ANALIZA WPŁYWU METODY ZAMOCOWANIA HYDRAULICZNEJ POMPY ZĘBATEJ NA CZĘSTOTLIWOŚCI WŁASNE ZESPOŁU PRZY WYKORZYSTANIU ANALIZY MODALNEJ - MES

FEM – NATURAL FREQUENCY ANALYSIS OF DIFFERENT MOUNTING ARRANGMENTS OF AN EXTERNAL GEAR PUMP

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Artykuł przedstawia zagadnienia modelowania drgań występujących w pompach zębatych. Przedstawiono wpływ połączenia miedzy elementami pompy oraz wpływ zamocowania na częstotliwości drgań własnych. Stworzony został przestrzenny model rzeczywistej pompy zębatej w dwóch konfiguracjach zamocowania. Geometria obudowy pompy została uproszczona i dla każdej konfiguracji zamocowania przeprowadzono analizę modalną. Porównano wyniki symulacji oraz zaproponowane zostały metody weryfikacji i ulepszenia modelu obliczeniowego.

This paper presents the problem of natural frequencies of vibration in hydraulic gear pumps. The influence of connection between the pump elements on vibration has been shown. CAD three dimensional parts of a gear pump and a pair of brackets were created, simplified, assembled. A FEM – Natural Frequency Analysis simulation was prepared with two types of connection between assembly components for each mounting arrangement. Results of the simulation were compered. Conclusions on achieved results were stated and model verification method was suggested.

Introduction

External gear pumps are one of the simplest and most common types of hydraulic pumps. Among few other elements such as bearings, thrust plates and sealing arrangements, the gear pump assembly always includes a set of identical gears. Rotational motion of meshing gears is used to create suction and pressure chambers that provide hydraulic power in form of fluid displacement under high pressure. Gear pumps are usually applied for pumping high viscosity fluids commonly used in industry e.g. brake systems, power steering systems, aircraft flight control systems, transmissions, lifts etc. Gear as a body possesses inertia and elasticity, as well as its support. The presence of elements with certain inertia and elasticity enables the systems to oscillate and excite vibration [1]. If the oscillation frequencies reach the resonant frequency the phenomena of resonance occurs. In theory in this state the energy is accumulated and even periodic forces of low value can produce large amplitude of oscillations. It's reasonable to assume that if the excitation frequency is equal, or is located nearby its resonant frequency, mechanical resonance will occur in form of strong vibration. The natural frequencies of a system are strongly dependent of parameters like stiffness, mass or damping [2].

Knowing the value ranges of excitation frequencies it's possible to investigate the frequency domain behavior gear pump. Changes in design may be possible. It's possible to influence the frequency related factors by changing the angular velocities of the elements, what in some cases could entirely change the performance of the device. As mentioned before, another way to influence the natural frequencies is to introduce changes in the housing design and mass [3]. Reduction of mass may weaken the structure and increase stress levels. Strong increase of mass is uneconomical therefore mass changes for obvious reasons are limited. Finally, resonating frequencies values can be change by adding additional damping or stiffness in form of mounting arrangements and damping elements. The shape of mounting brackets, additional flexible flanges or vibro-pads,

