INFLUENCE OF WORKING FREQUENCY ON DIMENSIONS OF TRANSFORMERS FOR AC RESISTANCE WELDING

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The paper deals with a resistance welding machine powered from a high-frequency mains. Effect of working frequency increase compared to industrial frequency on the volume of machine transformer core was studied. It is shown that frequency increase does not lower the overall dimensions and weight of the transformer and it is not rational to supply power to AC resistance welding machines of medium and high power from a higher frequency inverter.

Keywords: *resistance welding, inverter, welding machine, transformer, secondary circuit, magnet core volume*

Increase of working frequency is known to be an effective means of reduction of transformer dimensions and weight [1]. Reduction of weight and dimension characteristics is particularly rational for built-in transformers of welding tongues. Frequency triplers, motor generator sets or inductor generators were earlier used as the main power source [2], and now thyristor or transistor inverters are applied [3]. Unfortunately, frequency increase leads to increase of inductive resistance of the machine secondary circuit. To avoid welding current dropping in this case, secondary voltage of the transformer and, hence, its power have to be increased. Thus, increase of supply frequency has an ambiguous influence on the overall volume of transformers for AC resistance welding. Therefore, it is of interest to study the nature of influence of working frequency on overall volume and the associated weight of the transformer for AC resistance welding.

For transformers with minimum weight and dimension characteristics the following relationships are valid [1]:

$$V_{\mathrm{tr}} \approx 3V_{\mathrm{m}}, \quad 0.13V_{\mathrm{m}}^{4/3} = S_{\mathrm{m}}S_{\mathrm{ap}}, \quad S_{\mathrm{ap}} = (2.5 - 1.3)S_{\mathrm{m}},$$

where V_{tr} is the transformer volume; V_{m} is the magnet core volume; S_{m}, S_{ap} are the magnet core cross-section and its aperture area, respectively. Hence,

$$V_{\mathrm{m}} = (9.2 - 5.5)\sqrt[3/4]{S_{\mathrm{m}}},$$

i.e. transformer volume is directly related to magnet core section. Reduction of active section of magnet core material S_{m} with increase of frequency follows from a known formula:

$$S_{\mathrm{m}} = \frac{E_1}{4.44fw_1B}, \qquad (1)$$

where E_1 is the self-induction emf in the primary winding; w_1 is the number of primary winding turns; B is the induction. Unfortunately, with frequency increase the power of losses in the magnet core and additional losses in winding copper increases, leading to additional increase of the transformer winding. For frequency range up to units of kiloherz additional losses in copper through skin-effect are negligible. Dependence of specific losses in the magnet core on frequency has the following form [1]:

$$p = Af^{\alpha}B^2, \qquad (2)$$

where A are the losses in a unit of volume at $f = 1$ Hz; $B = 10^4$ T; $\alpha = 1.5$–2.0.

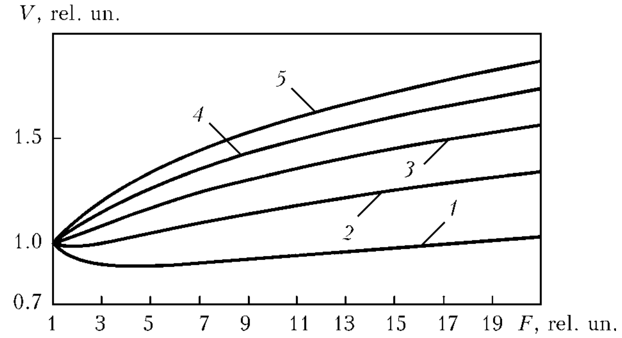
To ensure that the loss power in the magnet core and transformer overheating, respectively, stayed on the same level, it is necessary to lower the induction simultaneously with increase of frequency, as follows from (2). However, according to relationship (1), reduction of induction leads to increase of S_{m}. Thus, cross-section of transformer magnet core and, therefore, also its volume decrease markedly slower with increase of frequency than in inverse proportion to frequency. In addition, with reduction of transformer dimensions the cooling surface decreases and induction has to be lowered even further.

