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Creation of High-Performance Devices for Technological Equipment Electric Heating for Mining and Smelting Enterprises

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Low-temperature electric heating devices for manufacturing equipment adapted to mining maintenance are created, the advantages of electric heating are discussed, the results of existing electric heating devices analysis are given, the way of improving the vibration resistance of the heating elements.

Keywords: LOW-TEMPERATURE ELECTRIC HEATING DEVICES, THE EFFICIENCY OF ELECTRIC HEATING, VIBRATION, CONTACT CONNECTION

Introduction

It is acknowledged that electric heating in comparison with other forms of heating has a number of technical advantages. The most important of them are:

- The possibility of high power concentration in a relatively small volume;
- Obtaining of very high temperatures and release of heat energy directly into the heated material;
- Elimination of the effect of the heat source on the chemical composition of the medium, which is heated;
- The ability to control and regulate easily the amount of energy released;
- Ensuring the necessary accuracy and uniformity of heating.

Due to the high efficiency of electric heating in many industrialized countries national programs of replacement of technologies based on combustion of fuel for electric heating have long been developed and implemented. For example, in France the proportion of electricity used for heating reached 35%, while in Ukraine and CIS countries it does not exceed 10%. And it is despite the fact that compared with the beginning of 2007, when electric heating was 2.2 times more expensive than the gas one, in April 2011 the cost of gas and electric heating almost leveled off (the price of gas has increased in average 4 times - from 750 to 3000 UAH. per 1000 m3, and electric power 2 times - from 0.28 to 0.56 UAH / kW · h - with multi-tariff billing system). And if, until recently, electric heating was widely held back, mostly for economic reasons, it is now mostly due to the lack of affordable, energy efficient and, most importantly, reliable and adapted to real conditions of operation of heating devices.

Results and Discussion

The most widely used pipe electric heating units (heaters), which despite some advantages often do not provide the necessary technical and economic level of electric heating devices. Their main drawback in these cases is their form, because of which they create only concentrated heat release, and relatively high temperature of the heating element. At the same time the extremely broad class of devices that use eletric heating need distributed heat release at a certain area, often at relatively low temperatures. Sometimes the heating elements are subject to additional requirements due to technological, economic and constructional requirements, e.g. flexibility, thinness, low heat retention, vibration resistance, efficiency, etc., which can not be met through the tubular heaters.

According to this, recently more and more popular become the researches and development of electric heating devices with other types of active heating elements, including the use of new materials and technologies. **Table 1** shows the results of the analysis of electric heating devices, field and conditions for their use in steel, coke and mining enterprises.

During the last 8-10 years a sufficient quantity of low-temperature heating devices of different purposes and design, mostly foreign or manufactured in the joint ventures according to the imported technologies have appeared in the Ukrainian market. The most appropriate for heating manufacturing equipment are flexible silicone heating elements Hotform (Germany), flat heating elements of Russian enterprises such as ONYX, Special Systems and Technologies, Pribor, TeploRegion, Энергия тепла, etc. a wide range of heaters, "Nomacon" (Belarus), electric heating plate and flat heating elements of Ukrainian enterprises "STRUM", "Kvirin", SC "Intmaks", etc.

The heaters of each of these companies have their advantages, but none of them did not fully meet the requirements of electric heaters to process equipment of mining and metallurgical complex such as:

- High reliability, electrical and fire safety in conditions of sudden temperature fluctuations at high mass concentration of aggressive chemicals and dust in the air, typical for the coke and steel production;
- High energy efficiency;
- Ability to maintain performance under vibration loads, thermal cycling and bending deformations;
- Low price;
- Maintainability, and manufacturability;
- Providing of the desired uniformity of temperature field.

Thanks to a systematic approach to solving the problem of creating electric heaters that meet the specified requirements, the scientists Donbass State Technical University in collaboration with PJSC Alchevsk Iron and Steel Works and Alchevsk Coking Plant managed to develop, manufacture and implement a series of electric heaters of flat and cylindrical surfaces, adapted to real operating conditions.

Research, development and optimization of low-temperature heating devices were based on the necessity to ensure a high level of electrical safety, energy efficiency and reliability in operation under vibration, cyclic bending and thermal deformations, aggressive and dusty environment.

