Results of the modal analysis of the underground mine hydraulic leg in various modes of its operation

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Abstract. The article describes the construction of models and the initial conditions for the various modes of legs operation. The article presents the way of setting the initial conditions for the initial thrust with constant pressure and for leg operation in the mode of increased pressure caused by the lowering of the roof. The results of modal analyses conducted for 2 modes of leg operation are shown. It is shown that the form and frequency of natural oscillations of hydraulic legs are determined by their design, pressures of the initial thrust and nominal operating resistance, as well as by the operating modes which differ in schemes of interaction of leg elements with interacting elements of the support and the roof and floor strata. At the same time, changing the operating mode of the legs changes the natural frequency both to the higher and to the lower side, as well as the form of oscillations of certain frequencies. For more accurate calculation of the frequency response of hydraulic legs to the external load of frequencies, it is proposed to take into account not only their design and power properties, but also the modes of their loading.

1. Introduction

In mining the coal seams with hard-to-cave roofs, there are often situations in which the main roof rocks hang as a beam or cantilever plates, and further face advancing leads to their collapse accompanied by the dynamic manifestations of rock pressure [1-3]. According to the results of previous studies [4-6], the amplitude and speed of movement of the roof in such cases depend on the physical and mechanical properties and thickness of the roof rock strata, the pitch of its collapsing, and the type, size and distribution of the support resistance along the width of the near-face area.

The main element of the powered roof supports, preventing the lowering of the roof in the working face, is the hydraulic leg [7-11], failure of which negatively affects the operation of the whole longwall equipment. The total cost of the service of mining equipment for the service life can be 4-8 times the cost of its acquisition.

In this connection, an increase of hydraulic performance is an actual scientific problem. The dynamic loads due to lowering of the roof rocks and acting on the powered roof supports are the main cause of deformation and failure of the elements of hydraulic legs. If the frequencies of the external loads are close to the frequencies of the natural legs oscillation, occurrence of resonance becomes possible, which will lead to their destruction. To detect this condition in the designing of mining machines and their components exposed to dynamic loads, the modal analysis method is applied.

2. Model creation and implementation of the modal analysis

In most cases, the powered support legs have double extension. However, at a first approximation to get the results of modal analysis, the leg model can be made in a simplified way with one extension. This will significantly reduce the number of leg elements, simplify the model and decrease the computation time. As an example, the article presents a model of the leg with the main overall dimensions of the powered support 'M138' (Figure 1).

The model includes the following main elements: a hydraulic cylinder (consisting of cylinder 3, guide sleeve 4, nut 5, piston rod assembly 6), two mounting supports of powered support 2 and 7 simulating the base and the canopy, and two rock blocks 1 and 8 simulating floor and roof, respectively.

