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PHASE TRAJECTORY ANALYSIS IN INVESTIGATION OF SWASH PLATE DEGRADATION PROCESSES IN AXIAL PISTON PUMP

SUMMARY

Test of assessing a suitability of the phase trajectory pattern for diagnostics of condition changes of axial piston pumps is undertaken in the presented paper. Accomplishment reasons of investigations together with their laboratory realizations are given. They concerned the experimental comparison of changes in the phase trajectory patterns of the hydraulic pump working with a constant output pressure, in which an element of swash plate was degraded. The performed tests confirmed the suitability of phase trajectories in the recognition of degradation changes in axial piston pumps.

The paper signals the usefulness of considering the introduction of phase trajectory patterns of the monitored vibration signals into processes of the diagnostic inspection of the hydraulic pump structural elements.

***Keywords**: phase trajectories, displacement pump, technical diagnostics, forced hydraulics, signal analysis*

ANALIZA PRZEBIEGÓW TRAJEKTORII FAZOWYCH W BADANIACH WYPRACOWANIA TARCZY WYCHYLNEJ POMPY WIELOTŁOCZKOWEJ

W artykule podjęto próbę oceny przydatności obrazów trajektorii fazowych w procesie diagnozowania zmian stanu pompy wyporowej. Przedstawiono cele podjętych badań i ich laboratoryjną realizację. Dotyczyła ona eksperymentalnego sprawdzenia zmian trajektorii fazowych sprawnej pompy wyporowej pracującej, ze stałą wydajnością i przy stałym ciśnieniu, z pompą, w której element tarczy wychylnej uległ procesowi degradacji. Badania wykazały przydatność trajektorii fazowych do rozpoznawania zmian degradacyjnych w pompie wyporowej. Artykuł sygnalizuje celowość rozważenia wprowadzenia portretów fazowych monitorowanych sygnałów drganiowych do procedur nadzoru diagnostycznego stanu elementów konstrukcji pompy wyporowej.

***Słowa kluczowe**: hydraulika siłowa, diagnostyka techniczna, pompa wyporowa trajektorie fazowe, analiza sygnału*

1. INTRODUCTION

In hydraulic drive systems the positive-displacement pumps are one of the important elements. Proper work of these elements causes proper work of whole hydraulic system. The wear of pump elements causes pump's pressure lost and increase of volumetric losses, which lead to decreasing delivery of the pump and increasing in vibration and noise of its work. The run of vibroacustic diagnosis of pump is mainly guide to search: damage symptoms in vibration signals. In the case of high noise level and high level of mechanical complexity, the estimations of damage symptoms have big uncertainty. The diagnosis of process analysis shows only huge damage appearance which is critical in further exploitation. This methodology doesn't take into consideration development process so there are no possibilities to predict it (Batko 2007). The searches for new method of pump diagnosis are mainly based on assumptions which eliminate disadvantages of now use methods. This paper presents the possibility of phase trajectories use in detecting of swash plate were in axial piston positive-displacement pump.

2. SUBJECT OF STUDY DESRIPTION

The subject of the study was an axial multi-piston fixed displacement pump, which simplified diagram is shown in Figure 1. In a pump of this type, the rotor (2) together with a system of pistons (3) and a supporting bearing is mounted in alignment on a drive shaft (1). The shoes (4) of pistons cooperate with an immobile swash plate at α angle against the axis of the pump rotor. Pistons together with the rotor make a rotary motion, and their shoes (4) which slide on the surface of the immobile swash plate (5) additionally an extort progressive – adversive movement in the rotor cylinders. Additionally, the rotor slides on an immobile valve plate (6), where are placed suction and pumping openings of the pump.

The wear of displacement pump elements is caused by forces which occur during the cooperation of particular components which create motion pairs (for example, piston-cylinder, valve plate-rotor, piston shoe – swash plate) as well as by improper exploitation conditions of a pump, such as (among others):

– exceeding the normal working pressure of the pump,
– operating with too low viscosity of a working fluid,
– the lack or unsatisfactory filtration of a working fluid.

The most often occurring wear type of displacement pump elements is an abrasion type (Stryczek 1995). The wear of this type appears in all the elements of a pump, where exist a relative motion and a contact.

