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RESULTS OF MEASURING OF PARAMETERS OF WORKING PROCESSES OF THE PISTON AXIAL PUMP

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Abstract. In the scope of performed experimental testing was done a measuring of the pressure flow in the cylinder, discharge space and intake pipeline as well as vibration of the pump housing in dependence of the passed angle of the pump shaft. All pressures and vibrations were measured completely parallel on each cca 0.09^{o} of the pump shaft (exactly 4.096 times per shaft rotation).

As incremental giver of the angle an optical giver with 1024 pulses per rotation was used. Pulses of the giver of the angle were 4 times increased by the interface for the angle givers on the ADS 2000 system and so 4096 pulses per shaft rotation were obtained.

In order we might see the repetition of the consecutive cycles with the unchanged work regime 10 consecutive cycles were measured. At the same time, a time interval from angle to angle was measured as well in order to determine an even angle speed of the shaft and work control of the incremental giver of the angle.

All the analogue signals (pressure, vibrations) were parallely converted into cipher form by means of four ultra speed converters working simultaneously (parallel). The total number of measured data was (4+1) x 4096 = 20480 per rotation (cycle), that is, 204800 for ten consecutive cycles. The number of samples of 4096 was not chosen by chance, but purposely with the aim of the application of the fast Furie's transformation (FFT) of measured signals.
Measures were done for seven working regimes.

Keywords: piston axial pump, shaft, testing, measuring, pulses, cycle, pressure, vibrations, signals, FFT

EXPERIMENTAL TESTING THE PROCESS IN THE AXIAL PISTON PUMP

The axial piston pump type 3112 - 750. 020/ 02, made by the company "PPT - Hidraulika", was tested. The testing was done in the Laboratory for Development and Research in the company "PPT - Hidraulika", which is situated in Trstenik, and in cooperation with the Institute for Motors in the Faculty of Mechanical Engineering in Belgrade. The pump was, for the purpose of this experiment processed, to ensure that the necessary measuring up converter needed for measuring the characteristic parameters of the axial piston pumps with a combined distribution of working fluid.

Testing devices and system for data acquisition

The axial piston pump was tested by the devices which are made especially for this experiment done at the testboard in the Laboratory for Development and Research. Basic component of the testboard is driving elestromotor whose power is 137 kW and whose number of revolutions and torque are controlled by electromotive drive.

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Figure 1 shows the testboard used for testing the characteristic parameters of the axial piston pump having the following components:

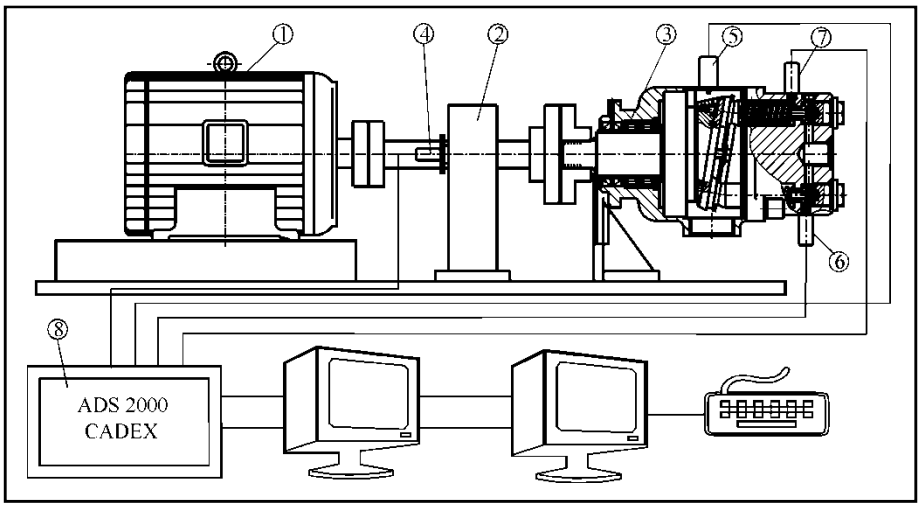

FIGURE 1. *Testboard used for testing the the axial piston pump*

1. Electromotor whose power is 137kW,1450min^{-1} with controlled number of revolutions
2. Reductor
3. Axial piston pump 3112 -750.020/02
4. Angle marker
5. Measuring converter of vibrations
6. Measuring converter of pressure in discharge chamber
7. Measuring converter of pressure in cylinder
8. System for measuring and acquisition ADS 2000 -CADEX [5].