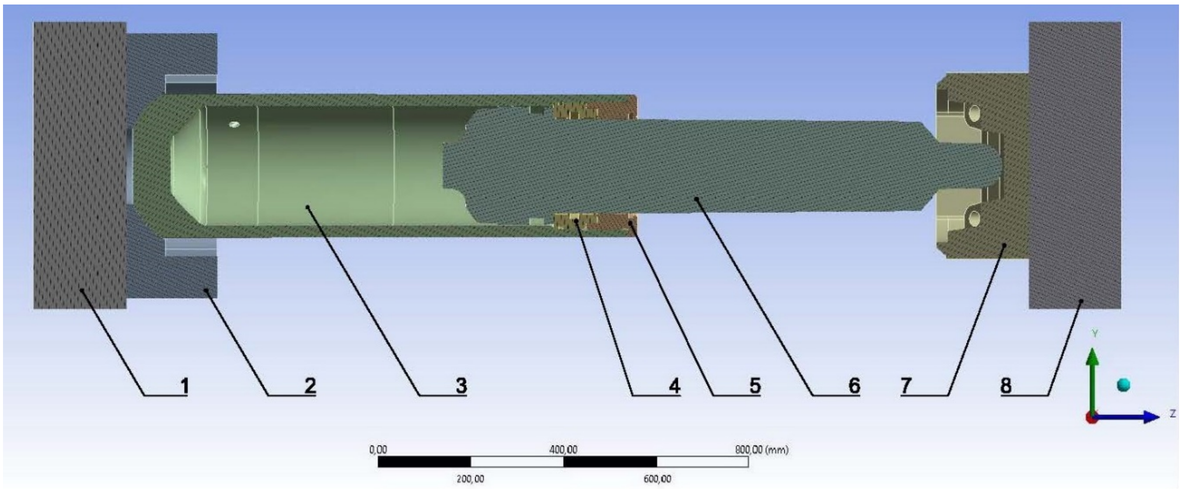

Figure 1. The leg model:
1 – floor block; 2 – lower support; 3 – cylinder; 4 – guide sleeve; 5 – nut; 6 – piston rod assembly;
7 – upper support; 8 – roof block.

All the elements of the model are assigned the density, Young's modulus, Poisson ratio and yield strength of the respective materials. For the hydraulic cylinder, this material is steel 30HGSA, for mounting supports, it is structural steel, and for blocks of the rock – sandstone.

To simulate movable joints in the supports (between the support and the cylinder, between the support and the rod), and movable joints of the leg seal assemblies (between the piston and the cylinder, between the guide sleeve and rod), contact pairs are created.

The principle of operation of the powered supports legs is the same for all, and is as follows. When the hydraulic fluid is fed into the piston chamber, the rod extends resting on the roof, and the pressure of the initial thrust (1st mode) is achieved. Then the pressure in the piston chamber increases due to the movement of the roof rock (2nd mode). When the limit pressure value in the piston cavity corresponding to the pressure setting of the safety valve is achieved, the leg transfers in the mode of constant resistance, i.e. in the operating mode.

To evaluate the effect of the leg operation modes on its natural oscillation frequency, two models are created for two modes of operation. The first model for the first mode corresponds to the leg operation during the initial thrust, wherein the travelling of blocks of roof rocks and floor rocks is prohibited, and constant pressure of 32 MPa is applied to the inside of the piston cavity.

In the second model, the floor block is fixed stationary and the roof block is assigned the travel in the axial direction corresponding to the increment of the pressure from the initial thrust to the working resistance, and the working resistance pressure is applied to the surfaces of the piston cavity of the hydraulic cylinder.

The initial conditions for the second mode of operation are shown in Figure 2.

