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Simulation Tests of the Welding Machine Secondary Circuit

Abstract: The article discusses the analysis of circuit parameters and power losses in the secondary circuit of the welding machine. The analysis was based on FEM calculations performed using the Ansys Mechanical APDL software programme. The tests resulted in the determination of the inductance of the secondary circuit of welding machine horns as the function of the overall dimensions of the above-named circuit. The foregoing made it possible to identify the current response of the circuit to applied DC rated voltage. The determination of power losses included the identification of the distribution of potentials (voltage drops) along welding machine horns, and, subsequently, the determination of the correlation of input power, output power and system efficiency. The tests involved the identification of primary sources of power losses, i.e. mechanical connections, mainly between electrodes and horns as well as in the elastic joint.

Keywords: secondary circuit of the welding machine, FEM, Finite Elements Method, Ansys ADPL, simulation tests

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Introduction

Present trends focused on the increasing of electric equipment efficiency, and, at the same time, the minimisation of adverse effect on the environment impose the detailed analysis of the distribution of power losses in electric devices, particularly in relation to resistance welding machines. In such devices, the minimisation of power losses is not only connected with the reduction of a negative effect on the environment but also with the reduction of the cost of a single weld and, consequently, the reduction of process-related running costs [1].

In today's welding machine solutions, the high-current circuit is a direct current (DC) circuit [2]. In the above-named systems it is possible to distinguish two primary groups of sources generating power losses, i.e. the inverter circuit and the high-current circuit (of the horns and of the inverter). Both of these elements can be subjected to optimisation in relation to power losses. This article is concerned with the high-current circuit. The minimisation of power losses in such a circuit must be preceded by the detailed identification of sources generating power losses and their space distribution. A popular tool used in such analyses is numerical modelling [3].

This article presents the FEM field modelling-based numerical analysis of the welding

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machine secondary (high-current) circuit. The above-named analysis enables the identification of sources of power losses and their further minimisation. The research work also involved the performance of comparative analysis concerning various dimensions of welding machine horns. The modelling was performed using a welding machine manufactured by Aspa [4].

Numerical Model of Welding Machine Horns

The numerical modelling of power propagation in the part of the welding machine limited by the output rectifier terminals (i.e. in supply conduits, electrodes and in the weld itself) was performed using the Ansys apdl software programme (based on a 3D static model) [5]. The modelling enabled the determination of space distributions of power losses, current loop impedance and current response to applied voltage surge. Figure 1 presents a numerical model of welding machine horns along with a fragment of a finite element mesh in the lower electrode fixing area. Further analysis was concerned with the geometry of the horns (depth, electrode length and horn width). The model involved the use of a uniform tetrahedral wall.

Analysis of the Inductivity of the Welding Machine Secondary Circuit

The inductivity of the secondary circuit significantly affects the rate of welding current

