MODELLING AND SIMULATION OF THE DYNAMIC STRUCTURE OF THE VIBRATION FORCING SYSTEM OF THE PRESTRESSING SYSTEM

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Summary

The intensive researches, which are conducted at the KAP AGH, led to a creation of the prestressing system. This system consists of among other the tensioning and transporting devices and the series of types of the anchoring block cooperating with the devices. The next stage of the development of this technology was the building of laboratory stand which enables to conduct the static and fatigue researches of the prestressing system elements. This stand consist of body with actuators system, hydraulic pulsator, universal station for plunger supplier, crosshead – connecting-rod system, cooling system, Spider-Hottinger measuring and control system. A definition of work parameters of the vibration forcing system and their effect on the obtained characteristics of the real system vibrations at high safety requirements calls for expensive experiments. The mathematical model of the vibration forcing system was built with the purpose of the minimization of this costs. This mathematical model was implemented in the Matlab Simulink program.The article presents the mathematical model and the results of simulation and operating research.

Keywords: vibration, prestressing, simulation.

MODELOWANIE I SYMULACJA STRUKTURY DYNAMICZNEJ UKŁADU WYMUSZANIA DRGAŃ USTROJU SPRĘŻAJĄCEGO

Streszczenie

Dzięki współpracy z przemysłem w AGH powstało Laboratorium Badań i Analiz Maszyn i Budowli wyposażone w stanowisko do badań statycznych i dynamicznych pras, bloków kotwiących, zakotwień oraz ustrojów sprężających. Stanowisko to składa się z ramy nośnej, układu siłowników oraz hydraulicznego, nurnikowego wzbudnika drgań. Zostało zaprojektowano zgodnie z wymogami Eurokodów i Euronorm, które zakładają uzyskanie wysokich parametrów niezawodnościowych w fazie projektowej oraz w fazie badań weryfikacyjnych ustrojów sprężających. Określenie parametrów pracy układu wymuszania drgań oraz ich wpływ na uzyskiwane przebiegi drgań rzeczywistego badanego obiektu przy wysokich wymaganiach bezpieczeństwa całego systemu wymaga wykonania szeregu kosztownych badań. Aby zminimalizować te koszty zbudowano matematyczny model układu wymuszania drgań, który zaimplementowano w środowisku Matlab Simulink. W artykule zaprezentowano budowę modelu matematycznego oraz wyniki badań symulacyjnych i eksploatacyjnych.

Słowa kluczowe: drgania, sprężanie, symulacja, badania.

1. INTRODUCTION

This article presents a results of researches, which were conducted in order to a definition of the influence of the constructional, hydraulic and electric parameters on the vibration characteristics in a real prestressing system. Because of the high cost of the real system research, the simulation research was conducted. For this purpose the mathematical model of the vibration forcing system was built. The elaborated model was implemented in Matlab Simulink program.

The laboratory stand to the strength research consists of the following components (fig. 1):

- frame (1),
- cylinders set of tensioning of prestressing system (2),
- operating elements of the hydraulic pulsator (3),
- hydraulic pulsator (4),
- electro-hydraulic set controlling the set of tensioning of prestressing system,
- cooling system (5),

- measurement and control system.

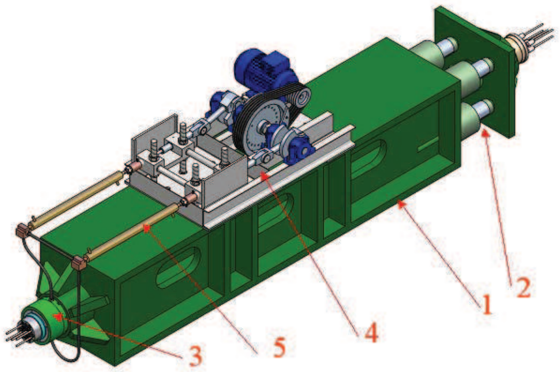


Fig. 1. View of the research stand

The hydraulic pulsator (fig. 2) consist of the frame (1), asynchronous motor (2), belt transmission (3), connecting rod (4), crosshead system (5), plungers and slides set (6), cooling system (7), operating element of the plunger hydraulic vibration generator (8).

