18/18	17/17	18/18	18/18
Average inj. signal duration:	518 us	519 us	516 us	528 us
Average pressure drop/ms:	9,55 MPa	6,09 MPa	5,32 MPa	6,92 MPa
Average fuel expense: P	751,8	470,7	413,1	554,9
Cycle deviation:	-10 us	+11 us	+16 us	-17 us

3600obr/m   154MPa
7,3s   7,9s

Avg. RPM:	RPM change:	Pressure pulsation:
3505 /min	17 /min	10,1 MPa

DTE DeltaTech Electronics ®   Recalc   Print

The results of the automatic analysis show that at approx. 3500 RPM and a pressure of approximately 150MPa, the fuel consumption of injector 1 increases significantly. This is also very clearly visible on the waveform:

START PREVIEW DELAY: 0 s ☑ PRESSURE ☑ FILTER ☑ 1 ☑ 2 ☑ 3 ☑ 4 MENU

8,090s 8,100s 8,110s 8,120s 8,130s 8,140s 8,150s 8,160s 8,170s 8,180s 8,190s

162,0 MPa
159,3 MPa
156,5 MPa
153,8 MPa
151,0 MPa
148,3 MPa
145,5 MPa
142,8 MPa
140,0 MPa

10 ms/dz   obciążenie.dlt   EDIA-PRO, www.auto-testers.com

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After replacing injector no. 1, the problems disappeared. A control measurement was performed under similar operating conditions:

In this case, the pressure drops are much more balanced - this is the correct operation of the system.

6. Faulty engine controller

A common cause of irregular engine operation are problems with the injectors. Most often the faults arise from mechanical wear of the components, while their electrical parameters remain normal. However, it sometimes happens that the fault in the injector relates to its electrical part. This can be, for example, a short circuit within the solenoid injector coil or damage to the piezoelectric stack. Problems with dirty contacts or wiring may also result in incorrect operation of the injectors. Damage to the controller is relatively rare, but these are usually difficult and troublesome cases to diagnose. In such situations, self – diagnostic mechanisms often fail, and the service technician is left to be reliant on other methods. Performing measurements with the EDIA-PRO device allows for quick identification of such problems.

Example: Opel Vectra 1.9 CDTi

Reported symptoms include irregular engine running and jerking, the symptoms only slightly decrease when the engine warms up. An initial measurement was performed in timing analysis mode:

An experienced user would immediately notice an unusual waveform shape in this case (Bosch electromagnetic injector). Next, a measurement was performed at idle speed in the „waveform analysis" mode, which allows for a more detailed examination of waveform shape.

The four overlaid control signal waveforms clearly differ in pairs: 1 and 4 and 2 and 3. The start of the injection signal waveform is identical on all four injectors, but the signal on injectors 1 and 4 quickly weakens (signals 2 and 3 are correct).

In such situation (differences in waveform shape), it's generally necessary to check the electrical parameters of the injectors (resistance, inductance), their connectors, and the wiring. In this example, all these components turned out to be in proper condition, pointing to a problem in the engine controller.

In fact, this particular measurement immediately indicates the location and nature of the fault.

The injector control starts by applying a high-voltage pulse to achieve a higher current and a shorter opening time – the initial peak on the graph. In this case, all waveforms initially overlap – the system switching on the high-voltage pulse work correctly.

Next, the injector is supplied with the system voltage to keep it open. If the current is more than sufficient to keep it open, it is reduced by the PWM signal (final part of the waveform of injectors 2 and 3). For the other injectors, this does not happen, and the current value is too low. This results in incomplete opening or premature closing of the injector and irregular engine operation.

The fault in the controller relates to the circuit supplying the low voltage to injectors 1 and 4. If the problem were with the wiring or injector coil, the waveforms would differ from the start of the injection signal. Furthermore, it is unlikely that an electrical fault would affect the two injectors in the exact same way.

7. Faulty camshaft position sensor

As the engine operating cycle involves two rotations of the crankshaft, an additional sensor is required in addition to the camshaft position sensor to provide information on the current camshaft position. The signals from these two sensors must be properly synchronized as a result of the respective mechanical position of the pulsators of the two sensors.

Problems with an incorrect signal or lack of synchronization are quite easily detected by the controller software.

