The Numerical Calculation of Short Circuit Resistance of Transformers of Inverter Power Source Welding Machines

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Abstract -The method of calculation of active and inductive resistance of the transformer with an armored magnetic conductor and the disk windings, based on use of a method of finite elements of the created machine is given. Reliability of this technique is confirmed with results of measurements of short circuit resistances of transformers. On the basis of theoretical researches of these resistances the design data influencing weight and a power consumption of machines of contact welding are allocated. The new arrangement of coils of primary and secondary windings is introduced. The example of use of results of this research is given.

Index Terms—electromagnetic field, transformer, eddy currents, energy consumption, optimization

I. Introduction

At present, most welding machines (MCW) have power supplies of industrial frequency. At the same time, work is underway to create inverter power source with straightening welding current and expanding their production. The world's leading global manufacturers of the welding equipment have such machines in the nomenclature of the products. The block diagram of an inverter source consists of the three-phase bridge rectifier with the capacitor filter, the inverter, the welding transformer to which secondary windings via the single-phase two-half-period rectifier with an average point welded details are connected (fig.1).

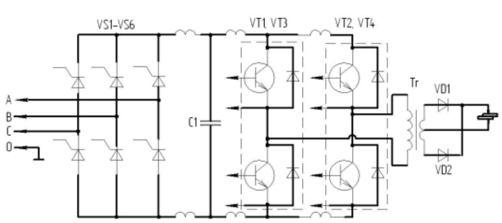

Fig.1 Block diagram of the MCW inverter power supply.

Frequency of the inverter is defined as production requirements when welding some details and the demands made to weight and dimensions of the transformer. Short-circuit (SC) resistance of the transformer affects the calculated value of the open circuit voltage and, therefore, the power consumption of the MCW and the section of the magnetic circuit. Therefore an important stage in creating a transformer is calculation of resistance of SC at a given frequency of the inverter.

II. The Method of Calculation

For calculation of active and inductive resistance of the welding transformer, calculation of a two-dimensional variation magnetic field of dispersion in a transformer window by finite element method using the package ELCUT [1] was carried out. The problem is formulated as a differential equation in partial derivatives with respect to the complex amplitude of the magnetic vector potential. Magnetic permeability of the magnetic circuit is $\mu = \infty$. This approach allows us to take into account the real shape of the cross-sections of the windings and the distance between the wires of the primary winding, which substantially affect the manifestation of the surface effect in the windings. The input data in the calculation of the currents in the coils are found from the condition of magneto motive force (MMF) windings (opposition mode):

$$I_1 w_1 = -I_2 w_2, \quad (1)$$

where I_1, I_2 - operating values of currents in primary and secondary windings, w_1, w_2 - number of turns of the primary and secondary windings. In (1) it is necessary to consider that current in a secondary winding flows only in one of its coils, as in each coil of a secondary winding current flows only during a half of the period of operation of the inverter.

Based on the calculation of the magnetic vector potential it is possible to find power losses in ELCUT per unit length coils and energy of a magnetic field of dispersion per unit length of the window of the magnet. Losses are used to calculate the resistance per unit length of coils. Energy of a magnetic field of dispersion is used to calculate inductance of dispersion of the transformer, reduced to the primary winding, per unit length of the window.

III. The Calculation Results

As the basic transformer for research the transformer with disk alternating windings and an armored magnetic conductor was chosen (fig.2). The primary winding consists of four series-connected coils made of wire with rectangular cross-section. The two secondary coils are made of copper tubes through which cooling water flows.

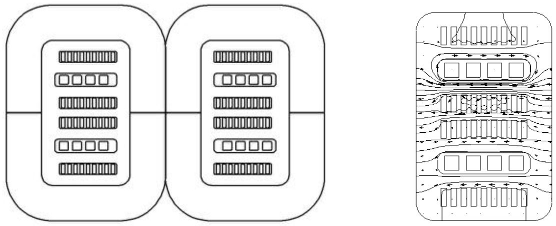

Fig.2. Design of the transformer with four primary coils and magnetic field of dispersion in the transformer window.

