

Adjustment and regulation of high-pressure pumps on the BOSCH test bench

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ABSTRACT

During decades of work on the development and improvement of engines intended for combat and non-combat vehicles of the Serbian Armed Forces, original methods were developed for setting, testing and checking the functionality of various types of high-pressure in-line pumps that are installed on those engines. These activities are not performed continuously, yet are performed as required by the job, often with very lengthy breaks. Through current research, development and functional tasks or periodic technical assistance in the comprehension of overhaul and production, these activities are frequently handled by highly qualified and narrowly specialized research staff. The goal of this paper is to describe the developed methods and the acquired experiences in as much detail as possible and to standardize them in certain way, so that they are not forgotten, but could be permanently available to the research staff dealing with this issue.

KEYWORDS

High-pressure pump, Engine, Camshaft, Injector needle, Injection pressure, BOSCH test bench.

1. INTRODUCTION

This paper refers to the procedure of adjustment and testing of newly developed or existing high-pressure in-line pumps up to twelve (12) elements on the BOSCH test bench, which are carried out through current research, development and functional tasks of the Ministry of Defence or periodic technical assistance in the overhaul process. The research is based on positive experiences during the development of domestic high-pressure in-line pumps of the P500 family, intended for special-purpose engines of different power levels (840 HP, 1000 HP and 1200 HP), as well as for the BOSCH P10 high-pressure pumps for a nominal engine power level of 1000 HP. The common characteristic of the engines on which the mentioned pumps are installed is that they have twelve (12) cylinders arranged in a V at an angle of 60 degrees, and that they are equipped with a complex piston mechanism (main and auxiliary piston rod). The paper describes the adjustment of the BOSCH in-line pump PE 10 P 100 A 320 LS 821 for the Mercedes Benz OM 403 engine, which, in addition to wide commercial exploitation (buses and trucks), also found its application as a power unit of a tracked combat vehicle. This engine has ten (10) cylinders with a 90 degree V arrangement.

The described procedure precedes or is performed in parallel with the application of more advanced methods of measurement and testing [1], representing a series of unavoidable, accompanying, often arduous actions in order to reach more meaningful scientific results [2-4, 12-19], which are sparingly, if at all, mentioned in the published papers. The procedure combines the specific configuration and designed capabilities of the BOSCH test bench [5] with theoretical settings originating from the field of working processes of internal combustion engines [6-9] in order to achieve the set goals [10-11].

2. PHASES OF THE FUEL SUPPRESSION PROCESS IN THE PUMP ELEMENT

For easier understanding of the presented text, it's worth reminding that the process of fuel delivery in the high-pressure fuel pump element occurs through the following stages:

- **pre-stroke ("pre-lift")** – piston movement of the pump element from the inner dead point until it closes the spill channel in the high-pressure pump gallery, i.e., when fuel delivery starts,
- **active stroke** – piston movement of the pump element during which the element injects fuel,
- **relief stroke** – piston movement of the pump element from the end of the injection process to the outer dead point.

3. ADJUSTMENT AND REGULATION PROCEDURE

3.1. Placing the high-pressure pump on the BOSCH test table and checking the tightening torques of certain pump assemblies

The pump is secured to the test bench via two or three supports, depending on the type of pump. The supports are specially designed for each type of high-pressure pump being tested. They can slide along a fixed rail, following the predetermined clamping principle (known as the "bird's tail"). For each type of pump, appropriate flanges and adaptation elements must be provided on the pump drive and/or the drive shaft of the test bench to connect the camshaft of the pump to the drive shaft of the test bench. Before finally securing the pump to the supports, alignment between the camshaft of the pump and the drive shaft of the test bench must be ensured. Figure 1 shows the drive components used in testing high-pressure pumps of the P500 family.