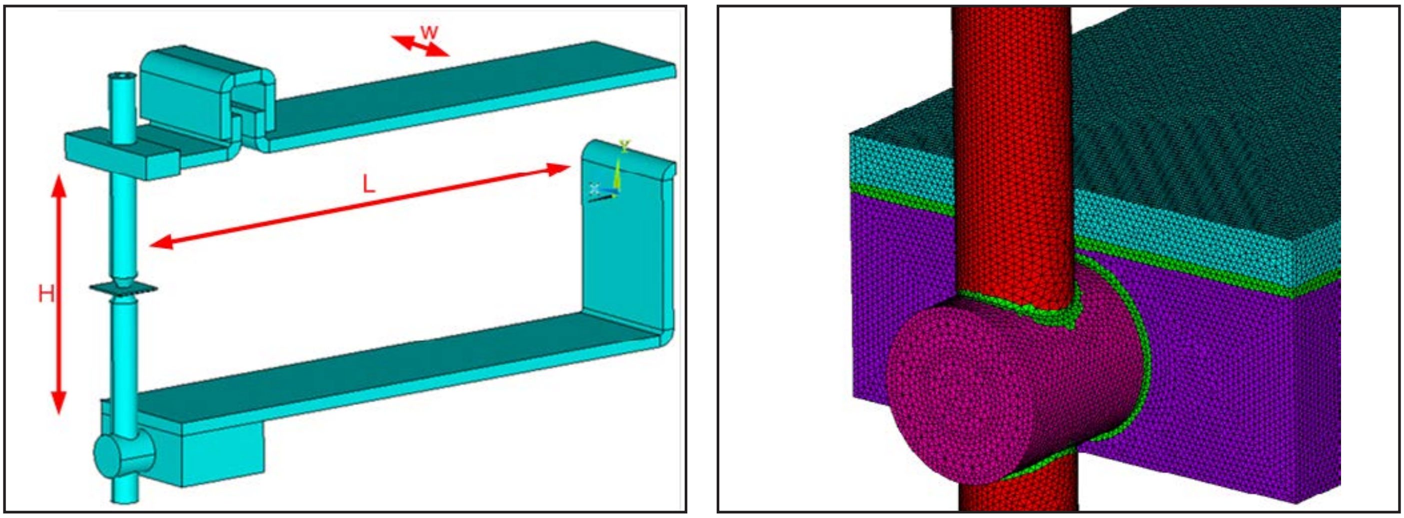

Fig. 1. Model MES 3D ANSYS of the welding machine horns along with the fragment of the finite element mesh

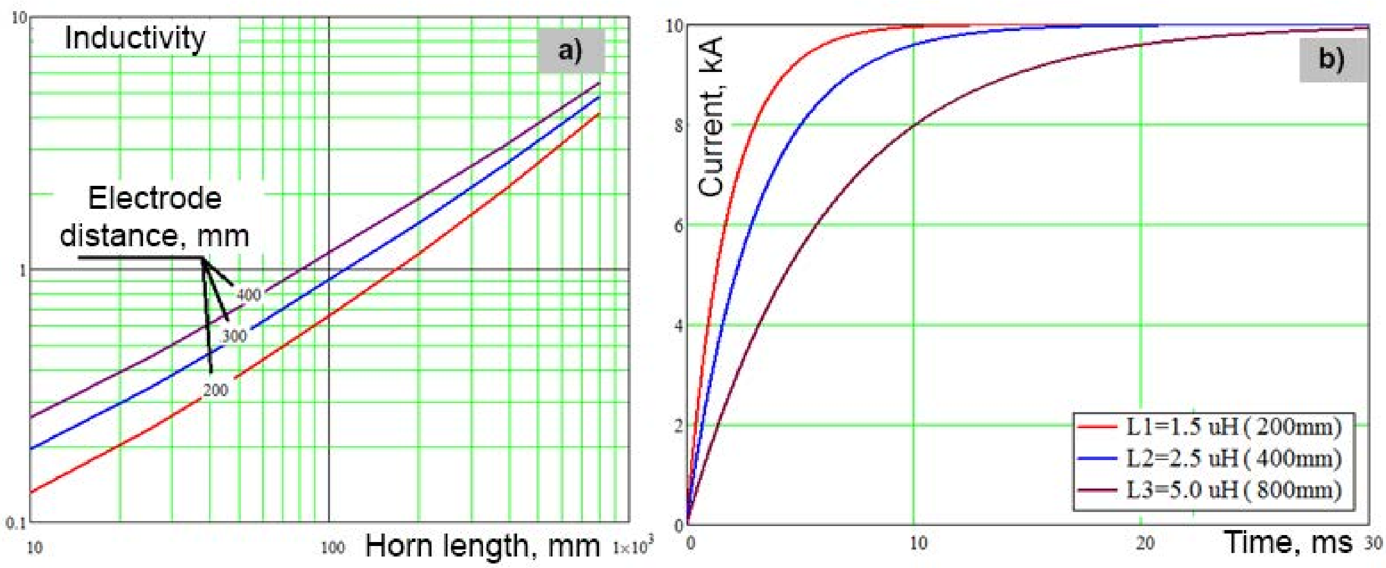

Fig. 2. Dependence of the inductivity of the current loop of the electrode machine horn on dimensions (a) and current response to nominal voltage in relation to various inductivity values (b)

up-slope. For this reason, comparative analysis involved the determination of the substitute inductivity of the loop in relation to three lengths of the horns and three distances between the horns (total length of the high-current circuit). The analysis results are presented in Figure 2a. The analysis revealed that both the length of the horns and the distance between them affect the value of inductivity. In the range of geometry changes subjected to the test, inductivity changed within the range of 1.5 to 5 μH.