The hydraulic pulsator is realized through two plungers system droved by crankshaft-crosshead system with pulsation frequency of 4-8 Hz. The supplier construction allow the vibration generator working control by the amplitude and hydraulic impulse shape changing. The schematic diagram of the stand construction is shown in fig. 1.

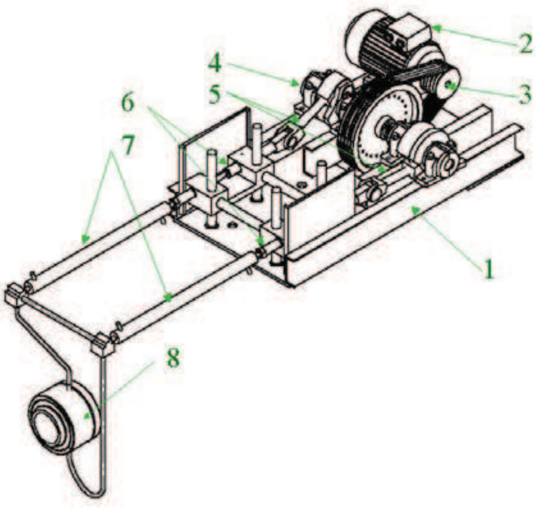


Fig. 2. View of the hydraulic pulsator

The operating element – hydraulic vibration generator is presented in fig. 3 i 4. The structure of this element enables the replacement of main seals without the interruption of research cycle. This assumption was basic in the design process of hydraulic pulsator.

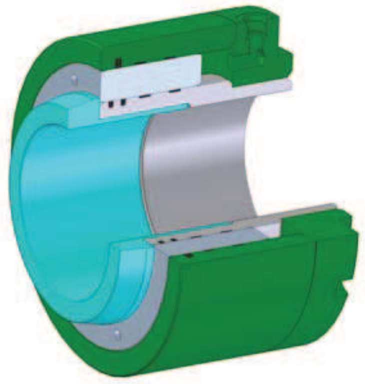


Fig. 3. The view of the vibration generator

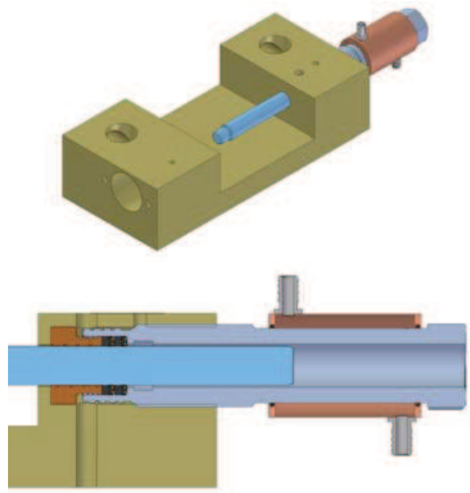


Fig. 4. The view and intersection of plunger block (piston)

2. ASSUMPTIONS OF THE MATHEMATICAL MODEL

Before beginning of studies simplifying assumptions for mathematical model were established.

1. Working medium temperature is constant, so that their properties are unchangeable.
2. String elastic forces are linear.
3. Elastic forces and moving elements friction resistances can be described by linear equations.
4. Losses caused by working medium leakage don't appear.
5. Till reaching maximum value of the pressure unit is supplying by constant efficiency source.
6. In all local elements there is turbulent flow.

These assumptions should be compared every time with calculations results.

3. MATHEMATICAL MODEL

After taking into consideration above model simplifying assumptions, the calculation scheme, which is shown in fig. 5, were constructed. Medium flow intensities in the analyzed unit and the elements influence on pressure and load balance are shown on those scheme. In case of limited length of this paper only hydraulic part of the model is presented.