This usually results in a corresponding error code, which makes it easier to diagnose the problem. However, it does happen that in such situations the controllers continue the operation without reporting codes. These cases are more difficult to diagnose and often require a dual-channel oscilloscope measurement.
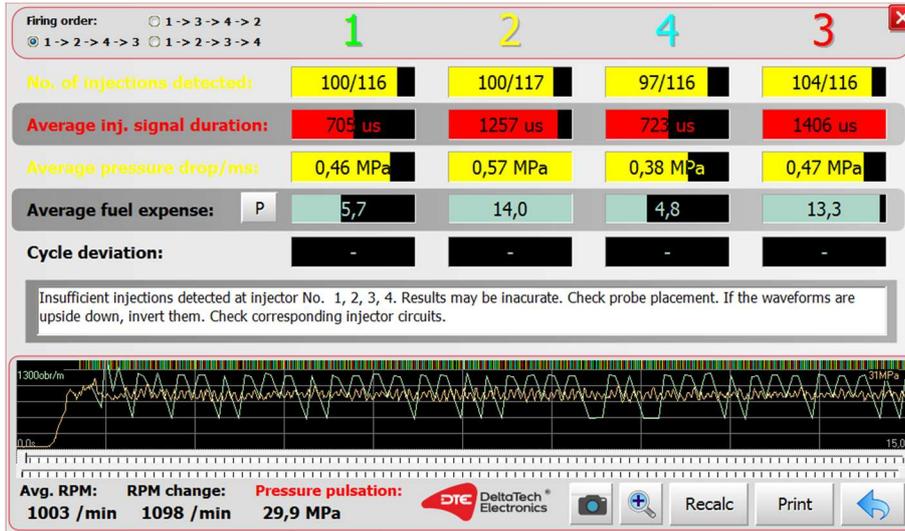
Example: Ford Fusion 1.4TDCi

Reported symptoms include very irregular engine idling, symptoms do not disappear once the engine has warmed up. A measurement was taken in timing analysis mode at idle:

The waveform and pressure values are typical for the system used with piezo injectors.

Automatic analysis mode is activated.

The results obtained are very unusual.

The first row of the table (number of injections detected) may suggest that the signal of the injectors was not detected correctly and the rest of the parameters should be expected to be unreliable.

The lower graph shows a very large jaggedness of the RPM graph – such changes are not physically possible, they are the result of an incorrect interpretation of next injections.

In such a situation, the waveform should always be reviewed to assess what is causing the anomaly. After rescaling the graph to display several next injections, this image was achieved:

The apparent order of the injectors is: 1-2-4-1-2-3-4-2-3. This sequence cannot be correct, even if the measuring probes are incorrectly positioned. The engine is running incorrectly, and the fuel is not delivered to the correct cylinder in each cycle. This is what made the automatic analysis mode used previously no longer useful. A correct injection sequence is a prerequisite for accurate measurement of the RPM and other parameters.

In this situation, suspicion falls immediately on the camshaft position sensor. After verifying the wiring, the sensor was replaced, which resolved the issue.

The measurement with the EDIA-PRO device proved helpful, even though it did not directly measure the faulty sensor's signal. This is due to the fact that we are observing the actual operation of the injection system. At the same time, by knowing the general working principles of the engine and controller, we can also indirectly detect this type of fault.

8. Faulty injector in a system with DPF

When performing diagnostics on a complex system such as a modern engine, it is important to remember that individual components influence one another. Therefore, a primary failure of one component can lead to the damage of others if not detected in time. Properly performed diagnostics can save significant time and unnecessary expenses.

Example: Fiat Ducato 2.3 Multijet 131KM

The reported issue involves heavy smoke emissions. The vehicle often generates significant amounts of white smoke while driving. The DPF had been professionally cleaned immediately beforehand, which did not solve the problem. At the first moment, a timing analysis measurement was performed at idle speed.

The injector signal shape appeared completely normal, showing four injection phases during idle:
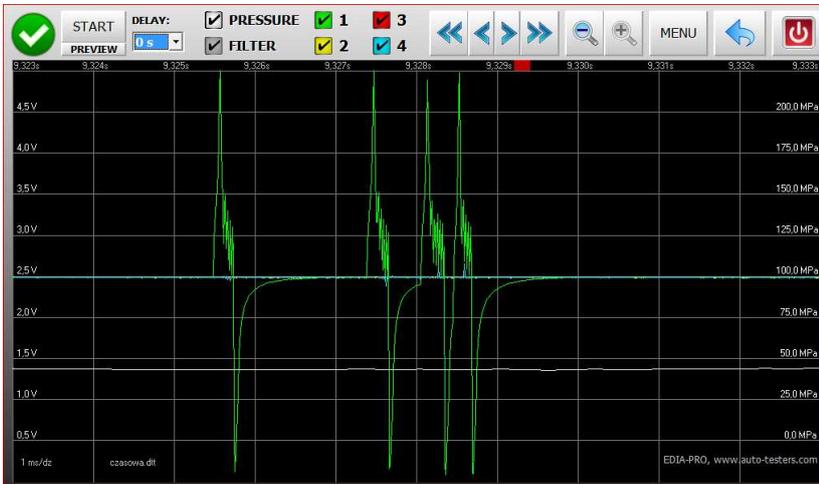

