PREDICTION OF THE OPERATE CHARACTERISTICS OF DESIGNED PUMP BASING ON A MATHEMATICAL MODEL

Andrzej JURKIEWICZ, Piotr MICEK, Marcin APOSTOŁ, Dariusz GRZYBEK

Department of Process Control, AGH University of Science and Technology
Kraków, Poland, Tel/fax: 0048 12 617 30 80, e-mail: jurkand@agh.edu.pl

Summary

The article presents a creation process of designed pump of 7 pistons. A several FEM models are presented with a simulation results. Apart from FEM models, the mathematical model of 1/7 pump was elaborated. This model, which contains piston set with input and output valves was implemented in MATLAB Simulink program. The mathematical model was used to the definition of movement parameters: piston displacement, input and output valves displacements as well as the influence of the work pressure on the movement range. The obtained simulation results from mathematical model can replace a part of the prototype researches.

Elaborated model was verified on a laboratory stand. A verification results are shown in this article.

Keywords: FEM, mathematical model, design, pump.

PREDYKCJA WŁASNOŚCI EKSPLOATACYJNYCH PROJEKTOWANEJ POMPY W OPARCIU O MODEL MATEMATYCZNY

Streszczenie

W artykule pokazano budowę nowo projektowanej pompy 7-mio tłokowej. Przedstawiono szereg modeli MES podstawowych jej części wraz z wynikami symulacji. Oprócz modeli MES opracowano model matematyczny 1/7 pompy (stanowisko badawcze) jako zespół pojedynczego tłoka wraz z zaworami ssawnym i tłocznym, który zaimplementowano w środowisku Matlab – Simulink. Model matematyczny pozwolił na określenie parametrów ruchowych jej głównych elementów tj. przemieszczenia tłoka oraz przemieszczeń grzybków w zaworach ssawnym i tłocznym, jak i wpływu zmian ciśnienia roboczego pompy na zakres tego ruchu. Otrzymane wyniki symulacji opracowanego modelu matematycznego 1/7 pompy mogą zastąpić przeprowadzenie wielu badań i symulacji prototypu, co wiąże się ze znacznymi oszczędnościami finansowym, a także umożliwią dobór odpowiednich parametrów konstrukcyjnych głównych elementów pompy.

Słowa kluczowe: MES, model matematyczny, projektowanie, pompa.

1. INTRODUCTION

A market competition is a cause of the increase of complex degree of the design process of new product. It is possible by the wide cooperation among specialists from different field of technology and science. This cooperation basing on a use of the computer techniques, which enable concurrent design and testing of created products. A solving of the constructional problems is situated at a pre-design and design levels instead at a prototype level. The main elements of contemporary design process are – apart from CAD (computer aided design) – a selection theory, CAT (computer aided testing), FT (fast prototyping). A connection of the application mentioned above tools of new product creation and a prediction of its operate characteristics basing on mathematical models enable a getting of defined features of product without a expensive and long-lasting researches and prototype experiments.

The article presents a creation process of designed pump of 7 pistons. A several FEM models are presented with a simulation results. Apart from FEM models, the mathematical model of 1/7 pump was elaborated. This model, which contains piston set with input and output valves was implemented in MATLAB Simulink program. The mathematical model was used to the definition of movement parameters: piston displacement, input and output valves displacements as well as the influence of the work pressure on the movement range. The obtained simulation results from mathematical model can replace a part of the prototype researches.

Elaborated model was verified on a laboratory stand. A verification results are shown in this article.

2. CONSTRUCTION OF THE PUMP

The pump (Fig. 1, 2, 3) is dedicated for pumping oil and water emulsion with 3 to 5% of oil contents. The basic requirements required by the ordering party for this pump are:

- nominal pressure at the outlet: 40 MPa,
- flow capacity: 320 dm^3/min,
- motor power output: 250 kW.

The proposed solution is a new construction solution of a radial piston pump. Its main working elements are seven pistons spaced radially around the shaft axle. The pistons move in the pump body in plane and return motion forced by the properly shaped cam set on the shaft pin. Lift spaces are connected with the inlet and outlet (pumping) pipes from the outside of the immovable cylinder block. Valve timing is used as the element controlling the flow of the liquid.