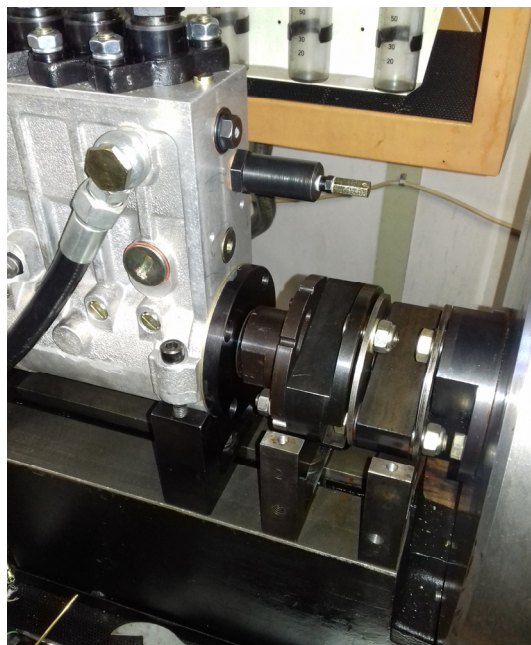


Figure 1: High-pressure P500 family pump drive elements

The drive shaft of the test bench features a cylindrical flywheel with an engraved angular division around the circumference of the front base circle and holes on the casing where a lever of circular cross-section can be inserted for manual operation, i.e., rotation of the camshaft of the pump. Thanks to these features, precise and easy rotation of the flywheel enables the necessary adjustments of pre-lift and phase (angular) adjustment of the start of injection of high-pressure pump elements in the specified sequence of fuel delivery, which will be discussed further in this paper. Within the test bench, depending on the type of pump being tested, the following configurations of laboratory tubes and nozzles are available:

- tubes $\varnothing 4 \times \varnothing 8 \times 1000$ and nozzles labelled 1 688 911 019
- tubes $\varnothing 3 \times \varnothing 6 \times 1000$ and nozzles labelled 0 681 343 009

By using specially designed adapters and nuts with right-hand threads on one end and left-hand threads on the other end (Figure 2), it is possible to overcome the issue of different thread diameters on the switching nuts of high-pressure laboratory tubes. This allows tubes with dimensions $\varnothing 4 \times \varnothing 8 \times 1000$ and nozzles labelled 1 688 911 019 to be used on high-pressure pumps intended for tubes with dimensions $\varnothing 3 \times \varnothing 6 \times 1000$ and nozzles labelled 0 681 343 009.

Special high-pressure tubes are manufactured for high-pressure pumps of the P500 family with the possibility of using original motorized nozzles (Figures 3 and 4). Additionally, for special measurements on high-pressure pumps of the P500 family, when it is necessary to determine the needle stroke of the nozzle as a function of the camshaft rotation angle [1], a specially designed assembly can be used, which includes the original nozzle, with the nozzle needle connected to an inductive position sensor (indicated by an arrow in Figure 3).



Figure 2: Specially constructed adapters and nuts that have a right-hand thread on one end and a left-hand thread on the other

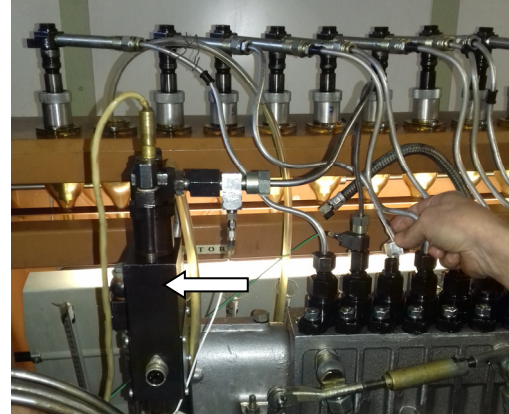


Figure 3: High pressure pipes with original engine injectors and a special assembly (indicated by an arrow) for measuring the stroke of the injector needle

All components of the tested pump must be tightened with tightening torques defined in the corresponding design or technical documentation. Tightening torques for pumps of the P500 family, which are still in the prototype phase at the time of writing this document, must be verified and are specified in the accompanying design documentation. Two fluid supply hoses (positions 1 in Figure 4) and one fluid drain (overflow) hose (position 2 in Figure 4) need to be connected to the pump. A special lever assembly, whose tension can be adjusted via a hexagonal rod with threads on both ends (position 3 in Figure 4), is used to regulate the injected quantity of fluid.

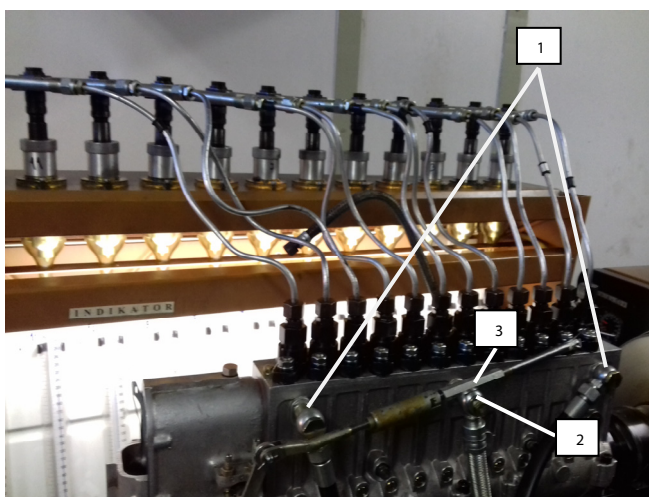


Figure 4: The supply and drain of working fluid, and the lever assembly for regulating the injected quantity of fuel



Figure 5: Measurement assembly for determining the pre-lift of the pump element for P500 pumps

For testing pumps on the BOSCH test bench, the use of working fluid with prescribed characteristics (known as "calibrol") is specified [20].