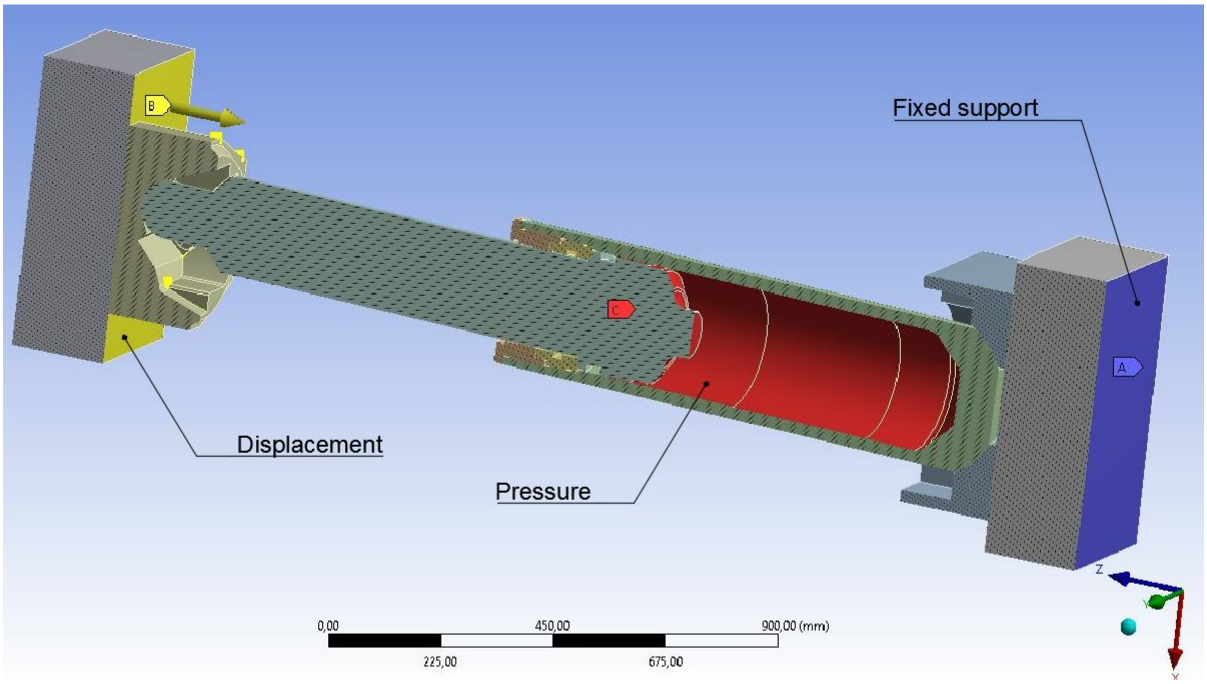

Figure 2. The Initial conditions for the second mode of operation

Pressure change ΔP in the piston cavity of the hydraulic cylinder depending on piston travel ΔL is called the elastic compliance value, the technique of its determination is presented by V.N. Khorin and is determined by the following formula.

$$\Delta P = \frac{\Delta L}{(2c+\beta)L},$$

where ΔL – change in leg extension, m;

L – leg extension, m;

β – the working fluid compressibility factor, m^2/N;

c – the coefficient taking account of the deformations of the working cylinder;

$$c = \frac{\dfrac{R^2+r^2}{R^2-r^2}+\mu}{E},$$

where, R and r – respectively the external and the inner radii of the working cylinder, m;

μ – Poisson ratio of the cylinder material;

E – Young's modulus of the cylinder material, Pa.

In order to solve the tasks of the modal analysis, the first 10 modes were used.

In accordance with the formulas given above, for the ‘M138’ leg the maximum working pressure in the piston of 42 MPa, corresponding to the nominal operating resistance, corresponds to the displacement of the rod by value ΔL = 5 mm.

Since the leg design is subject to loading corresponding to the initial conditions and the accepted modes of operation, in order to obtain the results of modal analysis the determination of the stress-strain state is performed at first.

3. Results of calculations

The results of the modal analysis presented as the values of natural oscillations and their forms for the first 10 events during the 1st and 2nd modes of the leg operation are shown in Figure 3 and Table 1 which show that in the 1st mode in the lowest modes, the cylinder has multiple frequencies of its own oscillations (except for modes 9 and 10), which is typical for structures with axial symmetry. In the second mode with increased operating resistance, this symmetry is broken.