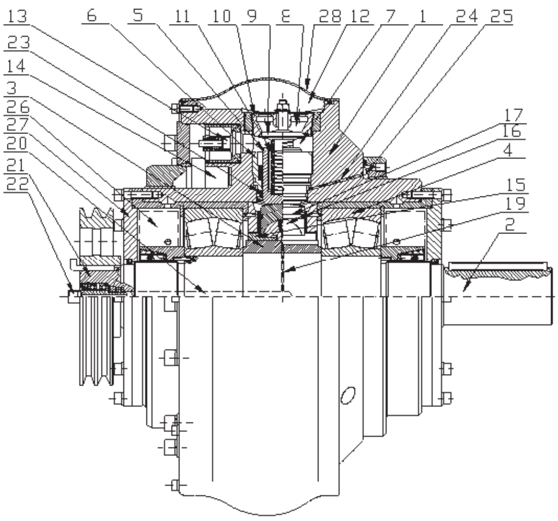

Fig. 1. Construction of the pump:
1 – pump body, *2* – shaft, 3 – eccentric pin, 4 – rolling bearings, 5 – small piston, 6 – small cylinder, 7 – lift chamber, 8 – inflow valve, 9 – inflow valve head, 10 - inflow valve seat, 11 - inflow valve spring, 12 – inflow collecting pipe, 13 – pumping valve head, 14 – pumping collecting pipe, 15 – bearing foot, 16 – ball-shaped pin, 17 - lifter, 18 – non-return valve, 19 – radial duct, 20 – axial duct, 21 – peripheral drive pin, 22 – rotating oil line, 23 - additional sealing, 24 – oil duct, 25 – oil collecting pipe, 26 - counterweights, 27 - cover, 28 - inflow collecting pipe casing

Fig. 2. View of the pump

Fig. 3. Building of the pump

3. STRUCTURE OF PUMP UNIT

Main element of plunger pumps unit, which is presented in fig. 4 and 5, is radius piston pump of T7-320-40 (1).

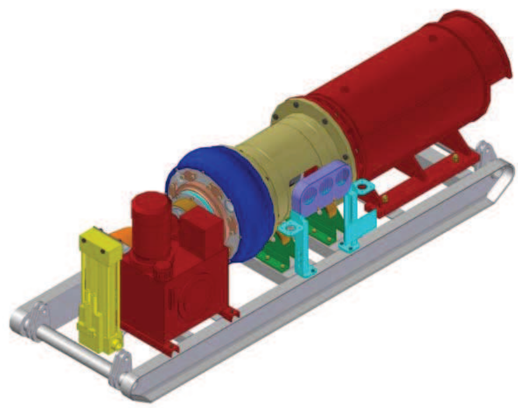

Fig. 4. View of the pump unit

The pump is preliminarily supplied by rotational pump of PJMP 65 (8). A shaft of the main pump is connected by a flexible clutch of SPR 90 (7) with motor of SGPL355 L-4 (6). The rotational pump is driven by a belt transmission (5), which are protected by shield (3). Apart from enumerated elements, the pump unit consist of following elements: water filter (4), hydraulic unit (9), manometers unit (10) and frame (2).

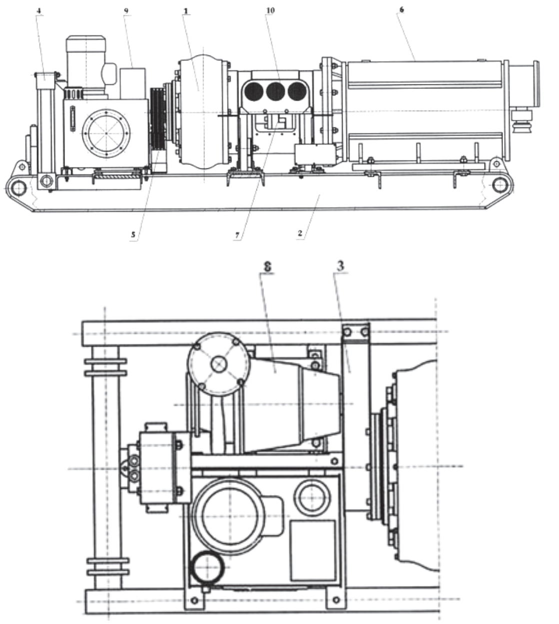

Fig. 5. Structure of the plunger pumps: 1 - radius piston pump of T7-320-40, 2 – frame, 3- shield, 4 - water filter, 5 - belt transmission, 6 – motor, 7 - flexible clutch, 8 - rotational pump, 9 - hydraulic unit, 10 - manometers unit