3.2. Determining the pre-lift of the pump element

The procedure for determining the pre-lift of the pump element depends on the design, i.e., the type of pump being tested or regulated. For pumps of the P500 family, a measurement assembly consisting of specially designed tools paired with a comparator is used (see Figure 5). The method is original and developed in the Vehicle Subsystems Testing Laboratory. The procedure consists of the following steps:

- The Relief Valve Support and Relief Valve Piston are removed from the corresponding pump element. A special measurement assembly shown in Figure 5 is inserted into the relief valve support position. A brass tube of smaller diameter than the circular opening through which it passes along its entire length is attached to the comparator of the measurement assembly. The lower end of the brass tube is placed against the face of the pump element piston, allowing the comparator needle to be “zeroed”.
- Fuel overflow on the high-pressure pump is blocked with a threaded plug to achieve a constant pressure of the working fluid in the pump gallery.
- The fuel injection quantity regulation lever is set to its maximum position (maximum fuel quantity).
- The test bench is activated, and the constant pressure of the working fluid in the high-pressure pump gallery is set on the rotating lever to not exceed 0.5 bar. The working fluid must flow through the brass tube of the measurement assembly (Figure 5) and the entire measurement assembly (as the Relief Valve Piston is removed). To reduce leakage and loss of working fluid during these tests, the measurement assembly is wrapped with a cloth, as shown in Figure 5.
- The lever is manually rotated until the comparator needle moves (indicating the start of the pump element lift), and the current angle value is read on the flywheel's graduated circle.
- The lever is continued to be manually rotated until the working fluid flow through the brass tube of the measurement assembly (Figure 5) ceases, specifically until one drop per second is reached. In this position, the pump element piston has closed the overflow channel in the pump gallery, having travelled from the inner dead point to the current position, defined as the “pre-lift”.
- The angle value traversed is again read on the flywheel's graduated circle, and the achieved stroke of the piston, i.e., the current “pre-lift” value, is noted on the comparator scale.
- The desired “pre-lift” value is achieved by inserting a Spacer washer of appropriate thickness between the element and the pump body, which is easily calculated based on the current value of this parameter.
- The entire procedure is repeated once again to confirm that the “pre-lift” on that pump element has been brought within the specified limits.

A similar procedure is applied for the P10 pump.

For the high-pressure pump PE 10 P 100 A 320 LS 821 (for the OM 403 engine installed in the BVP M80-A), a similar method for determining the “pre-lift” of the pump element has been developed, adapted to its construction design. The essential difference is that a special measurement assembly, as used for the P500 pump family and the BOSCH P10 pump, is not utilized. Instead, the movement of the first pump element piston during manual rotation of the flywheel on the test bench drive is monitored by removing the existing technological plug in the lifter area of the first pump element. Then, the comparator is positioned favorably and attached with a magnet to the test bench rail, and a thin metal rod is used. One end of the rod is firmly attached to the movable needle of the comparator, while the other end rests against the face of the pump element lifter. The desired “pre-lift” value is achieved by inserting a Spacer washer of appropriate thickness between the element and the pump body. Pre-lift is determined only on one pump element (usually the first), as prescribed by the accompanying documentation, while phase adjustment of the injection start of the pump is performed on the other pump elements according to the specified sequence of fuel delivery.

3.3. Phase (angular) adjustment of the start of injection of high-pressure pump elements according to the specified sequence of fuel delivery