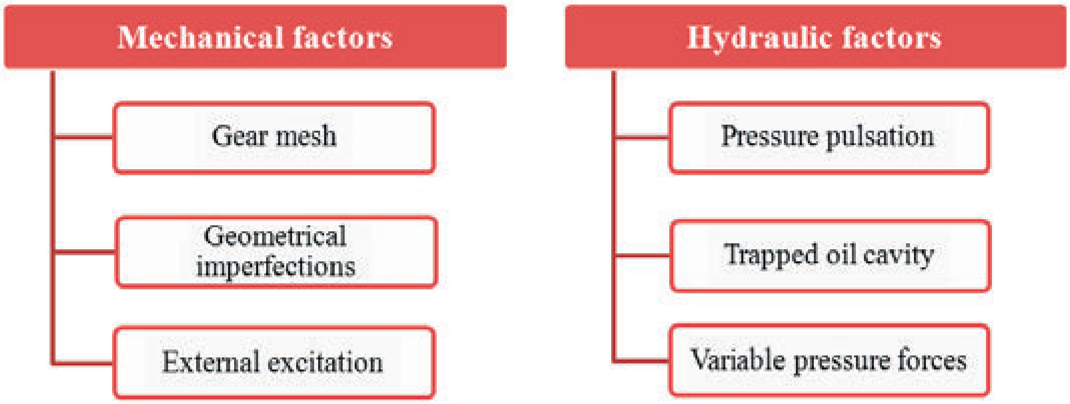

Fig. 1. Factors influencing the vibration in hydraulic gear pumps

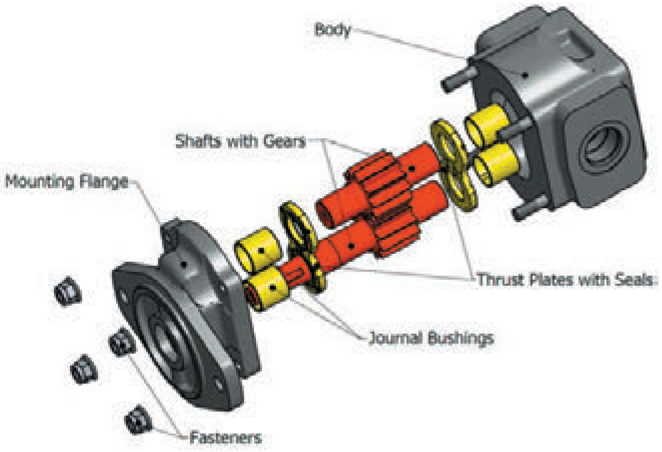

Fig. 2. Three-dimensional CAD model – Parker PGP 600 Series. Exploded view

amount of fixing screws can determine the frequency behavior of the whole system.

Advanced CAD software enables to preform natural frequency analysis of complex systems thanks to implementation of Finite Element Method – FEM. In order to preform natural frequency analysis it's necessary to acquire proper software and prepare a CAD model. All models and preformed calculations were conducted with use of Autodesk Inventor and Autodesk Simulation software. Assuming a possibility of future experiments an existing model of gear pump has been chosen for the analysis. A three dimensional model of Parker PGP-620 shown in fig. 2 was prepared for FEM analysis.

Mounting arrangements have a strong impact on the vibration levels [3]. The construction of mounting brackets can in some decrease vibration. Contrary to that, the bracket itself may be the source of increased vibration [3]. In order to perform a detailed natural frequency analysis standard SAE flange type B mounting brackets, were added to the hydraulic pump assembly. Fig. 3 presents a foot bracket used as a basis of the pump unit. This design can be applied for horizontal position only. Fig. 4 presents a bracket commonly called as "bellhousings". This design can be use both horizontally and vertically. Usually the bellhousing is used to connect the hydraulic pump directly to the body of an electrical engine. Both brackets are aluminum castings with machined connection surfaces and fastening elements. Three dimensional CAD models were created and implemented in the performed simulation. It's stated in the literature that each of the two types of brackets can be used in certain cases [5].

