INFRALOW FREQUENCY ENERGY CONVERTERS

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Semi-conductor switching transducer of 50 Hz mains voltage into a sinusoidal voltage of infralow frequency, as well as one of its applications for mixing the melt in induction crucible installations of high-frequency fusion of metals are considered.

Application of regulated infralow frequency voltage of about 0,2 – 2 Hz is required in a number of fields of industry and scientific research, such as hydrolocation, seismology and geological exploration. Whereas, the form of low frequency voltage must be virtually sinusoidal.

Voltages and energies of such frequencies can be acquired by the conversion of 50 Hz industrial mains voltage.

Production of electric machine engine-generators on such low frequencies is virtually impossible due to utter unreasonableness of electric machine constructions on such, rather low, rotational velocities, based on mass-dimensional and cost parameters.

Semi-conductor switching transducers on the basis of inverters or reversionary rectifiers, ensuring sinusoid form of output voltage, require a complex control system, powerful low frequency filters and are rather unreasonable as to mass-dimensional and cost parameters.

Semi-conductor transducer of 50 Hz mains voltage into a sinusoidal voltage of infralow frequency with intermediate of high frequency (about 1000 Hz or more) is considered below. The transducer scheme is given in Fig. 1.

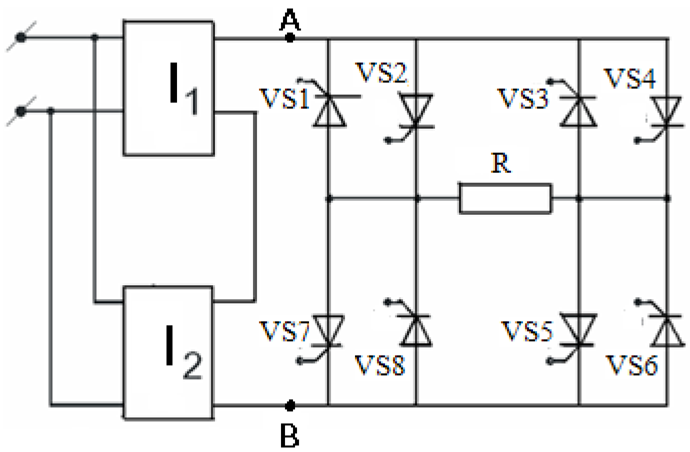

Fig. 1. Transducer scheme

The transducer consists of two inverters I_1 and I_2, the inputs connected in parallel to the voltage of 50 Hz industrial mains. The inverters are made with a section of direct current according to the "rectifier – high frequency stabilized inverter" scheme. Frequencies of output voltages of inverters differ on a small value, corresponding to infralow frequency output of the transducer. Inverter outputs are connected in series and hooked up to the load R through bidirectional

rectifier, consisting of two bridge rectifiers correspondingly on thyristors VS1, VS2, VS3, VS4 and VS5, VS6, VS7, VS8.

The diagram of transducer voltages is given in Fig.2.

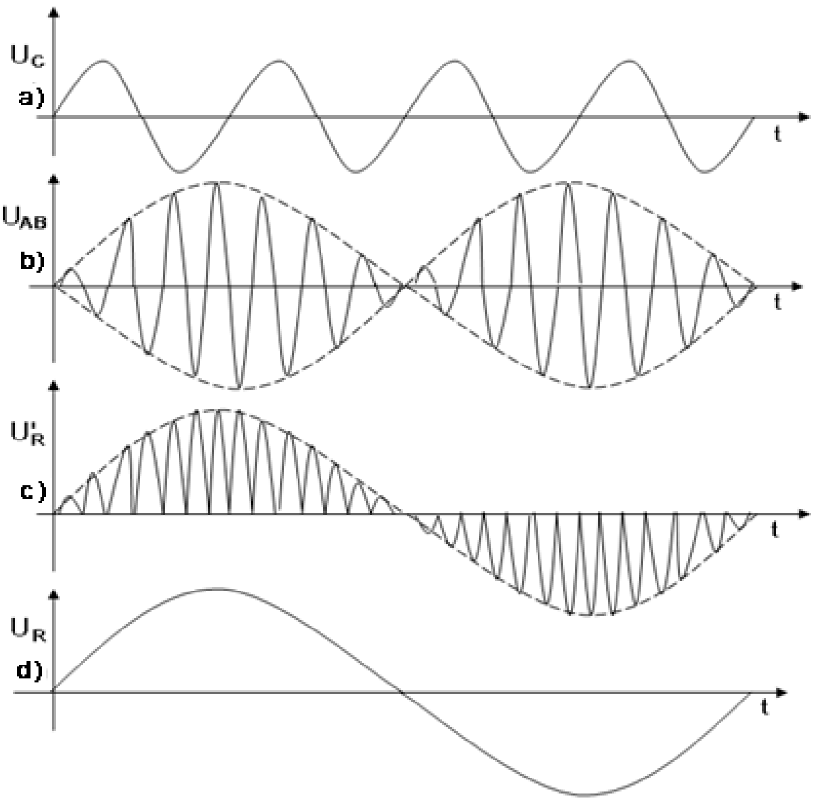

Fig. 2. Diagram of voltages

On the axes of the diagram: a) Uc – main voltage, b) U_{AB} – voltage on the inverter output, c) U_R' – reversed voltage on load, d) U_R – filtered voltage on load, are represented accordingly.

