LOW-FREQUENCY CHANNEL FACILITIES FOR THE ELECTRICAL MELTING OF LOW-POWER METALS

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A new design of low-frequency channel facility is proposed, for smelting of fusible non-ferrous low-power metals with a submersible magnetic core. This design has advantages over the facilities made of traditional schemes. The dependences of the power and productivity of the furnace, as well as the resistance of closed loop of the metal, from the design, the geometric dimensions of the bath, weight and type of metal that can be used for engineering calculations.

Electrical methods of heating and melting of metals have significant advantages over the methods of firing, as in this case energy losses are significantly reduced, the negative environmental impact on the environment by is reduced by eliminating the emissions of combustion products of fossil fuels, reducing overheating, process is more manageable, can be automated, etc.

The most popular methods of electrical melting of metals are means of induction heating. These methods and facilities are divided into two principal classes:

1. High-frequency crucible facilities (Fig. 1), where the heat comes from the flow of induced eddy currents in the metal, which is placed in a crucible, as well as in the crucible itself. Power supply of these facilities is performed by high-frequency transducers (under the "rectifier - inverter" schema) at frequencies up to tens of kilohertz. Regulation of the melting process is to regulate the value of electric power supplied to the melt - this is provided by varying the frequency at the output of the converter. Bandwidth efficiency is limited by the current frequency and depth of current penetration into the metal - theoretical efficiency does not exceed 0.68.

2. Low-frequency channel facilities (Fig. 2), where the heat comes from the ohmic heating of the metal, forming a short-circuited coil in the melting bath, from the induced current in it at frequency 50 Hz. Power supply of these facilities is carried out directly from the production network. Regulation of the melting process is provided by changing the inductor voltage by switching the supply transformer taps or through a thyristor voltage regulator - as indicated in Figure 2. Bandwidth efficiency is theoretically unlimited, almost large enough - at the level of 0.8 ... 0.9.

Induction facilities are continuously improved, the requirements for range and quality of melted metal are increased, the environmental standards to minimize negative environmental impacts of human activities as well as the operation of technical equipment are getting stricter. In the latter case we have in mind the negative impact on the mains supply - distortion of the voltage curve and the high-frequency noise in the radio range, including the frequency range of cellular telephony. Sharply increased demand for facilities of low and medium power.

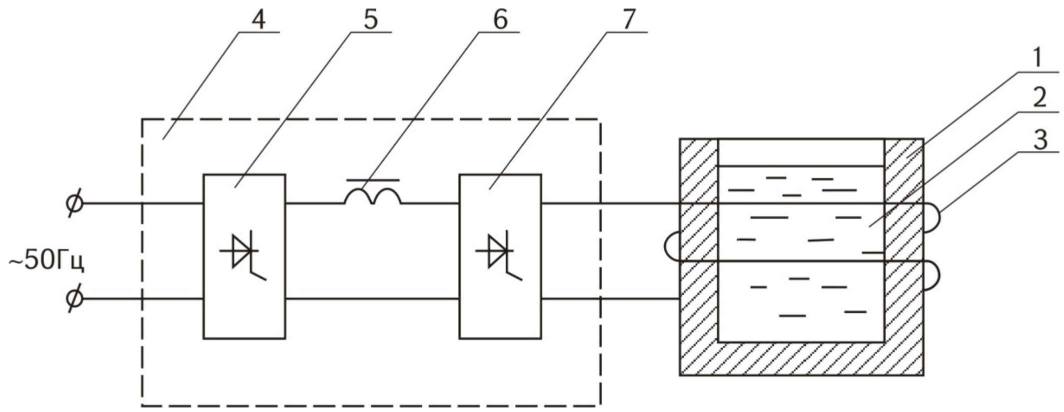

Figure 1. Block diagram of the high-frequency crucible facility: 1 – crucible; 2 – melt; 3 - inducer; 4 - frequency converter; 5 - rectifier; 6 - reactor; 7 - inverter