Fig. 3. SAE Foot bracket

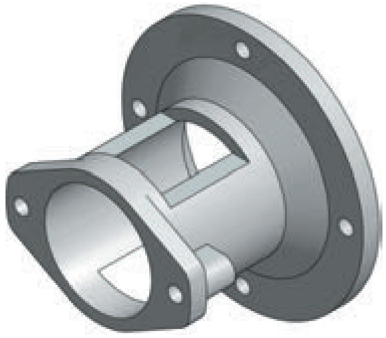

Fig. 4. SAE Bellhousing bracket

Setting up the simulation

The procedure of preprocessing consists of several operations. To conduct the natural frequency simulation it is necessary to prepare three dimensional geometrical models of the examined devices. Applying proper contacts between the elements of the assembly is essential in every FEM simulation. The hydraulic pump assembly is held together by a set of four fasteners placed in each corner of the pump housing (fig. 2) that the body part of the pump have four threaded rods also known as studs. The flange is mounted to the body by applying axial force to the fasteners. A similar solution is used for the connection between the mounting flange and the brackets. The axial force acting on the fasteners provides a compressive preload in the fastened parts ensuring no relative motion between connected parts. Contact types between assembly parts have a strong influence on the simulation results. Two types of approach on contact modeling were chosen and the simulation results were compared. The first approach was based on the assumption that all contact surfaces between parts participating in simulation were set as bonded. It means that if a node on the first connection surface deflects somehow the same would happen with the node of the second connection surface. The second approach used mesh models of fastening elements and contact type between connecting surfaces allowed relative displacement. Fastening elements were preloaded with tightening force corresponding to the strength class of the screw and its thread. Two types contact

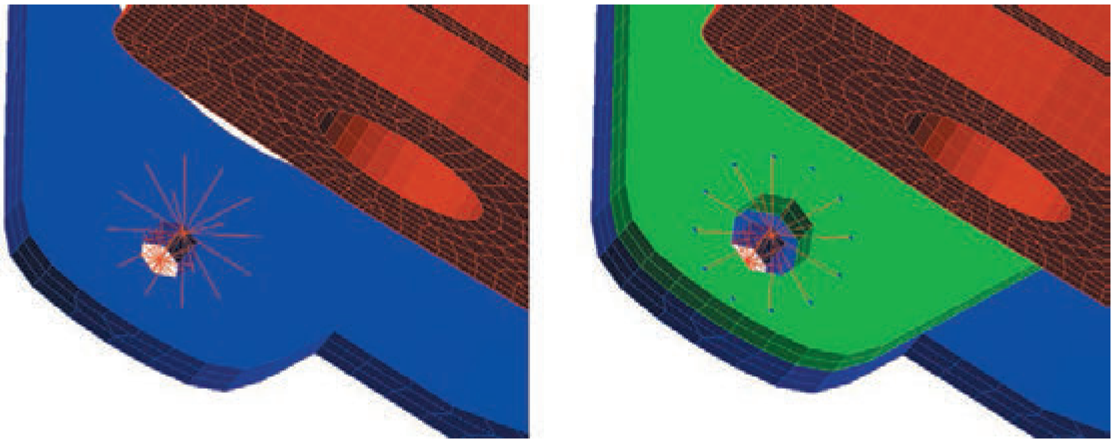

Fig. 5. Bolted connection mesh model. Mounting flange and bracket

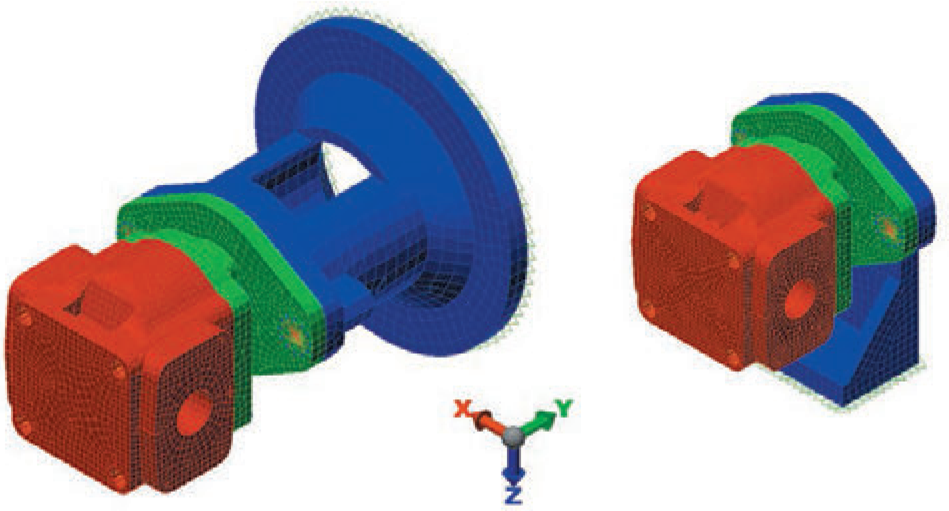

Fig. 6. Models with constrains and meshes

approaches were used for both mounting arrangements and the results of modal analysis were compared.