During operation of inverters their output voltages are vector-summarized and a.c. voltage of high carrier frequency, modulated by the voltage the frequency of which equals to the half-difference of frequencies of inverters I_1 and I_2 (Fig.2c) is formed in points AB.

When summing output voltages of high-frequency inverters, operating on close frequencies ω_1 and ω_2, instantaneous values of which have the appearance (Fig. 2)

$$u_1 = U_m Sin(\omega_1 t + \varphi_1); \qquad u_2 = U_m Sin(\omega_2 t + \varphi_2); \tag{1}$$

We will have:

$$U_{AB} = 2U_m Sin\left[\left(\frac{\omega_1+\omega_2}{2}\right)t + \frac{\varphi_1+\varphi_2}{2}\right] \cdot Cos\left[\left(\frac{\omega_1-\omega_2}{2}\right)t + \frac{\varphi_1-\varphi_2}{2}\right]; \tag{2}$$

where U_{AB} - is summary output voltage on the output of connected inverters in points AB, this voltage is low-frequency sinusoid voltage with angular frequency $\omega = (\omega_1 - \omega_2)/2$, populated with voltage with angular frequency $\omega = (\omega_1 + \omega_2)/2$.

The type of inverters – inverters of voltage, current or resonance, as well as the degree of approximation to harmonicity of their output voltage do not principally matter. Stabilization of

inverter voltages is ensured either by feeding voltage of direct current by means of phase control of rectifier or within the inverter by means of pulse-width modulation. Use of voltage inverters is more reasonable.

Further half-waves of modulated voltage of connected inverters (Fig. 2c) are rectified in turn by the reversible rectifier and, thus, a.c. voltage is formed on the transducer output, whose envelope represents a sinusoid of infralow frequency (Fig. 2d).

By the change of frequency of inverters or, at least, the frequency of one of them for a small value, the change of infralow frequency output of transducer on half-difference of inverter frequencies is achieved. Relation of frequencies in a transducer, available in the prototype is given in table 1.

Table 1

NN	Frequency of invertor И1, *f1*, *Гц*	Frequency of invertor И2, *f2*, *Гц*	Carrier frequency of output voltage *(f1+f2)/2*, *Гц*	Envelope frequency of output voltage *(f1-f2)/2*, *Гц*
1	1000	994	997	3
2	1000	995	997,5	2,5
3	1000	997	998,75	1,5
4	1000	998	999	1
5	1000	999	999,5	0,5
6	1000	999,5	999,75	0,25

The peculiarity and main advantage of the present transducer consists in the fact that harmonicity of output voltage is provided in scheme – by vector summation of output voltages of inverters. Low frequency filters are not required here. Smoothing of voltage of carrying frequency is provided by high-frequency filters of rather low power. If load is rather inductive then it can provide high-frequency filtration and high quality filters may not be required at all.

One of the uses of the mentioned infralow frequency transducer is given below.

It is necessary to mix the melt in the process of fusion in high-frequency metal fusion electrical power crucible installations for uniform distribution of temperature and for acquiring homogeneous chemical composition of metal.

Fig. 3 provides the scheme of high-frequency metal fusion induction crucible installation. Crucible 1 with the fusion mixture 2 placed in it is embraced by solenoid 3 of the inductor in which high-frequency current from the power supply 4 flows. Eddy currents, appearing in the metal mass release heat which melts the metal placed in the crucible.

High-frequency field of the solenoid inductor induces certain electromagnetic forces in the melt, mixing the mass of the melt.

The compression pressure induced by these forces increases from the surface to the axes [1,2], Fig.3. Simultaneously it is known that the induced force initiating mixing of the melt back-depends on the frequency of current in the inductor winding.

$$P_{eff} = 2\pi \cdot 10^{-7} p_0 \cdot \frac{\Delta}{p_2} = 3.16 \cdot 10^{-4} \cdot \frac{p_0}{\sqrt{p_2 f}};$$

where p_0 - is specific surface power, Вт/м^2 ; p_2 - is specific resistance of melt, Ом./м; Δ - is depth of current penetration into melt, м; f - is mains frequency Hz.

Considering that the frequency of operating current in the inductor winding is rather high, about tens of kHz, use of currents of infralow frequencies for mixing the melt in crucible furnace will bring to the increase of mixing forces hundreds of times (3), which is rather effective.

For inducing mixing forces of the metal mass under fusion by means of currents of infralow frequency the existing solenoid of inductor is used, which periodically switches off from the high-frequency power supply and connects to the transducer – infralow frequency power supply. (In Fig. 3 both power supplies are marked 4.) Alternating current flowing in the inductor solenoid generates a flux directed endwise 5, and secondary current 6 in the metal mass from the interaction of which radial forces directed to the center are induced 7.