4. SIMULATION RESEARCHES OF CHOSEN ELEMENTS WITH THE USE OF FEM

Most important elements of new pump were verified by strength analysis in FEM. A maximal value of pressure in system was assume as a boundary condition. A strength analysis of the elements of high pressure output of pump was made by the use of flat, axial symmetric models with taking into account of interaction among components of system. A model of the plunger pump body was made as spatial solid model.

A piston of the plunger was the first tested element. The analysis enables definition of the values of maximal displacements of piston, which enables the verification values of clearance and seals clamp.

An input valve of main pump was the second tested element. Two analysis of this element were conducted for extreme work conditions. Simulation research includes also analysis of several structure of valve head in order to a limitation of its mass and an undesirable dynamic phenomena in this system.

An body shield of main pump was the third tested element. The pressure of work fluid on input side of the main pump.

A pump body was the last tested element of created pump. A solid modeling was used to the creation of body model. A shape of body was divided to four-walls elements of tetra4 type. The maximal pressure in pump system was the boundary conditions.

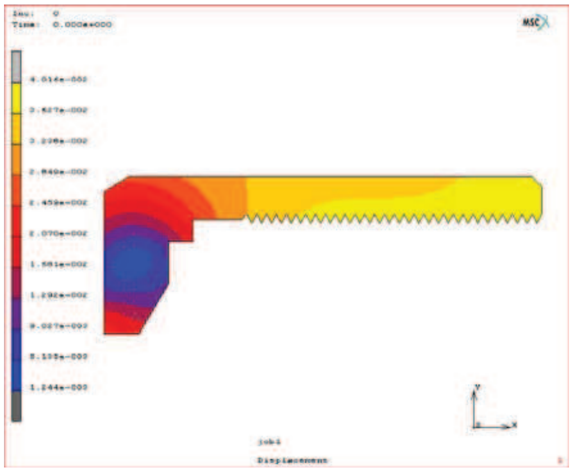

Fig. 6. Displacements distribution of the pump piston

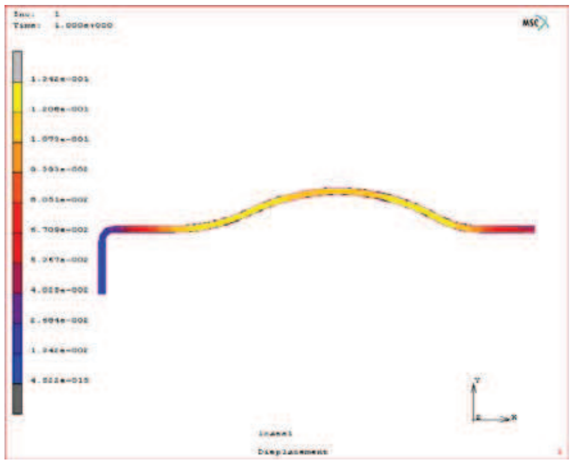

Fig. 7. Displacements distribution of the body shield

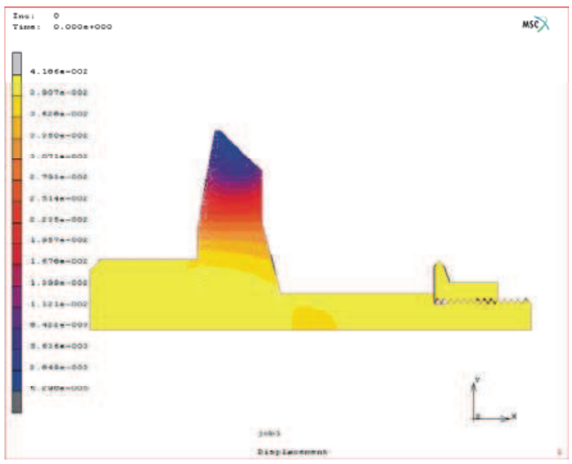

Fig. 8. Displacements distribution of the input valve

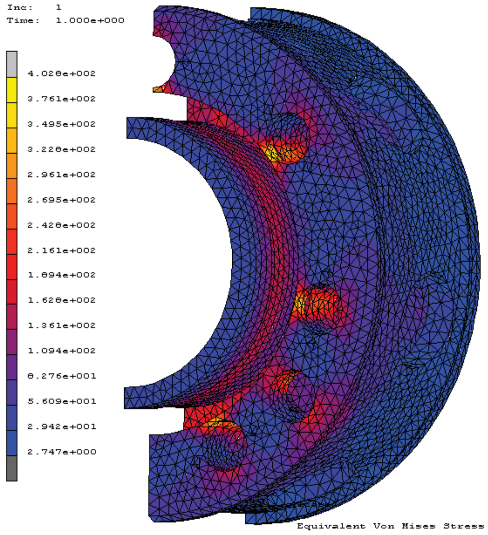

Fig. 9. Stresses distribution of the body shield

5. SIMULATION RESEARCH WITH THE USE OF MODAL ANALYSIS OF CHOSEN PUMP ELEMENTS