Including the stud joints in the simulation could be problematic. Instead of using additional parts in form of bolts, washers and nuts a special mesh tool was used. Thanks to that, it was possible to replace the studs with mesh beam elements bonded to the body part of the pump with spiders [6]. Nuts were modeled as a set of diametrically arranged spokes which are perpendicular to the center axis of the beam. Each of the joints was preloaded so that the connected surfaces are pressed against each other. A similar solution was applied for the mounting flange (green color) and brackets (blue color) presented in fig. 5. In this case instead of stud joints a pair of screwed joints was used with internal thread on the bracket side of the joint.

The hydraulic pump geometry presented in fig. 2 contains many details such as chamfers, fillets, small grooves as well as curved and complex surfaces that can be found in the mounting flange and body. All those minor geometry features mentioned above will strongly increase the number of subdivisions and due to that the calculation time will increase. In some cases small features may also lead to local distortion of results. In order to prevent errors and insure a short time of simulation the geometry of the pump as well as the brackets was simplified.

The next step is to reduce the number of parts participating in the simulation. The mass of thrust plates and seals is relatively small, and there is no direct influence on the stiffness of the structure so there is no need to include those parts in the model. The same can be done with the journal bushings Shaft journals placed inside the bearings are separated from each other by a thin layer of oil. It can be said that the shafts are not directly bounded to the structure of the pump and there should not be a stiff connection to the assembly. The mass of shafts with gears is approximately 10% of the total mass of the system and it cannot be ignored in the simulations. The solution considers the distributed weight of the shafts in the locations of the bearings.

The pair of mounting arrangements used in the simulation is shown in fig. 6. Both presented setups were simplified, constrained, meshed and material properties were applied. Mesh element size was firstly generated automatically with software default values. Secondly the mesh element size was reduced for each part separately so that no serious irregularities in mesh were present while the simulation time was still manageable. The mesh consisted of brick and tetrahedron elements. Contacts between assembly parts were set in bonded or sliding/no separation mode. Base surfaces of brackets ware constrained in all degrees of freedom.

Simulation results

The main goal of the conducted simulations was to obtain the information about natural frequencies of the gear pump-bracket system for various mounting arrangements and contact models. Software used for simulation allows animating the behavior of the simulated system for each natural frequency. The modes are different for each natural frequency. Normal modes can be useful for experienced designers as a tool of finding weak spots of the object.

For each mounting arrangement first five natural frequencies were calculated. For the purposes of this paper only the first three normal modes of each mounting arrangement were shown. The main idea of this paper is to check the influence of applied contacts on the simulation results in case of a hydraulic pump - bracket assembly. It can be assumed that the first three natural frequencies have a strong influence on the vibration of the assembly due to the high amplitudes.

The hydraulic pump - bellhousing assembly normal modes are shown in fig. 7. The normal modes shapes are similar for both cases of contacts although for the bonded type of contacts the natural frequencies reach higher values. Each normal mode was presented in a view position that ensures the best possible displacement observation. In the first mode strong bending of the bracket in the YZ plane takes place. In the second normal mode of the system another bending occurs in the XY surface and it is perpendicular to the first case. Small deformations of the mounting flange can be seen. The third mode is more complex due to torsional deformation of the bracket around Y axis and the mounting flange around Y and X axis.

Normal modes of the hydraulic pump – foot bracket assembly are presented in fig. 8. The normal modes shapes are as well as in the previous simulation similar for both cases of contacts. The similarity in higher natural frequency values for the bonded