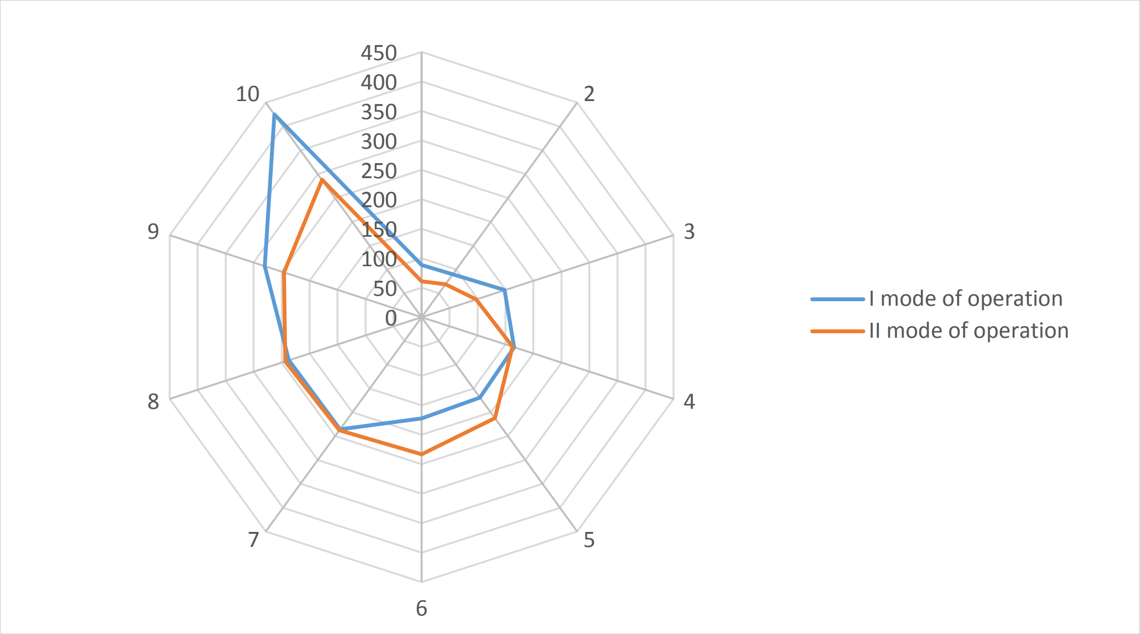

Figure 3. Natural frequencies for the first 10 modes

Table 1. Forms of oscillations of the first 10 modes of legs for various modes of their operation

Mode	Form of oscillation	
	I mode of operation	II mode of operation
1	lateral	lateral
2	lateral	lateral
3	torsional	torsional
4	torsional	lateral
5	lateral	torsional
6	lateral + torsional	lateral + torsional
7	lateral	lateral
8	lateral	lateral
9	torsional	lateral
10	torsional	lateral + torsional

For the modal analysis, the lowest natural frequencies are the most important, as in the event of resonance phenomena, the greatest deviations occur when external vibrations occur in the first (lowest) frequency (mode) of natural oscillations. When the frequency of the external load coincides with higher modes, the intensity of resonance phenomena decreases. Therefore, the properties of the design structure which include both structural features and load values can be characterized using the first frequency. The majority of the finite-element softwares solve the problem of determining the natural vibration frequencies with the best approximation for the lower frequencies and the first frequency does not change, even if the number of elements is increased many times.

This statement is consistent with the mining processes, because the frequencies of external loads from the cutter machine and secondary collapse of the roof are in the order of 100 Hz.

The presented data results of the modal analysis show that the increase of pressure and rod displacement occurring at the transition from the 1st mode to the 2nd lead both to reduction of the natural frequencies (modes 1, 2, 3, 9, 10), and to their increase (modes 5 and 6). In modes 4, 7, 8, the frequencies do not change. While the frequencies of natural oscillations vary on average by ± 10 to 15%. In addition, in modes 4, 5, 9, 10, the form of oscillation changes.

Figures 4 and 5 show the examples of oscillation in mode 4 for the first and second modes of operation.

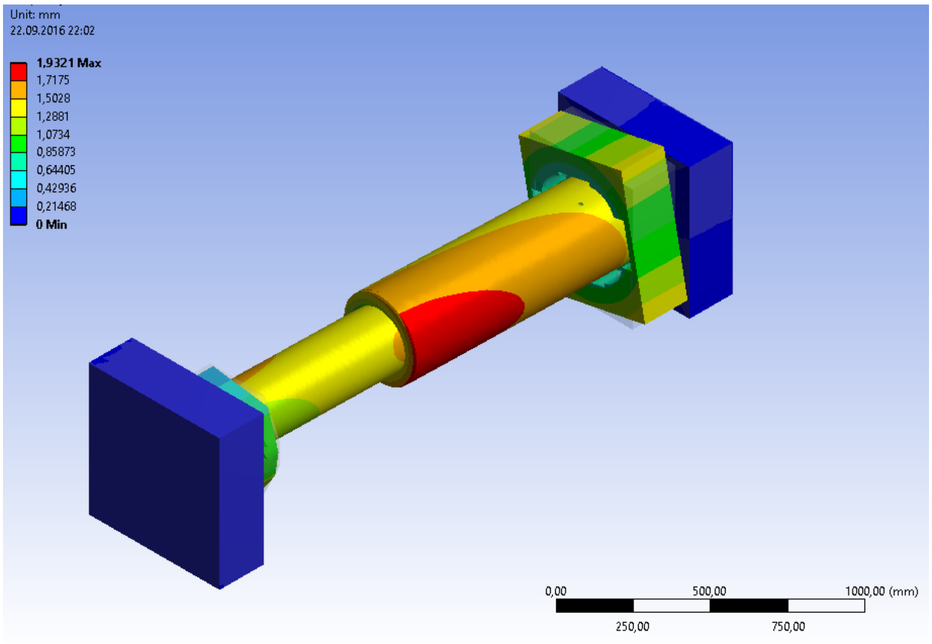

Figure 4. The form of natural oscillations in mode 4 of the 1st mode of the operation (torsial oscillations)