The object of simulation research was the body of a radius pump in the phase of concept design. The application of virtual prototyping, one of whose elements was modal analysis, was the requirement of the purchaser. The body was chosen with the connection of concentration of dynamic forces. Geometric measure and dimensions of the body were determined by assumptions determining the work of the pump as well as the measures and dimensions of other components used in the device. It allowed the execution of the technical documentation in CAD stage. On this basis, geometric model of the body was produced.

The method of finite elements and computational packet MSC Patran/Nastran were used to determine the modal model of the body. On the basic of the geometric model mentioned above a network of finite elements consisting of about 121000 quadrilateral, special elements was generated.

Fig. 10. The finite elements model of the body of pump

Taking into account the fact that the specific frequency and the form of specific vibrations, among others, are the functions of material properties and boundary conditions, to determine the modal model of the body we assume:

– constant material values for steel (E, ν , ρ),
– boundary conditions reflect the placement of the pump in the place of work (settled at shaft).

Taking into account the initial assumptions, parts of the body were determined, the first 10 of which are shown in table 1. The exemplary from of specific vibrations for first 2 frequencies are shown in fig.11.

Table 1. The specific frequencies of the body

L.p.	1	2	3	4
f [Hz]	1591.4	1594.7	1939.2	1975.7

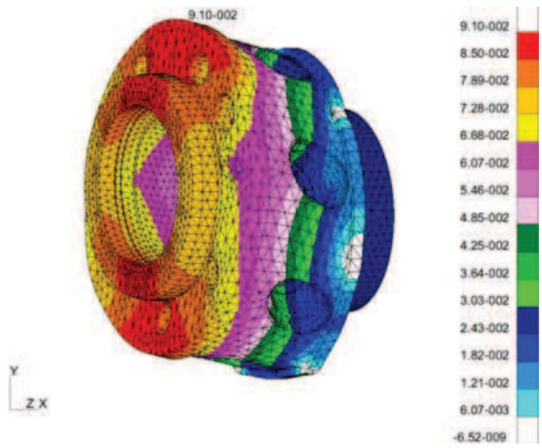

Fig. 11. The form of specific vibrations for frequencies 1591,4 Hz i 1594,7 Hz

For the designed pump following characteristic frequencies resulting from the conditions of work can be determined:

– the frequency coming from the circular velocity of shaft (for *n=1470 1/min*): $f_0=24,5$ *Hz;*
– the frequency coming from the periodic opening of valves on the circumference of the body: $f_z=171,5$ *Hz.*

The comparison of the acquired results with the specific frequencies of the body enables to state that force frequencies are placed in different division of value than specific frequencies. Hence we can reach constructions that at such model of force the resonance connected with these forces will not occur.

