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AN APPROACH IN REDUCING VIBRATION IN SEAWATER HYDRAULIC PISTON PUMPS FOR INCREASED OPERATIONAL EFFECTIVENESS AND EFFICIENCY

PRISTUP SMANJENJU VIBRACIJA HIDRAULIČNIH KLIPNIH PUMPI ZA MORSKU VODU U CILJU POVEĆANJA EFEKTIVNOSTI I EKONOMIČNOSTI RADA

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- hydraulics system
- piston
- vibration
- equipment

Ključne reči
- pumpa za morsku vodu
- hidraulički sistem
- klip
- vibracije
- oprema

Abstract

The seawater hydraulic piston pump has been used in ocean engineering and has become a key power component for underwater equipment due to energy efficiency and being environment friendly. Water hydraulics possesses advantages of low environment pollution, non-flammable, lower operating cost and so on, because it directly uses natural water as working medium instead of traditional mineral oil. It is more flexible in the underwater applications to build an open circuit system directly utilizing the seawater as working a medium and discharging drainage to the open surroundings without needing return hose and reservoir. These special characteristics make it widely used in underwater equipment, such as variable ballast system (VBS), bilge drainage system, high pressure water mist fire suppression system, and high pressure water jet propulsion system. With the missions of underwater equipment becoming increasingly complex and varied, such as military applications, inspection of underwater structures, exploration of unknown environment, oceanographic observations, submarine rescue, underwater animal behaviour research, and so on, underwater equipment with better stability, higher reliability, lower vibration, and noise characteristics is strongly required.

Izvod

Hidraulična klipna pumpa za morsku vodu se koristi u okeanskom inženjerstvu i postala je ključna komponenta napajanja za podvodnu opremu zbog svoje uštede energije i ekološke prihvatljivosti. Hidraulika vode ima prednosti malog zagađenja životne sredine, nezapaljivosti, nižih operativnih troškova itd., jer direktno koristi prirodnu vodu kao radni medijum umesto tradicionalnog mineralnog ulja. Fleksibilnije je u podvodnoj primeni da se izgradi sistem otvorenog kruga koji direktno koristi morsku vodu kao radni medijum i ispušta drenažu u otvoreno okruženje bez potrebe za povratnim crevom i rezervoarom. Ove posebne karakteristike ga čine široko primenjenim u podvodnoj opremi, kao što je sistem varijabilnog balasta (VBS), sistem za odvodnju kaljuže, sistem za gašenje vodenom maglom pod visokim pritiskom, sistem za propulziju vodenim mlazom pod visokim pritiskom. Kako misije podvodne opreme postaju sve složenije i raznovrsnije, kao što su vojne primene, inspekcija podvodnih struktura, istraživanje nepoznatog okruženja, okeanografska posmatranja, spasavanje podmornica, istraživanje ponašanja životinja pod vodom itd., podvodna oprema sa boljom stabilnošću, viša pouzdanost, manje vibracija i karakteristika buke su jako potrebne.

EXPERIMENTAL TESTING

The axial piston pump type 3112-750.020/02, made by 'PPT - Hidraulika' was tested. Testing was done in the Laboratory for Development and Research in 'PPT - Hidraulika', situated in Trstenik, and with the cooperation of the Institute for Motors of the University of Belgrade, Faculty of Mechanical Engineering /1-3/, regarding the purpose of the experiment processed, and to ensure that the necessary converter needed for measuring characteristic parameters of axial piston pumps has a combined distribution of working fluid.

Testing devices and system for data acquisition

The axial piston pump was tested by devices made especially for this experiment. Test were done at the test board at the Laboratory for Development and Research. The basic component of the test board is the electromotor drive of 137 kW power and whose number of revolutions and torque are controlled by electromotive drive. Figure 1 shows the test board used for testing characteristic parameters of the axial piston pump with following components: 1-electromotor of 137 kW power, and 1450 min^{-1} with controlled number of revolutions; 2- gearbox; 3- axial piston pump 311250.020/02; 4- angle marker; 5- measuring converter of vibrations; 6- measuring converter of pressure in discharge chamber; 7- measuring and acquisition system ADS 2000 - CADEX, /5/.