Next, parameters were determined using automatic analysis mode:
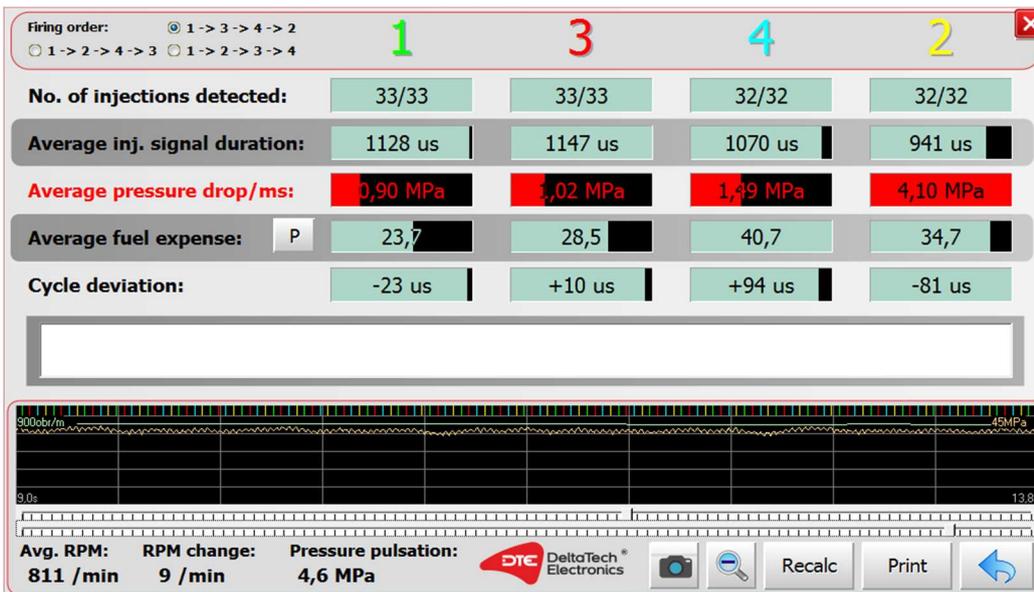
Concerns were raised by a significant scatter in the automatically determined fuel delivery and the „average drop/ms" parameter.

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However, upon closer look at the next injection pulses and pressure drops, it shows that this is not a significant problem:

The waveform proves that the way the system works, specifically the pressure fluctuations associated with pump operation adversely overlap with the drops associated with injection, which falsifies the automatic measurement (under idling conditions, the pressure fluctuations are greater than the drops associated with injection and occur simultaneously).

Despite this, the variation in „cycle time deviation" indicated that the engine is not running completely smoothly at idle. The compression measurement using the indirect method gave an aligned result in this case.

After the device was properly secured in the vehicle, an on-road measurement was performed under heavy load conditions (uphill driving). The following waveform was achieved:

It became evident that under increased load, there is a significant irregularity in the pressure drops associated with injection. At the same time, the measurement in automatic analysis mode for this section also gives

an increased cycle time deviation for the 4th cylinder of +37 us. This value would be good at idle, but for an engine at 3,000 rpm it is quite high.

The following abnormal waveform was recorded when heavy smoke occurred:

Here we see two consecutive injections – on injector 3 (red), and 4 (blue). Simultaneously with the injection on injector 3, fuel is injected into cylinder 1 (green), and the next injection is accompanied by the injection of fuel additionally into cylinder 3. The waveform shown illustrates the DPF regeneration process. The first injection in cylinder 3 (two injection stages) initiates the work stroke, the next injection (four stages) occurs at the start of the exhaust stroke – the fuel goes to the exhaust and the filter where it raises the temperature, leading to the combustion of soot particles.

Based on the measurements taken, the 4th injector was identified as suspicious. After replacing it, the system problems disappeared. In this case, the malfunction of the injection system was the cause of excessive soot production, which led to the rapid filling of the diesel particulate filter. The cleaning procedure, which was triggered regularly, generated significant amounts of light-colored smoke. The presence of the DPF masks one of the symptoms, which is black smoke – soot is accumulated in the filter. If the injector fault is not diagnosed in time, this will lead to premature wear of the diesel particulate filter, which will significantly increase the cost of the repair.