The layout of measuring converters of pressure and vibrations is shown in Figure 2.

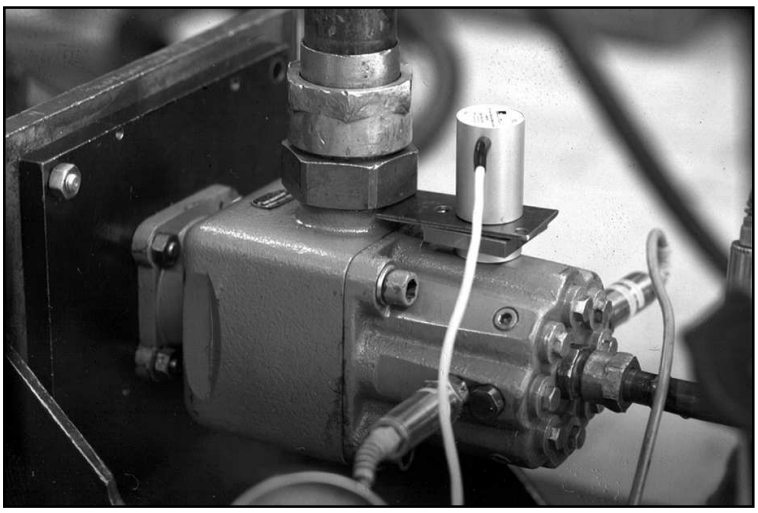

FIGURE 2. Layout of measuring conveters

The following quantities were measured:

1. Pressure in the cylinder which depends on the angle of driving shaft
2. Pressure in the vale chamber which depends on the angle of driving shaft
3. Pressure in the discharge pipeline which depends on the angle of driving shaft
4. Vibrations of the pupm housing which depends on the angle of driving shaft
5. Angle of driving shaft
6. Pump flow
7. Temperature of working fluid
8. Number of revolutions of driving shaft.

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Measuring converters of pressure, type P3MA, were used to measure pressure. These converters are based on measuring tapes and they are made by the company "Hottinger", Germany; their measuring range is 500bar, class of accuracy is 0.1 and transmission range is 100kHz. Flow was measured by measuring turbine, type RE2 25/180 l/min. Its class of accuracy is 0.4. and it is made by the company "Hydrotechnik", Germany.
Incremental sensor, type ROD 426E, made by the company "Heidenhain", Germany, was used to measure the rotation angle of the pump shaft. It has 1024 optical markers and its maximum number of rotation is 12000 min^{-1}. The accelerometer whose measuring range is up to 5 [m/s^2] and is made by the company " Brüel & Kjaer", Denmark, was used to measure the vibrations of the pump housing.
Ultraspeed measuring system ADS 2000-CADEX, was used for acquisition. The system provides continual measurement and calculation of characteristic parameters of working cycle in real time. The system ADS 2000-CADEX, which is used to develop highly dynamic mechanical objects by integrated measuring and calculating technique, is based on the following components:
- VME-bus CPU with graphics,
- VME-bus ADC,
- VME-bus PGA
- CDM Interface

The processor receives data from A/D converter in real time directly in CPU-DRAM. The processor simultaneously controls the amplyfing and multiplexer cards in real time. The software was developed especially for this system in order to measure cyclic and non-cyclic processes with graphical on-line display. Statistic processing of measured data is done with graphical display. 50.000.000 data were measured at maximum speed of 3MHz by 6...12 simultanous A/D converters. Up to 4 VME-CPU cards with processors Motorola 68020...68060, Intel Pentium, Digital Alpha or Motorola Power PC, can be integrated into the system.
VME-bus ADC contains two A/D converters with simultaneous working speed of 2 · 350 kHz at 1bit and 1 timer. Start of each conversion is done by pulses of angle sensor or timers with hardware registration of referent mark of incremental angle sensor in order to 100% control the proper work of angle sensor in real time. It is possible to integrate up to six A/D cards into the system. i.e. 12 A/D converters. Two VME-bus ADC modules were installed into this system.
VME-bus PGA multiplexer and amplifier modul has six fast instrumental amplifiers used for direct connection between the sensor and measuring tapes tied in full bridge with DC supply_of 5V (options 12 or 15). Maximum speed of conversion is 150 kHz. Four VME-bus PGA modules were integrated in this system.
The system has an interface for incremental angle sensors with DC supply and for multiplying the pulses of angle sensor.Up to four interfaces can be integrated into the system.
The applied measuring system enables simultaneous measuring at four fast analogous canals with parallel measuring of time periods from the angle mark to the mark of incremental angle sensor.

