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FEM - NATURAL FREQUENCY ANALYSIS OF DIFFERENT MOUNTING ARRANGMENTS OF A POSITIVE DISPLACMENT HYDRAULIC GEAR PUMP ASSEMBLY.

This paper presents the operation principles and the problem of vibration in hydraulic gear pumps. The connection between the hydraulic unit frequency domain and its vibration was 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 contacts 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. It can be said that hydraulic gear pumps operation principle is based on a rotational movement of the gears. Each gear as a body possesses inertia and elasticity and the same can be said about elements coupled with gears. 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 value the phenomena of resonance can occur. In theory in this state the damping coefficient ratio value is nearly zero so there is no energy dissipation in the system, the energy is accumulated and even periodic forces of low value can produce large amplitude oscillations. It's reasonable to assume that if the excitation frequency equals, or is located nearby its resonant frequency, mechanical resonance will occur in form of strong vibration. The natural frequencies value of a system is strongly dependent of parameters like stiffness, mass or damping [2].

The phenomenon of vibration itself is common especially in rotary motion, for example due the imbalance or misalignment. As long as the vibration level does not exceed a certain value it shouldn't have any negative impacts on the device. It's stated in the literature that high vibration levels may lead to fatigue, increased wear, increased failure rate and high noise levels [1] [2]. Causes of vibration in hydraulic pumps can be divided into two groups as shown in figure 1. The first group named random factors contains phenomena that may occur randomly during the work cycle of a device such as dynamic workloads, power supply variation, device component failure or changes in the positioning of the device. The second group sums the factors influencing the vibration is called frequency factors. It's a group of characteristic frequencies or frequency ranges of considered system such as shaft frequencies, bearing frequencies, gear mesh frequencies and other frequencies related with periodic motions or functions of the system [1].

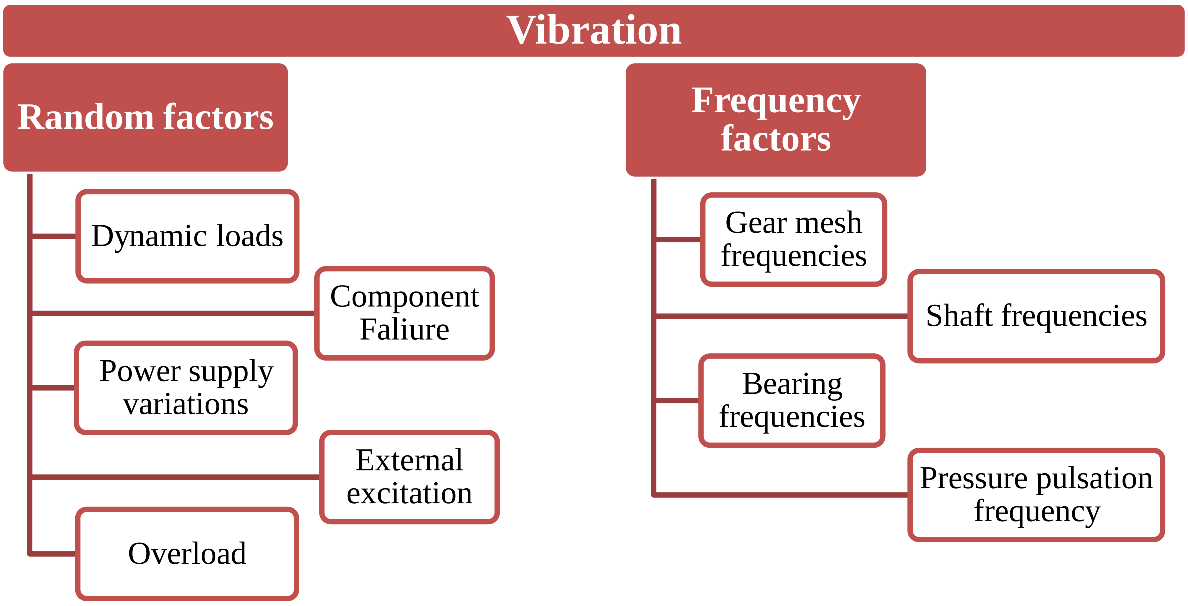

Fig.1 Factors influencing the vibration in hydraulic gear pumps.