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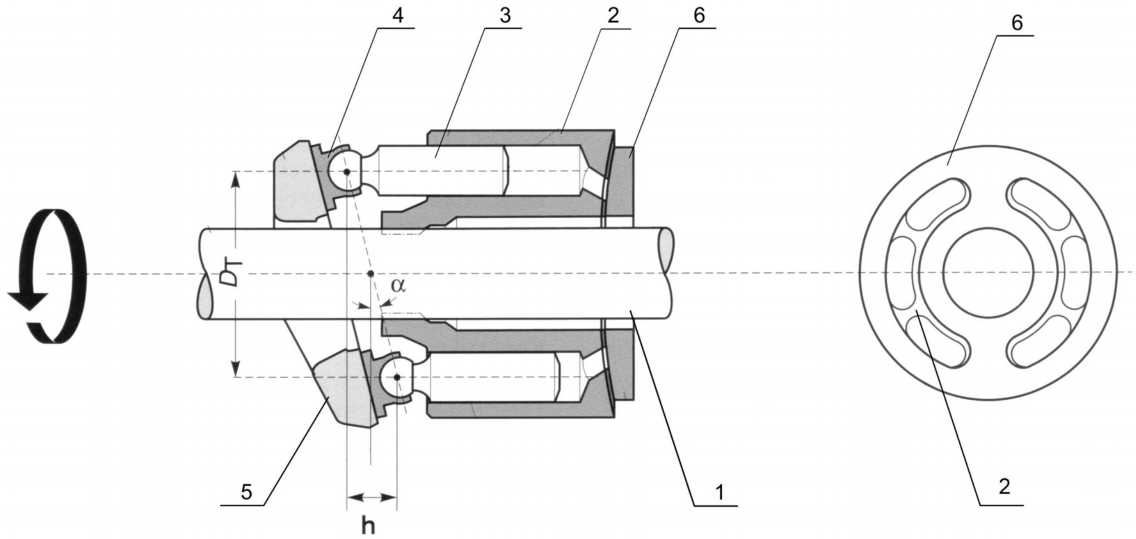

Fig. 1. Schematic diagram of axial piston pump 1– shaft, 2 – rotor, 3 – piston, 4 – piston shoe, 5 – swash plate, 6 – valve plate (Basic Principles and Components)

In presented type of axial pump it manly occur between swash plate surface and sliding on it piston shoes (Fig. 2).

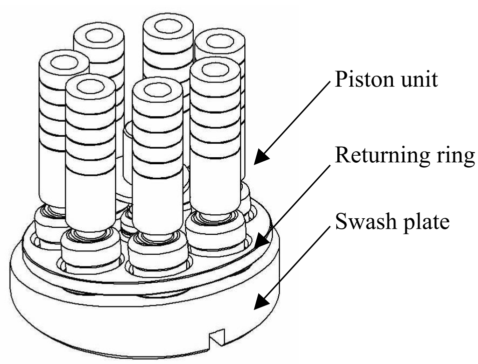

Fig. 2. Collaboration of swash plate – piston shoe kinematic pair in axial piston pump

The cooperation of these elements bears some loses stemming from the friction on their surfaces. The minimization of loses, and therefore, an increase in mechanical and hydraulic efficiency of the pump is guaranteed by hydrostatic support the shoes against the shield surface. In case of a disappearance of such a propping, there follows a gradual wear of the shield surface (and piston shoes), which leads to creating an elliptical deepening on its surface and to its total wearing out (Fig. 3).

3. DESCRIPTION OF PHASE TRAJECTORIES METHOD

Classic methods of a vibration and acoustics diagnostics of machines, which base on a time or a time-frequency analysis of the measured signals, require some experience from a person interpreting the received results (Cempel 1992). It is especially important in case of analyzing the results of vibration and acoustic processes of machines and appliances with big complexity, in which the movement of components overlap. Additionally, more than once proper interpretation of the received time and time-frequency schedules is hampered by the existence of parasitic components (disturbances), which come from elements (appliances) not connected with the researched object. In the search of a method whose results would allow for a faster and easier interpretation of the state of the researched pump, the author of the thesis suggested using a collation of phase trajectories for this purpose.