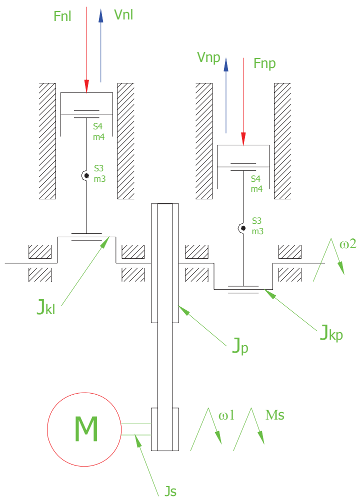


Fig. 5a. Calculation scheme of the drive part

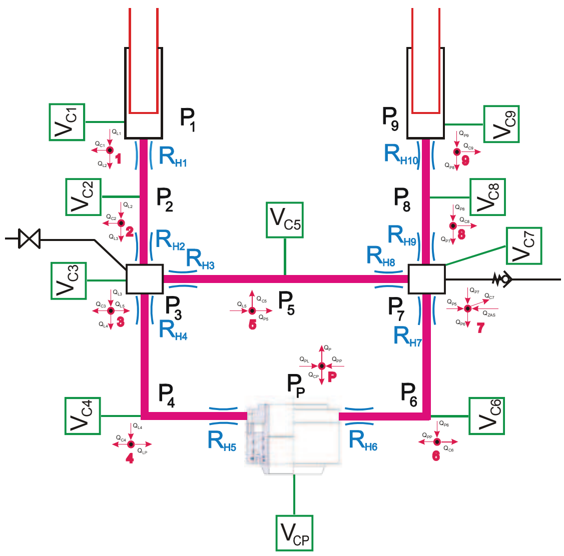


Fig. 5b. Calculation scheme the hydraulic part

The mathematical model of the plunger supplying hydraulic system consists of the following basic equations:

– dynamic equation of the hydraulic pulsator working elements motion
– flow intensity balance equation for the hydraulic system specific nodes.

The hydraulic pulsator (fig. 6) force balance equation:

$$F_c + F_B + F_m - F_p - F_{op} = 0,$$

hence:

$$m\frac{d^2x}{dt^2} + B\frac{dx}{dt} + k_c x = A_p \cdot P_p + k_{op} \cdot x \tag{1}$$

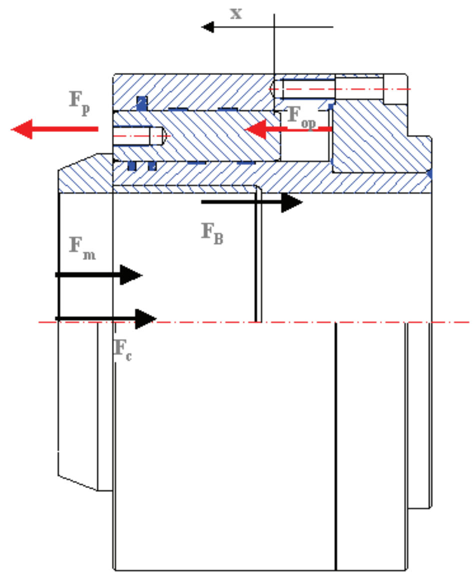
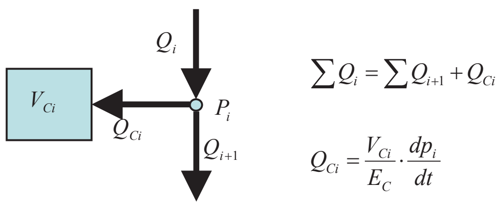


Fig. 6. The force distribution of the hydraulic pulsator

The medium pressure in the specific nodes were calculated from the flow intensity balance $Q_{ci} = \sum Q_i$ after substitution $Q_{ci} = \frac{V_c}{E_c} \cdot \frac{dp_i}{dt}$ and bilateral integration: $p_i = \frac{E_c}{V_c} \int \sum Q_i \cdot dt$.



