EXPERIMENTAL RESEARCHES REGARDING TESTING LIFETIME AND MONITORING THE BEHAVIOUR OF THE VARIABLE VALVE TIMING SYSTEM ELECTROVALVES ON A TEST BENCH

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ABSTRACT – The article presents the determination of the maximum number of electrovalve switchings until malfunction (valve lifetime), using different contamination oil conditions (size and type of particles) in case of a test bench used for studying contaminantion behaviour of some components of the vehicle engine variable valve timing system. An analysis of the hauling time estimation in case of vehicles equiped with this type of electrohydraulic valves until this device fail due to contamination with particles from the oil was also presented in this paper. It was also created a database with tested electrovalves.

During the paper we present two monitoring types on the test-bench, developed in case of the electrovalves, and a determination of the variation law of the diagnostics parameter which describes behaviour of the electrovalve.

These test-bench researches accomplished, we consider useful for electrohydraulic valves manufacturers, vehicle engines manufacturers in order to improve their products and also for the maintenance service to assure a better quality of the process.

Consequently the researches made opens a “bridge” for future research directions, like different other type of monitoring systems or testing electrovalves using other conditions as could be other particles, materials, sizes, or contamination classes. Another future research direction could be testing other types of electrohydraulic valves using this test bench, with minimum costs (only with valve tested block switching). The developping of some monitoring on-board diagnostics systems procedure for the valves, could also in future be developped starting from this point of researches.

MAIN SECTION - A test bench was developped at the Transilvania University under the guidance of Schaeffler KG Germany, in order to study the lifetime of some electrohydraulic valves, component parts of a variable valve timing system, which are influenced by contaminated particles from the engine oil.

During the flowing process, due to entering the particles from the contaminated oil between the moving parts of the valve, is influenced their normal operation (by blocking parts), eventually resulting valve failure.

As a result, may be assumed that the role of the electrohydraulic valve as part of the variable valve timing system is essential, requiring the need for better monitoring on a test bench to be developped (figure 1).