A detection of an initial damage phase of particular pump elements (such as valve plate, rotor or swash plate) should be independent from disturbances connected with the work of the remaining components. However, it is impossible to reduce information components connected with a specific element from an available diagnostic signal. Thus, we deal with a machine, an appliance, an element

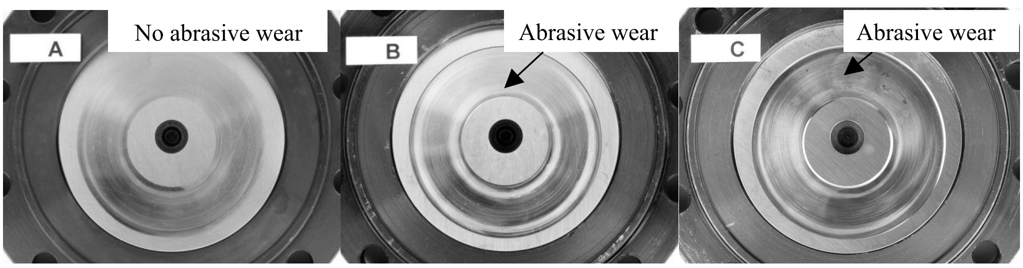

Fig. 3. Pictures of proper (A) and damage (B, C) swash plate surfaces

working surrounded by other machines, appliances or elements. The influence of the surroundings on a researched element, notwithstanding the character of the effect, can be described by functions later called as stable working disturbances. The problem formulated in this way is described in specialist literature as stability in the Lapunov sense or technical stability (Bogusz 1972, Kudrewicz 2007).

Analyzing a concrete element of a multi piston pump, which is affected by forces coming from other elements of the pump or from hydraulic system objects, the equation of the studied movement can be formulated in the following way:

$$\ddot{x} = f\left(\dot{x}, x, t\right) \tag{1}$$

This equation has synonymous solutions defined by initial conditions. Providing for the influence of the surroundings on a studied element, described in the form of a stable working disturbance equation „*R*", we receive:

$$\ddot{x} = f\left(\dot{x}, x, t\right) + R\left(\dot{x}, x, t\right) \tag{2}$$

The solution of the above equation is conducted by replacing and reduction of its row, and by this we receive:

$$\dot{x} = f\left(x, t\right) + R\left(x, t\right) \tag{3}$$

Taking into consideration the fact that the function $R(x, t)$ allows for acceptable deviations from the agreed state and for a change of initial conditions, as well as for expected internal and external disturbances affecting the element in question (an object or a configuration), which has random or periodic character, it is possible to define a dynamic state of an object by the term of technical stability (Bogusz 1972).

The suggested attitude does not require full identification of the system structure, that is it does not require precise defining of the $f(x, t)$ function, concentrating only on the solutions of the equation (3). An effective tool for studying the systems of differential equations is a trajectory analysis in phase space. A definition of the technical stability system says that if for initial conditions included in the area of ω of the phase space, the solutions of the system (3) stay in the area Ω, then the studied element (a configuration, an object) is technically stable (Fig. 4a).

While studying a realistic object, which is a multi-piston pump, we deal with its numerous components that influence each other. The stability of a system can be defined by a measurement of a movement parameter of particular elements. Physically, there are available only elements connected with the pump casing. Vibration parameters of the pump are connected with the movement of pump components. Therefore, a proper place on the casing, geometrically connected with the studied pump elements, should be chosen. Measurements of the dislocation and the speed of vibrations of a chosen point referred to the phase space will cha-racterize a class of solutions for partial equations connected with particular pump elements. The problem of defining the Ω area can be solved in several ways. In case of multi piston pumps, a preferred attitude will be defining the Ω area on the base of the dynamics analysis of a pump which is not worn out.

The study of the phase trajectory for a pump in working order, providing for external disturbances, will allow to define this area. In case of a vibration analysis of displacement pump casings, we deal with an effect of non- dampened vibrations around the location of balance. The picture of the phase space for such an object then will be a phase space with so called border cycle (or limit cycle) (Stryczek 1995). It occurs in a case when the phase trajectory does not reach the balance point, but changes into a closed curve which surrounds that point (Fig. 4b).

The observation of changes of the area containing the trajectories will be used for creating a diagnostic symptom, and next it will lead to posing a diagnostic hypothesis.

