OPTYMALIZACJA CHARAKTERYSTYK DYNAMICZNYCH WIELONACZYNIOWEJ KOPARKI KOŁOWEJ NA ETAPIE PROJEKTU WSTĘPNEGO

BUCKET WHEEL EXCAVATOR DYNAMICS OPTIMIZATION ON THE STAGE OF PRELIMINARY PROJECT

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Maszyny podstawowe górnictwa odkrywkowego należą do grupy maszyn roboczych poddawanych silnym obciążeniom dynamicznym, w dużej części o charakterze stochastycznym, na które nałożone są ciągłe pulsacje obciążeń, wynikające z procesu urabiania (w przypadku koparek kołowych lub łańcuchowych). Ponadto praca obiektów tego rodzaju ma wymiar całodobowy, a czas eksploatacji sięga nawet pięćdziesięciu lat. Odpowiednie dostosowanie charakterystyk dynamicznych obiektu przekłada się na jego wydłużoną i bezawaryjną pracę. Zaprezentowano proces badania charakterystyk dynamicznych wielonaczyniowej koparki kołowej na etapie projektu wstępnego. Wykazano wpływ modyfikacji strukturalnych na lokalne oraz globalne postacie drgań własnych. Przeprowadzenie symulacji na modelu numerycznym umożliwiło dostosowanie charakterystyk dynamicznych koparki optymalnie do przewidywanych warunków pracy. W rezultacie, zredukowane do minimum drgania, wynikające z charakterystyki samej maszyny, przełożą się na trwałość konstrukcji.

Surface mining machinery belong to the group of heavy duty machines that are strongly exposed to the dynamic loads. Acting load derives from excavating system and its periodicity is directly related with the system characteristic. Machines operational time is round the clock and it lasts even till 50 years. Proper identification and tuning of the modal characteristics of the object, positively influence on the durability and failure-free operation. Presented results show investigations of the dynamic characteristics of bucket wheel excavator on the stage of preliminary project. The influence of the structure modification on the local and global eigenfrequency is shown. With the use of the numerical model simulation, performed for proper tuning of the modal characteristics, the structure was optimized. As a result, the reduced vibrations amplitude, will increase the durability of machine and its operational time.

Słowa kluczowe: *koparki wielonaczyniowe, górnictwo odkrywkowe, analiza modalna*
Key words: *bucket wheel excavators, surface mining, modal analysis*

Introduction

Energy production in Poland is supplied mainly by the power plant fed with the lignite. To provide sufficient amount of the rough material it is needed to keep working machines in good technical conditions. While many of them is decades old, there is also need of simultaneous construction of the new objects.

Lignite mining heavy duty machines, especially bucket wheel excavators, requires special approach to the problems of dynamics, so the influence of the operational conditions must be considered. Coal and overburden excavation forces can be described as alternating trace in time frequency domain. The periodicity of the load is determined by the construction of the excavating system (bucket wheel velocity, buckets number). In cases of overload, the nominal excavation forces are exceeded several times. The occurrence of ultimate forces is determined by the geological conditions. It is direct result of the type of the excavated material and amount of solid obstacles (rocks etc.). The consequences of dynamic overload can be failures and disasters of machines [3], [5], [7].

Common use of numerical methods enables the application of numerical modal analysis in field of open pit mine machines construction [2]. Such a approach, facilitate identification of dynamic characteristics on the preliminary project stage. Analytical methods of solving characteristic equation are complicated, time consuming and not accurate enough. As a result, in case of complex structures, determination of normal modes is very problematic. Application of numerical simulations allows to face with the issue of complex steel structures dynamics in effective way [1], [6], [9].

Investigated object description

Presented case considers numerical modal analysis of the bucket wheel excavator of 1500 dm^3 bucket capacity. The machine is dedicated mainly for overburden excavation but also of the coal if required. The nominal excitation frequency derives from dumping periodicity which equals 1.04 Hz.

Preliminary simulations – numerical modal analysis

In purpose of dynamic characteristics identification, complex finite element model was prepared (fig. 1).

Structural members were substituted by the beam-shell

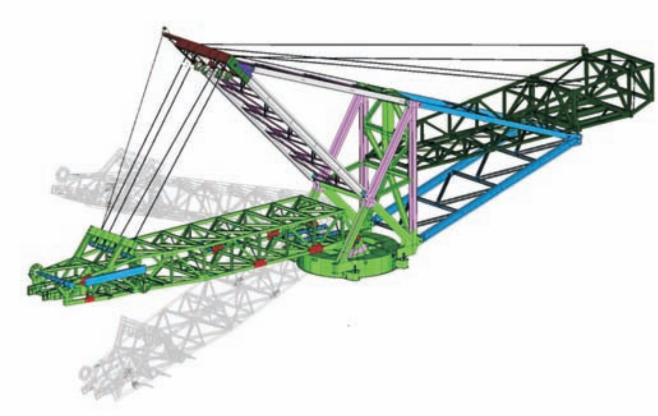

Fig. 1. Bucket wheel excavator finite element model

model. Detailed representation of the superstructure was required for popper simulations. The subassemblies of the lower part like undercarriage, were replaced by the deformable elastic elements of corresponding stiffness [4], [10].

