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Ways to improve the efficiency of cleaning cutting fluids

***Abstract**. The article deals with the problem of improving technologies and technical means of magnetic cleaning of cutting fluids from mechanical impurities. To solve this problem, the authors propose a scientifically based analysis of the interaction of particles of various shapes with a magnetic field in the deposition process to develop mathematical methods for calculating an electromagnetic sump. A technological scheme for the extraction of ferromagnetic impurities is proposed.*

***Streszczenie.** Artykuł dotyczy problemu doskonalenia technologii i środków technicznych magnetycznego oczyszczania cieczy chłodząco-smarujących z zanieczyszczeń mechanicznych. Aby rozwiązać ten problem, autorzy proponują naukowo opartą analizę interakcji cząstek o różnych kształtach z polem magnetycznym w procesie osadzania w celu opracowania matematycznych metod obliczania studzienki elektromagnetycznej. Zaproponowano schemat technologiczny ekstrakcji zanieczyszczeń ferromagnetycznych. (**Sposoby poprawy efektywności czyszczenia płynów obróbkowych**)*

Keywords: magnetic field, cutting fluids, electromagnetic sump, mechanical impurities.
Słowa kluczowe: pole magnetyczne, ciecze chłodząco-smarujące, studzienka elektromagnetyczna, zanieczyszczenia mechaniczne.

Introduction

It is known that great difficulties arise in the abrasive treatment of parts restored by surfacing, spraying, and other metal surfacing methods. These difficulties are due to the uneven allowances, the instability of the properties of the deposited metal and other factors that worsen the working conditions of the abrasive tool. At the same time, one of the main reasons affecting the quality of the restored surfaces of the part is the level of contamination of the cutting fluid with mechanical impurities [1, 2].

Solid particles, getting into the contact zone of the tool with the workpiece, because increased wear of the working surfaces of the tool, worsen the microgeometry of the machined workpiece surface, cause blunting of the abrasive grains and clogging of the abrasive wheel. As a result, the zone of stability of the processing process is significantly narrowed, and the roughness parameters increase.

The simplest devices for cleaning lubricating-cooling liquids from mechanical impurities are settling tanks, which are based on the principle of gravitation - the action on particles of only mass forces of gravity.

Currently, most of these devices are structurally imperfect, have low productivity and do not allow a high degree of purification, since they require additional costs for the process. The development and creation of technologies and devices to improve the process of cleaning cutting fluids today is one of the main tasks of high-quality restoration of automotive parts.

The intensification of the process can be carried out by chemical or biological means, which leads to environmental pollution or the use of electrical technologies. The introduction of electrotechnological methods provides an increase in labor productivity, saving material and labor resources, and reducing the harmful effects on the environment [3,4].

Our studies [5] have shown that the vast majority of mechanical impurities, as a rule, have magnetic properties. Therefore, there is a real prospect of using an electromagnetic sump.

Thus, it is possible to increase the efficiency of cutting fluids from mechanical impurities using a technological scheme for extracting ferromagnetic impurities with an electromagnetic sump.

Information analysis of research and publications

The process of sedimentation of mechanical impurities is well studied and successfully used to purify cutting fluid in settling sumps [6,7]. Despite this, predicting the operation of electromagnetic sump in the design of sedimentation in heterogeneous suspensions has not gained significant popularity. This is due to the complexity of the mathematical description of the particle settling process, which depends on a large number of interacting factors: the concentration of mechanical impurities and their settling rates, the nature of the liquid flow inside the settling tank, etc.

The use of mathematical models based on a single parameter (for example, the residence time of mechanical impurities in the sump) reflects only the average performance of the sump and gives only a qualitative idea of the process.

To calculate the required traction force, which ensures the deposition of a certain recoverable body on the surface of the pole system of the sedimentation tank, it is necessary to solve a complex dynamic problem of particle motion through a liquid medium.

In horizontal settling tanks, the supply and discharge of liquid is carried out continuously, without any supply and mixing devices, therefore, the movement of the medium is steady or laminar, that is, the particle velocity v_p coincides with the flow velocity v_f at any point.

The ratio of the inertial forces to the friction forces arising from the motion of a particle in a liquid medium is characterized by the Reynolds number, the value of which should be less than unity [8]:

(1) $$\mathrm{Re} = \frac{d_p \cdot v_p \cdot \rho_d}{\eta_l} < 1$$

where d_p - particle diameter, m; ρ_d - medium density, kg/m^3; η_l - dynamic viscosity of the liquid, Pa·s.