Relating to the title of this article, knowing the value ranges of excitation frequencies it's possible to investigate the frequency domain behavior of designed device such as hydraulic gear pump in order to avoid resonance cases and as a result prevent vibration in early production stage. On the other hand, changes in design may be problematic. 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 body shape 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 vibrio-pads, 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 - numerical method of solving differential equations by finding approximate solutions [4]. The idea of FEM is to divide the object domain to a finite amount of small subdomains represented by number of differential equations. The subdivision ensures the capture of local effects and a possibility to properly represent complex geometry with variable material properties.

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 and used in analysis.

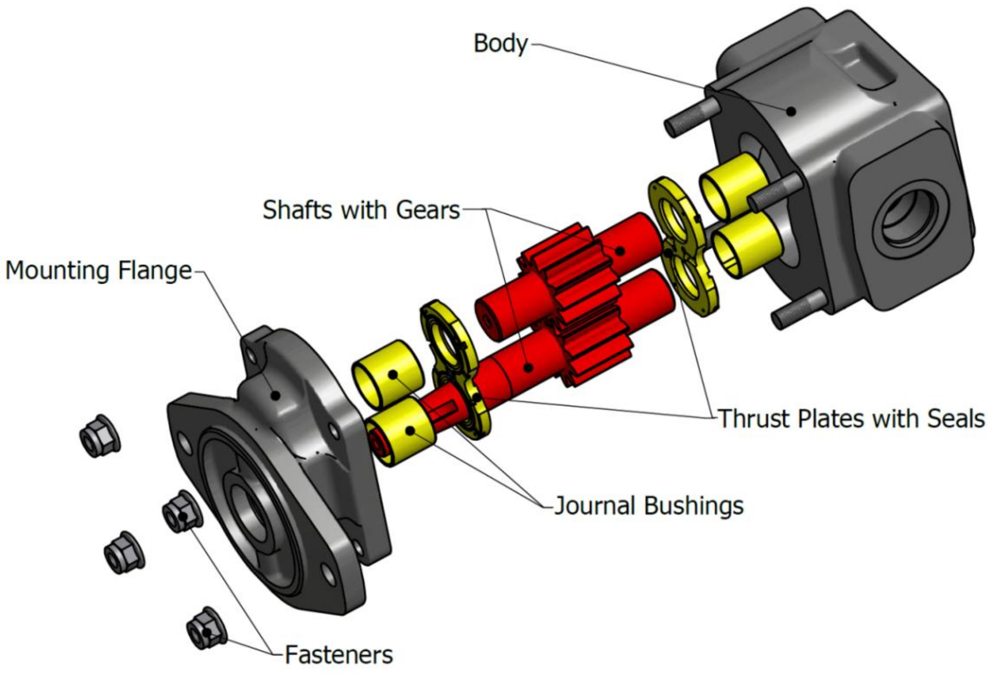

Fig. 2 Three-dimensional CAD model - Parker PGP 600 Series. Exploded view.

Mounting arrangements have a strong impact on the vibration levels [3]. The construction of mounting brackets can in some cases add energy dissipation possibilities in the system and as a fact decrease vibration. Contrary to the previous fact, the bracket itself may the source of increased vibration [3]. In order to perform a detailed natural frequency analysis standard SAE flange type B mounting brackets ware 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 perform better in certain cases [5].

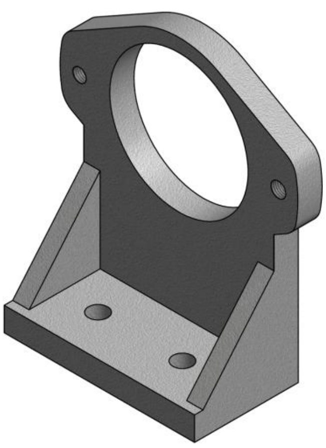

Fig.3 SAE Foot bracket.