Simulation of concept structure were performed in purpose to establish resonance range. To tune dynamic characteristics, optimization of the upper part of bucket wheel excavator was done.

Preliminary simulation pointed out that the second harmonic of the excitation frequency is close the range of the 6th structural mode of the excavator and equals 2.03 Hz. The deflection shape is directly related with the support of the counterweight of the machine. It is very flexible and in the front part of the counterweight boom has possibility of large displacement. The scheme of the counterweight support is shown in figure 2.

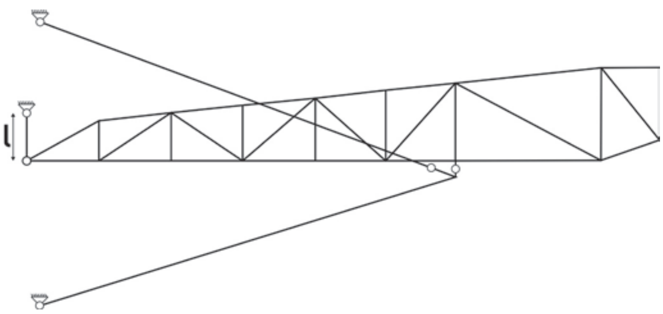

Fig. 2. Scheme of the counterweight support in preliminary version

The deflection shape characterizes with large horizontal displacement of counterweight boom and vertical displacement of its supporting structure (fig. 3).

Fig. 3. 6th normal mode of the excavator

Fortunately, any of the primary modes do not to correspond directly to the excitation frequency. In such a case, with relatively low excitation energy, it would be possible to cause resonance. The vibration amplitude could finally lead to the immediate structure failure. The first three modes are show in figures 4 to 6.

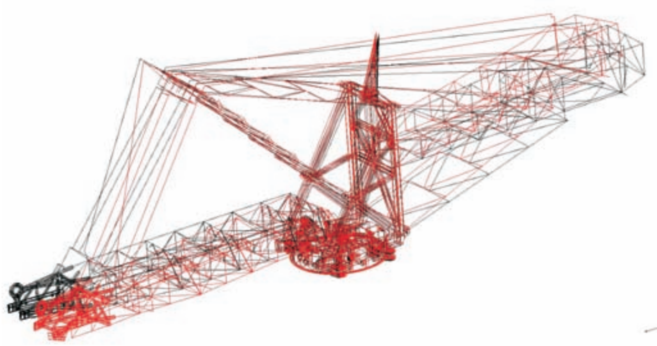

Fig. 4. 1st modal mode ~ 0.671 Hz

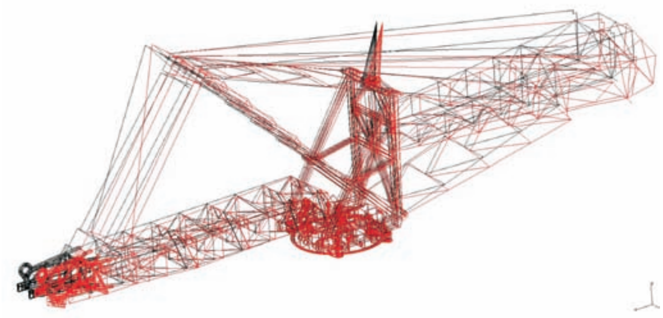

Fig. 5. 2nd modal mode ~ 0.829 Hz

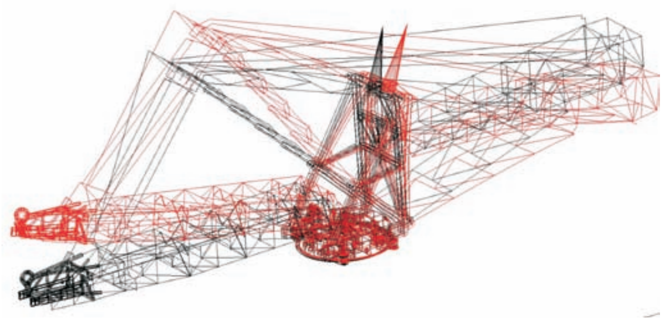

Fig. 6. 3rd modal mode 0.835 Hz

To excite the 6th normal mode, much bigger portion of energy is required. There is low probability to lead to the immediate failure of the structure. However, the construction will operate with the increased vibration amplitudes. In longer time period, with high probability, this will lead to fatigue damage of structure members. Increased vibration amplitude is also unfavorable in aspect of the staff operating the machine. Eventually, down time and maintenance time will increase.