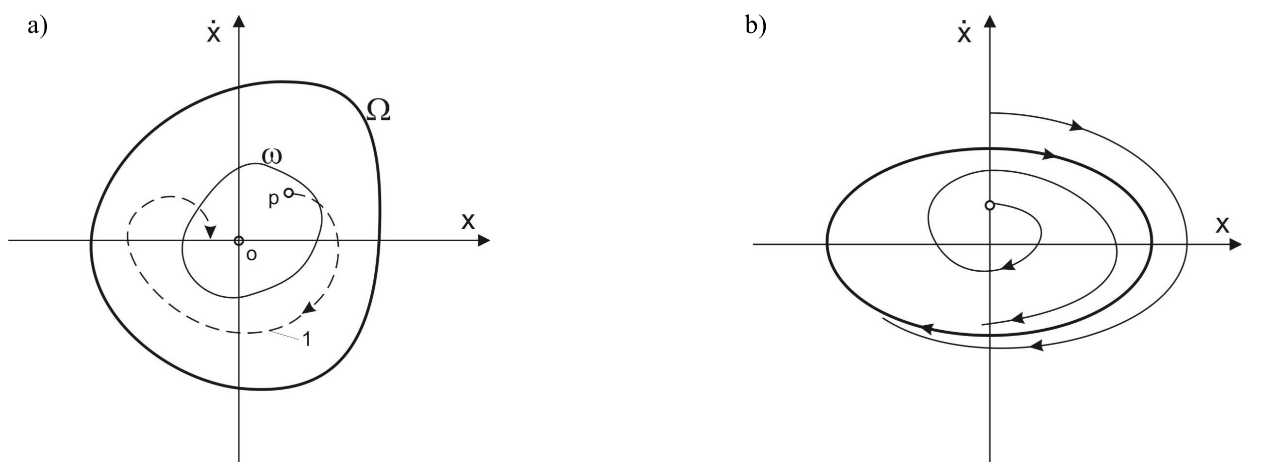

Fig. 4. The concept of technical stability: a) 1 – phase trajectory, Ω – area of permissible deviation of equilibrium state, ω – area of initial conditions, *p* – initial state of system after out of balance „o"; b) phase trajectory with limit cycle

It stems from theoretical deliberations (Batko 2007) that it is not known how the Ω area, acknowledged as technically stable, will change as a result of a given element degradation. In the phase space information about stored energy (a sum of kinetic and potential energies) of a given object is included. It results from a machine model serving as energy processor (Cempel 1992) that in case of an increase in aggregate energy of a studied element, the surface area of the Ω area will expand. This prerequisite will allow identifying energy structure of a studied object. Observing the elements connected with the working process of a pump (producing Q_r expense or working pressure p_r), in case of a fall of energy efficiency one can expect reducing the Ω area. For elements, where a destructive coupling of input energy will happen, this area should expand.

4. MEASUREMENT DESCRIPTION

The study of the wear of multi piston pump elements were conducted on a special study stand, built specially for this purpose; whose principal element was multi piston axis pump with a stable delivery, together with hydraulic accessories and installed measure transducers (vibration acceleration, dynamic and static pressure and delivery).

Examinations of the influence of swash plate abrasive damage on the positive-displacement pump operation were conducted via changing worn swash plates in the pump body. Plates used in the examinations were differed in the depth of elliptical deepening wear from 0.1mm depth for plate of type B to 0.5 mm for swash plate type C. Additionally, for comparative purposes, examinations of new pump with not worn swash plate (plates of type A, Fig. 3) have been executed. Measurements of physical values (vibration, flow, static and dynamic pressure) have been executed in the pump operation in following conditions:

- no pressure at the pump outlet,
- loading of the pump outlet with static pressure of 70 bar,
- loading with dynamic, periodically variable pressure.

The measures of vibration acceleration of the body pump were conducted for three measurement axes (*X*, *Y* and *Z*), after having installed transducers on the body pump near the swash plate, and valve plate. In the measurements of the physical quantities, 16-bit measurement cards were used, which cooperate with conditioning system and are programmed with the help of LabView program. The measured runs had been archivized on a computer disk, after which they were numerically analyzed with the Matlab-Simulink packet.