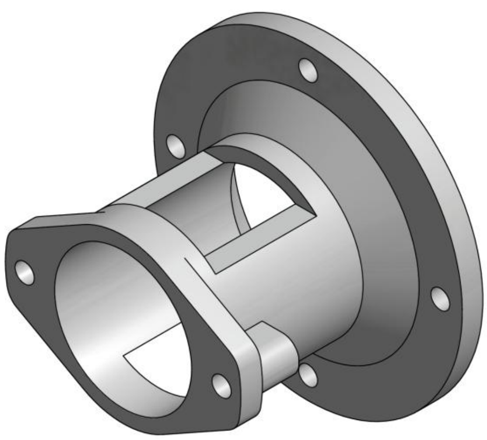

Fig. 4 SAE Bellhousing bracket.

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 body. It can be seen in 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 bolt and its nominal of the thread. Two types contact approaches were used for both mounting arrangements and the results of modal analysis were compared.

Including the stud joints in the simulation could be problematical. 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 mating 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.

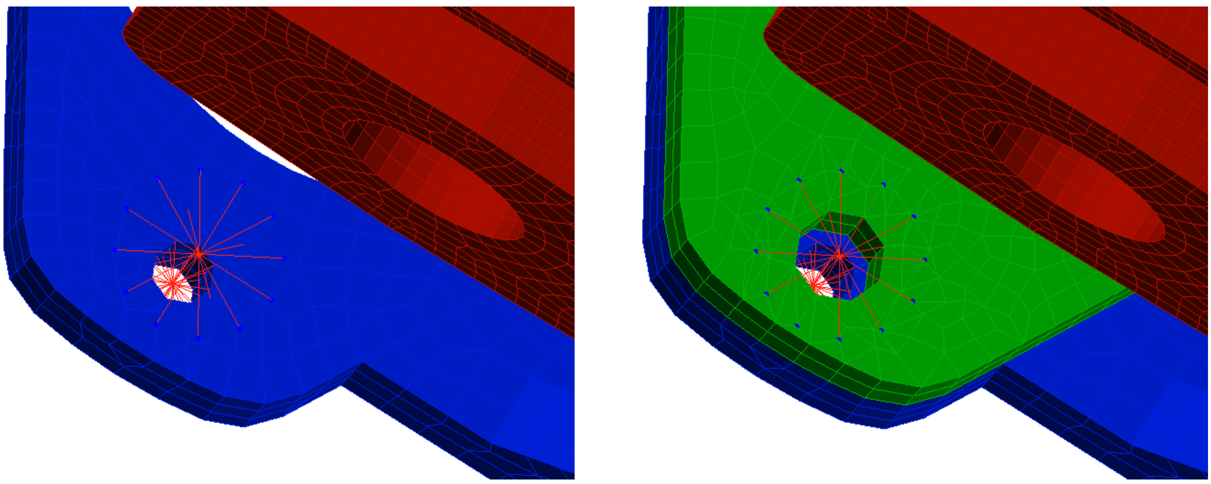

Fig. 5 Bolted connection mesh model. Mounting flange and bracket.

The hydraulic pump geometry presented in fig.2 contains many details such as chamfers, fillets, small grooves as well as curved and complicated 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 as a result 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 hydraulic unit 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 although the decision about excluding them from the simulation is not only based on the low mass but mainly on the complex nature of the phenomena occurring in the thin film oil area. The bearing arrangement of the pump highly increases the complexity of the device. Shaft journals placed inside the bearings are separated from each other by a thin layer of lubricator, which in case of the hydraulic pump is the hydraulic fluid displaced by the pump. It can be said that the shafts are not directly bounded to the structure of the pump and there should not be a strong increase of stiffness in 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 was to spread the weight of the shafts in the locations of the bearings.