RESULTS OF MEASURING, STATISTIC AND FFT ANALYSIS OF WORKING PROCESS IN THE AXIAL PISTON PUMP

Results of Measuring the Pressure of Working Process in the Axial Piston Pump

The measurements were done for seven working regimes with the parameters shown in table 1. The results for R09 are presented in the paper:

TABLE 1: Working regimes applied in experimental testing

No.	Example	Nominal pressure [bar]	Number of revolutions [min^{-1}]
1.	R03	180	1000
2.	R04	50	800
3.	R05	160	800
4.	R06	180	800
5.	R07	200	800
6.	R08	200	1000
7.	R09	200	875.6

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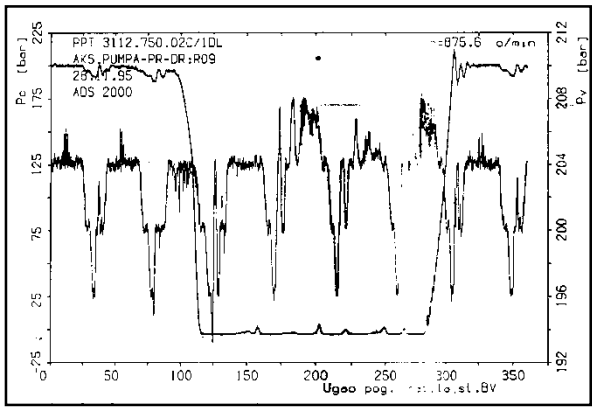
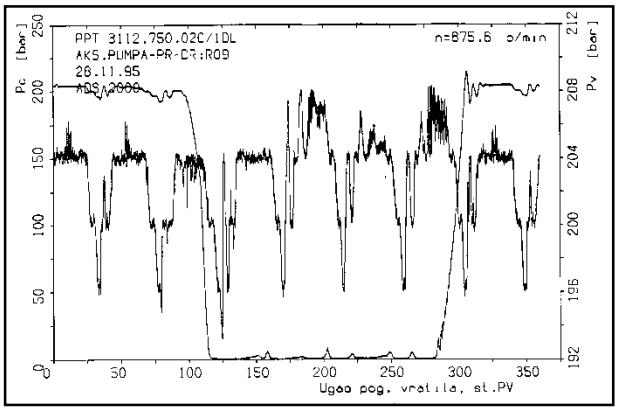
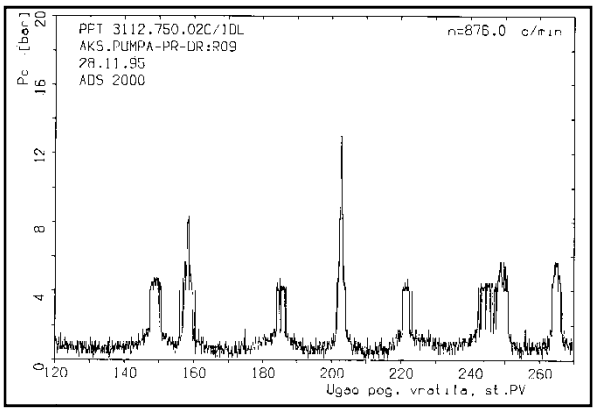


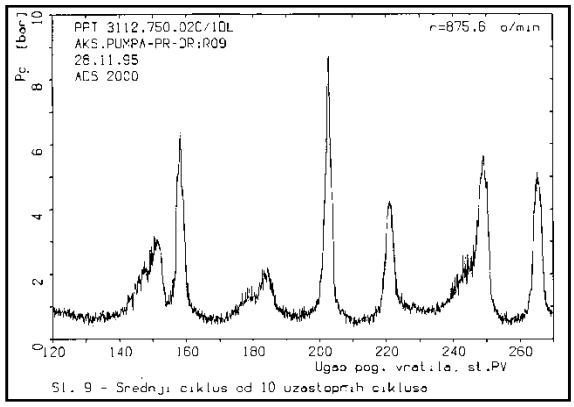
a) Pressure in the cylinder (p_c) and pressure in the discharge chamber (p_v) for one cycle