When regulating high-pressure pumps on the BOSCH test bench, precise phase adjustment of fuel injection per pump elements must be performed according to the engine's construction design and ignition sequence. High-pressure pumps of the P500 family and the P10 pump are installed on V engines with 12 (twelve) cylinders, where the angle between cylinders is 60°. Therefore, they must be adjusted according to the following injection sequence per pump element: 1-4-9-8-5-2-11-10-3-6-7-12. For these high-pressure pumps, a phase gap of **30°** of crankshaft rotation is specified between pump elements according to the following injection sequence: 0°-30°-60°-90°-120°-150°-180°-210°-240°-270°-300°-330°, corresponding to the given injection order. However, since these engines have a complex piston mechanism with a main piston (on the left side of the engine) and an auxiliary piston (on the right side of the engine, connected to the main piston via a special lug and pin), there are certain differences in the kinematics of piston group movement, total piston stroke (and thus cylinder volume), and angular spacing between the top dead centres of the

engine pistons between the left and right sides of the engine. Taking this into account, more precise phase adjustment of these high-pressure pumps is achieved by setting a phase gap of **30.5°** of crankshaft rotation between even and odd pump elements, while maintaining a phase gap of **60°** of crankshaft rotation between the closest odd pump elements according to the injection sequence: 0°-30.5°-60°-90.5°-120°-150.5°-180°-210.5°-240°-270.5°-300°-330.5°.

Other characteristic example is the previously mentioned high-pressure pump PE 10 P 100 A 320 LS 821, intended for the ten-cylinder Mercedes Benz OM 403 engine, where the injection sequence per pump element is as follows: 1-8-7-6-3-5-2-10-9-4, and due to the fact that it's a V engine with a 90-degree angle between cylinders, the phase gaps between injections per crankshaft angle for the pump, as derived from the engine's first-order star, are as follows: 0°-27°-72°-99°-144°-171°-216°-243°-288°-315°.

This operation can be performed in two very similar ways.

The first method involves using laboratory tubes and nozzles. Special attachments consisting of bent tubes (known as "swan necks") and screws are present on the supports of both types of laboratory nozzles (see Figure 6). By loosening the screw, it's possible to direct the flow of working fluid from the pump element through the tube before it reaches the nozzle in the laboratory nozzle.

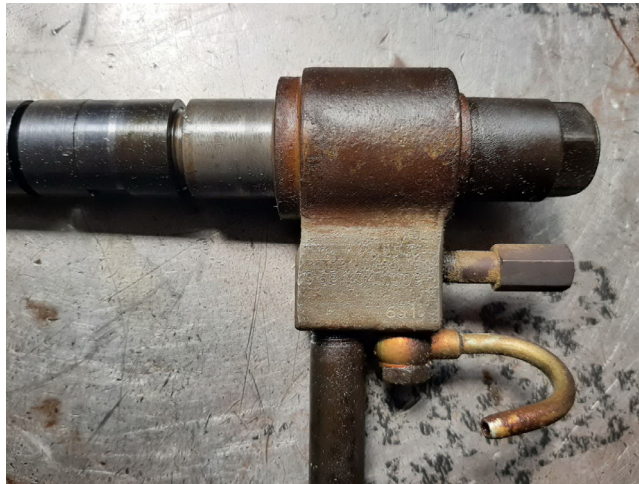


Figure 6: The screw and bent tube (known as "swan neck") on the laboratory nozzle with the label 0 681 343 009

The method itself is similar to determining the pre-lift of the pump element and consists of the following steps:

- Fuel spillage on the high-pressure pump is blocked by a threaded plug to achieve a constant pressure of the working fluid in the pump gallery.
- The fuel injection control lever is set to the maximum position (maximum fuel quantity).
- The test bench is activated, and a constant pressure of the working fluid in the high-pressure pump gallery of 30 bar is adjusted on the rotational lever.
- The screw on the nozzle connected to the element where the pre-lift was previously determined is loosened so that the working fluid begins to flow through the bent tube.
- The drive wheel on the test bench is manually rotated until the flow of the working fluid through the tube on the nozzle stops, i.e., dripping one drop per second.
- The current angle value of the camshaft is read on the graduated circle of the drive wheel, which can be "zeroed" or set to a whole number value by moving the sliding pointer.
- The screw on the nozzle connected to the next element in the injection sequence is loosened.
- The drive wheel on the test bench is continued to be manually rotated until the flow of the working fluid through those nozzles stops, i.e., dripping one drop per second.
- The current angle value is again read on the graduated circle of the drive wheel.
- The required value of the phase (angular) adjustment on that pump element is achieved by inserting a Spacer washer of appropriate thickness between the element and the pump body.

For high-pressure pumps of the P500 family and the P10 pump, empirical recommendation suggests that a correction of one degree (1°) of phase difference can be achieved by adding (if there is a smaller phase difference than required) or subtracting (if there is a larger phase difference than required) a total thickness of Spacer Washer of 0.3 mm.

- After that, the entire process is repeated for the given element to confirm that the phase difference in injection on that pump element is brought within the prescribed limits, or the readjustment is performed until it is brought within the prescribed limits.

- Phase adjustment is then sequentially performed on the other high-pressure pump elements, respecting the specified angular injection order, according to the algorithm described above, for the second element in the injection order.