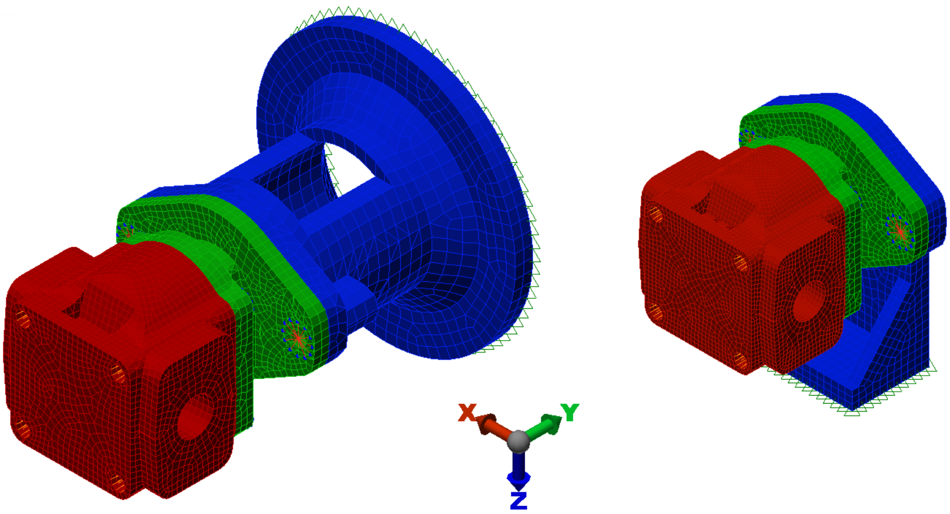

Fig. 6 Models with constrains and meshes.

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 constrain in all degrees of freedom.

ANALYSIS

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 to animate the behavior of the simulated system for each natural frequency. This sinusoidal pattern of motion that can be seen in the state of resonance is called the normal mode. The modes are different for each resonance frequency. Normal modes can be useful for experienced designers as a tool of finding weak spots of the object. It is possible to change the simulation properties in order to get a higher number of normal modes or to conduct the simulation in a certain range of frequencies what could be useful when dealing with complex models. Modal analysis can be performed in smaller frequency ranges assuming that the excitation frequency is known and it is located in the simulation range.

For each mounting arrangement first five natural frequencies were calculated. For the purposes of this article only the first three normal modes of each mounting arrangement were shown. The main idea of this article 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 occurring in these states. In order to visualize the displacement of the assembly scale factor of 10 was implemented.