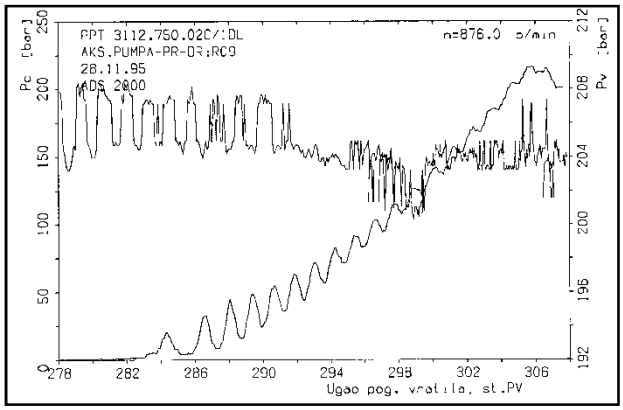
b) Pressure in the cylinder (p_c) and pressure in the discharge chamber (p_v) for the middle cycle



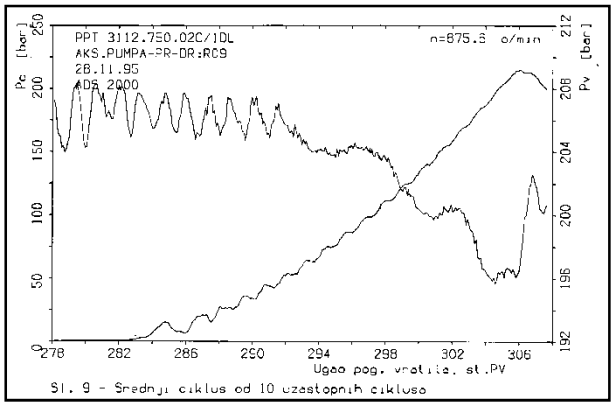
c) Pressure in the cylinder (p_c) for one cycle within the angle range of $120^o \div 270^O$



d) Pressure in the cylinder (p_c) for the middle cycle within the angle range of $120^o \div 270^O$



e) Pressure in the cylinder (p_c) and pressure n he discharge chamber (p_v) for one cycle within the angle range of $278 \div 307^O$



f) Pressure in the cylinder (p_c) and pressure n he discharge chamber (p_v) for the middle cycle within the angle range of $278 \div 307^O$

FIGURE3. Pressures measured at the working regime n =875.6 min^{-1} and p_n =200 bar.

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Figure 3 (a ÷ f) shows the measured pressures both for single cycles and for ten consecutive cycles of theaxial piston pump. The results are related to the experiment no. 7 and example R09 at the working regime n = 875.6 min^{-1} and p = 200 bar.
There is a great similarity between the measured pressure for the first cycle (MERF) and the middle one (MERM).
Figures 3a and 3b show the measured pressure change in the cylinder (p_c) for one and middle cycle out of 10 consecutive cycles depending on the angle of drive shaft. There are pressure gradients during compression and expansion, and pressure peaks during suction phase. The above mentioned figures also show the measured pressure change in the discharge chamber (p_v) for one and middle cycle out of 10 consecutive cycles depending on the angle of drive shaft. Pressure pulses in the discharge chamber depend on the number of cylindres which is obvious in this case because the pump has eight cylindres.
Pressure peaks (p_c) in the cylinder which occur during suction phase for one and middle cycle out of 10 consecutive cycles within the angle range of 120-270° are shown in figures 4c and 4d, respectively.
Figures 3e and 3f show the measured pressure change in the cylinder (p_c) for one and middle cycle out of 10 consecutive cycles within the angle range of 278-307°. It is the base for detailed analysis of gradient of pressure rise during compression phase. The above mentioned diagrams also show the pressure pulses in the discharge chamber (p_v).

Results of Statistic and FFT Analysis

In order to make a detailed analysis of the amplitudes of some harmonics, logarithmic scale is used in the paper, which widens the area of higher frequences. Decibel scale, figure 4, provides easier comparison of apsolute level of measured amplitudes and referent level.
The level of vibrations is defined by amplitude relation:

$$N[dB] = 20\log_{10}\frac{A}{A_{\mathrm{Re}f}}$$

where:

N - number of decibels
A - measured level
$A_{ref}=10^{Kref}$ - referent level

Exponent K_{ref} at the diagrams stands for the referent level.
Figures 4 and 5 show the results of measured pressures, vibrations and time intervals for the middle cycle out of ten consecutive cycles. Diagrams of harmonic analysis of pressures in the discharge chamber show a dominant order for maximum amplitudes of pressures which has he module equal to the number of cyclinders ($\sigma = z \cdot n$, where z - number of cylinders, n = 1,2,3...). The quantities of measured vibrations of the pump housing (figure 4 and 5) for the middle cycle out of ten consecutive cycles also indicate the peaks of amplitudes for harmonics $\sigma = z \cdot n$.