The second procedure is in many respects similar to the previously described one. It does not rely on the use of laboratory tubes and nozzles with screws and bent tubes (Figure 6), but rather the high-pressure pipe is completely disconnected from the element under consideration. It consists of the following steps:

- Fuel spillage on the high-pressure pump is not blocked by a threaded plug but rather allows normal flow of the working fluid through the pump gallery.
- The fuel injection control lever is set to the maximum position (maximum fuel quantity).
- The test bench is activated, and a constant pressure of the working fluid in the high-pressure pump gallery of 1.5 bar is adjusted.
- The drive wheel on the test bench is manually rotated until the fuel push is noticed at the threaded connector of the element.
- The current angle value is read on the graduated circle of the drive wheel, which can be "zeroed" or set to a whole number value by moving the sliding pointer.
- The laboratory tube connected to the element next in the injection order is disconnected.
- The drive wheel on the test bench is continued to be manually rotated until the fuel push is noticed at the threaded connector of the element.
- The current angle value is again read on the graduated circle of the drive wheel.
- The required value of the phase (angular) adjustment on that pump element is achieved by inserting a Spacer Washer of appropriate thickness between the element and the pump body, as described earlier.
- After that, the entire process is repeated for the given element to confirm that the phase difference in injection on that pump element is brought within the prescribed limits, or the readjustment is performed until it is brought within the prescribed limits.
- The phase adjustment is then sequentially performed on the other high-pressure pump elements, respecting the specified angular injection order, according to the algorithm just described for the second element in the injection order.

Neither of the two described procedures can be considered completely reliable since both rely on the subjective assessment of the person performing the adjustment, so errors in phase adjustment of the pump of up to one degree (1°) per element can be expected. These errors can be corrected after a much more reliable measurement of the stroke of the nozzle needle of the pump elements [1].

3.4. Adjustment of the all-mode speed regulator

High-pressure pumps of the P500 family, as well as PE 10 P 100 A 320 LS 821 and P10 pumps, are equipped with all-mode speed regulators, and the procedures for their adjustment would apply in finer details even if they were similar constructions of single-mode or dual-mode speed regulators.

The all-mode regulator operates in all engine speed modes, depending on the position of the control lever. The position of the control lever determines the speed at which the pump camshaft, with the help of the all-mode regulator, will rotate at a constant, or more precisely, slightly variable angular speed. In other words, the task of the all-mode speed regulator is to meter the injected fuel quantity at a certain number of pump camshaft, or engine, revolutions per minute (rpm), between the minimum ($n_{\min}$) and maximum ($n_{\max}$), depending on the variable external load of the engine, while maintaining the desired number of pump camshaft, or engine, revolutions per minute within certain, narrow limits.

More detailed research of the operation of the all-mode speed regulator by its nature can be highly extensive and time-consuming [2]. However, during the adjustment of the all-mode speed regulator operation, it is assumed that it is structurally and functionally correct, and actions are taken to ensure that it satisfies the following basic functions:

- Stable operation at neutral mode (so-called "idle"), when the engine is not loaded but the high-pressure pump needs to provide the minimum required amount of fuel for the stable operation of the engine, in place, i.e., at the neutral gear of the transmission, overcoming only its own mechanical losses and moments for driving auxiliary devices on the vehicle,
- Achieve the nominal speed (start of governor action) of the camshaft of the pump or the crankshaft of the engine, within narrow prescribed limits,
- Fuel injection cut-off modes (fuel cut-off mode) and end of governor action must also be within prescribed limits.

For pumps of the P500 family, there are two Limit screws of the lever on the body of the all-mode speed regulator (Figure 7), with corresponding nuts that fix their position, one of which is used to adjust the nominal speed of the camshaft of the pump (position 1 in Figure 7), and the other for approximate adjustment of the cycle fuel quantities at idle (position 2 in Figure 7).

