UDC 621.65

M. A. VASILYEVA, *Associate Professor, Candidate of Engineering Sciences, saturn.sun@mail.ru*

Saint-Petersburg Mining University, St. Petersburg, Russia

MAGNETIC PERISTALTIC PUMPS FOR BACKFILL

The third of the mineral mining companies in the world use systems with backfill. Backfilling is intended to enhance safety, implement ground control, reduce possible losses of minerals, prevent underground fires, or coal and gas outbursts, and to protect objects in residential areas from destruction.

In view of the features of backfill mixture components, specificity of flow to filling points and the required backfill quality standards, it is increasingly urgent to have novel technologies for backfill mixture handling. A cardinally new approach to transportation of liquid and viscous media is the use of low-frequency magnetic peristaltic pumps based on the nature likeliness.

Key words: *backfill, magnetic pumps, hydraulic transport, hybrid materials, pipelines, nature-like technologies, pumping equipment.*

DOI: *10.17580/em.2019.01.08*

Currently hydraulic method takes around 85% in amount of backfilling while mechanical stowing makes only 15%. Haulage of backfill materials in mined-out voids is the critical link in the chain of mineral mining processes [1].

Transport of backfill mixes at long horizontal ranges needs various auxiliary equipment, including vibratory, as power of hydraulic mix flow become insufficient due to high head losses [2–4]. Pipeline transportation of backfill mixes suffers from rapid wear of pipes due to high abrasiveness of solid in hydraulic fluid. At the same time, when backfill flows at the velocity lower than the critical value, the flow splits, which results in slitting of pipes, nonuniform feed of backfill and, consequently, degradation of solid backfill mass quality [5, 6].

In many mines, aiming to improve flowability of hydraulic fluid, backfill mixture is added with excess water, which decreases strength of the backfill mass due to extra water content. As a consequence, binder is washed away from the backfill mass, layering of the latter is intensified, and and its seismic activity grows after completion of backfilling [7–11].

At the same time, design features of modern pumping equipment places essential constraints on concentration of backfill mixtures, and even a slight increase in the concentration of the pumped material greatly affects operation efficiency and power demand of the pumps during hydraulic fluid transportation. Around 50% of total energy consumption falls at the mineral mining and processing sector, including 40% of energy spent to provide transport processes. The majority of the existing systems of hydraulic transport operate with low concentrations of solid in backfill mixture flow, which impairs technical-and-economic efficiency of the transport and largely increases water inflow in mines. On the other hand, high-performance handling of heavily thickened mixtures by soil pumps causes complexities due to prevailing nonlinear dependence between the efficiency and solid concentration as well as the kinematic viscosity coefficient. Furthermore, hydraulic transport technologies insufficiently take advantage of proportioning of mixture feed in pipeline, as well as adjustment and control of parameters. As a consequence, hydraulic transport systems of mine operate in uneconomical and unstable modes.

Actually the market present various design pumping equipment capable to pump hydraulic fluid with high content of solid—to 80 mass percent. The dominant types of positive displacement pumps are piston and peristaltic pumps. In recent years, peristaltic pumps become more used for metering flow of hydraulic fluids [12]. Improved design and technological advances in development of materials to manufacture operating channels allow expanding the application range of such pumps. From market research, manufacture and use of peristaltic pumps are booming due to universal advantages of the machines. The peristaltic pumps currently in use are equipped with special rigid rod with thick walls and heavy reinforcement, and more than half of the energy consumed spreads in thermal emission in the material the operating channel is made of.