The above-named changes significantly affect the current up-slope rate. For the determined range of inductivity changes in the current loop (from 1.5 to 5 μH), the current up-slope from 0 to 10 kA was determined in the function of time in relation to a supply voltage of 8 V applied in a surge-like manner. The current response waveform is presented in Figure 2b. An increase in inductivity significantly affects time required to obtain the steady value of current. For instance, the obtainment of 8 kA in relation to 1.5 μH takes approximately 4 ms, whereas in relation to 5μH – 10 ms. The above-named time becomes significantly extended where expected current is close to the nominal current value (in relation to 10 kA – 10 ms and 30 ms respectively).

Analysis of Power Losses in Elements of the Secondary Circuit

The analysis of the propagation of power, or, more precisely, the losses of power in the welding machine horns (effective power is only absorbed by the weld nugget, remaining elements constitute sources of power losses) was performed in relation to a model operated in the thermally steady state. The analysis also took into consideration the higher temperature of the weld area (weld resistivity was established on the basis of experimentally recorded courses) as well as of the horns and the electrodes (the analysis took water cooling of the electrodes into consideration). The modelling was used to determine the distribution of current density in the entire model and, based on the preset resistivity of individual elements of the model, corresponding voltage losses on individual elements. It should also be mentioned that experimental tests were used to estimate resistivity values related to the mechanical joints in the current circuit (including the resistivity of the horn-electrode joint). The distribution of electric potential along the 400 mm long and 150 mm wide horns being 300 mm away from each other is presented in Figure 3. The same