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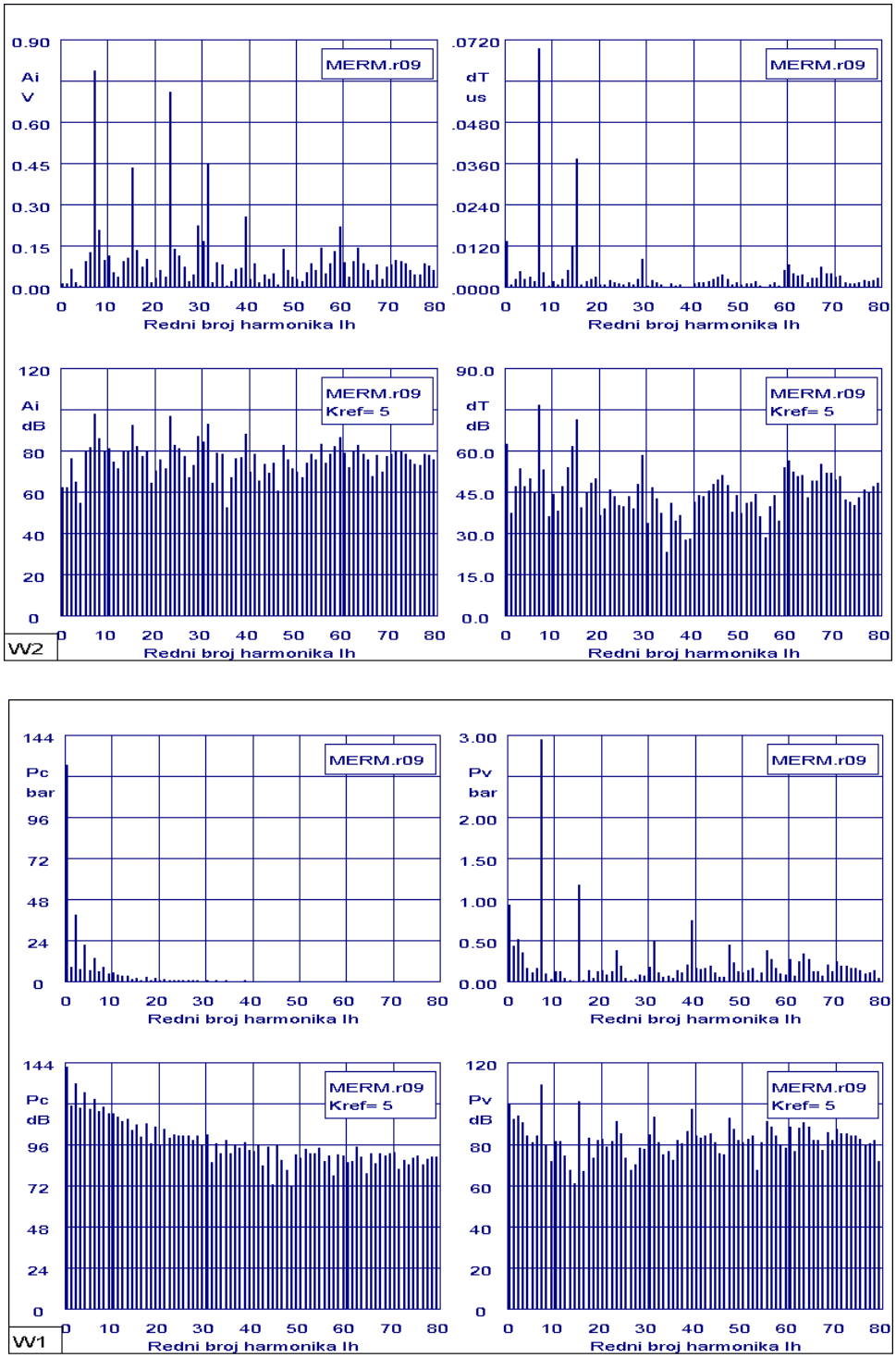

FIGURE.4 Results of harmonic analysis of measured pressures, vibrations and time intervals for the middle cycle out of ten consecutive cycles at n=875.6 min^{-1} and p=200 bar with graphical display of 80 harmonics