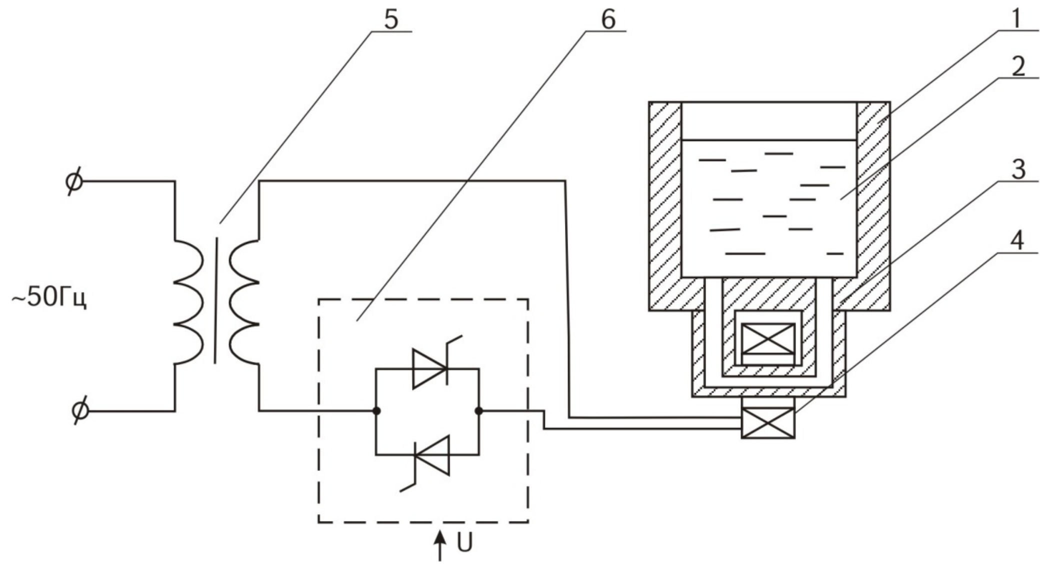

Figure 2. Block diagram of the low-frequency channel facility: 1 - melting bath; 2 - melt; 3 – channel; 4 - inducer (primary coil); 5 - transformer; 6 - thyristor voltage regulator

These issues are particularly relevant for facilities of small and medium-sized capacities - capacities from a few to several tens of kiloWatts. This is explained as follows:

- Low-power facilities have been developed and spread in relatively recent times, and are not perfect,

- Low-power plants have a pronounced specific techno-economic and energetic character, but they extend approaches and technical solutions typical to powerful facilities, which is unjustified and gives negative results,

- High-frequency crucible sets are traditionally favored, which is not fully justified, especially in the case of low-power installations,

- Existing low-frequency channel settings, having principal advantages due to the use of power-frequency (without high-frequency conversion), at the same time have significant disadvantages of a constructive nature, hindering their improvement,

- Low-power settings are subject to the production of individual and private businesses, which have the economic characteristics of the preferred value, but this has not been given sufficient attention.

The features of induction channel systems are the high electrical efficiency, which does not depend on the filling of the furnace with melt, which is sufficient for most processes within the circulation of the molten bath at a relatively calm mirror of the metal, as well as the ability to create furnaces with a large-capacity. On the other hand, the mandatory condition of operation of induction channel furnaces is to preserve the leftover of the melt in the furnace from the previous heat (typically 25-30% of the total capacity of the furnace) to save the initial conductivity of closed loop. Induction channel furnaces are designed for continuous operation with rare transitions from one brand of a metal to another.

The result is a number of following benefits of the low-frequency channel units with respect to high-frequency crucible ones:

- eliminating the need to use or create a special power supply - high-frequency transformers, which provides much lower installation costs,

- absolute stability of the switching power supply - a thyristor voltage regulator, as the principle of natural commutation of thyristors is implemented there,

- theoretically high efficiency, while the efficiency of high-efficiency crucible systems theoretically is limited to 68% [3,4], so the specific energy consumption of low-frequency channel settings on the melting of the metal (e.g. aluminum) is less than about 1.5 times than it is for the high-frequency coreless units.