A simplified diagram of the vibration measurement of the body pump with the locations of the vibration transducers are presented below (Fig. 5).

5. STUDY RESULTS AND FINAL CONCLUSIONS

The measured vibrations signals from pumps body (which were received for assumed measure direction) had been put on numerical analysis. The next step was determination of phase trajectories. The methodology of phase trajectories estimation used so as to detect wear of swash plate in positive-displacement pump was based on integration of numerical acceleration's runs, measured in assumed points of pump's body. Obtained phase trajectories runs had been shown in Figures 6 and 7.

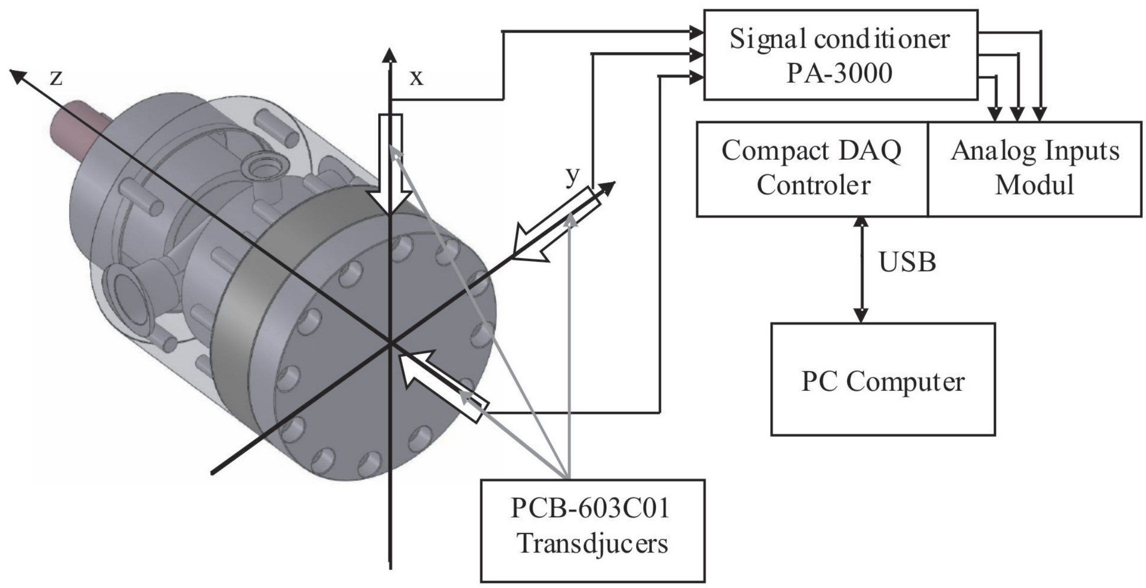

Fig. 5. The view of laboratory station with examined pump

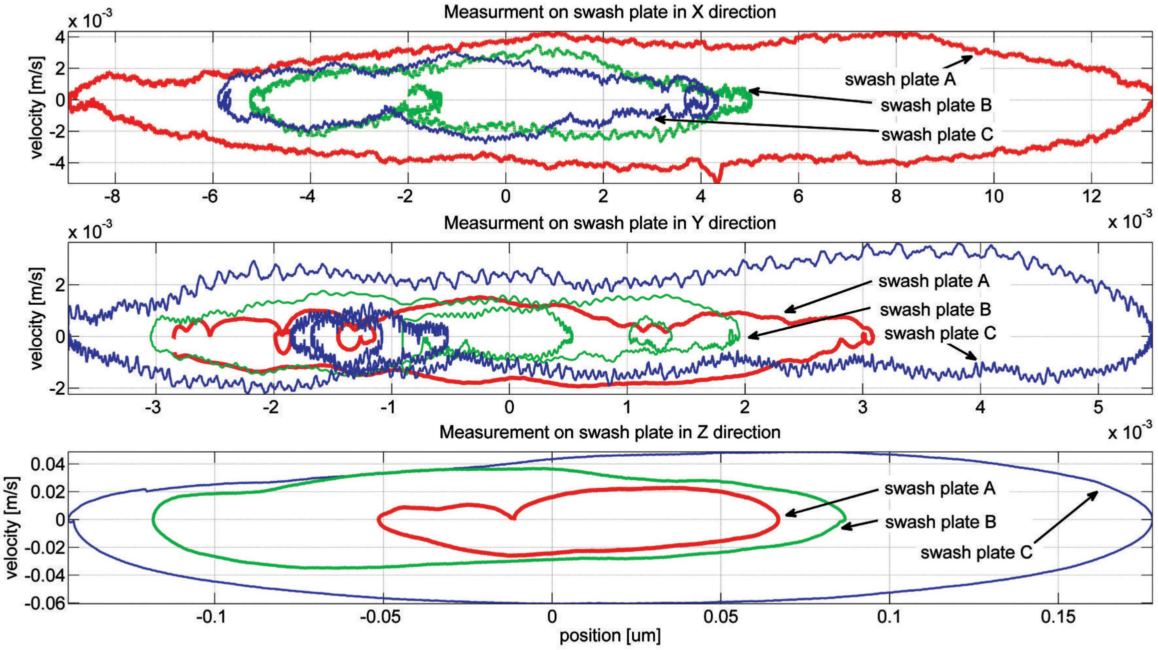

Fig. 6. Phase trajectory runs estimated for different swash plate surfaces in *X*, *Y*, *Z* direction – transducers mounted on swash plate