High level of electrical safety and energy efficiency are the key indicators of any heating device, determining its reliability, performance and economic characteristics. During the study it was necessary to resolve two conflicting objectives: on the one hand, provide the necessary quality of electrical insulation, which is necessary to increase the insulation thickness, on the other hand, minimize the temperature difference ΔT between the active element of the heater and the heated object, what requires the reduction of the insulation thickness. Besides, the provision of a minimum ΔT has affects continuous operation resource of both temperature radiator and insulation package. It is known, for example, that lowering the temperature of nichrome wire from 1000 to 500 ° C increases its continuous operation resource from 6000 to 10000 hours. The dependence of lifetime from overheating for electrical insulation is more illustrative: according to Montzinger rule ΔT long temperature exceeding above permissible for each 10 ° C shortens twice the life of the insulation.

As a result of the research a number of heating devices for various purposes were developed on the basis of a multilayered structure with insulation package of new composite materials of high heat resistance and electric strength, what helps reduce the ΔT down to 50°C and increase the insulation resistance 1000 times greater than the normalized values in accordance with "Rules for electrical equipment installation". Besides, the presence of layers of material with low friction coefficient and low adhesion properties in the insulation package allows heating devices to operate continuously in conditions of thermal cycling and bending deformations. The multi-factor studies on the stand, showed that with the amount of deflection of 20 mm and at the temperature of 150-200°C heating elements without reducing the insulation can withstand at least 7000 cycles of bending deformations, what corresponds to approximately 6.5 years of daily three-shift operation of the heaters in the conveyor belts vulcanizers.

Almost all electrical equipment, which is operated by mining companies, regardless of where and how it is installed, is exposed to external and (or) internal loads: vibration, bump and various kinds of deformations. At the same mechanical effects occur both in working electrical equipment - if it is installed on a mobile object, and in non-working - during the transportation of the equipment to the place of operation. The most difficult in terms of mechanical loads are objects that are simultaneously exposed to both technological and transportation vibration.

One of these objects is a loading tamping machine. Such three machines operate in coke department number 3 of Alchevsk Coking Plant. Functional feature of these machines is the tamping process of the charge coal before loading it into the furnace, as well as periodic displacement

Table 1. The list of manufacturing equipment for heating

Heating objects	Heating product	Heating objective	Required product temperature, °C		Usage frequency	Production conditions	Recommended type of electric heater	Price of an electric heater
			min	max				
Fixed bunkers	Coal, charge, coke, mined rock, etc.	Freezing and sticking control	+40	+80	Cold season	Placement category I, dust level, aggressive environment	Silicone heater hotform (Hotset GmbH – Germany) Heating module of bunkers (JSC Энергия тепла, Russia) Heating element ТПН (JSC Kyirin, Ukraine) Heating element НЭП-222/380 (DSTU, Ukraine)	264 UAH/dm^2 952 UAH/dm^2 100 UAH/dm^2 68 UAH/dm^2
Fixed bunkers	heavy coal-tar products	Provision with the necessary viscosity (fluidity)	+70	+90	Constantly			
Moving bunker (transfercars, etc)	Coal, charge, mined rock, etc.	Freezing and sticking control	+40	+80	Cold season			
Vibrating chute, vibrating feeder	Coal, charge, mined rock	Supplementary freezing and sticking control	+20	+40	Cold season	Vibration, dust level	Heating module of bunkers (JSC Энергия тепла, Russia) Heating element НЭП-222/380 (DSTU, Ukraine)	264 UAH/dm^2 68 UAH/dm^2
Pipelines, pneumatic pipelines	Water, condensate	Freezing protection	+5	+20	Cold season	Aggressive environment, vibration	Self-regulating heat tape FSR, FSE. JSC Специальные системы и технологии, Russia Heating pipeline elements НЭП-222/380 (DSTU, Ukraine)	140 UAH/m 78 UAH/m
Oil pipelines, hydroarmature	Oil	Provision with the necessary viscosity of oil	+40	+60	Constantly or start heating			
Cabinets, instrumentation and automated control systems	Measuring devices, sensors, pulse tubes	Provision with the continuous work of instrumentation and automated control systems	+5	+20	Cold season	Aggressive environment	Cabinet heaters Elcer Cabinet heaters ОШ-420 (DSTU, Ukraine)	850 UAH/pce 780 UAH/pce
Equipment for conveyor belts and portable cables vulcanization	Rubber	Vulcanization	+140	+150	During repair work	Operating vibration, bend deformations	Silicone heater hotform (Hotset GmbH – Germany) Heating element НЭП-222/380 (DSTU, Ukraine)	264 UAH/dm^2 68 UAH/dm^2

of the machine on rails along the coke furnace battery. Usually, the choice of methods to protect electrical equipment from mechanical loads on the basis of the actual design of the object to depends on the developing of mathematical and (or) physical model, the analysis of which helps decide, what method of protection is the most rational. Because of the complexity of the object and effect of many factors it was decided to investigate the vibrational field in the current loading tamping machine at characteristic points of the vibration analyzer.