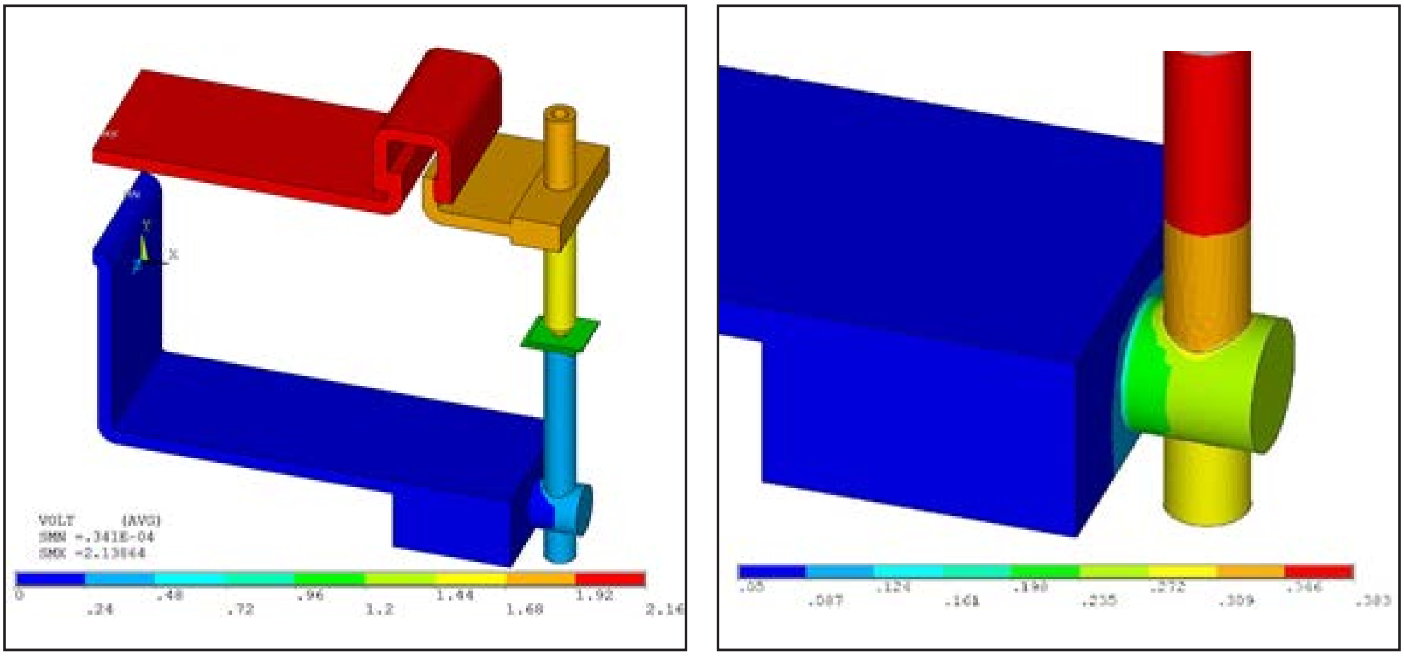

Fig. 3. Distribution of potentials (voltage drop) along the welding machine horns along with a magnified fragment in the horn-lower electrode joint area

figure also presents the distribution of potentials in the horn-electrode joint area. The distributions revealed that primary losses in the current circuit were generated in the joints characterised by the greatest voltage drops.

Power losses in individual elements were analysed as proportional to the voltage drop (DC flowing through the entire circuit); the distribution of power as the following:
- power supplied to the horns: 21.6 kW,
- power emitted in the element subjected to welding (absorbed): 13.5 kW,
- power losses in the horns: 2 × 300 W,
- power losses in the elastic element of the upper electrode: 1.6 kW,
- power losses in the joints between the electrodes and the horns: 1.7 kW in the upper and 3.3 kW in the lower,
- power losses in the electrodes: 2 × 400 W.

The above-presented analysis indicated that efficiency related to energy supplied to the electrodes and energy absorbed in the weld amounted to approximately 62%. The analysis also revealed that the major sources of power losses were mechanical joints, particularly those between the electrodes and the horns as well as in the elastic joint.

Comparative Analysis of Power Losses in the Function of Circuit Dimensions

Because of the fact that welding machine horns can be made in various dimensional configurations (depending on process requirements), the comparative analysis of the distribution of power losses was performed as the function of selected dimensions of the horns. The analysis involved the effect of horn lengths, distances between the horns and their widths.

The comparative analysis results are presented as the function of power losses, efficiency and voltage drops along individual elements of the circuit (proportional to power losses). The dependence of input power, output power and efficiency as well as of the voltage drop along the horns in the function of horn lengths are presented in Figure 4. Because of direct welding current (DC), power supplied to the weld is constant. In turn, the increasing length of the horns is responsible for the linear increase in the voltage drop and the square power gain. This results in the decrease in efficiency along with the increase in the horn length, where the efficiency loss does not exceed 10% (efficiency drop from 60% to 50%) for the extension of the horn length from 200 mm to 800 mm.

The increasing of distances between the horns (extension of the welding machine electrodes) increases voltage drops along the electrodes as well as increases the voltage drop along the lower horn, where the above-named voltage drop does not occur along the horizontal part of the horn but along the vertical lead (visible in the model in Figure 1).