On a particle, that moves in a flow of a viscous non-magnetic fluid along the *y*-axis under the influence of a magnetic field, in addition to the resistance force of the medium F_m, the forces of gravity and Archimedes F_A, magnetic field F_M, magnetic coagulation F_k (Fig. 1).

Since the extraction of a particle is a dynamic process, the calculation of such a motion can be based on the equation of dynamics according to Newton's second law. If you compose and solve an equation that includes the acting forces, then you can get the trajectory of the particle, which gives an idea of the extraction of particles

(2) $$\frac{d}{dt}(m\bar{v}_p) = \bar{F}_m + \bar{F}_A + \bar{F}_M + \bar{F}_k$$

where m - particle mass, kg; v_p- particle speed, m/s.

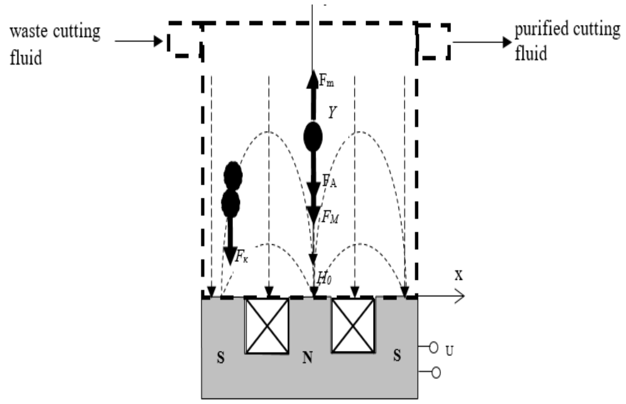

Fig. 1. Forces acting on a particle in the working area of an electromagnetic sump

Such an approach to the solution, without estimating each of the forces, leads to unjustified complication and cumbersomeness of the equations. This eliminates the possibility of deriving the final equations characterizing the magnetic capture of particles in an analytical form, as well as equations that are convenient in engineering calculations. Therefore, to create new or improve existing calculations, first, it is necessary to consider the basics of the theory and make an analysis of the methods currently used.

Taking into account (1), the applicability of the law of resistance of the medium F_M, which is determined according to the Stokes law, is determined:

(3) $$F_M = 3 \cdot \pi \cdot d_p \cdot \eta_l \cdot (v_f - v_p) \cdot k_f$$

where v_f - fluid flow rate, m/s; k_f - dynamic particle shape factor.

When moving, the particle is affected by gravity and the Archimedes force:

(4) $$F_A = V \cdot g \cdot (\rho_p - \rho_l)$$

where V- particle volume, m^3; g - free fall acceleration, m/s^2; ρ_p - particle density, kg/m^3.

At present, the strength of the magnetic field acting on a particle in cleaners of various designs is determined from the expression [9]:

(5) $$J = \sum_0^{\infty} A^2 \sin \omega t + \int_0^{\infty} \sqrt{B_1^2 + C_2^2} + \frac{4\pi}{\mu_0} \int_V \frac{J \times r}{r^3} dv$$

where μ_0 = cons = 4π·10^{-7} - magnetic constant, H/m; χ - magnetic susceptibility; V - volume of the particle, m^3; H, *gradH* - the intensity of the magnetic field and its gradient, A/m and A/m^2, respectively.

For magnetic materials magnetic susceptibility, is a function of the magnetic field strength. For any values of H, the magnetic susceptibility of metal-magnetic materials can exceed the magnetic susceptibility of diamagnetic materials by hundreds of thousands of times; therefore, the magnetic force F_M acting on a magnetic body in an inhomogeneous field will be hundreds of thousands of times greater than the force acting on a particle from a diamagnetic material. This is the basis for the extraction of magnetic particles (metal particles) from liquid media.

The derivation of formula (5), accepted in theory, is based on the energy method, which is based on the use of the energy formula for dia- and paramagnets in a magnetic field. However, since magnetic settling sumps are intended mainly for the extraction of ferromagnets, in this case such an energy approach needs to be clarified. In addition, for the "magnetic field source - moving ferromagnet" system, the problem of energy balance in the general case (without assumptions about the constancy of currents or source flux linkages) has not been solved, which creates certain difficulties in applying the energy method to the "sump - recoverable particle" system.