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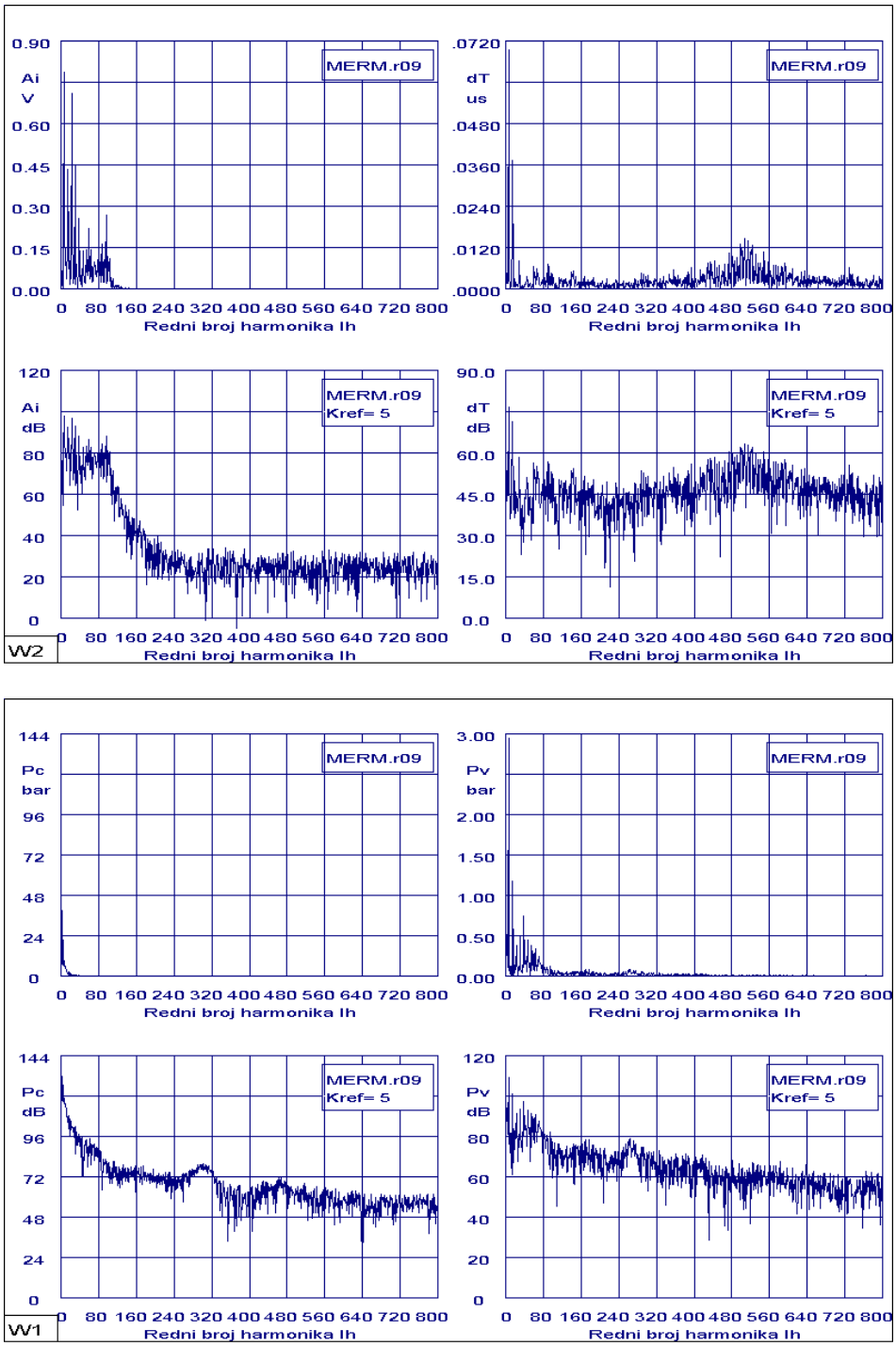

FIGURE.5 Results of harmonic analysis of measured pressures, vibrations and time intervals for the middle cycle out of ten consecutive cycles at n=875.6 min^{-1} and p=200 bar with graphical display of 80 harmonics

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CONCLUSION

General conclusions of the presented results relate to all tested working regimes of the axial piston pump.It is not possible to define precisely the parameters of hydrodynamic processes in the axial piston pump by experiments only, or by mathematical modelling only. Precise parameters can be obtained if the following methods are combined: measurement of pressure changes in the cylinder, mathematical modelling of real hydrodynamic process and nonlinear optimization. At the same time, systematic errors of measuring and unknown parameters can de defined this way.

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