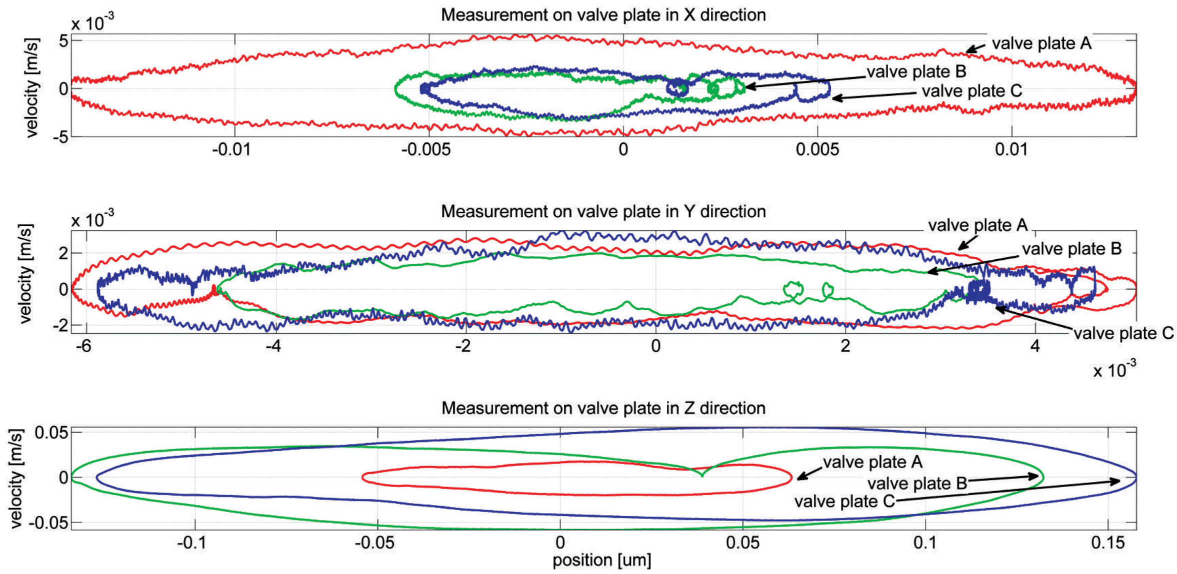

Fig. 7. Phase trajectory runs estimated for different swash plate surfaces in *X*, *Y*, *Z* direction – transducers mounted on valve plate

The runs of phase trajectories received from the conducted study experiment showed substantial sensitivity of the changes of their area (in all three measurement directions) together with an increase in the damage of swash plate. Referring to the energy model of the machine, one may conclude that in the adopted area of vibrations measurement (on the swash plate and valve plate) for transducers placed on all three measurement axis, there occurs limiting in the total energy of the studied pump, together with a progressive degradation of its components. The study results, put together on Figures 6 and 7 shows that using phase trajectory may be a good indication of symptoms for diagnostics and monitoring of the wear condition of a displacement pump.

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