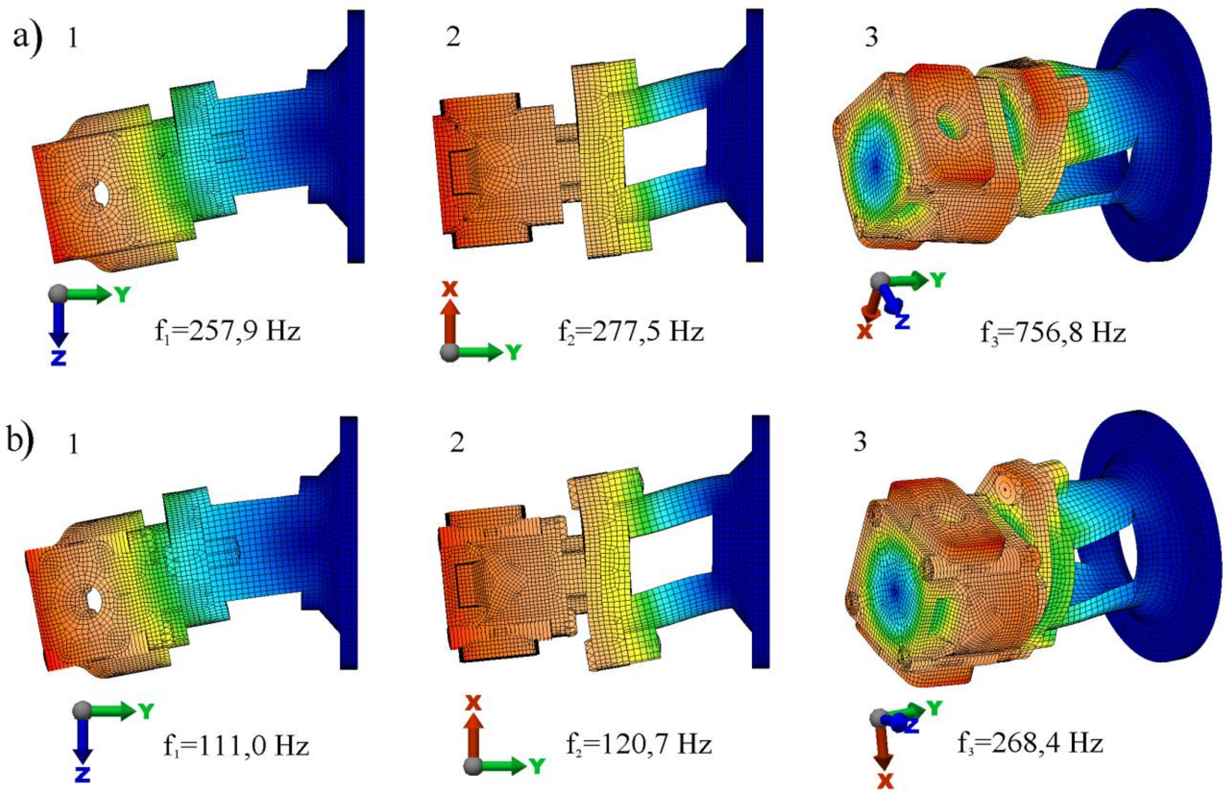

Fig. 7 Normal modes for first three natural frequencies – Pump with bellhousing bracket.
a) - Bonded type contacts, b) - Bolted connections.

The hydraulic pump - bellhousing assembly normal modes are shown in fig.7. The results of simulation with bonded type contacts is marked as case *a*. Results of simulation with bolted connections is marked as case *b*, numbers *1,2,3* correspond to the mode number. 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 its 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 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 hydraulic unit and the mounting part of the bracket twist around the Z axis. The third mode consists of several features. Translation of the hydraulic unit in the Y axis and bending in the YZ plane can be seen.