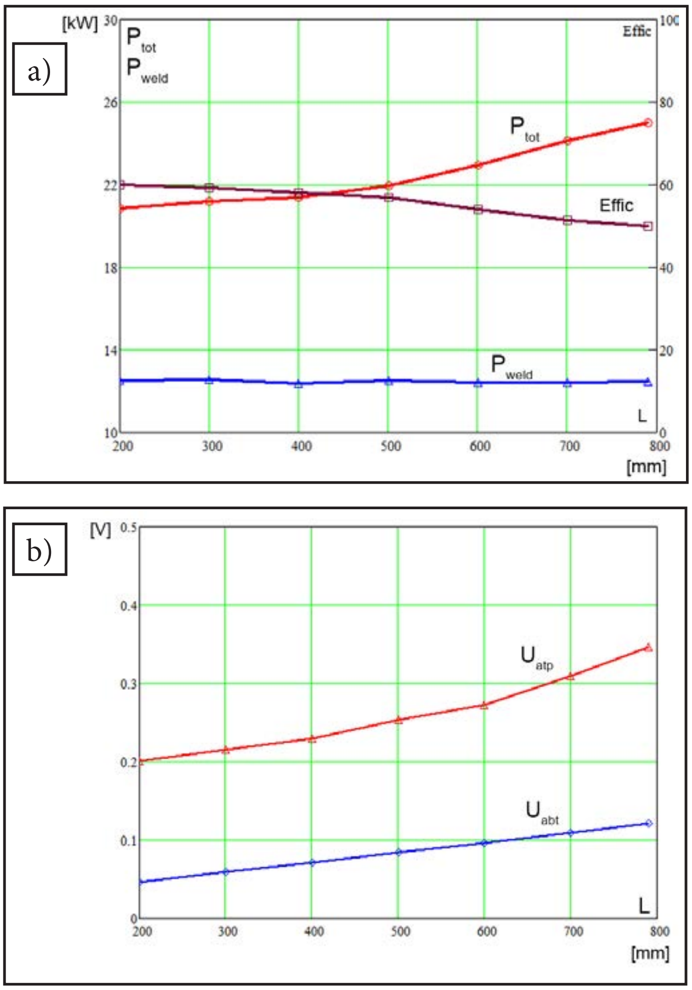

Fig. 4. Dependence of a) input power (Ptot), output power (Pweld), efficiency (Effic) and b) voltage drops along the upper horn (Uatp) and the lower horn (Uabt) as the function of welding machine horn length

The distributions of the above-named voltage drops and the resultant efficiency of energy supply to the weld as the function of the distance between the horns is presented in Figure 5. Power losses in the electrode horns can be affected by changes in the cross-section of the current circuit. Figure 6 presents the analysis of changes in voltage drops along the horn as well as in the connecting elements in relation to the electrode width. The characteristics reveal that power losses generated in the welding machine horns decrease slightly. Because of differences in the design of the mechanical joints between the electrodes and the horns, changes in the width of horns affect losses in the upper joint; the losses in the lower joint remain unchanged.

The efficiency of energy supply to the weld grows by the increasing of the width of the welding machine horn. However, it should be noted that the increasing of the cross-sectional area of electrodes increases the welding machine weight, and, consequently, decreases the density of supplied energy. As the above-named action proves to lead to undesirable consequences, it is necessary to try and work out a compromise between power losses and the density of supplied energy.

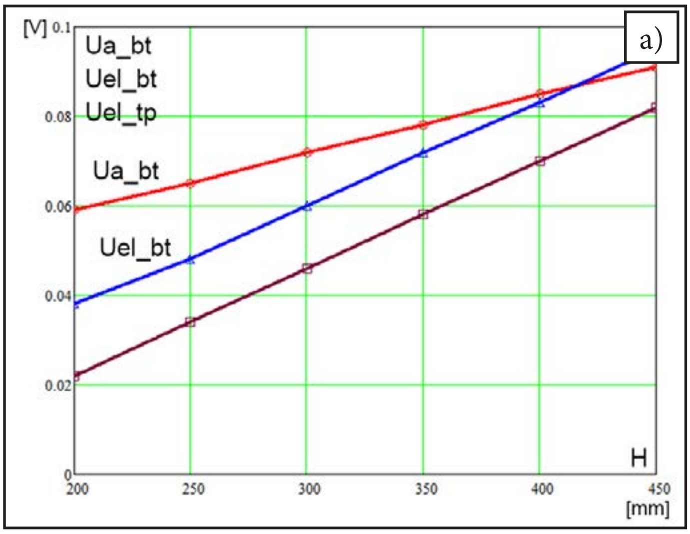

Fig. 5. Dependence of: a) voltage drops along the lower horn (Ua_bt), upper electrode (Uel_tp) and lower electrode (Uel_bt) as well as b) the efficiency of the entire process as the function of the distance between the welding machine horns