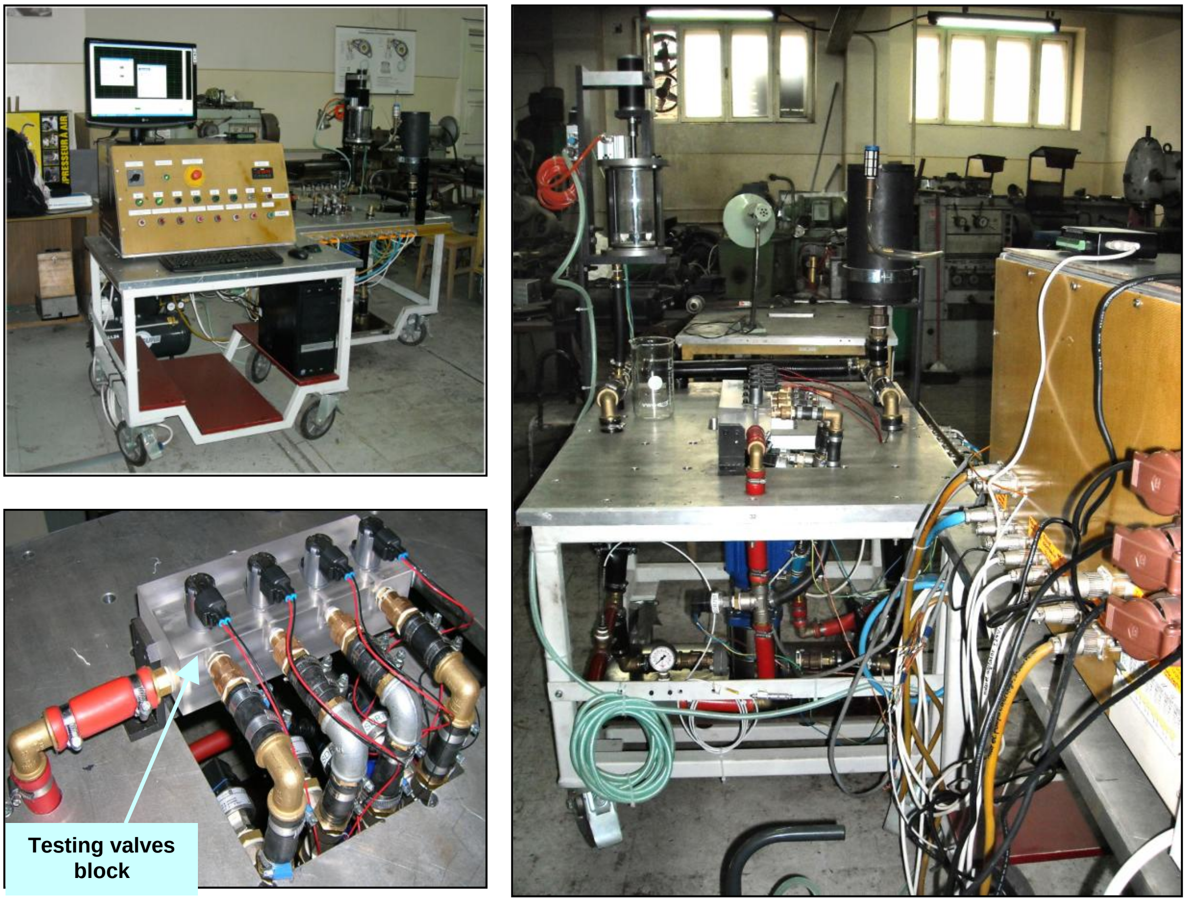

Fig. 1 Overview of the test bench developped for electrohydraulic valve test

Experimental research of the tested valves, had the following purposes:

- Determine the maximum number of valve openings until they fail (number of on/off switchings) due to mechanical particles existing inside the oil with which it works.
- Determine the diagnostic parameter, which describes the limit beyond the solenoid failure is imminent.
- Establishing a database containing information about the values of all parameters for each electrovalve tested at different times.
- Determine mathematical function for the variation law of the diagnostic parameter that describes the technical evolution of the valve.

The experimental data obtained after 24 valves were tested on the test bench developped, are shown in table nr. 1.

In figure 2 is presented as histograms of the average number of switchings until solenoid failure, using different types of materials and particle sizes for the contaminants introduced inside the oil.

Also be made clear that the experimental tests were performed with a higher oil contamination grade, equivalent to class 15 standard NAS 1638, in order to shorten the testing times. In the normal operation, vehicle engine oil is contaminated with a much smaller amount of impurities (grade 9, according to NAS 1638).

As you can see, generally blocking probability increases with reducing particle size used. The theoretical study has determined that small quantities of impurities, could increase valve blocking problems. A great influence has also the contaminant material and some combinations between different types.

Table 1

Experimental results after testing 24 valves on the test bench

Nr. of test	Type of contaminant introduced in oil	Number of on/off switchings of the valve solenoid until valve fail				Average value	% of standard test
		Valve nr. 1	Valve nr. 2	Valve nr. 3	Valve nr. 4		
01	FeCr18/Ni10/Mo3 (d ≤ 150 μm)	6483	7763	7130	7186	7141	100 %
02	FeCr18/Ni10/Mo3 (d ≤ 150 μm)	10161	9205	9733	10945	10011	140 %
03	FeCr18/Ni10/Mo3 (d ≤ 45 μm)	7650	6600	8500	6700	7363	103 %
04	Al50/Fe50 (d ≤ 150 μm)	4800	4900	5650	5030	5095	71 %
05	FeCr18/Ni10/Mo3 mix between d ≤ 45 μm ş i d ≤ 150 μm	5217	5676	5910	5425	5557	78 %
06	Mix between FeCr18/Ni10/Mo3 ş i Al50/Fe50 (d ≤ 150 μm)	4061	3874	4162	3700	3949	55 %

