Modelling the movement of slurry in the channel of a nature-like pump used for the safety laying of the worked out space

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Abstract. The most important task of the production of the mineral raw materials industry is to increase the efficiency of the equipment and infrastructure in operation. In particular, this also applies to the need to create transport systems with high productivity while reducing the cost of transporting mineral raw materials and waste from its processing. Particular attention is paid to the use of hydraulic filling systems as a measure to prevent man-made tectonic earthquakes during prolonged and continuous development of deposits. In this paper, we consider the problem aimed at solving the fundamental problems of developing effective methods for controlling the flow of pasty substances in pipelines of variable cross-section, intended for the production of pumping equipment and used in such industries as mining, chemical, food, etc.

1. Introduction

Nearly half of the world's mining companies use mining systems at their facilities, associated with laying out the developed space. Activities for laying work are carried out in order to increase the safety of mining operations, namely, to control rock pressure, reduce possible loss of minerals during excavation, prevent the occurrence of underground fires, as well as sudden emissions of coal and gas, protect against destruction of objects in residential areas [1].

A study of the long-term effect of the laying works on the seismic potential of the workings shows that these works help to stabilize the disturbed rock mass not by a one-time decrease in the intensity of the process of its destruction, but as a decrease in the period of seismic activity after laying. A study of the workings using filling materials of various compositions made it possible to establish that hydraulic filling leads to earlier (approximately 10 years faster) seismicity attenuation (figure 1).

During hydrotransport of the filling mixture into the worked out chamber, it is impossible to place it under the working roof due to the peculiarity of the hydraulic mixture spreading process, which leads to the appearance of empty cavities [4]. The consequence of an incomplete backfilling is the subsidence and collapse of the roof of the worked out space, a violation of the strength of the formed filling array, as well as the formation of cavities for the breakthrough of groundwater [3].
2. Materials and methods

Efficient transportation of thickened filling mixtures with soil pumps is difficult due to the existing non-linear relationship between the efficiency and the concentration of the solid phase, as well as the kinematic viscosity coefficient [4, 5].

Most existing hydrotransport systems operate at low solids concentrations in the backfill stream. This causes a decrease in the technical and economic efficiency of filling complexes, as well as a significant increase in water inflow in the workings. In addition, it is worth noting, that in hydrotransport technologies, the dosage of the material supply to the pipeline is insufficiently used, as well as the adjustment and control of the parameters of filling mixtures, as a result, the hydrotransport systems of the filling complexes of mining enterprises operate in non-economical and unstable modes.

Taking into account the properties of the materials used as a binder, activator, and filler in the process of preparing the filling mixture to obtain an array of the required parameters, the specifics of the process of pumping the mixture to the place of laying, the use of fundamentally new hydrotransport technologies is becoming increasingly relevant [6].

At St. Petersburg Mining University, work is underway to create a pumping unit - an induction peristaltic mono-pump. The equipment transports the hydraulic mixture by moving local waves of deformation of the working chamber-channel, made of a magnetically active elastomer, arising under the influence of a traveling electromagnetic field.

A traveling magnetic field arises in the space surrounding the array of alternating current conductors displaced in phase and arranged in sequence along the length of the array. Denoting the direction and density of the lines of force emerging from the plane of a given lattice in the form of a curve, we can obtain the distribution of the normal component of the induction of the traveling magnetic field over the inductor for a given moment in time. In the ideal case, this curve is a sinusoid (figure 2).

The wave process in which a field appears in some places along the inductor and disappears in others is comparable to the translational motion of a wave. The translational motion of the traveling magnetic field wave externally manifests itself as the actual movement of the magnetic poles induced on the surface of the inductor and the magnetic field lines associated with it.
3. Discussion
During the simulation, the motion of the magnetic field wave was interpreted as a sequence of superposition of forces corresponding to the alternate switching on and off of magnets. The diagram of the inclusion of magnets is shown in figure 3. Since the magnetic forces are clamping, they act against the Y axis and are set with a minus. In turn, the switching circuit is designed so that at least one point always remains active.

During the simulation, rubber (silicon rubber) was adopted as the matrix material of the magnetically active elastomer [7]. Technical characteristics of the final material are given in table 1.

The camera-channel of a mono-pump can be considered as a flexible body along which forced waves of deformation of contraction and elongation move. In this case, there is no movement of particles in the pipeline. In a certain section, the pipeline is compressed, reducing the cross-sectional area, and subsequent sections expand. Moving sequentially along the length of the camera channel, a moving wave is formed. Compression of the pipe allows the mixture to be pumped in a laminar flow with a relatively low shear stress.

Figure 2. The mechanism of formation of a traveling magnetic field: the direction of the currents in the conductors of the inductors.

Figure 3. Scheme of the force action of magnets on the camera-channel.
Table 1. Technical characteristics of magnetoactive elastomer.

| Characteristic                              | Value  |
|--------------------------------------------|--------|
| Density, kg/m³                             | 1200   |
| Breaking stress, MPa                       | 9.4    |
| Tensile strength, MPa                      | 2.55   |
| Offset yield strength, MPa                 | 1.7    |
| Modulus of elasticity, MPa                 | 6.8    |
| Elongation at conditional yield strength, %| 26.4   |
| Elongation at maximum load, %              | 94.2   |
| Elongation at fracture, %                  | 26.1   |

In order to take into account the influence of the slurry accompaniment located in the working chamber-channel of the pump, Hydrostatic Pressure was created acting on the inner surface of the tube (figure 4). The density of the liquid is set to 3000 kg/m³, taking into account the influence of acceleration of gravity.

![Figure 4](image-url)  
**Figure 4.** Deformation of the chamber-channel of the pumping unit under the influence of the passage of the "wave" of the magnetic field.

Depending on the characteristics of the pumped substance, the relief and the cross-sectional area of the chamber-channel varies to achieve optimal performance and energy efficiency [16, 17].

The relief of the inner surface of the pipeline provides structuring of the flow, as well as its mixing at the same time as transportation, which prevents delamination of inhomogeneous media (figure 5) [15, 16].

![Figure 5](image-url)  
**Figure 5.** The working chamber channel of the peristaltic mono pump with a raised internal surface: 1 - general view; 2 - particle trajectory in the channel (from right to left).
Based on the known properties of the chamber-channel material and the parameters of the transported medium, the model allows one to evaluate the bursting forces on the pipe walls, as well as evaluate the necessary force to move a portion of the substance.

The sum of all the forces acting on the hydraulic mixture in the chamber channel is equal to:

\[ F = (\rho_r g - \rho_{\infty} g - \delta B) \]

where \( \rho_r \) - is the density of solid particles, \( \rho_{\infty} \) - is the density of the liquid phase of the slurry, \( g \) – is the acceleration of gravity, is the current density, \( \delta \) - is the current density, \( B \) – is the magnetic field induction.

4. Conclusion

The use of a peristaltic nature-like mono-pump in development systems with laying out the mined-out space will allow creating “mobile” filling complexes that allow work to be carried out in remote areas, in workings in which drawdown of the filling array is observed.

Increasing the completeness and uniformity of filling the worked-out space with a filling mixture of workings will limit the negative impact of underground mining on adjacent territories and reduce the risk of man-made earthquakes.

The developed mathematical model makes it possible to take into account the design parameters of the working chamber channel (position, dimensions, material, etc.) of a nature-like peristaltic pump, sets the laws for changing the hydraulic resistance parameters under conditions of wave changes in the internal section of the peristaltic mono-pump section under the influence of magnetic field energy.

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