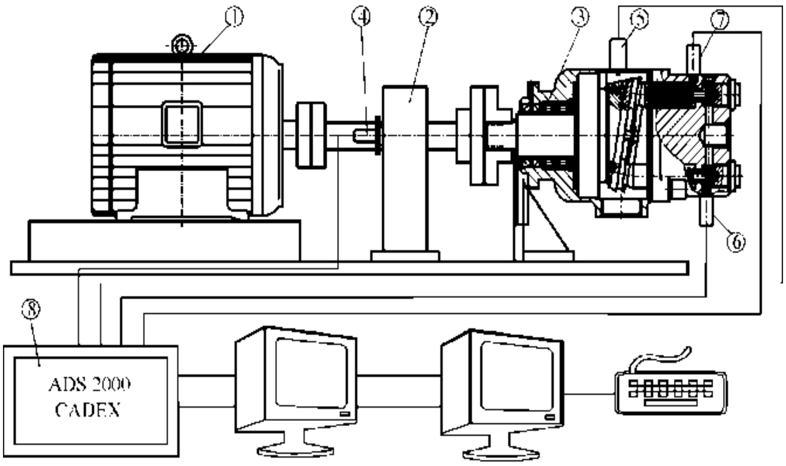

Figure 1. Test board used for testing the axial piston pump.

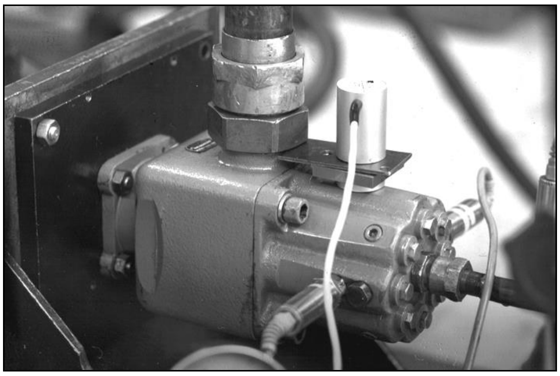

Figure 2. Layout of measuring converters.

The following quantities are measured:
- pressure in the cylinder that depends on the angle of the driving shaft,
- pressure in the valve chamber that depends on the angle of the driving shaft,
- pressure in the discharge pipeline that depends on the angle of the driving shaft,
- vibrations of pump housing that depend on the angle of the driving shaft,
- angle of the driving shaft,
- pump flow,
- temperature of working fluid,
- number of revolutions of the driving shaft.

Measuring converters of pressure, type P3M, are used to measure pressure. These converters are based on measuring tapes and are made by ‘Hottinger’, Germany. Their measuring range is 500 bar, class of accuracy 0.1, and transmission range is 100 kHz. Flow is measured by measuring turbine, type RE2 25/180 l/min. Its class of accuracy is 0.4, and is made by ‘Hydrotechnik’, Germany, /4/. Incremental sensor, type ROD 426E, made by ‘Heidenhain’, Germany, is used to measure the rotation angle of the pump shaft. It has 1024 optical markers, and its maximal number of rotations is 12 000 min^{-1}. The accelerometer whose measuring range is up to 5 m/s^2 is made by ‘Brüel & Kjaer’, from Denmark, and is used to measure the vibrations of the pump housing.

Ultra speed measuring system ADS 2000-CADEX is used for acquisition. The system provides continual measurements and calculates the characteristic parameters of the 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 the A/D converter in real time directly in CPU-DRAM. The processor simultaneously controls the amplifying and multiplexer cards in real time. The software is developed especially for this system in order to measure cyclic and non-cyclic processes with graphical on-line display. Statistic processing of the measured data is done with the graphical display. 50.000.000 data are measured at maximum speed of 3 MHz by 6...12 simultaneous 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 1 bit and 1 timer. Start of each conversion is done by pulses of angle sensor, or timers with hardware registration of reference mark of incremental angle sensor in order to have 100 % control of the proper work of the 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 are installed into the system, /5/.