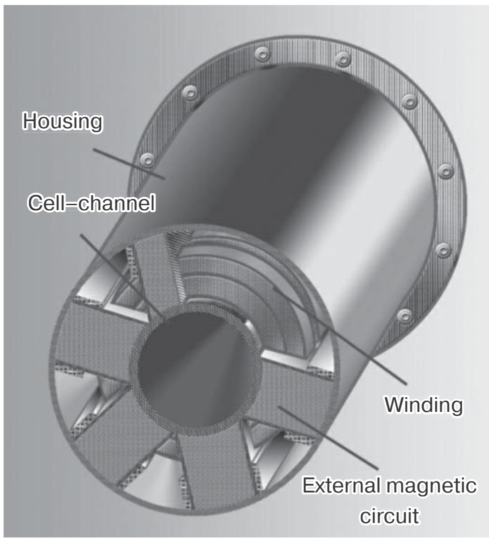

Fig. 1. General view of low-frequency magnetic peristaltic pump

A cardinally new approach to transportation of paste and viscous backfill mixtures at long ranges and to hard-to-reach areas in mines is employment of low-frequency magnetic peristaltic pulsation pumps engineered at the Saint-Petersburg Mining University. The housing of the pump protects the operating channel made of magnetically active elastomeric material. The inner surface of the operating channel has twist guideways to ensure agitation of hydraulic fluid and to prevent its splitting [13, 14]. Around the operating channel, the travelling magnetic field inducers are arranged (**Fig. 1**). The key distinction of this equipment is the absence of extra mobile parts to act upon the operating channel of the pump.

Hydraulic fluid flows under the action of local wave-like deformation of the operating channel made of magnetically active elastomeric material (**Fig. 2**). Contraction of the operating channel and, as a consequence, displacement of the fluid are cased by traveling magnetic field induced in the space around the lattice of dephased conductors definitely alternating along the winding.

The traveling electromagnetic field mechanism is illustrated in **Fig. 3**. The vectograms are presented for different moments, sequentially, in 1/6 ac cycle. The arrows show directions of the rotating current vectors above the abscissa axis in the given phase of the winding (Fig. 3a). Accordingly, when the current vector in this phase is under the abscissa axis, it has the opposite direction.

Having denoted directions and densities of force lines coming out of the plane of the current-carrying lattice, we obtain distribution of normal component of the traveling magnetic field induction above an inducer at the given moment of time (Fig. 2b). The length of this sinusoidal wave equals the double distance between the same phase conductors with oppositely directed currents, i.e. the double distance between the looped conductors. This distance is governed by the polar pitch of the winding.

The wave process, such that field appears at some places and disappears at the other places along the length of an inducer, looks like progressive motion of wave. The wave motion of the traveling magnetic field presents as variation of altitudes of magnetic poles induced on the surface of the inducer and the related force lines of magnetic flux.

The wave velocity is determined by the wave motion by its length equal to 2τ in the time of the ac period: $T = 1/f$, where f is the frequency, Hz.

The efficient length of EMF per unit length of conductor is found from the formula: $E = \sqrt{2}B\tau f$, where B is peak value of the magnetic field induction, T; τ is the polar pitch of the winding. The value E is necessary for the peak/effective value conversion of the magnetic field induction.

The average electromagnetic force per unit length of conductor is $F = B^2\tau f\gamma$, where γ is the conductor metal conduction.

The pressure of the electromagnetic forces is found as the ratio of the summed electromagnetic forces across the width of the channel to the channel cross-section area:

$$D = \frac{\sum Fs}{l \cdot \Delta} = B^2 \tau f \gamma s l \tag{1}$$

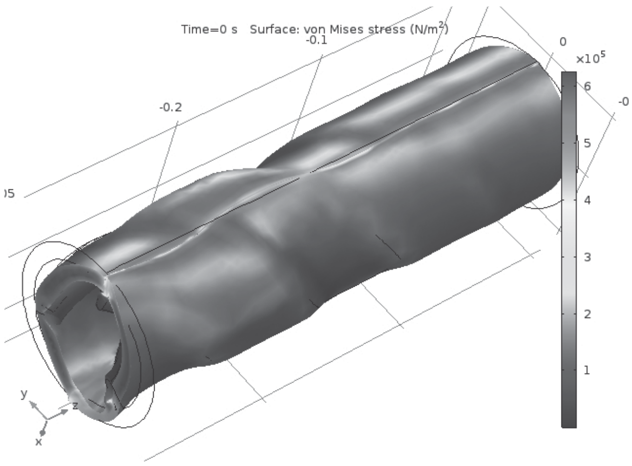

Fig. 2. Travel of local strain wave in the variable section operating cell–channel