There are several design techniques for providing normal operation of electrical equipment: removing the possibility of resonance, the use of various types of shock absorbers and dampers, as well as rational distribution of equipment in areas with less congestion. There is the only technically and economically acceptable way to prevent resonance in the heating systems of the manufacturing equipment.

In accordance with the amplitude of the forced motion X of any mechanical system during power harmonic action under the influence of the disturbing force F is determined by the expression

$$X = \frac{F}{K\sqrt{\left(1-\omega^2/\omega_0^2\right)^2 + \left(2\varsigma\omega/\omega_0\right)^2}} \qquad (1)$$

where K – elasticity coefficient of the mechanical system; ω - the imposition frequency of the disturbing force; ω_0 - the free frequency of the system; ς - the damping factor of the system.

As it is seen from the formula (1) the greatest dynamic loads occur with the minimum value of the damping factor and close values of the imposition frequency of the disturbing force - ω, the free frequency of the system - ω_0, and reach their maximum (resonant) value at $\omega = \omega_0$.

In this case the damping factor of the system is calculated by

$$\varsigma = \frac{M_\partial}{2\sqrt{mK}}, \qquad (2)$$

where Ì ä - damping coefficient of the system; m - lumped mass of the system.

Analysis of formulae (1) and (2) shows that in order to prevent mechanical resonance at fixed values Ì ä and *K* it is necessary to downsize the system and, what is more important, ensure that the conditions under which $\omega_0 >> \omega$ or $\omega_0 << \omega$ (first condition is preferable during the obvious buff loads, the second - during vibration loads).

In order to determine the actual imposition frequency of the disturbing force with the help of vibration analyzer АГАТ, the spectra featured on **Figure 1** a spectrum of displacement, vibration velocity and acceleration of the fluctuations of hydraulic system line Τ3ΒΜ during tamping cycle of charge coal were obtained. The graph shows that the maximum amplitude of all three parameters is observed at frequency from 5 to 50 Hz. The free frequency ω_0 of the heating elements must not obviously be in the range. The free frequency ω_0 of the fluctuations of heating elements of various designs was determined by the same applied shock. This method is a simplified form of the definition of the free frequency and the obtained curved lines can not be considered absolutely correct, however, the highs of the lines correspond to the true values of free frequencies fluctuations. **Figure 2** shows the results of shock test of the pipes with a 30 mm diameter heater with bolt contact connection (**Figure 2a**) and with welded contact connection (**Figure 2b**). Prior to the analysis of the curved lines it should be noted that the most vulnerable node in the design of any heating device, operating under conditions of vibration exposure is a contact connection of the active element with current-carrying copper conductor. The use such means as screw joint, twisting, hammering, brazing, pressing, etc. as an electrical connection for various reasons is of little use when working in conditions of vibration. In some cases, cause of contact disruption can be intolerable weight of the contact elements, in others - the emergence of so-called "solder gap" due to different coefficient of linear expansion of the contact connections materials. To reduce the amount of solder gaps, the temperature coefficients of linear expansion α of contact materials should be almost identical. In this regard, materials such as nichrome X20H80 and copper are perfect to each other, since the nichrome $\alpha = 16{,}3 \cdot 10^{-6}\,^{\circ}C^{-1}$, and copper $\alpha = 16{,}6 \cdot 10^{-6}\,^{\circ}C^{-1}$. In order to connect the active element nichrome wire and current-carrying copper wire in DSTU heaters, a patented method in which the connection is in the "welding and soldering" without any fluxes and