The procedure for determining the nominal speed consists of the following steps:

- On the side of the pump, towards the drive, the assembly consisting of the Protective sleeve with the corresponding washer, screw, and nut is removed, and in their place, a specially made comparator holder and comparator are installed (see Figure 8). In addition, the comparator can be "zeroed" or set to a whole number value for easier tracking of the stroke of the toothed rack. The assembly being removed is clearly visible in Figure 1, and during this procedure, it must ensure that the maximum stroke of the toothed rack is identical to the stroke achieved with the assembly being removed.
- The fuel injection control lever is set to the maximum position (maximum fuel quantity).
- The test bench is activated, and the pump speed is increased. The current value of the nominal speed is determined by monitoring the pointer on the comparator, and it is defined by the moment when the pointer starts moving to the left, i.e., when the centrifugal regulator begins to "reduce fuel".
- If the determined nominal speed is not within the prescribed limits, the pump camshaft speed is decreased to zero.
- In case the determined nominal speed is lower than expected, the locknut of the Control lever limit screw, represented as position 1 in Figure 7, is loosened, the screw is turned in for a certain value, the pump speed is increased, and the entire procedure is iteratively repeated until the nominal speed is achieved within the desired limits.
- Conversely, if the determined nominal speed of the pump camshaft is higher than expected, the locknut of the Control lever limit screw is loosened, and the screw is turned out for a certain value. The logical sequence of already described iterative steps is applied until the nominal speed is brought within the prescribed limits.

For pumps of the P500 family and the Bosch P10 pump, it is prescribed that the nominal speed (start of regulator action) should be achieved at a camshaft speed of $1030^{-15} \text{ min}^{-1}$.

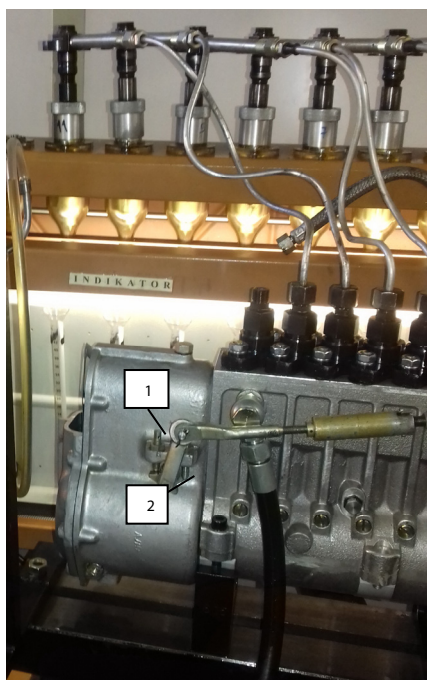


Figure 7: Screws on the body of the governor of the P500 pump family for adjusting the nominal speed and approximate idle adjustment

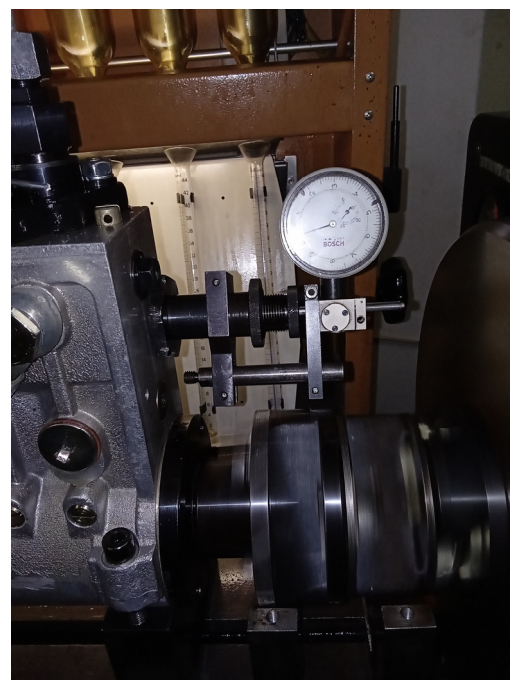


Figure 8: Comparator holder and comparator that is mounted in place of the protective sleeve, along with the corresponding washer, screw, and nut

Once the nominal speed is within the specified limits, the fuel injection shutdown mode (mode without fuel injection) is verified. When the outer lever of the regulator is pulled to the maximum (to the stopper), the injected fuel quantity must be zero at a camshaft speed lower than 1150 min^{-1} . It is allowed that, at a camshaft speed of 1150 min^{-1} , there is a flow of working fluid, but only to a maximum of 4 nozzles, in an amount not exceeding 5 cm^3 for 500 strokes of the pump piston. The occurrence of working fluid is not permitted on the remaining 8 elements or nozzles.

The end of the regulator action is defined as follows: when the outer lever of the regulator is pulled to the maximum (to the stopper), as the camshaft speed increases, the regulator should ensure that the movement of the toothed rack is in the direction of decreasing the injected fuel quantity by at least 2 mm compared to the position in the shutdown mode. When the outer lever of the regulator is resting on the idle stop (position 2 in Figure 7 for pumps of the P500 family), and at the engine camshaft speed corresponding to idle (for high-pressure pumps of the P500 family, this is 400 min^{-1}), the cycle fuel quantities should correspond to the values given in the respective Product Quality Regulations (PKP) [10, 11] or other appropriate technical documentation. For pumps of the P500 family, the approximate values of injected fuel quantities at idle can be adjusted by tightening or loosening the idle stop screw, marked as position 2 in Figure 7, and the final adjustment is made on the idle control levers, immediately after the engine is installed in the vehicle.