- significantly lower levels of distortion of voltage and noise across the field, especially in the high-band reception of cellular telephone service.

The main disadvantages of channel furnaces are: the complexity of the design heating unit with a dedicated channel, as well as the lack of reliability due to the location of the primary coil in the hot zone, as well as special conditions for starting the furnace, and their mobility is lower in comparison with the crucible ones. Therefore, channel furnaces usually operate in a continuous loop. Furnaces of this type are well used to melt large amounts of one metal or alloy, as well as to maintain the temperature of already molten metal.

As a high-frequency crucible facilities, as well as low-frequency channel facilities of low-power, have certain common flaws caused by the fact that in low-power crucible and channel facilities that technical solutions are duplicated which are used in power plants. Such an approach cannot be considered appropriate. These deficiencies in the plants of small and medium power are becoming more relevant due to a larger quantity of distribution and other conditions of low-power facilities. Scientific and technical support of low-power plants of melting of metals needs to be addressed.

It is highly relevant to use the advantages and exclude disadvantages of low-frequency channel units.

We present a new concept of creation the channel settings of low-power for melting metals. We propose the construction, which eliminates the above drawbacks of existing constructions and method of economical calculation of low-frequency channel setup, performed at the level of patent of innovation (Fig. 3) [1].

The difference between the proposed channel installation and the existing ones [2-4] is the maximum coupling of induces transformer and a bath, which leads to an increase in the

coefficient of power transfer, reduces flows of scattering and increases the efficiency with simultaneous removal of the primary winding from the heated zone.

Channel furnace consists of a melting bath, a magnetic wire, the primary winding which is installed on the magnetic yoke, the yoke and the other part of the rods which are immersed in a molten metal blend. So, the primary winding is out of a furnace and connected to an adjustable power supply of 50 Hz power frequency.

Secondary winding is short-circuited coil, which is formed by blend and molten metal, which covered part of the yoke and embedded cores.

After the voltage is supplied to the coil, magnetic flux occurs in the magnetic wire, which induces an EMF in short-circuited loop consisted of coil and metal. Under the influence of EMF, current occurs in the entire bath, under influence of which the blend is heated. The resistance of closed loop depends on the volume of bath loading, the location of the rods, i.e. the sections of the closed loop, the contact resistance of blend pieces, the degree of melting, temperature of melt. In the process of heating, the temperature and the resistance of the coil are dynamically changing.

For given geometrical dimensions of the bath and the magnetic core of the inductor, the volume of blend loading and productivity (melting time), the main parameter that determines all the rest, is the active resistance of metal of the short-circuit loop - as the secondary winding of the inductor transformer.

To determine the active resistance of the metal of the closed loop, please see the calculated projections of the channel furnace given in Figure 3.

The short-circuit loop of the metal consists of the following, connected in parallel sections (Fig. 3):

two rod areas, bounded by lines of 1-2-7-4, and 2-7-10-3, each with a resistance Rc, (hereafter the indices are relatively small);

the two upper corner areas, bounded by lines 4-6-12-11, and 10-8-16-17 with resistance Ru1;

two bottom corner areas, bounded by lines of 6/12/13 and 8-16-15 with resistance Ru2;

the ground area, bounded by lines 6-8-15-13 with resistance Rd;

Taking a short-circuited loop in the monolithic metal state at a temperature of 20° C, the resistance of each section Rxi is determined by well-known expression:

$$R_{xi} = \rho \frac{l_i}{S_i}$$

where ρ - resistivity of the metal at a temperature of 20^0C, l_i - the average length of the coil on the given area, S_i - section of the coil at the site.
The resistance of the rod section is:

$$R_c = \rho[\frac{2a_1 + (p_1 + p_2) + (m_1 + m_2)}{ch_1} + \frac{b_1 + c}{(p_1 + p_2)h_1} + \frac{b_1 + c}{(m_1 + m_2)h_1}]$$

where the marks – are linear dimensions in Figure 3., a_1, b_1 - the size of the rod of magnetic core, taking into account the thermal insulation layer.