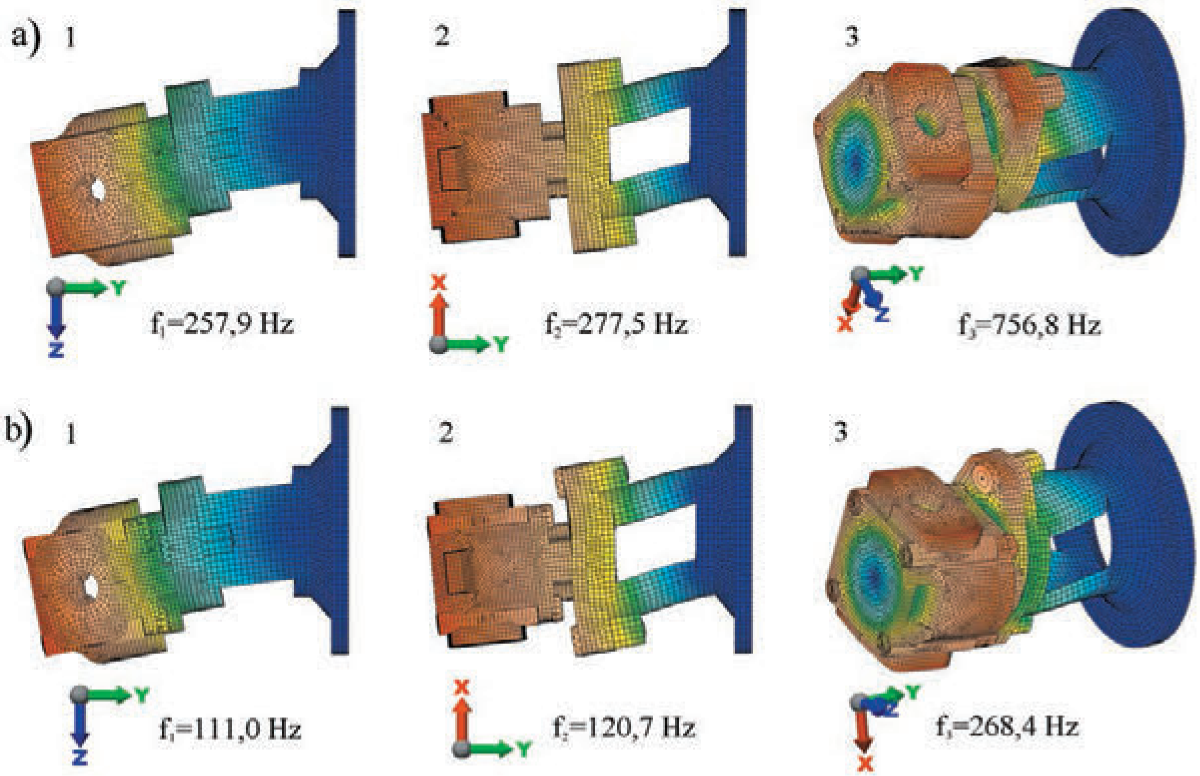

Fig. 7. Normal modes for first three natural frequencies – Pump with bellhousing bracket: a) Bonded type contacts, b) Bolted connections

type of contacts can be also observed. The first normal mode occurs similarly to the first mounting arrangement, the bracket is bended in the YZ plane. In the second mode the pump and the mounting part of the bracket twist around the Z axis. The third mode consists of translation of the hydraulic unit in the Y axis and bending in the YZ plane.

Natural frequency values for each simulation case are shown in tab.1. It can be seen that the type of contacts has a strong influence on the value of natural frequencies. Natural frequen-