Dynamic force trajectories appearing in the mass of the melt and which cause mixing are shown in Fig. 4. (Keys in Fig.4 are the same as in Fig.3).

Irrespective of current direction and magnetic flux radial forces (7) are always directed from the wall of the crucible to the center (Fig. 3,4) in the result of which the current flowing through the inductor winding (3) induces unidirectional forces of low frequency from the wall of the crucible to the center (7) (Fig. 3,4). In induction furnaces molten metal undergoes radial pressure (compression) under the influence of which shift of metal mass in the direction 8 (Fig. 4) and rise of hot metal line on crucible axes to the height in respect to the level of edges takes place (meniscus is formed). Molted metal flows down along the surface of the meniscus and the crucible, rises again along the axes, i.e. mixing of the entire metal mass takes place.

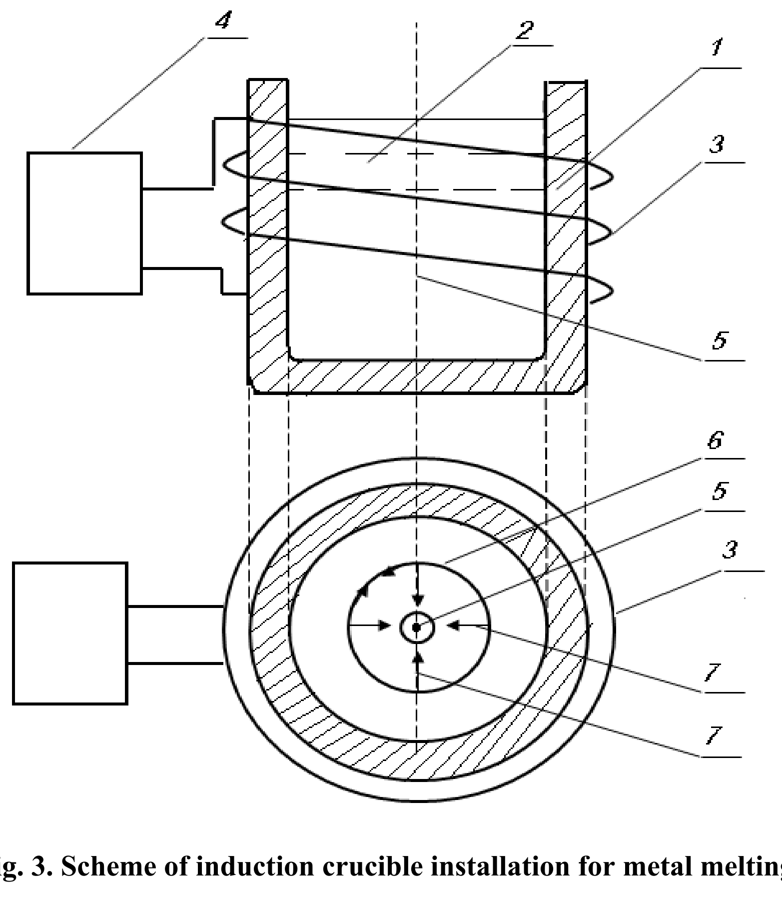

Fig. 3. Scheme of induction crucible installation for metal melting

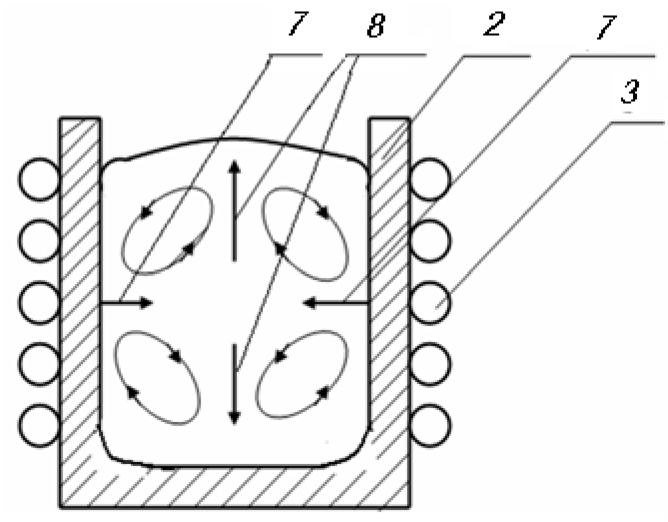

Fig. 4. Metal mass shift

R E F E R E N C E S

1. Shamov A.N., Bodazhkov V.A. High-frequency Installations Design and Exploitation. Leningrad: Machine Building. Leningrad department. 1975.
2. Induction Heating Installations for Students of HEE//Edited by A.E. Slukhotskiy. Leningrad: Energoizdat. Leningrad department. 1981.
3. Valve Frequency Converters, Schemes and Switching Processes. Theses of the reports of all - USSR conference. Sverdlovsk. 1997.
4. Davidyan J.D., Gasparyan R.T. Melt Mixing Node in Induction Crucible Furnace. Invention Certificate N 2451A. Armenia. 2010.

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