The flow intensities coming in and out of the node were calculated as a difference of pressures between nodes. The pressure losses in lines and losses caused by medium inertia are situated at some characteristic places of system were assumpted. For model simplifying losses were concentrated at elements causing local pressure losses. The equation [1] describes the pressure between the specific nodes:

$$p_i - p_{i-1} = \lambda_i \cdot \rho \cdot \frac{L_i}{2 \cdot D_i \cdot A_i^2} \cdot |Q_i| \cdot Q_i + \xi_i \cdot \frac{8 \cdot \rho}{\pi^2 \cdot D_i^2} \cdot |Q_i| \cdot Q_i + \frac{\rho \cdot L_i}{A_i} \cdot \frac{dQ}{dt} \tag{2}$$

After integration of both sides of the equation:

$$Q_i = \frac{A_i}{\rho \cdot L_i} \int \left(p_i - p_{i-1} - \lambda_i \cdot \rho \cdot \frac{L_i}{2 \cdot D_i \cdot A_i^2} \cdot |Q_i| \cdot Q_i - \xi_i \cdot \frac{8 \cdot \rho}{\pi^2 \cdot D_i^2} \cdot |Q_i| \cdot Q_i \right) dt \tag{3}$$

Above equations were used to all nodes in system, however flow intensity produced by plungers and hydraulic pulsator movement is written as:

$$Q_{Ai} = A_i \cdot \frac{dx_i}{dt}. \tag{4}$$

4. SIMULATION RESEARCH

The mathematical model was elaborated on the basis of the taken assumptions and the computational scheme. It consist of several basic elements: hydraulic cylinder model (hydraulic pulsator), mechanical and hydraulic supplying system as well as the model of the asynchronous motor.

A lot of the simulation research of the generator was conducted. The verified laboratory research of the vibration generator was also conducted. The measurement scheme is shown in fig. 7. The exemplary results of the laboratory research are shown in fig. 11-16.