The VME-bus PGA multiplexer and amplifier module has six fast instrumental amplifiers used for direct connection between the sensor and measuring tapes tied in full bridge with DC supply of 5 V (optionally 12 or 15). Maximum speed of conversion is 150 kHz. Four VME-bus PGA modules are integrated in this system. The system has an interface for incremental angle sensors with DC supply and for multiplying the pulses of the 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 marking to the marking of incremental angle sensor, /11-12/.

Table 1 presents the results of the measurement of working processes.

Figure 3a-f shows the measured pressures both for single cycles and for ten consecutive cycles of the axial piston pump. The results are related to experiment no.7 and example R09 at 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 3 (a) and (b) show the measured pressure change in cylinder (p_c) for one and mid cycle, out of 10 consecutive cycles, depending on the angle of drive shaft.

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

(a) (b) (c) (d) (e) (f)

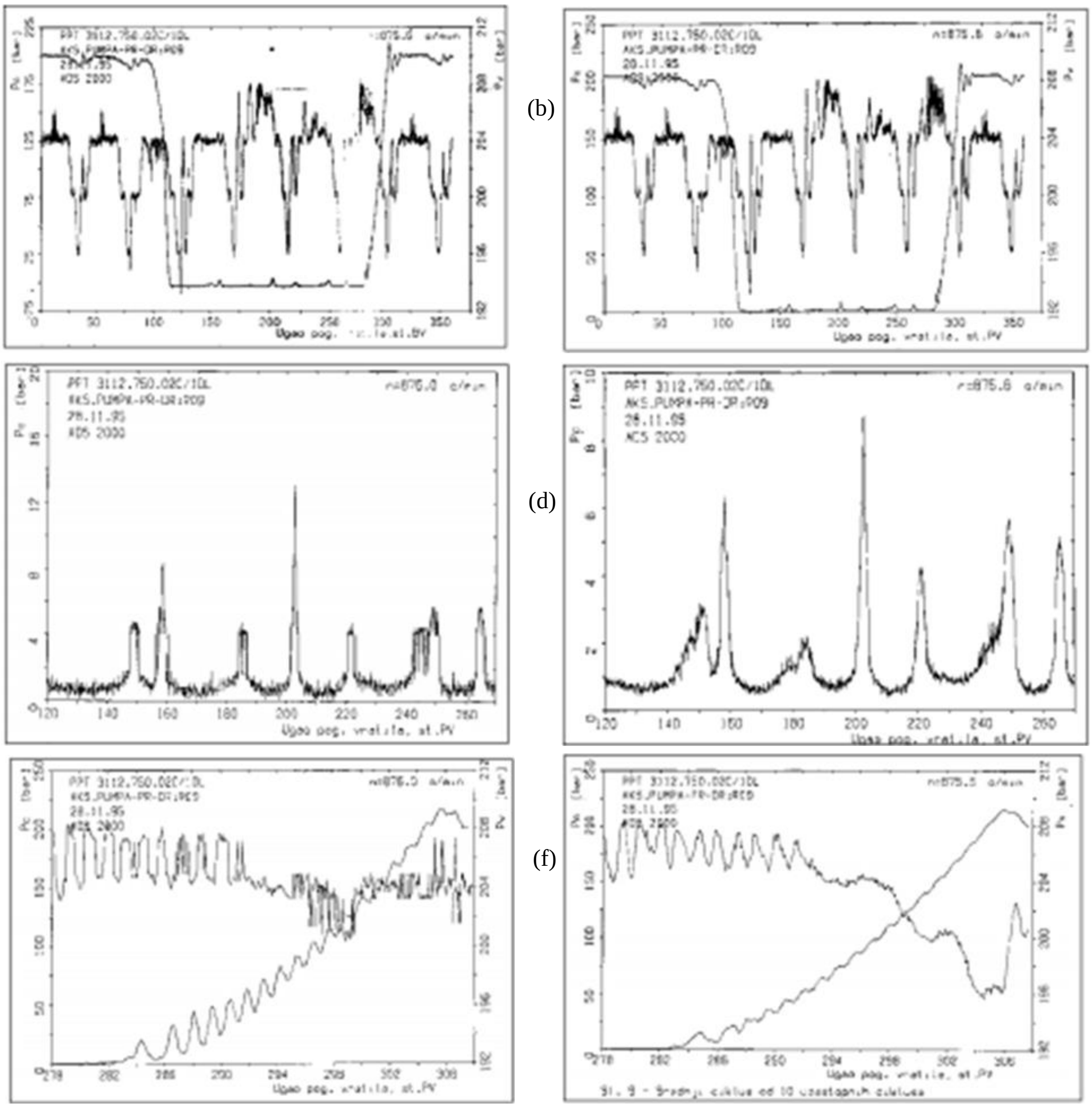

Figure 3. Pressures measured at working regime n = 875.6 min^{-1} and p_n = 200 bar. a) Pressure in cylinder (p_c) and in discharge chamber (p_v) for one cycle; b) pressure in cylinder (p_c) and in the discharge chamber (p_v) for the mid cycle; c) pressure in cylinder (p_c) for one cycle within range of angle 120-270 °; d) pressure in cylinder (p_c) for mid cycle within the range of angle 120-270 °; e) pressure in cylinder (p_c) and in discharge chamber (p_v) for one cycle within range of angle 278-307 °; f) pressure in cylinder (p_c) and in discharge chamber (p_v) for mid cycle within range of angle 278-307 °.