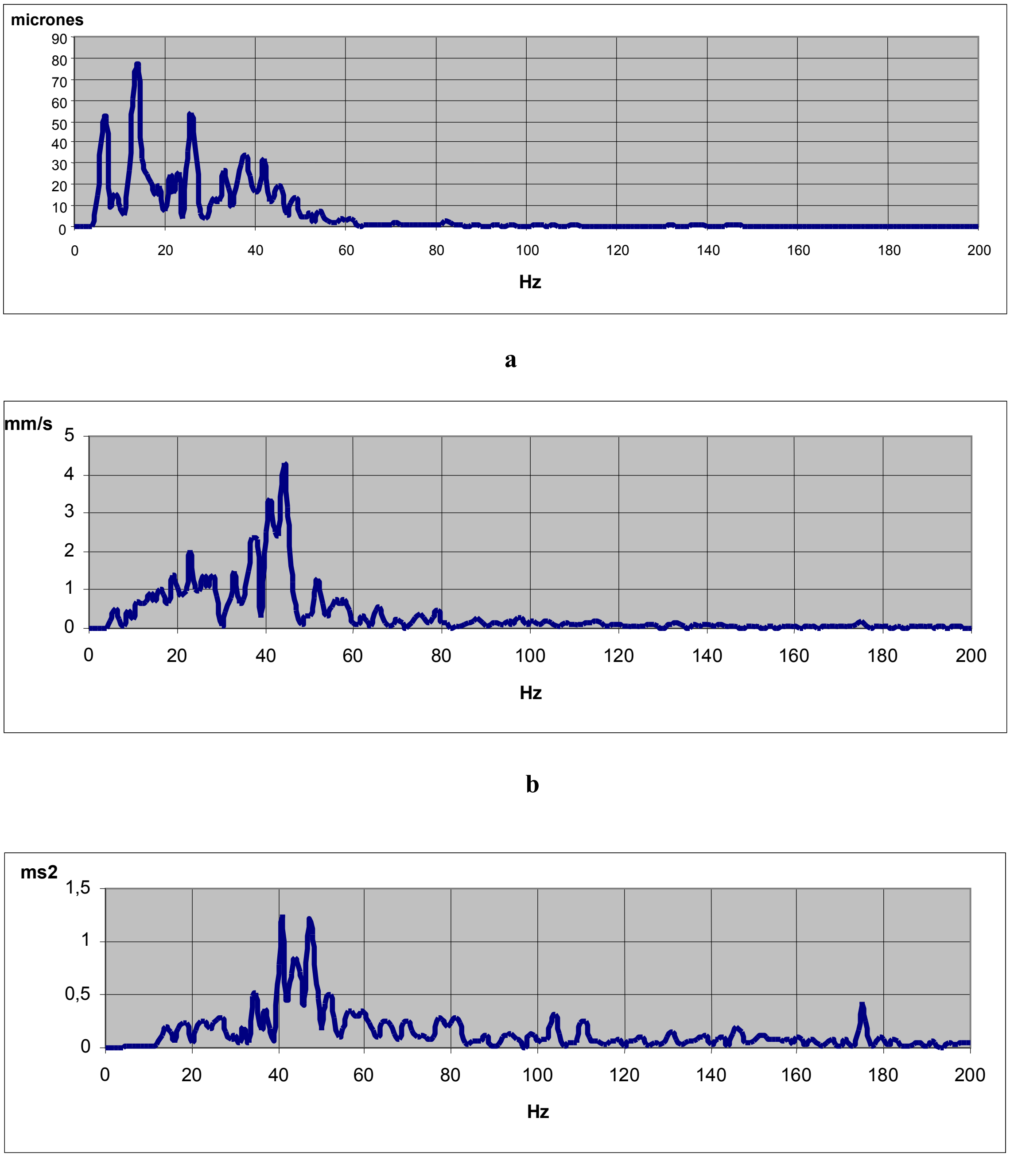
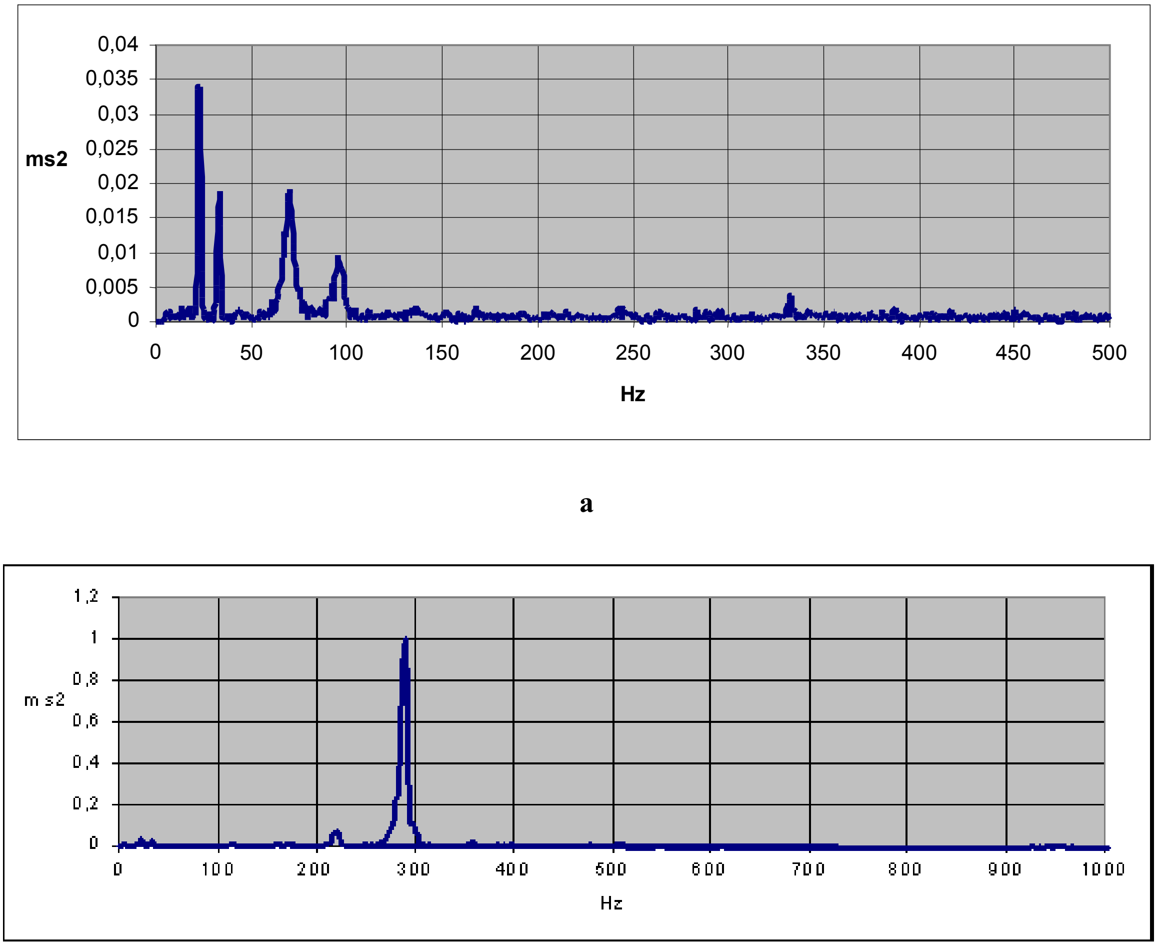