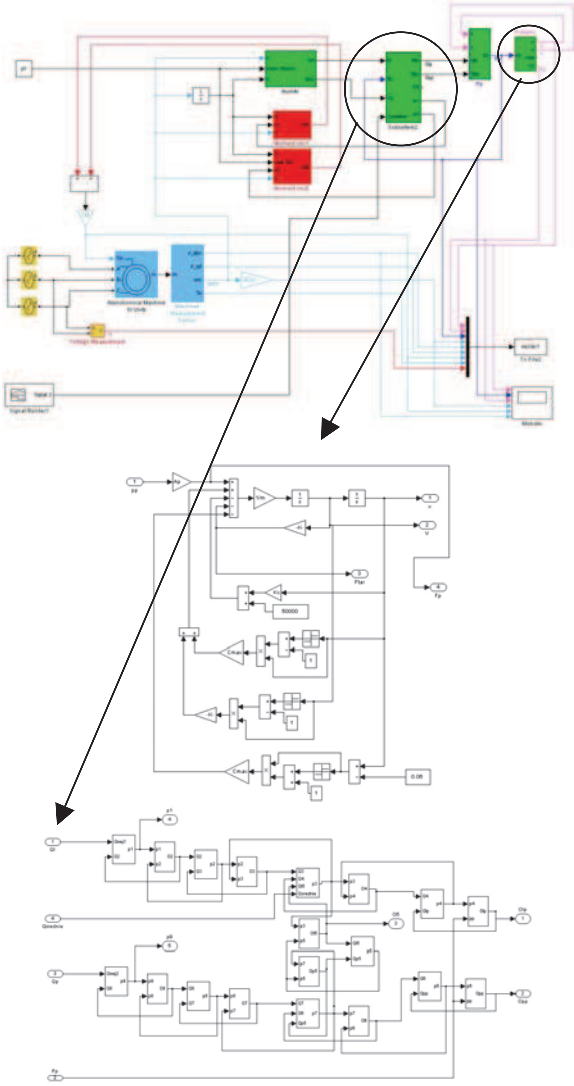


Fig. 7. Simulation diagram for the hydraulic pulsator

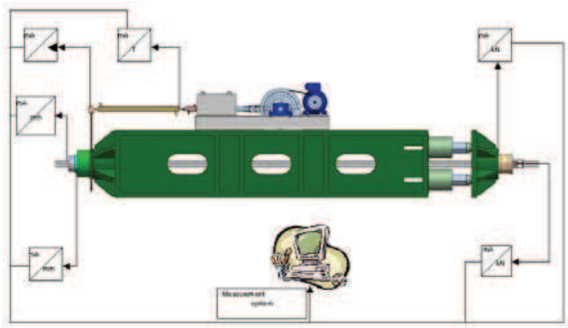


Fig. 8. Schema of the measurement system in the laboratory stand

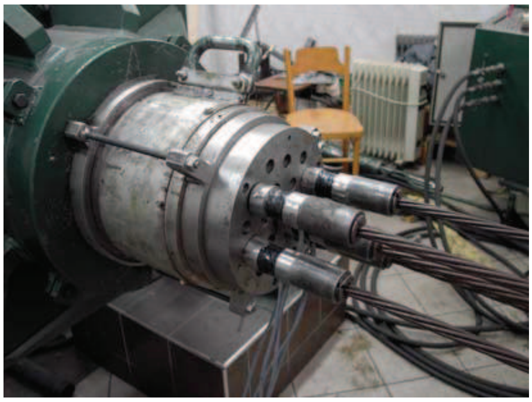


Fig. 9. View of the fasten of force sensors

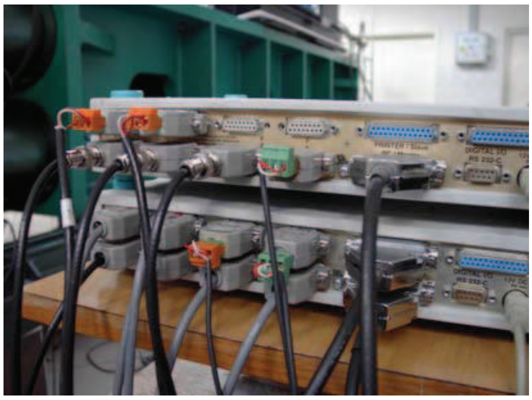


Fig. 10. View of the SPIDER 8 measurement system

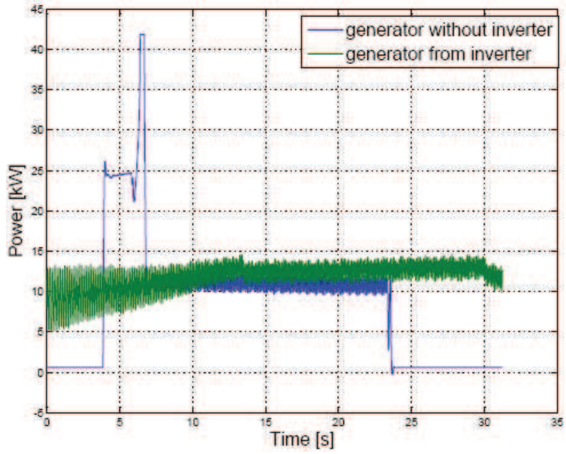


Fig. 11. The comparison of the useful power of generator for the motor feeding from electrical system and from frequency inverter

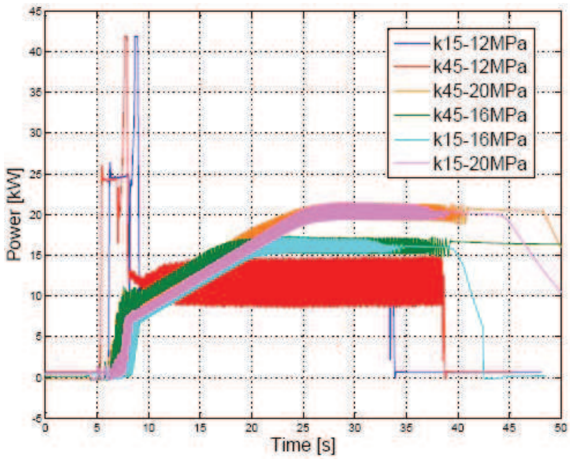


Fig. 12. The comparison of the useful power of generator for the different angles of the phase shift of split pulley and different supplying pressure

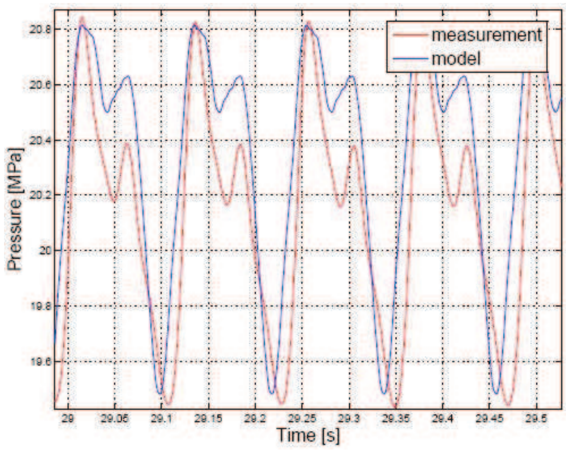


Fig. 13. The verification of the generator pressure for the angle of 45° phase shift of the split pulley