Calculations showed that the maximum additional losses are allocated in the central coils of primary winding. A slight deviation of the primary winding coil thickness from the critical value [2] at frequencies above 1 kHz leads to a large increase of the additional losses. Based on numerical calculations, we have results specified in comparison with analytical values [3] of critical thickness of coils of primary winding and the admissible density of current in them at frequency change to 20 kHz.

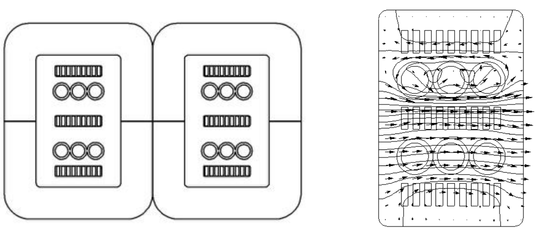

Fig.3. Design of the transformer with three primary coils and magnetic field of dispersion in the transformer window.

In order to reduce the additional losses in coils of primary winding and inductive resistance of dispersion of the transformer with high frequencies it is suggested to change the arrangement of the coils. We consider two versions of the transformer - with three (Fig. 3) and two (Fig. 4) primary coils. All options considered have the same magnetic area of the window. In the design in Fig. 4, all the turns of the primary winding are located in the two coils and both disks of a secondary winding - between them, that is considerably to change the traditional transformers MCW of industrial frequency alternation of primary and secondary windings (one primary coil on both sides of the disc of the secondary coil). This leads to essential reduction of inductance of dispersion of the transformer and additional losses in coils of primary winding.

The new constructive solution is implemented in a transformer for the MCW inverter power supply with a nominal frequency 7.5 kHz (Fig. 4). The application of this design of the transformer to the MCW inverter power supply with the single-phase two-half-period rectifier with an average point in a circuit of welding current with a frequency of 7.5 kHz and welding current of 6 kA will almost halve the power consumption of the MCW and the consumption of electrical steel and copper in comparison with the transformer

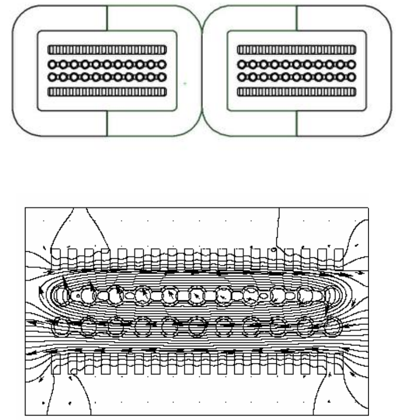

Fig.4. Design of the transformer with two primary coils and magnetic field of dispersion in the transformer window.

of a traditional design calculated on the same frequency and welding current. For this design, even a significant deviation of thickness of the primary winding of the coils from the critical value does not lead to a large increase of the additional losses in them. In fig. 5 experimental values of inductive resistance of the transformers, reduced to primary winding are given. Calculated and experimental values differ by no more than 10%.

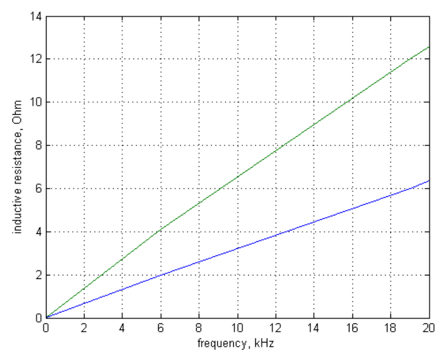

Fig.5. Experimental values of inductive resistance of the transformers with four (upper) and two (lower) primary coils.

IV. Conclusions

It is shown that the transformer with two coils of primary winding between which disks of the secondary winding are located, at high frequencies is much less resistant to short circuits than the traditional welding transformer MCW.

V. References

[1] Software package for numerical simulation of electromagnetic and electromechanical devices ELCUT, www.elcut.ru/demo/manual.pdf

[2] I. Lammeraner, M. Shtafl. Eddy currents. / Energy M. –L. 1967, 207 p.

[3] Sakhno L.I., Sakhno O. I., Likhachev D. I. Engineering method of calculation of critical thickness of disks of windings of transformers of machines of contact welding. // Welding production, 2010. - No. 1. – Page 17-18.