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 mid cycle out of 10 consecutive cycles depending on the angle of drive shaft. Pressure pulses in the discharge chamber depend on the number of cylinders, which is obvious in this case, since the pump has eight cylinders.

Pressure peaks (p_c) in the cylinder occurring during the suction phase for one and the mid cycle out of 10 consecutive cycles within the angle range of 120-270 ° are shown in Fig. 3 c and d, respectively, /6-7/.

Figures 3e and 3f show the measured pressure change in the cylinder (p_c) for one and the mid cycle out of 10 consecutive cycles within the angle range of 278-307 °. It is the base for detailed analysis of pressure gradient rise during the compressive phase. The above mentioned diagrams also show 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, the logarithmic scale is used, which widens the area of higher frequencies. The decibel scale, Fig. 4, provides easier comparison of absolute level of measured amplitudes and the reference level.

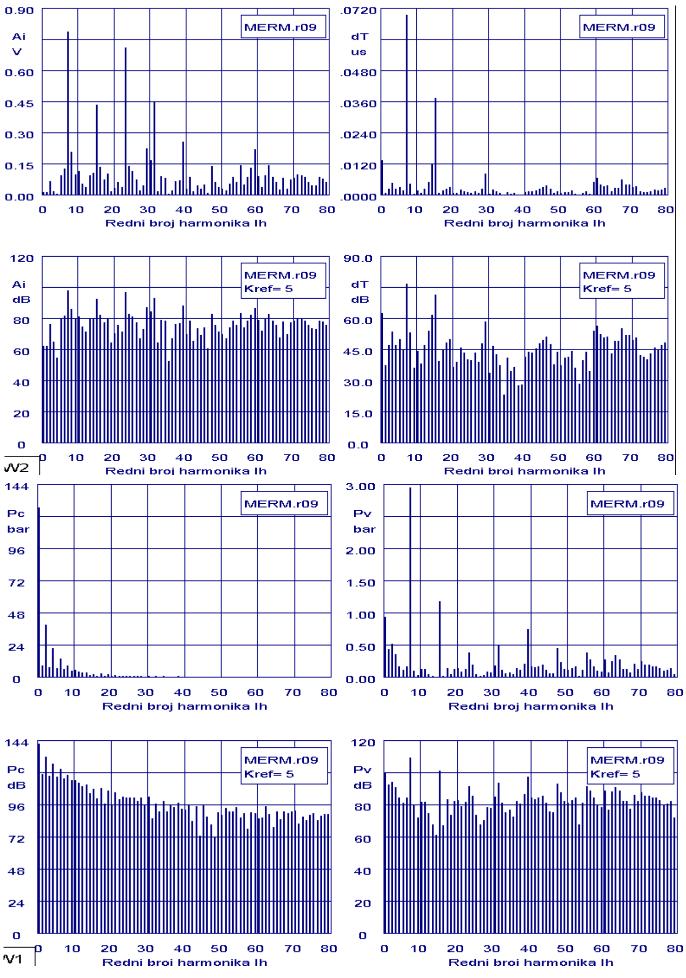

Figure 4. Results of harmonics analysis of measured pressures, vibration and time intervals for the mid cycle out of 10 consecutive cycles at n = 875.6 min^{-1} and p = 200 bar with graphical display of 80 harmonics.