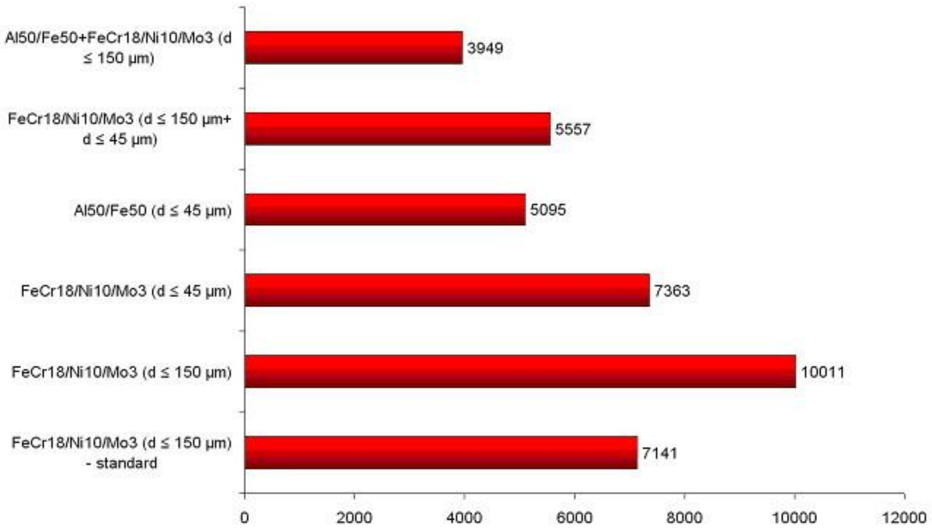

Fig. 2 Medium number of on/off switchings of the valves until failure

On the test bench the tested valves monitoring can be performed in two ways:

- the visual mode due to the transparency material used for the valves block;
- the monitorisation using the pressure sensors.

Valves visual monitoring during their operation consists in tracing the flow of oil from the hydraulic circuit of the test bench, during the period the valve solenoid is not energized.If it functions properly during this period valve is closed, with no oil flow inside of it from the feed to the consumer port.

In case of failure, the valve remains partially opened during this period, because the valve is blocked in a particular position because of impurities from oil. Consequently, there is oil flow through the port within the valve to the power consumption, which can be observed in oil output channel corresponding valve in question (figure 3).

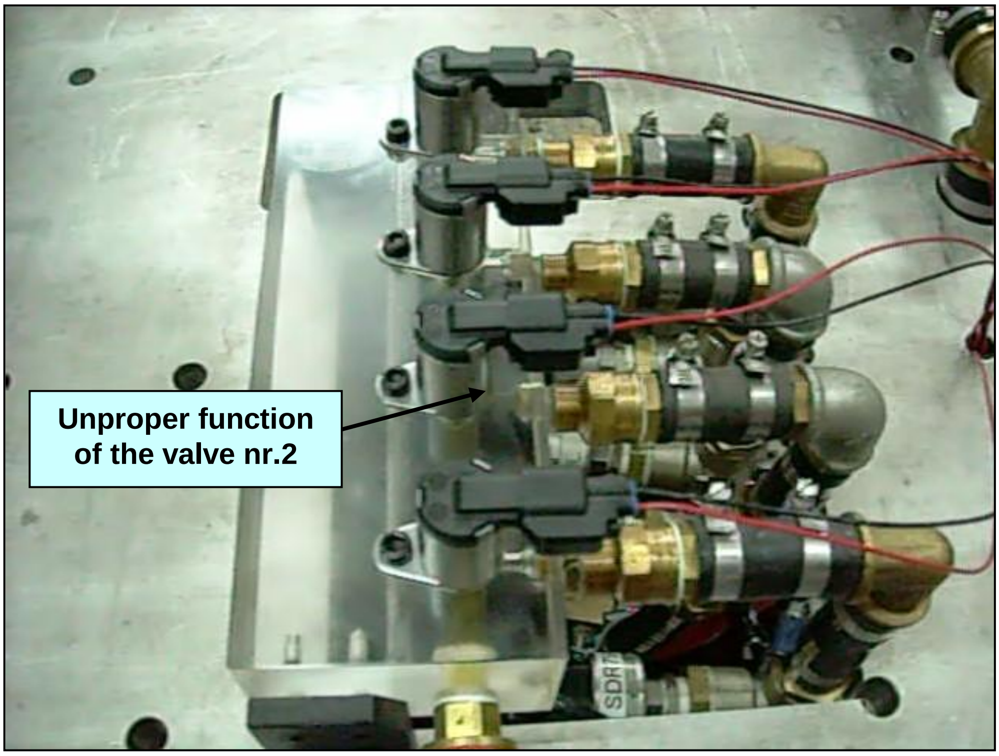

Fig. 3 The visual monitoring mode of the valves functioning

Valves operation monitoring with pressure sensors means the growth observation of the pressure gradient (dp / dt) using the pressure sensors, during the valve solenoid is energized. For this one pressure sensor for each valve mounted on the test block is used, which is placed at the exit of the consumption port of it.