In [1] the theory of similarity was used to derive the following expression for transformer magnet core volume V_{m}:

$$V_{\mathrm{m}}(f) = 1.5\sqrt{\frac{Ak_{\mathrm{ad}}}{k_{\mathrm{m}}}}\,\frac{P}{\sqrt[4]{f}\Delta T}, \qquad (3)$$

where P is the power; k_{ad} is the coefficient of additional losses in copper; k_{m} is the coefficient of magnet core aperture filling with copper; ΔT is the transformer overheating. Expression (3) was derived for active load and without allowing for scattering inductance of transformer windings. A feature of AC resistance welding machines is inductive-active nature of transformer load

$$Z_2(f) = \sqrt{(R_{\mathrm{c}} + r_{\mathrm{p}})^2 + (2\pi fL_{\mathrm{c}})^2}, \qquad (4)$$



Dependence of dimensionless volume of transformer magnet core on dimensionless frequency at different power factors of the machine at industrial frequency: *1* — cos φ = 0.9; *2* — 0.8; *3* — 0.7; *4* — 0.6; *5* — 0.5

where R_c is the ohmic resistance of machine secondary circuit; r_p is the resistance of the welded part; L_c is the inductance of machine secondary circuit. In this case, expression (3) becomes

$$V_m(f) = 1.5\sqrt{\frac{Ak_{ad}}{k_m}}\,\frac{Z_2(f)I_2^2}{\sqrt[4]{f}\,\Delta T}, \tag{5}$$

where I_2 is the resistance machine secondary current.

In order to study the influence of frequency on magnet core volume, it is convenient to go over to dimensionless parameters of the transformer, taking the following as basic transformer parameters at 50 Hz industrial frequency: $V = V_m(f)/V_m(50)$ is the transformer relative volume, $F = f/50$ is the relative frequency.

Let us assume that at change of frequency R_c, r_p, L_c, k_{ad}, A, I_2 and ΔT remain unchanged. Considering that

$$\frac{2\pi 50 L_c}{R_c + r_p} = \text{tg}\,(\varphi), \tag{6}$$

$$\frac{2\pi f L_c}{R_c + r_p} = \text{tg}\,(\varphi)F, \tag{7}$$

where φ is the shear angle between current and voltage in the secondary circuit at working frequency equal to 50 Hz, from equations (4)–(7), omitting intermediate transformations, we will have the dependence of relative volume of transformer magnet core on working frequency and cos φ (power factor) of the machine:

$$V = \frac{\sqrt{\cos^2(\varphi)(1 - F) + F}}{\sqrt[4]{F}}. \tag{8}$$

Dependencies of V on F and cos φ, calculated by formula (8), are given in the Figure. As follows from the Figure, for machines with cos φ = 0.9 of the secondary circuit at industrial frequency a lowering of magnet core volume maximum by 11 % is found with increase of the working frequency. At cos φ ≥ 0.8 the magnet core volume only rises with increase of working frequency. Usually, cos φ of resistance machines of 50 Hz industrial frequency is in the range of 0.4–0.7, and the maximum possible range is 0.2–0.8 [4]. Therefore, increase of working frequency of AC resistance welding machines for reduction of transformer overall dimensions is not rational, as for real secondary circuits of machines the transformer overall dimensions are not reduced, but, on the contrary are increased. The above calculations were made using a number of simplifying assumptions. However, their influence has the second order of smallness, and does not seriously affect the obtained regularities.

Real reduction of the dimensions and weight of the transformer can be achieved when using increased frequency in resistance machines with rectifiers in the secondary circuit.

Increase of working frequency unambiguously improves the adjustment characteristics of machines for resistance welding through increase of the control system dynamic characteristics. This has a marked effect at application of the time of welding current pulse below 5–10 periods of 50 Hz mains. Therefore, AC machines of industrial frequency are not used for microwelding requiring less than 10–30 ms time of welding current running. In this case, it is the most rational to apply higher frequency machines with and without rectifiers in the secondary circuit, which have incomparably better adjustment characteristics than the most widely accepted now capacitor machines.

CONCLUSIONS

1. Increase of working frequency (application of inverters) does not provide a reduction of overall dimensions and weight of the transformer of AC resistance welding machines.

2. Increase of working frequency in some cases can reduce the overall dimensions and weight of resistance welding machines with a rectifier in the secondary circuit, thus improving the dynamic characteristics of the system of welding current control, which is particularly appropriate for microwelding.

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