A similar procedure is applied when adjusting the centrifugal speed regulator of the Bosch P10 pump, taking into account the design differences regarding the position of the screws for adjusting the nominal speed and idle speed (Figure 9). Unlike the P500 pump family, with the P10 pump, the idle stop screw is not removed after adjusting the regulator; instead, the pump is installed in the vehicle with this screw. The method of securing the comparator is shown in Figure 10.



Figure 9: Screws on the body of the all-mode speed regulator on the P10 pump for adjusting the nominal speed and idle speed

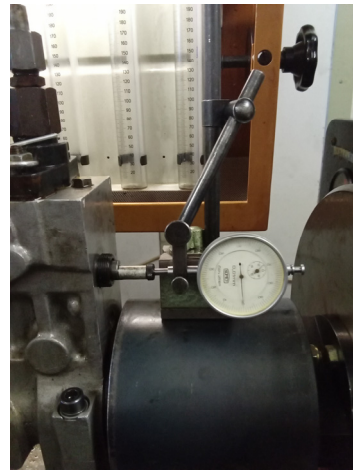


Figure 10: Comparator holder and comparator placed in the position of the protective sleeve on the P10 pump

For the high-pressure pump PE 10 P 100 A 320 LS 821 (engine OM 403) equipped with the all-mode speed regulator RQV 350 1250 PA 378 9, the nominal speed (start of regulator action) is achieved by rotating the shaft with the thread (position 4 in Figure 11) in one direction or the other using a screwdriver, thereby altering the pre-tension of the springs connected to the rotating weights of the regulator.

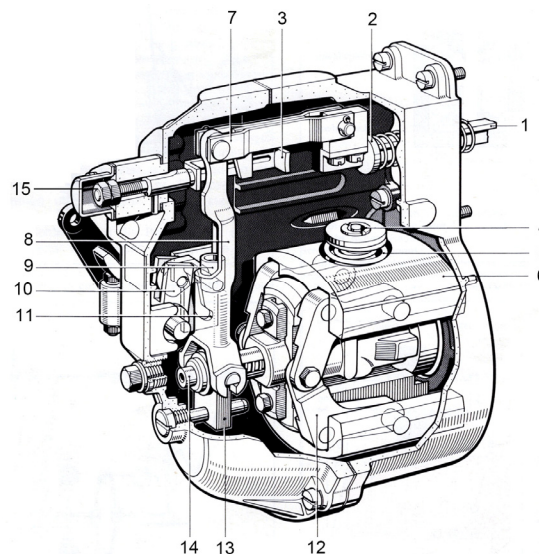


Figure 11: RQV 350 1250 PA 378 9 all-mode speed regulator for PE 10 P 100 A 320 LS 821 high-pressure pump (Mercedes Benz OM 403 engine)

3.5. Adjustment of cycle fuel quantities per pump elements

The fuel quantities delivered by individual high-pressure pump elements must correspond to the values prescribed by the relevant technical documentation (Product Quality Regulations, abbreviated as PKP in Serbian, or other technical documents for the pump), for different speeds of the pump camshaft. These adjustments, in terms of increase or decrease, are generally achieved by adjusting the stroke of the toothed lever.

For high-pressure pumps of the P500 family and the BOSCH P10 pump, the increase or decrease in the mean values of cycle fuel quantities is achieved by turning the screw and nut on the assembly consisting of the protective sleeve with the corresponding washer, and the screw and nut in question (see Figure 1). For the high-pressure pump PE 10 P 100 A 320 LS 821 (engine OM 403), the increase or decrease in the mean values of cycle fuel quantities is achieved by loosening or tightening the pair of nuts on the centrifugal speed regulator RQV 350 1250 PA 378 9, indicated as position 15 in Figure 11.

Fine adjustment of cycle fuel quantities delivered by individual pump elements is performed by relative rotation of the cylinder in relation to the piston, thereby changing the moment when the spiral channel on the piston closes the spill channel on the cylinder, thus achieving a larger or smaller active stroke of the piston. Figure 12 illustrates the direction of rotation of the cylinder element of the pump leading to an increase in the cycle fuel quantity of that element. The opposite direction of rotation would result in a decrease in the cycle fuel quantity delivered by the given element. These procedures imply that the nuts tightening the cylinder element to the pump body via dowel screws must be removed.