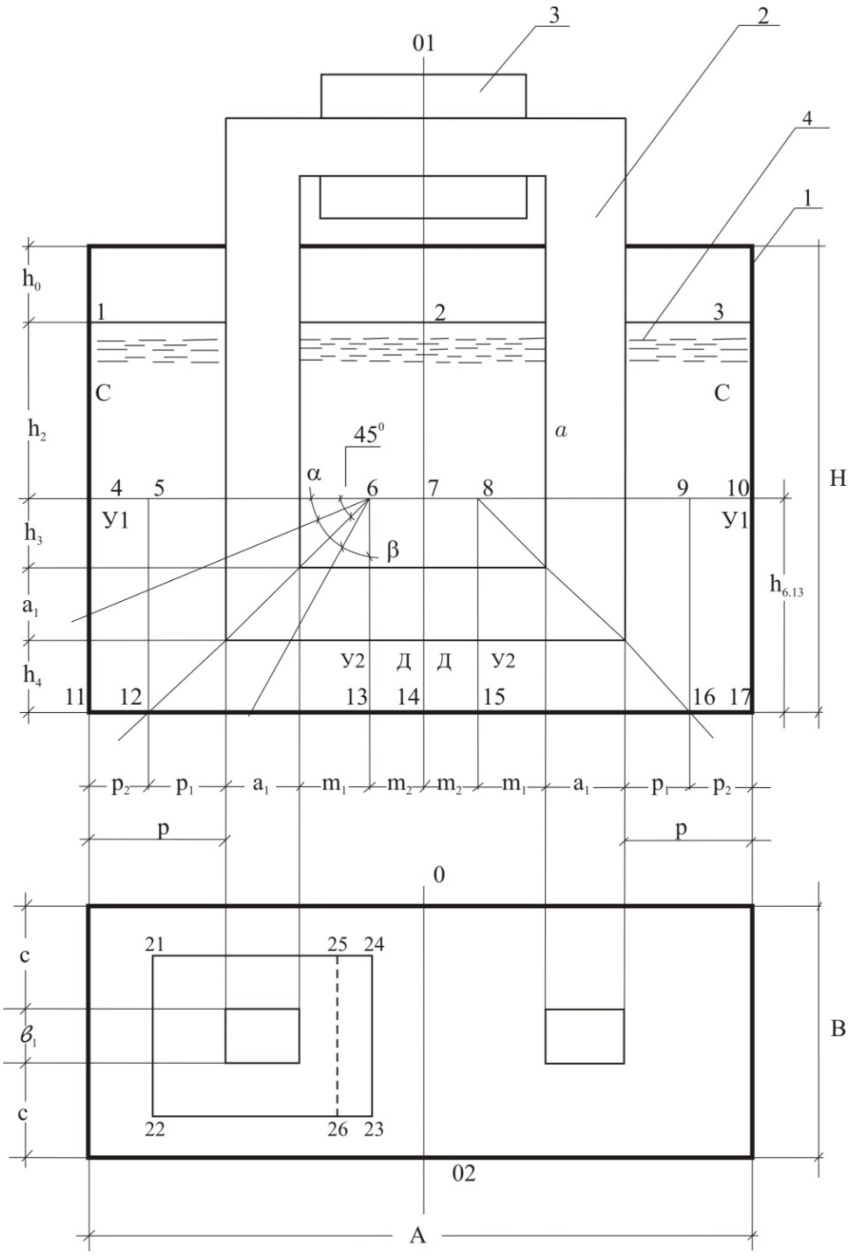

Figure 3. The general form and the calculated projection of the proposed channel furnace: 1 - melting bath; 2 - magnetic wire of the oven; 3 - the primary coil; 4 - blend