Many different support types and its influence on the structure dynamics were considered during numerical analysis. The length of the hanging member "l" (fig. 2) were reduced from initial 2010 mm to 1050 mm and finally up to 200mm. The influence on the 6th mode frequency was not significant. Changes in the structure did not affected on the remained modes.

In a consequence, new solution in the counterweight boom were introduced. Hanging member was replaced with a joint with only one (rotational) free DOF. Additional DOF (along longitudinal machine axis) on supporting structure joint was released (fig. 7). Modifications described above, influenced on the dynamic characteristics of the bucket wheel excavator.

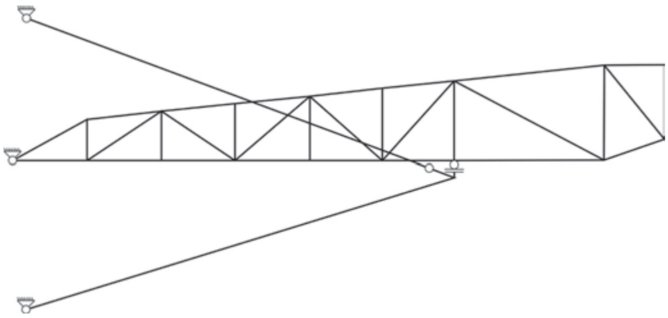

Fig. 7. Scheme of the final counterweight boom support

Eventually, the unfavorable mode observed in the preliminary design of the excavator do not occur any more. Structural mode of higher frequency (2.92 Hz) was released (fig. 8).

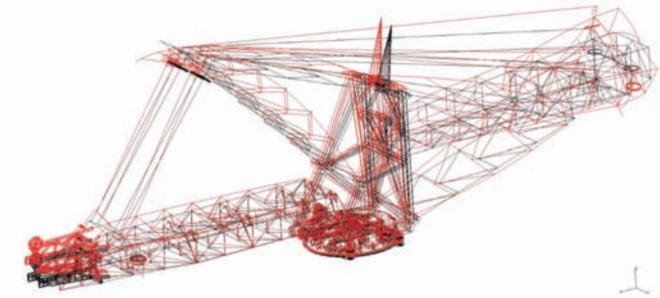

Fig. 8. Mode released after support modification

The deflection shape takes form of counterweight boom twisting and bending of the bucket wheel boom jib. The "new" mode do not refers to the excitation frequency and any of its harmonics. The changes in the eigenfrequencies of the remained modes are listed in table 1.

For the first three modes frequency increase with decreasing length of the hanging member. The biggest influence is observable in case of mode with major booms bending in the horizontal plane. In the primary solution it occurred as a second mode. After changing in the support, the mode was shifted to the 3rd position. For remained modes, except two last – already mentioned, no influence was observed.

Tab. 1. Normal modes frequencies

Mode	Frequency [Hz]				Mode
	l=2010	l=1050	l=200	support 2	
1	0,671	0,679	0,696	0,708	1
2	0,829	---	---	---	---
3	0,835	0,803	0,802	0,827	2
---	---	0,838	0,860	0,894	3
4	1,65	1,62	1,62	1,64	4
5	1,86	1,86	1,87	1,88	5
6	2,03	2,04	2,02	---	---
7	2,47	2,50	2,50	2,49	6
---	---	---	---	2,92	7

Summary and conclusions

Numerical modal analysis of the complex multibody structures (bucket wheel excavators, spreaders) is multi stage process requiring experience in the field of object dynamic analysis. Correct results can be achieved after taking into account interactions between many subassemblies, especially hoisting system. Influence of the operational conditions should be also taken under consideration.

Presented approach to the construction and design procedure is advanced and complex way of structure dynamics optimization in the preliminary project. Moreover, it was revealed that significant influence on structural modes can be done by changing support type without mobility change. Presented approach to the design process of new structurally complex objects, positively affects on the methodology of the project and the final product.

Regardless of the complexity of the methodology and use highly advanced tools, the dynamic characteristics identified on the way of simulations and calculations can differ from the characteristics of the real objet. Production and assembly process of steel load carrying structures like bucket wheel excavators, spreaders etc. introduce to many changes into the final product. Moreover, models used in simulation are the simplified one. Boundary conditions base on assumptions and may slightly differ from the real one. Plenty of the external factors are neglected. Some of them may influence on the final construction. To find out what the exact dynamic characteristics of final product are, field testing are required. Application of experimental and operational modal analysis will give complex information about the normal mode of idle machine and under operational load. With those information it is possible to plan the most appropriate operation and maintenance. As final result, the down time will be decreased and the durability will be higher [8].

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