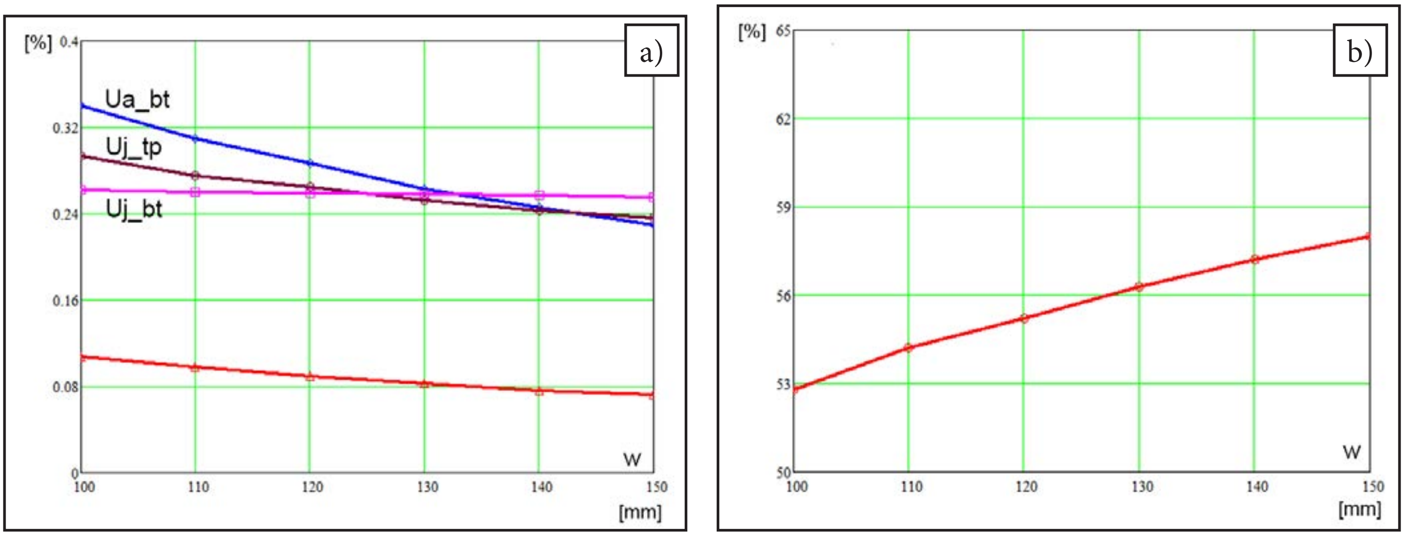

Fig. 6. Dependence of: a) voltage drops along the upper horn (Ua_tp), lower horn (Ua_bt), connection between the upper electrode and the horn (Uj_tp), connection between the lower electrode and the horn (Uj_bt) and b) the efficiency of the entire process as the function of welding machine horn width

The above-presented analysis includes the propagation of power in the final part of the weld supply process in resistance welding, i.e. in the welding machine horns and electrodes. As the above-named part participates in the conduction of direct current, it is not dependent on the frequency of current generated by the inverter and transformed by the transformer. However, the aforementioned current (welding current) is high and its analysis as well as optimisation make it possible to determine the existence and types of efficiency improvement possibilities in this area, and, consequently, possibilities of decreasing the current load of the system elements situated in the initial parts of the current flow circuit.

Summary

The analysis based on FEM numerical modelling and described in this article enabled the formulation of the following conclusions:

- key element in the design of welding machine horns are the joints between the electrodes and the horns as well as the joints of the movable elements of the horns. The above-named areas could generate up to 70% of total power losses generated in the current circuit of the horns;
- analysis of power losses along with the length of the current circuit revealed that the above-named changes were relatively low in percentage terms and their value could be modified through the appropriate design of the current circuit;
- efficiency related to energy supplied to the electrodes (welding machine transformer output) and energy absorbed in the weld amounts to approximately 67%. The major sources of power losses are mechanical joints particularly those between the electrodes and the horns as well as the elastic joint.

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