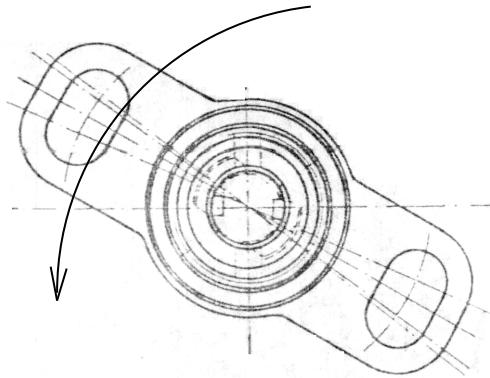


Figure 12: The direction of rotation of the cylinder element of the pump leading to an increase in the element's cycle fuel quantity

For the high-pressure pumps of the P500 family, as well as for the P10 pump, there is a specific requirement for adjusting different cycle fuel quantities for odd and even pump elements, since due to the complex piston mechanism with main and auxiliary pistons, the strokes of the pistons, i.e., the working volumes of the cylinders on the left and right sides of the engine, are different. These pumps are adjusted so that the odd elements deliver 3 to 4% more fuel compared to even elements. An example of a set pump from the P500 family for an engine with a nominal power of 840 HP is shown in Figure 13. The obtained values of injected fuel quantities relate to 500 consecutive "strokes" (working cycles of the pump), which as an option is offered by the BOSCH test bench.

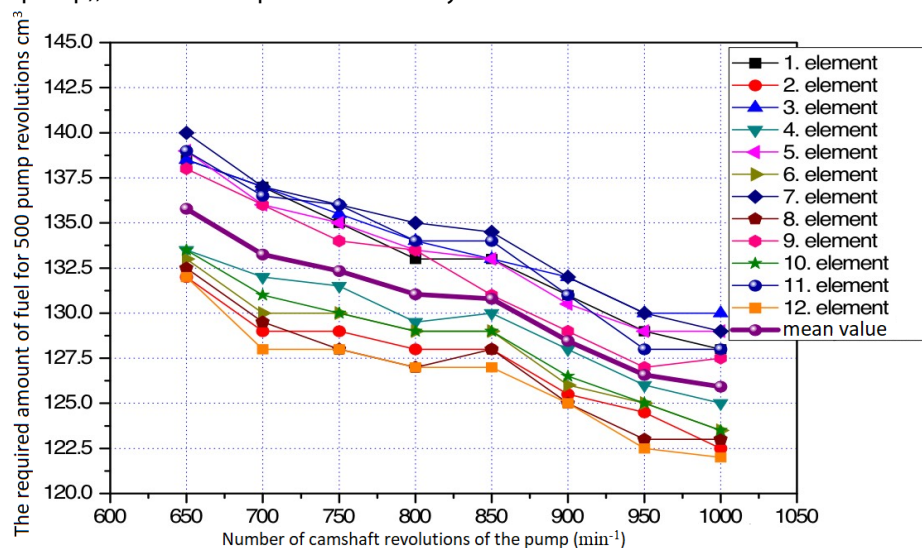


Figure 13: Example of set fuel quantities at the P500 pump family for an engine with a nominal power of 840 HP

4. CONCLUSION

The paper describes the procedure for adjusting and testing high-pressure in-line pumps with up to twelve (12) elements on the BOSCH test bench, which consists of five (5) separate operations (phases):

- 1) Placing the high-pressure pump on the BOSCH test table and checking the tightening torques of individual pump assemblies,
- 2) Determining the pre-lift of the pump element,
- 3) Phase (angular) adjustment of the beginning of the injection of the high-pressure pump elements according to the set sequence of fuel injection,
- 4) Setting the all-mode speed regulator,
- 5) Equalization of cyclic fuel quantities by pump elements.

Three (3) in-line high-pressure pumps for special-purpose engines (Serbian Armed Forces) were selected as examples, which, in addition to conceptual similarities, are characterized by a number of constructive specificities and differences.

This paper has two (2) main objectives:

- 1) To serve as a manual of its own kind for researchers who deal with direct tests of the improvement of working processes of diesel engines equipped with high-pressure in-line pumps in the process of experimental validation of the achieved results, and
- 2) To indicate a series of unavoidable, accompanying, often arduous actions that precede or are carried out in parallel with the application of more advanced methods of measurement, testing and development in an effort to achieve serious scientific results, which are very little or not at all mentioned in the scientific studies and papers produced.

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