When formula (5) is used in practice, it is recommended to calculate the product *HgradH* for the point corresponding to the center of gravity of the extracted particle. However, this makes it possible to obtain an exact result only for the case when the condition *HgradH=const* is satisfied in the entire volume of the extracted particle. In magnetic fields of real designs of settling tanks, the product is not constant, but the error in the practical use of formula (5) can be reduced, for example, by multiplying the force F_M by some correction factor. Thus, in [10], by modeling magnetic particles, it was shown that the calculation of the magnetic field strength can be carried out according to the traditional formula (5) with the correction of the result by a special coefficient, which is introduced into formula (5). An analytical relation for the coefficient k_F was obtained, in the practical use of which it is necessary to take into account its dependence on the particle size and the distance of the particle to the surface of the poles of the magnetic system:

(6) $$\kappa_F = \frac{2}{3} \cdot \frac{\left[Y^2 + 0{,}25 \cdot s_p^4\right]^{1.5}}{d_p s_p} \cdot \left[\left[Y^2 + 0{,}25 \cdot (s_p - d_p)^2\right]^{-1.5} - \left[Y^2 + 0{,}25 \cdot (s_p + d_p)^2\right]^{-1.5}\right]$$

where s_p - interpole pitch, m.

Of course, when calculating magnetic sedimentation tanks, other formulas can also be used, but the applicability of formula (5) seems to be the most convenient for several reasons: for small sizes of a magnetic particle, it can be characterized by a constant parameter for the entire volume of the particle (depending only on the material, shape, and particle size ratio); secondly, formula (5) contains one characteristic of the magnetic field - the strength H, to determine which, based on the analysis, there are various calculation methods and direct measurement.

In practice, the problem with the choice of a constructive variant is solved experimentally. For this it is not required to know the absolute values of the attractive forces, it is only necessary to take into account the ratio of forces for various options.

Based on the foregoing, we can conclude that the existing calculation methods are not correct, which is due to the complexity of the mathematical description of the process of particle settling in settling tanks. Therefore, additional, both theoretical and experimental studies are needed.

Materilas and methods

The development and modernization of magnetic devices for cutting fluids from mechanical impurities are based on the following principles:

– the use of analogues and prototypes with optimal parameters (simplicity of manufacture, reliability and high efficiency in operation);

– the applied energy of the magnetic field in the working areas of the devices being developed was used in such a way that the force effect on the magnetic particles would maximize the efficiency of their extraction.

The principles listed above slightly increase the material costs for the manufacture and operation of the structures being developed, with a significant increase in the efficiency of their work.

Mathematical models of the process of extraction of particles in a magnetic field and their deposition on the poles of the magnetic system, calculation methods qualitatively (revealing the mechanism) and quantitatively (determining the numerical values of the parameters) were tested on a specially designed installation.

The scheme of the installation, with the help of which the experiment on the extraction of particles in a magnetic field was carried out, is shown in fig. 2. The installation consists of an electromagnetic winding (with the following parameters: number of turns 354; rectangular wire 3.5 × 2.4 mm; wire cross-section 13,2 mm^2; wire material - copper), block of rectifier diodes, ammeter, voltmeter, step-down transformer 220/12, regulating transformer LATR.

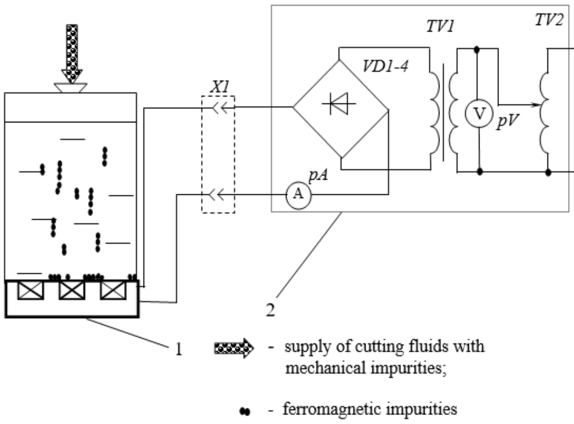

Fig. 2. Electrical circuit diagram of the experimental setup

We studied the movement of particles in a magnetic field created by the *W* - shaped magnetic system, the speed and time of extraction (deposition) at different parameters of the field strength, as well as other parameters necessary for mathematical modeling of processes and calculation of magnetic devices.