Experimentally was observed that when a valve block of the four tested simultaneously appeared, there is an increase in pressure gradient (dp / dt) per unit time, to its corresponding sensor placed at the exit of the block valves.

Valve solenoid locks in an intermediate position, permitting the oil flows from the supply port (P) to consumption port (A) all the time even when the valve is not actuated and should be closed.

The valve does not lock suddenly, but over time. Until „full-blocking" when oil flows continuously between the two ports, was recorded the gradually increases in oil flow, extending the time period in which the solenoid is not energized.

In figure 4 the oil pressure variation at the entrance/exit of the tested block, under the normal function of the valves, is presented.

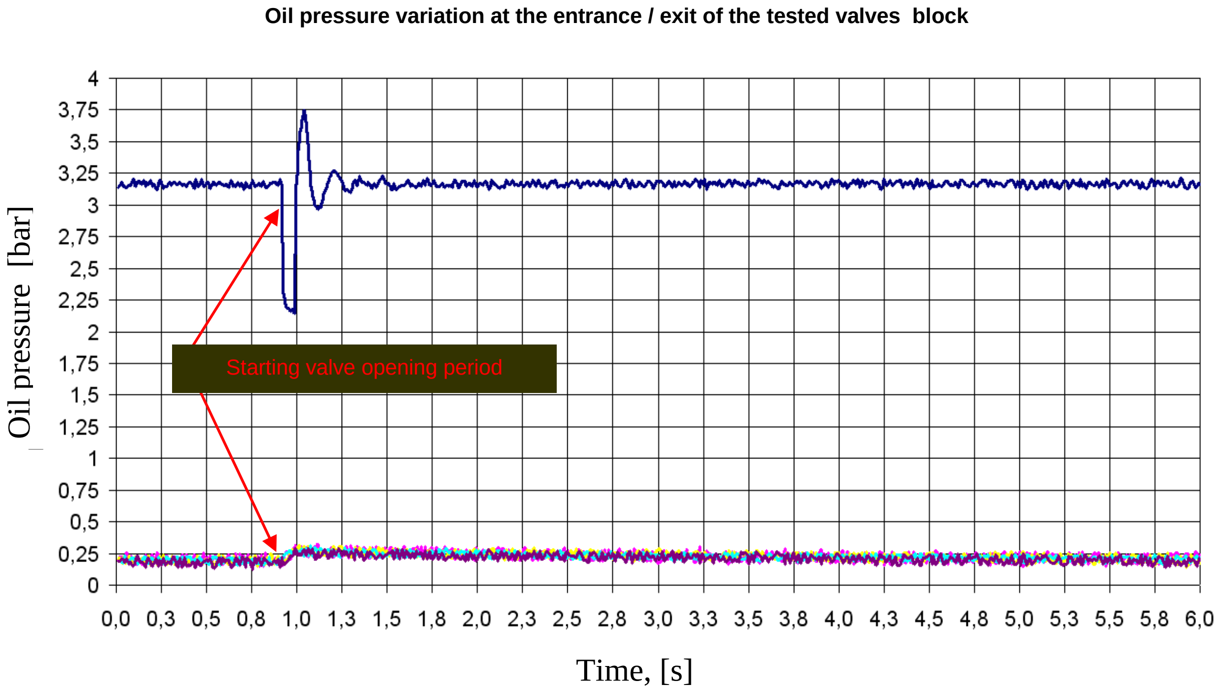

Fig. 4 Oil pressure variation at the entrance / exit of the tested valves block

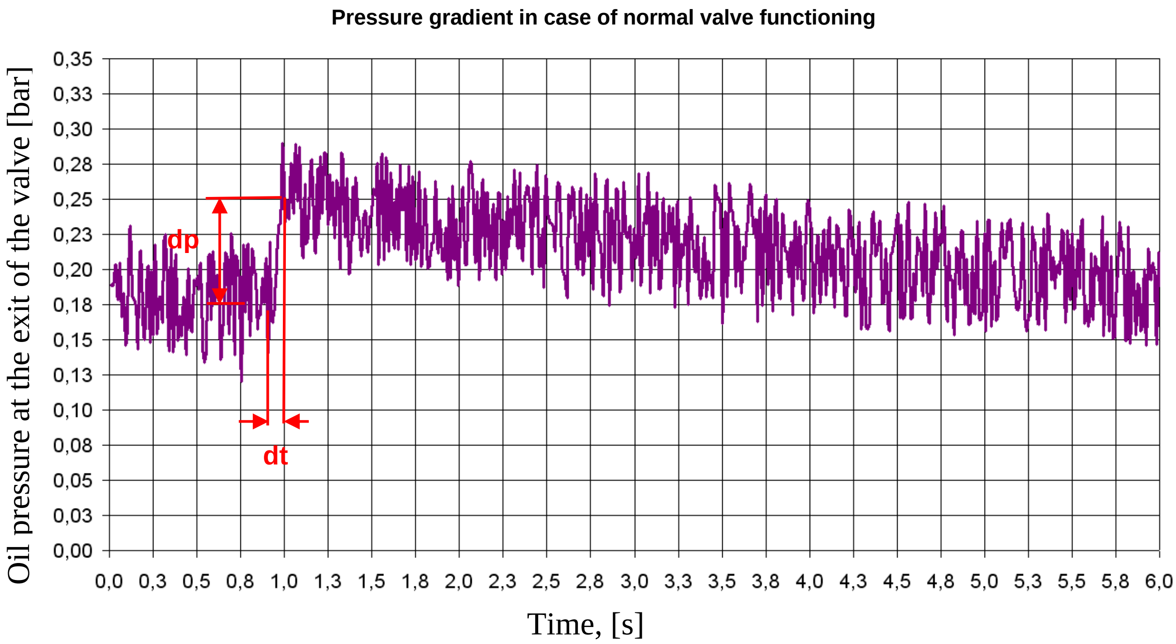

Fig.5 Pressure gradient for one valve in case of proper functioning

Further testing the valves on the test bench, the pressure gradient gradually increases over time and finally reaching a value indicating the start of solenoid failure (figure 6).