The level of vibrations is defined by amplitude relation:

$$N\ [\text{dB}] = 20\log_{10}\frac{A}{A_{ref}}\,, \qquad (1)$$

where: N - number of decibels; A - measured level; $A_{ref} = 10^{Kref}$ - reference level. Exponent K_{ref} in the diagrams stands for reference level, /8-10/.

Figures 4 and 5 show results of measured pressures, vibration and time intervals for the mid cycle out of 10 consecutive cycles. Diagrams of harmonics analysis of pressures in the discharge chamber show a dominant order for maximal amplitudes of pressure which has the module equal to the number of cylinders ($\sigma = z{\cdot}n$, where z - number of cylinders, n = 1, 2, 3 ...), /13-14/. The quantities of measured vibrations of the pump housing (Figs. 4 and 5) for the mid cycle out of 10 consecutive cycles also indicate the peaks of amplitudes for harmonics $\sigma = z{\cdot}n$.

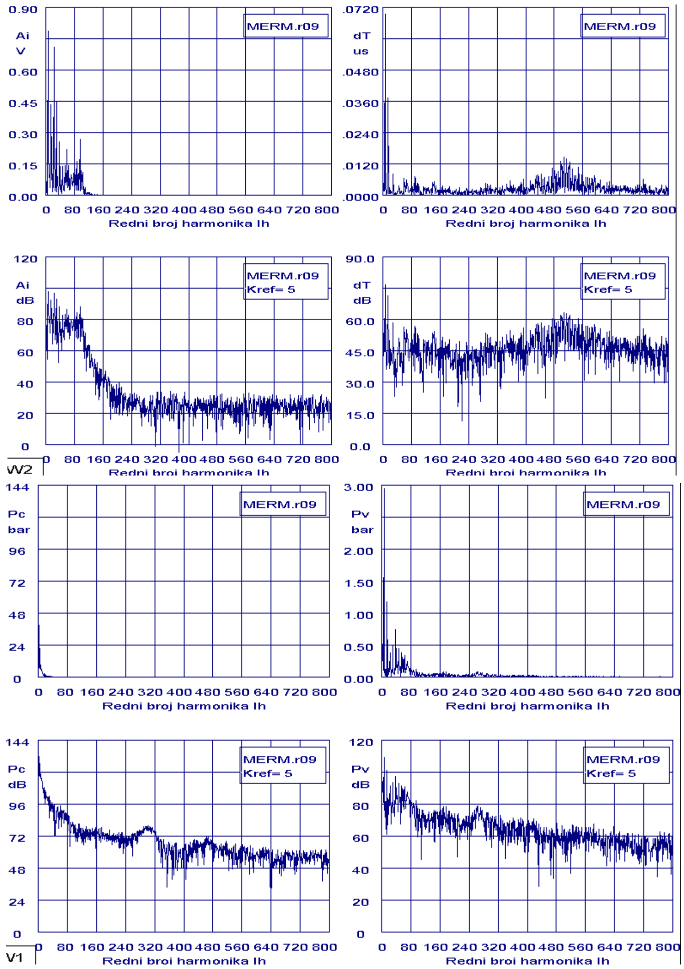

Figure 5. Results of harmonics analysis of measured pressures, vibration and time intervals for the mid cycle, out of 10 consecutive cycles at n = 875.6 min^{-1} and p = 200 bar with graphical display of 80 harmonics.

CONCLUSIONS

General conclusions of the presented results relate to all tested working regimes of the axial piston pump. It is not possible to precisely define 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 change in the cylinder; mathematical modelling of the real hydrodynamic process and nonlinear optimisation. At the same time, systematic errors of measuring and unknown parameters can be defined this way.

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