The resistance of the upper corner of the site is determined by integrating over the angular position of the elementary cross section (corner of α), given that the length and area of each elementary section are in functional connection with the angular position of the cross section:

$$\mathbf{R_{Y1} = \rho[\frac{F_1(a_1,p_1,p_2,m_1)}{F_2(a_1,p_1,p_2,m_1)} + \frac{b_1 + c}{(p_1 + p_2)(h_3 + a_1 + h_4)} + \frac{F_1(a_1,p_1,p_2,m_1)}{F_2(a_1,p_1,p_2,m_1)} + \frac{b_1 + c}{m_1(h_3 + a_1 + h_4)}]}$$

where $F_1(a_1,p_1,p_2,m_1)=\int_0^{45^0}\frac{2a_1+(p_1+p_2)+m_1}{2\cos\alpha}d\alpha$,

$$F_2(a_1,p_1,p_2,m_1)=\int_0^{45^0}\frac{c(a_1+p_1+p_2+m_1)}{2}\cdot\frac{\sin\alpha}{\cos^2\alpha}d\alpha$$

The resistance of the lower angular region is determined the same way, by integrating over angular position β:

$$R_{Y2}=\rho[2\frac{F_1(a_1,p_1,p_2=0,m_1)}{F_2(a_1,p_1,p_2=0,m_1)}+\frac{b_1+c}{p_1(h_3+a_1+h_4)}+\frac{b_1+c}{m_1(h_3+a_1+h_4)}]$$

The resistance of the ground region equals to:

$$R_g=\rho[\frac{b_1+c}{h_3m}+\frac{2a_1+h_3+h_4}{cm}+\frac{b_1+c}{h_4m}]$$

The conductivity of the closed loop of the metal equals to the sum of conductances connected in parallel sections. From there, the total active resistance of the closed loop of the metal is determined, Rx:

$$R_X=\frac{R_CR_{Y1}R_{Y2}R_g}{2\left(R_{Y1}R_{Y2}R_g+R_CR_{Y2}R_g+R_CR_{Y1}R_g+R_CR_{Y1}R_{Y2}\right)}$$

The resistance of the closed loop is expressed by given geometric dimensions of the bath, the inductor, the height of the metal filling the bath and the resistivity of the metal in the cold state (15^0C).

However, the dynamic resistivity of the metal and, consequently, the impedance of the closed loop, drastically changes in the process of heating and melting, for the following reasons.

1. Raising the temperature of the metal during the heating process leads to a sharp increase in its resistivity.

2. The blend which is filled into the bath for heating is usually a scrap of metal pieces of various sizes. The active resistance of the blend is determined by the size of pieces of metal and the state of their contacting surfaces. The resistance of the blend is higher than the resistance of a monolithic metal due to the greater length of the path of current flow on the metal pieces of arbitrary shape and the presence of contact resistance. As of the heating, the blend is fused, passing into monolithic state. Accordingly, the resistance of the blend decreases gradually, becoming, in full meltdown, equal to the resistance of monolithic metal.

Dynamic resistivity and impedance, susceptible to these changes, can be expressed as follows by the corresponding coefficients:

$$\rho_g=K_0K_t\rho=K_\sigma\rho \qquad R=K_0K_tR_X=K_\sigma R_X$$

where k_t – heat coefficient, showing the change in electrical resistance of the metal when the temperature changes, k_o - volume factor, showing an increase in electrical resistance in case the metal is not monolithic, but fills the volume in the form of scrap, i.e. in the form of

the blend, which volume exceeds the volume of monolithic metal, $k_σ$ - the dynamic coefficient of variation of the resistance of the impact of both factors.

Heat coefficient is the well-known dependence of electric resistance and temperature:

$$K_t = \frac{273 + t}{273 + t_0}$$

where t_o - the normalized temperature at which the resistivity and impedance of the metal are known (determined) $ρ$ *and* R_x, t - the temperature, at which the dynamic resistivity and impedance of the metal are determined.