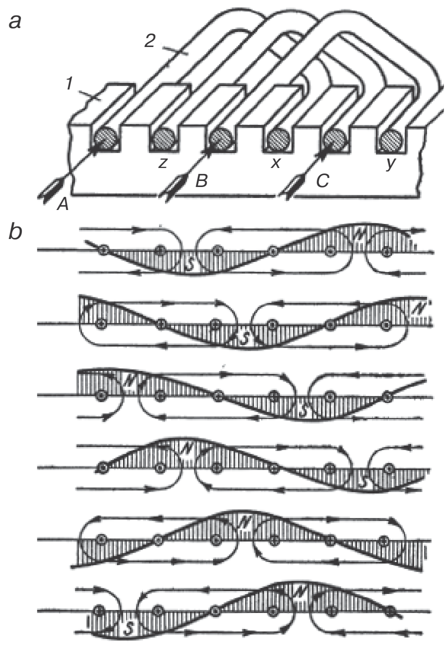

Fig. 3. Traveling magnetic field mechanism:
a—inducer; *b*—current directions in inducer conductors: *1* — magnetic circuit; *2* — winding; signs + / – define current directions

The pressure of the pump is governed by the shape of the loops of the currents induced by the traveling magnetic field. When the operating channel is narrow and the induction currents loops are elongated, the ratio of the active and inactive sections of the loops is unfavorable, and the pressure of electromagnetic forces, all other conditions being equal, is much lower than with the comparatively wide operating channel. This distinction limits the option of pressure increase by arbitrary enlargement of the polar pitch of the winding as follows from (1).

Furthermore, spreading of induction currents in the cross sections of the loop closer the the channel end causes nonuniform distribution of electromagnetic forces

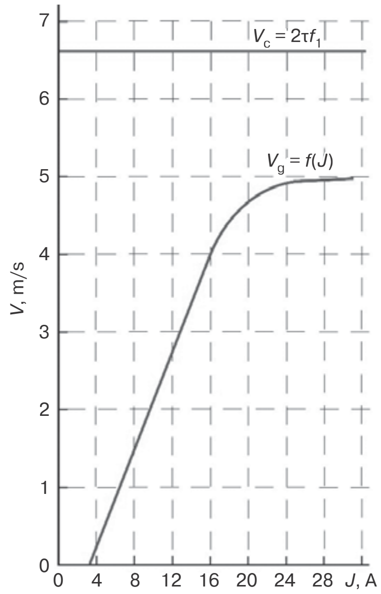

Fig. 4. Influence of current force in magnetic field generator coils on local strain wave velocity in operating cell–channel

across the cross-section area of the channel. These phenomena make the edge effect which lowers the electromagnetic force pressure. In this respect, this pressure is determined from Fridkin's formula [15]:

$$D = B^2 \tau f \gamma s l K_\Delta. \quad (2)$$

The value of K_Δ is found from Voldek's analytical formula [16]:

$$K_\Delta = 1 - \frac{th\left(\pi \frac{c}{\tau}\right)}{\pi \frac{c}{\tau}} \quad (3)$$

where c is the half-width of the channel.

The observations show that the local strain wave velocity is sufficiently stable during transportation of different materials and weakly depends on the material viscosity (**Fig. 4**).

As against the current designs of backfill pumps, the magnetic peristaltic pumps permit varying the material handling velocity in a wide range directly during operation.

Conclusions

1. The known merits of underground mineral mining with backfill are sometimes unimplemented due to imperfection of the applied technologies. Recently the technologies and equipment based on the nature-likeliness enjoy vivid development.