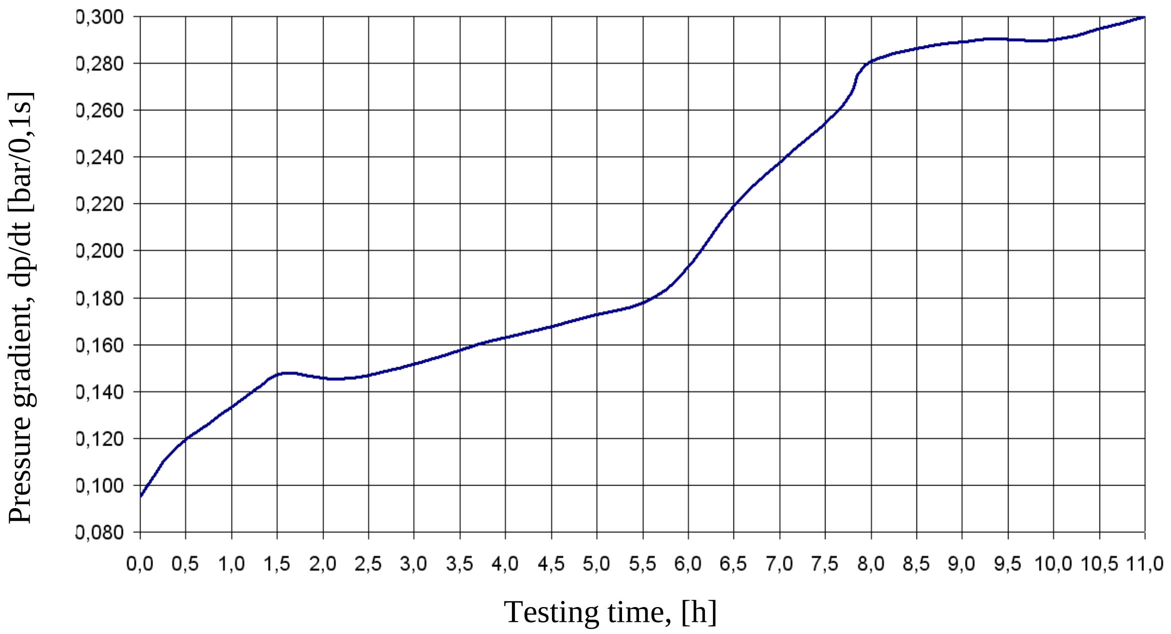

Fig.6 Pressure gradient variation vs. testing time

In case of a solenoid failure, there is an output pressure increase of the corresponding valve, when the solenoid valve is actuated and when the oil flows from the supply port to its the consumption port. Pressure gradient (dp / dt) in this case has a higher value than for normal operation, reaching a very small time interval of 60 ms to a value of 0.3 bar (figure. 7).

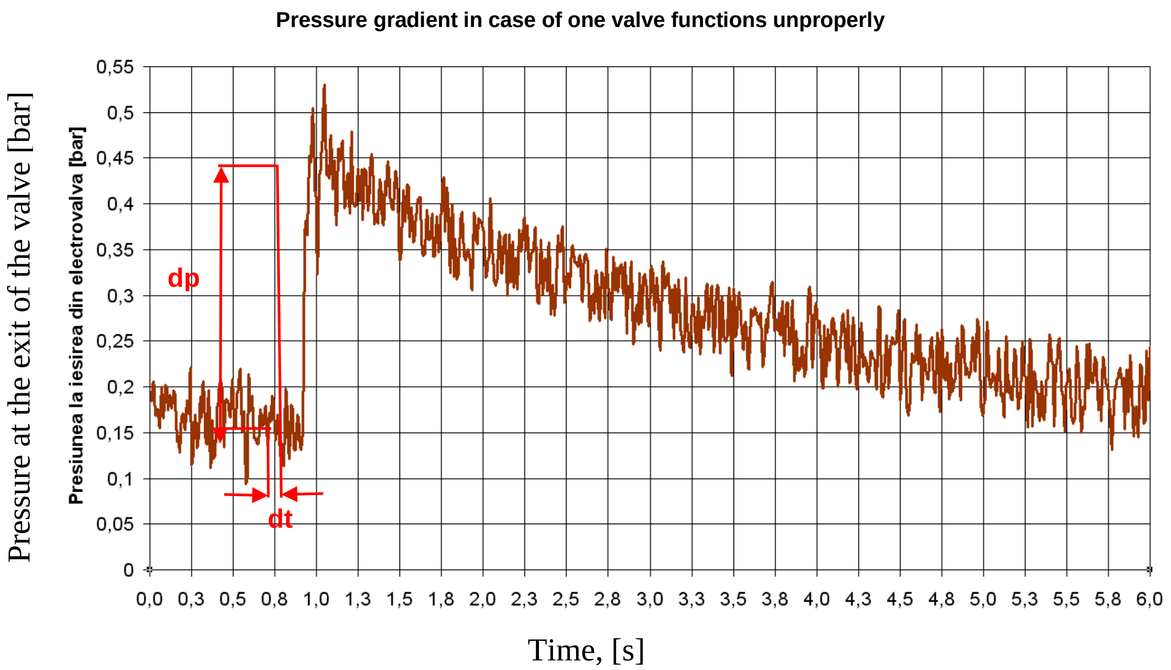

Fig.7 Pressure gradient for one valve in case of malfunction

If a solenoid locks, testing process does not stop but continue to block all four valvesof the test. Thus, the pressure gradient will continue increasing to reach its maximum value when all the test valves were blocked and malfunctioning, in that case reaching values above 1.5 bar within about 200 ms. The gradient reached is more important in case of the failure of the first solenoid, since this factor could be used to further a vehicle diagnostic monitoring this parameter. Of course this could be achieved if inside the engine would be placed a pressure sensor to record the gradient above mentioned.