The analysis of the modal model of the body of the pump in design enables to define of following conclusions:

1. There is not threat of resonance occurrence at the characteristic frequencies resulting from the conditions of the pump's work.
2. The value of deformation of the body, which occurs at force with characteristic frequency 24,5 Hz, is leaving out.

6. MATHEMATICAL MODEL OF MAIN PUMP

6.1. Simplification assumptions

1. Constant temperature of the work fluid (constant characteristics of the work fluid).
2. Elasticity force is described by linear equation
3. Leakage doesn't appear.
4. Losses caused by local and linear resistances doesn't appear in the input conduits.
5. Force from the pressure in the gaps in input and output valves are negligible small.
6. Viscous friction force in gaps in input and output valves are negligible small.
7. Flow have a turbulent characteristic in each local elements.
8. Flow have a laminar characteristic in each linear elements.

6.2. Mathematical model

Talking into account presented above assumptions, structure of the pump and functioning of the pump, calculating schema of valves system was elaborated. This schema is presented in fig. 12. Its implementation in Matlab-Simulink is presented in fig. 13.

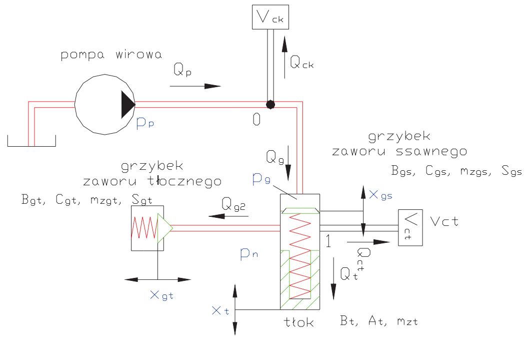

Fig. 12. Calculating schema of the plunger radius pump of T7-320-40

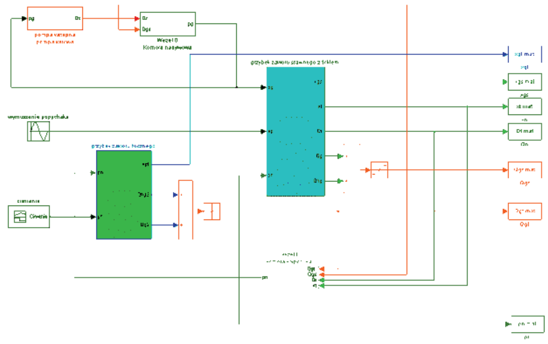

Fig. 13. Calculating diagram of the valves system of the plunger radius pump

7. SIMULATION RESEARCH RESULTS

Characteristics of the valve head displacements for input valve and output valve, piston displacement, flow intensity through valve head was got for established input parameters. Exemplary course of the valve head displacement as well as flow intensity in output valve are presented in fig. 14. Time range from 0 to 0.2 s was established from the point of view of periodicity of the motion of the pump elements.

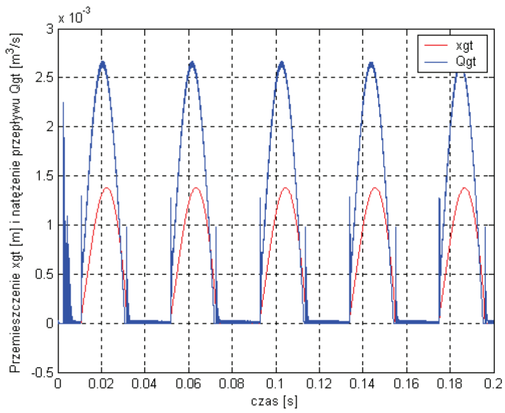

Fig. 14. Displacements of the valve head x_{gt} of the output valve and flow intensity through output valve Q_{gt}

8. CONCLUSIONS

Piston radius pump of T7-320-40, which was elaborated for water-oil emulsion, is described in this article. Measurement description of parameters and diagrams of unit is very hard because of compact construction. In case of that obtaining of pump mathematical models were needed for simulations. After implementing of model in Matlab–Simulink environment, leading series of simulations and experimental researches it was found that obtained model is enough for exact determination of real parameters diagrams. Simulation researches allow for recognition of mutual hydraulic, energetic and geometric relationships between parameters and caused in activities for unit construction optimization.

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