Figure 1. Dependence of the amplitude of displacement (a), vibration velocity (b) and vibration acceleration(c) on the fluctuation frequency of pipeline hydraulic system T3BM during tamping cycle of charge coal

solders, is used. As a result a small-sized and highly reliable contact connection is obtained, one of the most important its advantages of which is its very low weight. This advantage is confirmed by experimental data: **Figure 2a** shows that the free frequency of the heating element with bolt connection is in resonantly dangerous area of 25-100 Hz, while the welded connection "welding and soldering" increases the free frequency to 300 Hz, what eliminates resonance.

The designed heaters are installed in such production facilities of Alchevsk Coking Plant as a coke screen batcher, heavy coal-tar products decanter, hydraulic system T3BM № 1, № 2. Heating equipment for cabinets, pulse tube for desulfurization plants and flexible hydraulic connections T3BM № 3 are developed. Besides, conveying belts and flexible cables vulcanizers are equipped with the heating elements at PJSC Alchevsk Iron and Steel Works, DONETSKSTAL

Iron and Steel Works, JSC Балаклавское рудоуправление, Georgian company Georgian magnezian, LLC Ukrremservis, CJSC Zaporozhye Iron Ore Works, JSC Запорожское карьероуправление, etc.



b

Figure 2. Dependence of the amplitude vibration acceleration on free frequency fluctuations of the heating element with bolt contact connection (a) and with welded contact connection (b).

Conclusions

High-performance heating elements of manufacturing equipment, adapted to the conditions of the enterprises of mining and smelting complex were researched, developed and implemented.

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Создание высокоэффективных устройств электрообогрева технологического оборудования для предприятий горно-металлургического комплекса

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Созданы устройства низкотемпературного электрообогрева технологического оборудования адаптированные к условиям эксплуатации горно-металлургических предприятий, рассмотрены преимущества электронагрева, приведены результаты анализа существующих электронагревательных устройств, описан способ повышения виброустойчивости нагревательных элементов.