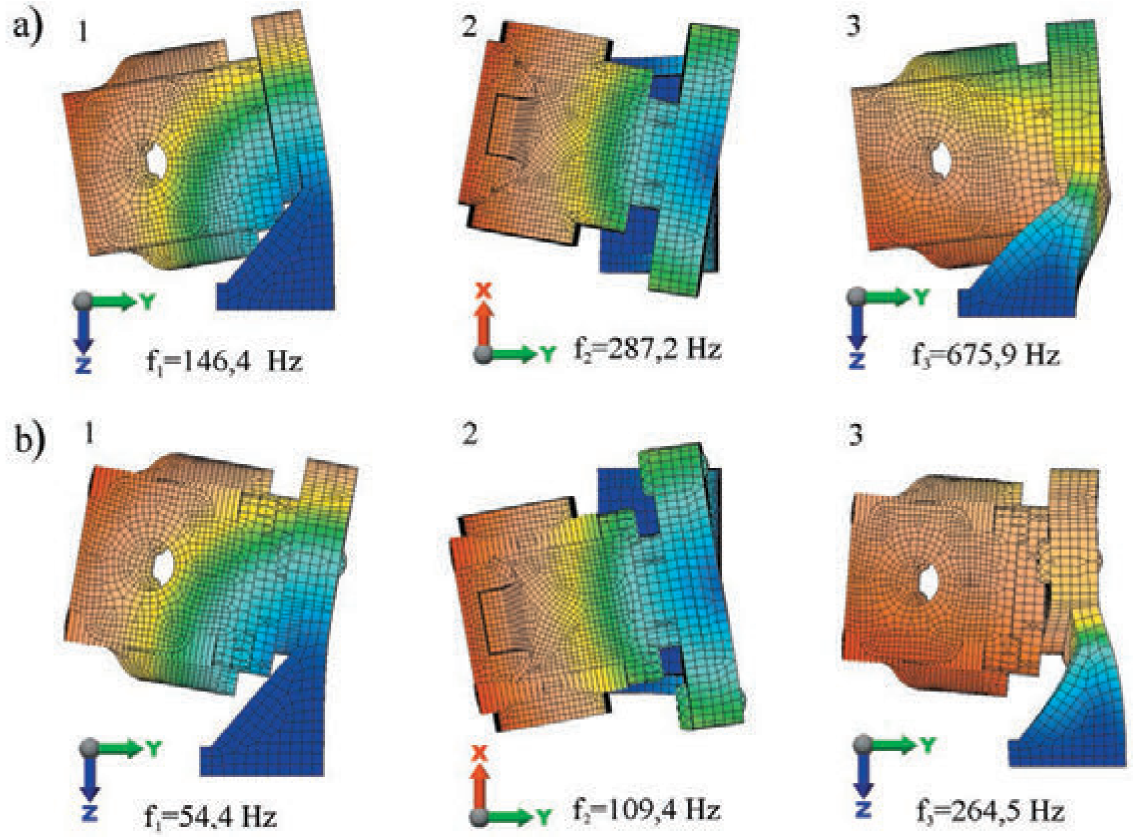

Fig. 8. Normal modes for first three natural frequencies – Pump with foot bracket: a) Bonded type contacts, b) Bolted connections

Table 1. Natural frequencies comparison

	Natural frequencies [Hz]			
	Hydraulic unit - Foot bracket		Hydraulic unit – Bellhousing bracket	
Mode Nr	Bonded	Bolted joints	Bonded	Bolted joints
1	146,4	54,4	257,9	129,8
2	287,2	109,4	277,5	146,6
3	675,9	264,5	756,8	335,5
4	1058,0	315,8	1051,3	573,2
5	2074,7	652,9	1204,3	651,4

cies obtained with bonded type contacts are significantly higher than the vales form simulations where bolts were modeled.

Conclusions

The knowledge about the dynamical behavior of any mechanical systems is essential and should be considered in all designs. Simulations using FEM allow to perform modal analysis simulations in early stage of design. The complexity of mechanical devices may cause many difficulties in set up of boundary conditions. Simplifications of geometry and connections between parts have a strong impact on the results. Relating to this paper the influence of contact types between parts of hydraulic pump and brackets has been considered.

The results obtained in this paper confirm a big influence of the connection between pump elements on the results of modal analysis. Additional research and experimental investigations are needed to designate a proper contact model approach. Experimental modal analysis known from literature [1, 2] could help to adjust the FEM model in order to get high accuracy of the results. The results could be then compared with excitation frequencies that result from the frequency factors shown in fig.1. Excitation forces in the pump have a strong influence on the system vibration not only at the fundamental frequency but also at its successive harmonics [1, 3].

Future work should also include the model of contact between shafts and journal bearings. Also the influence of the static pressure inside the pump should be included. It was already indicated in literature [3] that high pressure values can change the natural frequency of the gear pump housing. The presence of hydraulic fluid in the pump housing can also influence the results, so it should be as well included in the simulation.

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