For a better visual display, the results of the modal analysis of the first mode of the operation for the torsional oscillations at a frequency of 165.45 Hz are enlarged 50 times, for the second mode of the operation during the lateral oscillations at a frequency of 155.61 Hz, they are enlarged 5 times.

During torsional oscillations, the maximum displacements occur at the junction of the hydraulic cylinder bottom and the lower support. During transverse oscillations, the maximum displacements occur in the area of the piston location. The amplitude of the transverse oscillations is about 1.7 times higher than torsional oscillations.

Changing of the forms of oscillations during increasing operating resistance indicates the presence of bifurcation points, the location of which is determined when all other things are equated by the working fluid pressure in the piston cavity of the hydraulic leg. This circumstance must also be taken into account when designing the sections of powered supports for specific geological conditions.

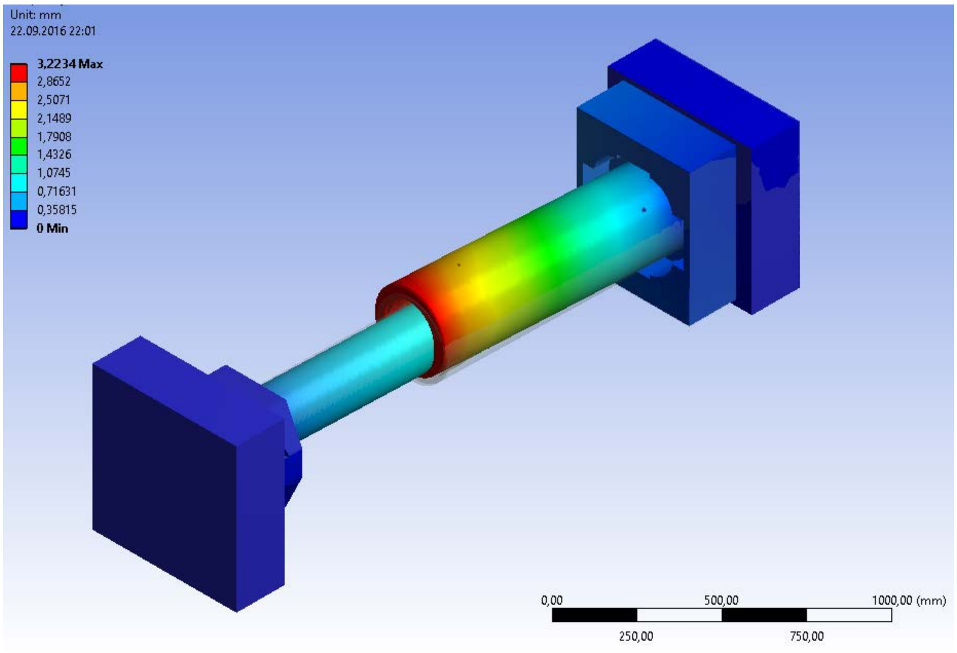

Figure 5. The form of natural oscillations in mode 4 of the 2nd mode of operation (lateral oscillations).

4. Conclusion

The form and frequency of natural oscillations of hydraulic legs are determined by their design, pressures of the initial thrust and nominal operating resistance, as well as by the operating modes which differ in schemes of interaction of leg elements with interacting elements of the support and the roof and floor strata. At the same time, changing the operating mode of the legs changes the natural frequency both to the higher and to the lower side, as well as the form of oscillations of certain frequencies.

For more accurate calculation of the frequency response of hydraulic legs to external load of frequencies, it is proposed to take into account not only their design and power properties, but also the modes of their loading.

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