For zinc, heated of the normalized $t_o = 20$ degrees C to the melting temperature of $t = 420$ degrees C, the value of the heat coefficient is:

$$K_{t(\text{цинк})} = 2.36$$

Volume factor k_o is expressed through the relative volume of the blend, assuming, that the larger the volume of blend is for a given mass of metal, i.e. more pieces of metal in the blend, the greater the resistivity and complete electrical impedance.

The relative volume of the blend represents the ratio of the volume of the blend, $V_ш$, to volume of the monolithic metal $V_м$ of the same mass:

$$K_ш = \frac{V_ш}{V_м}$$

The volume of metal is:

$$V_м = \frac{G}{g}$$

where G – is the mass of the metal, g – specific gravity of the metal.

The volume of the blend $V_ш$ or the metal $V_м$ placed in the bath, can be expressed in terms of the dimensions of bath and height of the blend (metal) in the bath, minus the volume of the submerged part of the magnetic circuit (Fig. 1), as follows:

$$V = AB - a_1 b_1 [2(h_1 - h_4) + m] \quad (1)$$

Hence, the height of the blend (or metal) can be expressed - h_1-size required for the subsequent calculation:

$$h_1 = \frac{\frac{V}{a_1 b_1} + m - 2h_4}{\frac{AB}{a_1 b_1} - 2} \quad (2)$$

The volume of the blend, thus, can be determined by measuring the height h_1 of filling the bath by formula (2). The volume of the metal can be determined by its mass (1) or in a similar way to (2).

Figure 4 shows the experimentally determined dependence of the volumetric coefficient k_o of the relative amount of the blend $k_ш$.

The energy required for heating and melting the metal is:

$$W = W_Н + W_П = q_Н G(t - t_0) + q_n \cdot G$$

where $W_н$ – energy, required for heating the metal with mass G of the initial temperature t_o = 20 degrees C to the melting point of t - for zinc $t = 420° C$, $q_н$ - specific heat of metal, W_n - the energy required for melting the metal mass of G, q_n - specific heat melting of metal.

Power required for heating and melting the metal:

$$P = \frac{W}{T},$$

where T – given time for the heating and melting the metal.

The productivity of the process is defined as:

$$\Pi = \frac{G}{T}$$

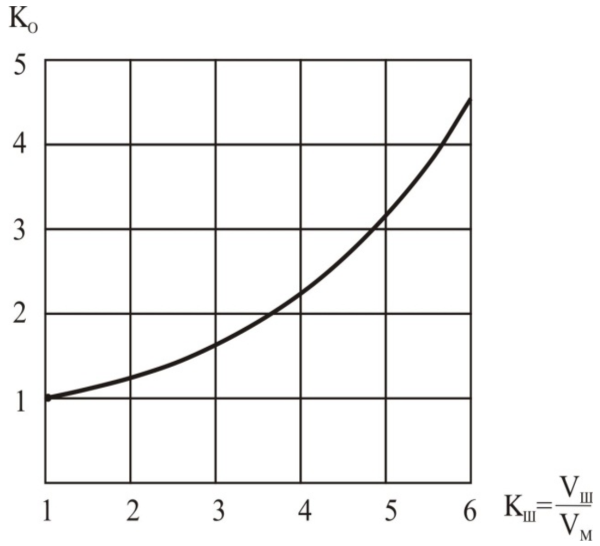

Figure 4. The dependence of the volumetric coefficient k_o of the relative volume of the blend $k_ш$

The temperature of the submerged part of the magnetic circuit should be no higher than the point of the magnetic transitions (which for electrical steel is 740° C). This is achieved by:

- The use of the proposed design for melting fusible metals, for which the melting temperature does not exceed the Curie point (for example, zinc melting point is 420° C), or

- Thermal insulation or cooling of the magnetic circuit, in case if the melting temperature is above the Curie point.

Conclusion

1. Low-power facilities for electrical melting of fusible non-ferrous metals should be performed according to the scheme of low-frequency channel units with power supply directly from the production network with frequency of 50 Hz.

2. The proposed design of the channel facility with a submerged magnetic circuit and the calculated ratio can be used for engineering practice.

R E F E R E N C E S

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