In this paper, to determine the optimal law of variation which estimates the best the technical behaviour of the valve was used the method of determining the regression function.

As was determined after mathematical algorithms, the function that leads to the best approximation of the pressure gradient behaviour in case of valve monitoring is a polynomial regression function which has the expression as below:

$$y = 0{,}000006 \cdot x^6 - 0{,}000181 \cdot x^5 + 0{,}001757 \cdot x^4 - 0{,}005678 \cdot x^3 - 0{,}002383 \cdot x^2 + 0{,}042612 \cdot x + 0{,}097188 \quad (1)$$

In figure 8 are represented with the blue colour, the pressure gradient (dp / dt) increase during the tests until failure for the one valve and the polynomial regression function of degree 6 (with orange colour), which is the function that best approximates the law of variation of this parameter diagnostic (dp / dt).

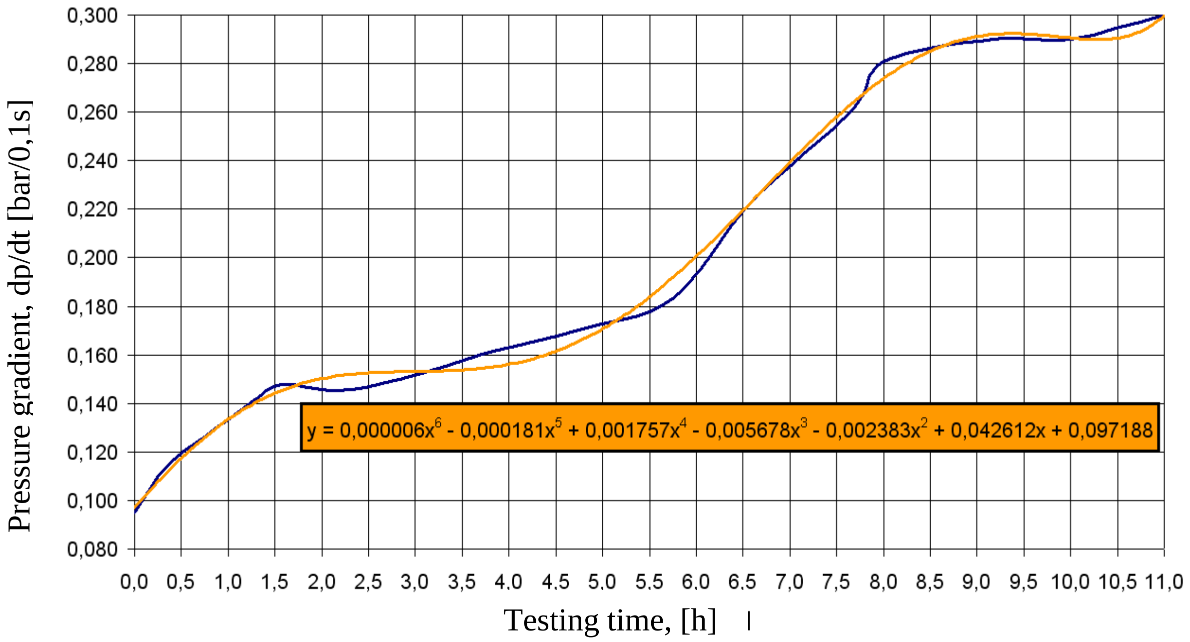

Fig.8 Pressure gradient variation for one valve tested and its polynomial regression

CONCLUSIONS

During the paper was determined the maximum number of electro-valve switchings until malfunction (valve lifetime), using different contamination oil conditions (size and type of particles) using the test bench developped at the university.

Two monitoring types on the test-bench, in case of the electro-valves and a determination of the variation law of the diagnostics parameter which describes behaviour of the valve were also presented.

These test-bench researches accomplished, can be considered useful for electrohydraulic valves manufacturers, vehicle engines manufacturers in order to improve their products and also for the maintenance service to assure a better quality of the process and gives some directions for future researches, including perhaps in near future developping of some monitoring on-board diagnostics algorithms for this type of valves which could be maybe integrated in some future diagnostics systems.

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