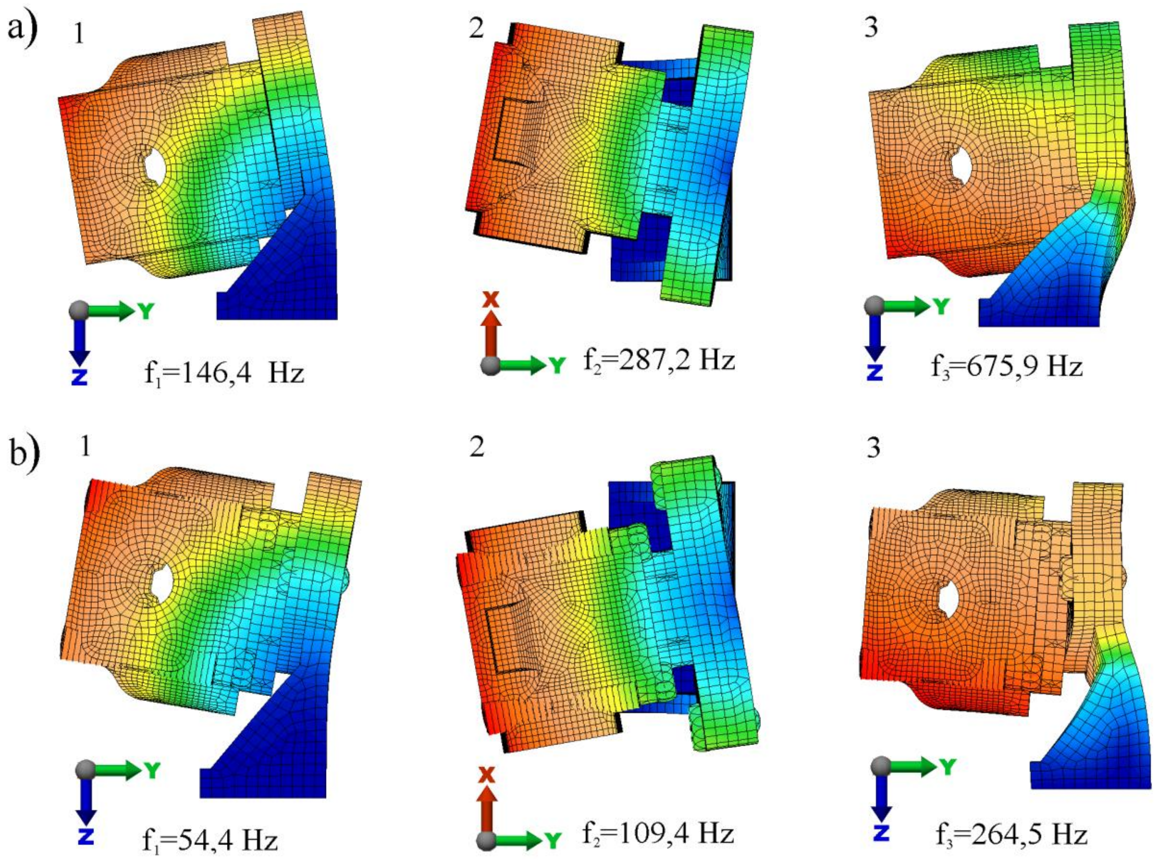

Fig. 8 Normal modes for first three natural frequencies – Pump with foot bracket.
a) - Bonded type contacts, b) - Bolted connections

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 frequency value. Natural frequencies obtained with bonded type contacts are much higher than the vales form simulations where bolts were modeled.

Tab.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

CONCLUSIONS

The knowledge about the frequency domain of any mechanical systems is essential and should be considered in all designs. Computer simulations using FEM allow to perform modal analysis simulations in early stage of production. The complexity of mechanical devices may cause many difficulties in preparing the simulations. Simplification of geometry and physical phenomena has a strong impact on the results obtained from simulation. Relating to this article the influence of contact types between parts of hydraulic pump units and brackets was partially exanimated. The inconsistency in results obtained with different contact types may indicate some defects or inaccuracies in the model. Additional research and experiments need to be conducted 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 fidelity results. The results could be then compared with excitation frequencies that result from the frequency factors shown in fig.1. Each type of excitation has a strong influence on the system vibration not only at the fundamental frequency but also at its successive harmonics [1] [3].

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

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ANALIZA WPŁYWU METODY ZAMOCOWANIA HYDRAULICZNEJ POMPY ZĘBATEJ NA CZESTOTLIWOSCI WŁASNE ZESPOŁU PRZY WYKORZYSTANIU ANALIZY MODEALEJ - MES

Streszczenie

Artykuł przedstawia podstawowe zagadnienia dotyczące pomp zębatych oraz drgań występujących w jednostkach hydraulicznych. Przedstawiono zagadnienia związane częstotliwościami drgań własnych układów hydraulicznych. Stworzony został przestrzenny model rzeczywistej pompy zębatej w dwóch konfiguracjach zamocowania. Geometria zespołu została uproszczona, dla każdej konfiguracji zamocowania przeprowadzono analizę modalna dla dwóch przypadków kontaktu pomiędzy elementami zespołu. Porównano wyniki poszczególnych symulacji oraz zaproponowane zostały metody weryfikacji i udoskonalenia modelu zastosowanego w symulacji.