2. The operating cell–channel made of magnetically active elastomeric material to replace the conventional roller system in pumps, to structure fluid flows and prevent fluid splitting can expand application range of pumping equipment.

3. The pumping equipment design such that backfill flow velocity and the pump pressure are independent of the backfill mixture viscosity but directly depend on the electrical parameters will enable efficient backfill operations in distant openings in mines.

References

1. Starkov L. I., Zemskov A. N., Kondrashev P. I. Development of machine-assisted potash mining. Perm : PGTU, 2007. 522 p.
2. Aleksandrov V. I., Kibirev V. I. The Kachkanarsky MCC iron ore processing tailings slurry hydraulic transport parameters determination. *Obogashchenie Rud*. 2018. No. 1. pp. 56-63. DOI: 10.17580/or.2018.01.10
3. Aleksandrov V. I., Kibirev V. I. Estimation of efficiency of hydrotransport pipelines polyurethane coating application in comparison with steel pipelines. *Obogashchenie Rud*. 2016. No. 2. pp. 51-56. DOI: 10.17580/or.2016.02.07
4. Blekhman I. I., Blekhman L. I., Vaisberg L. A. Vibration overcomes gravity—Nonlinear effects, simple models. *Dynamics of Percussion–Vibration (Highly Nonlinear) Systems : Proceedings of XVIII International Symposium Devoted to the 100th Anniversary of Doctor of Engineering Sciences, Professor A. E. Kobrinsky*. Moscow, 2015. pp. 64–72.
5. Pushkarev A., Podoprigora N., Dobromirov V. Methods of providing failure-free operation in transport infrastructure objects. *Transportation Research Procedia*. 2018. No. 36. pp. 634–639.
6. Liss N. Y., Kremcheev E. A., Afanasiadi K. I. Reclamation of salinized land at tailings ponds at ALROSA. *Gornyi Zhurnal*. 2017. No. 10. pp. 65-69. DOI: 10.17580/gzh.2017.10.14
7. Guidelines for mine flooding safety and protection of undermined objects in mining the Upper Kama potash salt deposit (production procedures). Saint-Petersburg : VNIIG, 2008.
8. Aglyukov Kh. I. Ground control with creation of high-density artificial filling masses. *Izvestiya vuzov. Gornyi zhurnal.* 2004. No. 5. pp. 9–15.
9. Verkholantseva T. V., Dyagilev R.A. Influence of backfilling on seismic activity in potash mines. *GIAB*. 2016. No. 12. pp. 222–224.
10. Borzakovsky B. A., Papulov L. M. Backfill operations in the Upper Kama potash mines. Moscow : Nedra, 1994. 234 p.
11. Adushkin A. A., Turuntaev S. V. Stimulated seismicity—induced and triggered. Moscow : IDG RAN, 2015. 364 p.
12. Vasilyeva M. A. An overview of development trends for the pumping equipment of mining and processing enterprises. *Obogashchenie Rud.* 2019. No. 1. pp. 51-56. DOI: 10.17580/or.2019.01.08
13. Vasilyeva M. A. Perspectives of application of 3D shape memory composite materials for peristaltic transportation of slurries. *Key Engineering Materials*. 2015. Vol. 685. pp. 291–294.
14. Fuhrer R., Schumacher C. M., Zeltner M., Stark W. J. Soft iron/silicon composite tubes for magnetic peristaltic pumping: Frequency-dependent pressure and volume flow. *Advanced Functional Materials.* 2013. Vol. 23(31). pp. 3845–3849.
15. Birzvalks Yu. A. Equivalent circuit of the dc pump channel and maximum efficiency pump design. Applied Magnetodynamics: Transactions of the Institute of Physics. Akad. Nauk LatSSR, 1961.
16. Kovalenko A. I., Klimova T. G. Determining the parameters of a synchronous generator with the use of synchronized phasor measurements. *Izvestiya vysshikh uchebnykh zavedenii. Elektromekhanika*. 2018. No. 1. pp. 20–24.