The main materials used in the experiment were: particles of spherical and ribbon shape (ρ_h=7,8·10^3 kg/m^3, m_h=3·10^{-3} kg), and glycerol was adopted as a medium (η_C=0,33 Pa·s, ρ_C=1,26·10^3 kg/m^3).

The use of this form of particles in the experiment was justified by the fact that they do not differ from the shape of particles of impurities in the coolant [5], and the use of glycerol makes it possible to study the dynamics of the behavior of single particles in a wide range of largenesses in a magnetic field, which is difficult to do in coolant. The main requirements for the experiment were: minimal material costs and maximum reliability of the results obtained.


Fig. 3. Experimental studies

The study of the extraction of single particles was carried out according to the following technique. Initially, the experiment was conducted in the absence of a magnetic field. A particle was placed in a glass ditch with glycerin and through certain parts of the path the stopwatch recorded the time of its deposition (Fig. 3).

The change in the field strength *H*, and hence the *gradH*, was regulated by the change in current *I* in the winding of the electromagnet. At different values of current *I*, the deposition of particles of spherical and ribbon shape was investigated.

Based on the experiments conducted, average dependencies have been constructed showing the change in the time of attraction of the particles of various shapes to the pole of the magnetic system (Fig. 4).

Results and discussion

Because of the obtained results, the following conclusions were made:

– the influence of the particle shape on the attraction time is insignificant, therefore, for the simplicity of the mathematical description, the shape of the particles can be assumed to be spherical;

– the time of attraction of particles to the pole with increasing field strength is reduced compared to the time of free deposition of 1,7; 2,1 and 5,3 times at *I* = 5A; 10A; 15A; 25A respectively.

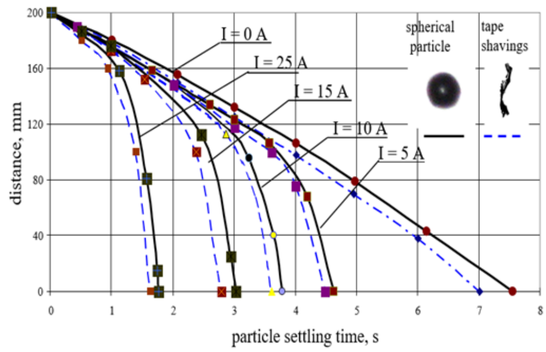

Fig. 4. Average dependences showing the change in the time of attraction of particles of different shapes to the pole of the magnetic system.

Based on the studies carried out, a technological scheme for the extraction of ferromagnetic impurities was proposed.

The technological scheme (Fig. 5) includes an inlet pipe 1, a working chamber 2, an outlet pipe 7, a magnetic wire 3 assembled from *W*-shaped plates, which are assembled in sections; an electric winding 4, a return pipe 6, a device 5 for determining the overall dimensions and shapes of ferromagnetic particles are installed and fixed in the grooves of the sections of the magnetic circuit 3 are installed and fixed in the grooves of the sections of the magnetic circuit. graph.

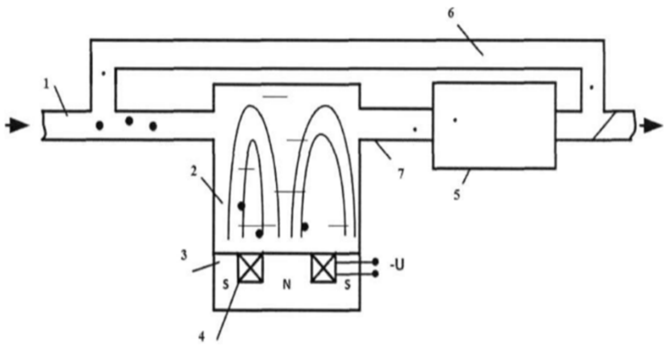

Fig. 5. Technological scheme of extraction of ferromagnetic impurities.