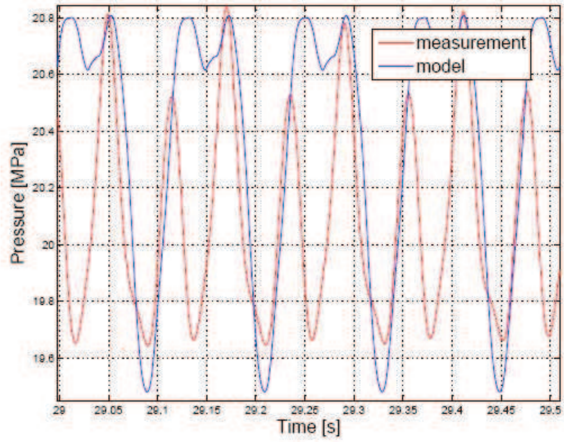


Fig. 14. The verification of the generator pressure for the angle of 15° phase shift of the split pulley

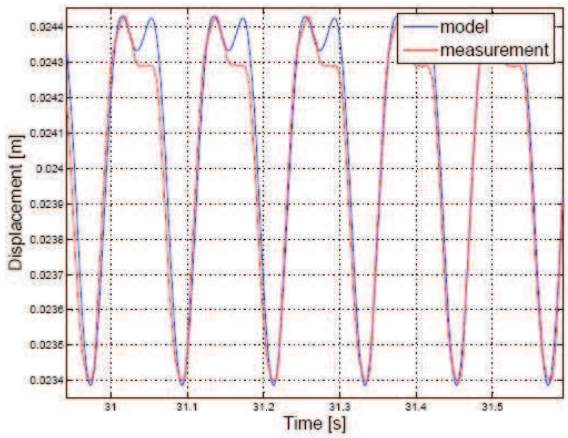


Fig. 15. The verification of the piston displacement of the pulsator for the angle of 15° phase shift of the split pulley

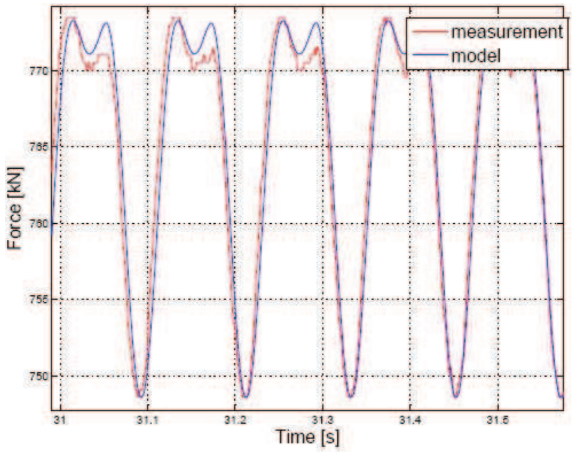


Fig. 16. The verification of the generator force for the angle of 15° phase shift of the split pulley

5. CONCLUSIONS

The presented above model of the vibration forcing system enables:

- research and testing of different structure. Due to it the correction of the research parameters like temperature, energy consumption and dynamic parameters is possible,
- analysis of the effect of crank and phase shift of the split pulley on the energy parameters,
- analysis of the effect of eccentric shift on the correction of amplitude, the energy and dynamic
- research of the different control algorithms of research parameters particularly maximal pressure value (medium),
- analysis of the other solution of the operating elements which can give energy recovery (parallel cylinder, disc with springs).

The results of the conducted simulation in Matlab Simulink program as well as the laboratory experiments confirm the correctness of elaborated mathematical model. The simulation tests give the knowledge about the interactions between hydraulic, geometric and energetic parameters in the system and become the contribution to the stand construction optimization.

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