The scheme works as follows: the contaminated liquid is fed through the inlet pipe 1 into the working chamber 2. When the electric winding 4 is connected to a DC source 3, floccules and ferromagnetic particles are deposited on the poles of the electromagnet. The purified liquid enters the outlet 7. For a more accurate determination of the small particles remaining in the liquid, the liquid through the outlet 7 enters the device 5 for determining the overall dimensions and shapes of ferromagnetic bodies. In device 5, the liquid is scanned to determine the particles that remained after deposition. If the device 5 detects unremoved particles, the liquid enters the return pipe and is cleaned again [11].

Thus, the use of a technological scheme will allow increasing the degree of purification.

Conclusions

Because of the studies, the following conclusions were drawn:

- the influence of the particle shape on the attraction time is insignificant;
- time of attraction of ferromagnetic particles in a magnetic field is reduced in comparison with free deposition;
- the proposed technological scheme of magnetic cleaning of cutting fluid improves the quality of cleaning and reduces the frequency of regeneration.
- application of the scheme will also save energy consumption for regeneration.
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REFERENCES

[1] Nadolny, K., Kieraś, S. & Sutowski, P. Modern Approach to Delivery Coolants, Lubricants and Antiadhesives in the Environmentally Friendly Grinding Processes. Int. J. of Precis. Eng. and Manuf.-Green Tech. 8, 639–663 (2021). https://doi.org/10.1007/s40684-020-00270-y

[2] Wu X, Li C, Zhou Z, Nie X, Chen Y, Zhang Y, Cao H, Liu B, Zhang N, Said Z, Debnath S, Jamil M, Ali HM, Sharma S. Circulating purification of cutting fluid: an overview. Int J Adv Manuf Technol. 2021;117(9-10):2565-2600. doi: 10.1007/s00170-021-07854-1. Epub 2021 Aug 26. PMID: 34465936; PMCID: PMC8390089.

[3] S. L. Gundebommu, M. Victor, R. Olena, and B. Yurii, "Justification and development of methods building curves boundary deformation of metals," in *Materials Today: Proceedings*, 2021, vol. 38, pp. 3337-3344.

[4] Yermakov, T. Hutsol, S. Glowacki, V. Hulevskyi, V. Pylypenko. Primary Assessment of the Degree of Torrefaction of Biomass Agricultural Crops. *Environment. Technologies. Resources*. 2021. pp.264-267. https://doi.org/10.17770/etr2021vol1.6597

[5] V. Prosvirnin, V. Hulevskyi, B. Savchenkov. Analiz zabrudnen' mastyl'no-okholodzhuval'nykh ridyn pry vidnovlenni detaley transportnoyi tekhniky. *Visnyk KHNTUS·H. Kharkiv,* 2008. Vol. 69. pp. 162-167. http://elar.tsatu.edu.ua/handle/123456789/5106

[6] M. Henze, P. Harremoes, J. La Cour Jansen and E. Arvin, "Wastewater Treatment Biological and Chemical Processes," 3rd Edition, Springer, Berlin, 2001.

[7] Iowa Waste Reduction Center, "*Cutting Fluid Management: Small Machining Operations*" (2003). Iowa Waste Reduction Center Book Gallery. 12. https://scholarworks.uni.edu/iwrc_facbook/12

[8] Jeffery G.B: The motion of ellipsoidal particles immersed in a viscous fluid, *Proc. Roy. Soc*. A102 (1922) pp. 161 – 179.

[9] Purcell, Edward M. Electricity and magnetism / Edward M. Purcell, David J. Morin, *Harvard University, Massachusetts. – Third edition. pages* cm ISBN 978-1-107-01402-2

[10] Al'-Zureykat Fauzi Mansur Makhmud. Pidvyshchennya efektyvnosti zastosuvannya shkivnykh elektromahnitnykh separatoriv : avtoref. dys... kand. tekhn. nauk: 05.09.01 / Al'-Zureykat Fauzi Mansur Makhmud ; Donets'kyy natsional'nyy tekhnichnyy un-t. Donets'k, 2003. 19 s.

[11] Hulevskyi, V., Haliman, L., Nesterchuk, D., Voronovskyi, I., Petrov, V. *Elektromahnitnyy vidstiynyk: pat.* 128571 Ukrayina: MPK (2006.01): V02S 1/00, V02S 1/02. № a 201803339; zayavl. 30.03.2018; opubl. 25.09.2018, Byul. № 18. http://elar.tsatu.edu.ua/handle/123456789/6838