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Selected Aspects of the FEM-Based Numerical Modelling of Current Propagation in the Resistance Multispot Cruciform Welding of Bars

Abstract: The article presents selected aspects of the FEM-based analysis concerning resistance welding processes performed using multispot welding systems. The analysis was based on a three-spot welding machine used for the joining bars in the cruciform configuration. Both two and three-dimensional modelling was performed as the comparative analysis of two computing software packages, i.e. the commercial ANSYS Mechanical software package and the ARTAP software package, available on an open access basis. The research work involved the determination of current propagation in various welding process configurations as well as the identification of the percentage loss of welding current and power resulting from the bridging of current by neighbouring welds. The article discusses the effect of the method of the power supply and the earthing of the system of electrodes along with the welded material on the manner of current propagation. The analyses presented in the article were performed in relation to the DC power supply (inverter welding machine). Related calculations were performed using averaged (in terms of heat and resistance) material parameters.

Keywords: resistance welding, multispot welding machines, welding current, numerical modelling

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Introduction

Resistance welding is increasingly often used in numerous industrial joining processes. This technology, enabling the fast joining of metallic elements in a manner ensuring the obtainment of appropriate mechanical parameters, is used within a wide range of dimensions and shapes of elements [1]. The primary form of the process is single-spot welding, where subsequent welds are made sequentially. Regrettably, the process has certain disadvantages when making a large number of joints, i.e. time needed for making the entire set of joints and the effect of subsequent welds leading to material deformation. The aforesaid disadvantages inspired the development of a variant of the resistance welding process known as multispot welding. Resistance multispot welding is characterised by the simultaneous making of between several and tens of welds. Such a process is no longer characterised by the disadvantages typical of single-spot welding (i.e. time necessary for making

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welds and the deformation of material by previously made welds). Nonetheless, the multispot welding process has its own problems which need to be addressed. These disadvantages include the necessity of generating sufficiently high current flowing in parallel through many welds at the same time and the need for ensuring the uniformity of current at individual welding spots. For these reasons, multispot welding can be regarded as a complex process. However, in spite of the above-named issues, multispot welding has found numerous industrial applications, e.g. when making wire nets, trusses, and various openwork elements [2].

Resistance multispot welding machines available on the market are usually DC inverter welding machines. The application of an inverter characterised by higher frequency (in relation to 50 Hz) makes it possible to reduce the size of the welding (high-current|) transformer and use the modular welding machine power supply [3]. Typical AC inverter frequency is restricted within the range of 400 Hz to 4000 Hz. There are also multispot welding machines powered by alternating current having a frequency of 50 Hz. It should be noted that multipoint welding machines are usually customised devices designed to meet specific welding process-related expectations. Depending on requirements, welding equipment can also be provided with appropriate automatic elements needed for the entire welding process (e.g. automated feeders of material to be welded) [4].

However, the proper performance of the multipoint welding process requires knowledge of certain phenomena taking place during the process so that their unfavourable effect can be eliminated or minimised. One of the best and commonly used methods to become familiar with phenomena accompanying technological processes (including multipoint welding) is the numerical modelling, particularly using the Finite Element Method (FEM) [5]. The article presents the exemplary modelling of the three-point cruciform welding process. The modelling was performed in relation to a specific assumed model of the system geometry and involved the use of two different computing packages, i.e. ANSYS and ARTAP. The modelling process is discussed in detail in the remainder of the article.

Numerical model structure

Simulation tests reflecting the operation of a multispot welding system were performed using two different numerical models. The first model (developed as a 3D electric-flow model) was based on the ANSYS software, whereas the second (2D geometry) model was based the non-commercial ARTAP software.

Both models were based on the basic geometry of the test object presented in Figure 1 and, in cross-section, in Figure 2. The geometry was composed of a three-module (three-spot) resistance welding system powered by a common upper busbar with electrodes connected to it. The lower busbar was composed of the bar made of the work material, on which three transverse bars were placed at equal distances. Each of the aforesaid bars was connected to the electrode powered by the upper busbar.

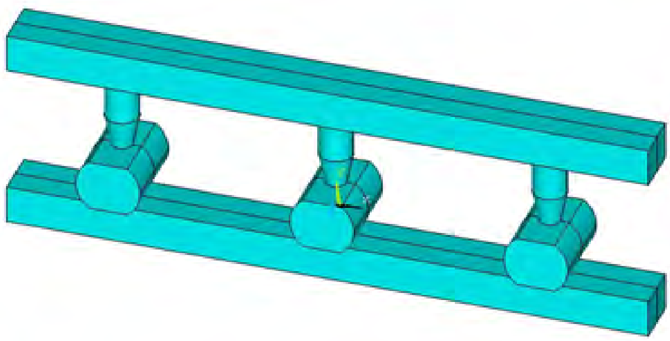

Fig. 1. Basic geometry of the three-spot welding system

The upper busbar and electrodes were made of a material characterised by high electric conductivity. During modelling, the value of 50 MS/m (corresponding to A2/2 class electrodes) was adopted. The transverse bars and the lower busbar were made of a material characterised by slightly lower conductivity (than that of the upper busbar and electrodes). During modelling, the value of 27 MS/m (corresponding to A3/1-3 class electrodes), i.e. corresponding to the conductivity of aluminium at slightly elevated temperature was adopted [6]. Between the conduits there was a thin layer of material responsible for the resistivity of the surface layer (see Figure 2). In the model, the aforesaid layer was the area of the primary emission of heat and the formation of a joint. The adopted basic conductivity value of such a layer amounted to 0.1 MS/m. The key geometrical parameters included the cross-section of welded wires amounting to 60 mm², the distance between the wires amounting to 30 mm, the area of the contact layer amounting to 40 mm² and the thickness of the contact layer amounting to 0.6 mm.

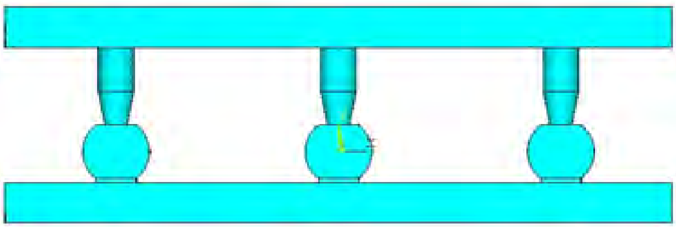

Fig. 2. Basic geometry of the three-spot welding system in cross-section

As mentioned above, the developed FEM numerical model was three-dimensional. The modelling process involved the application of tetrahedral elements [7]. The complete numerical model contained approximately 500 thousand finite elements and approximately 60 thousand nodes. Apart from the area of flat elements corresponding to the resistance of the contact area (where the mesh density was three times higher), it was assumed that the size of the mesh was homogenous and that the characteristic size of an element amounted to 0.75 mm. A fragment of the model with the visible mesh of finite elements is presented in Figure 3.

The numerical analysis was performed in relation to forced current. The lower busbar of the welding system was earthed (preset potential V=0). A forced current of 4000 A was applied to the upper busbar. In the primary model, earthing and forced current were applied uniformly to the entire upper area of the upper busbar and to the entire lower area of the lower busbar. In the comparative analysis (discussed in Section 4), the areas of applied forced current and earthing were changed accordingly.

Analysis of the system properties in relation to the variable resistivity of the contact layer

The first stage of numerical analysis involved tests of current propagation in relation to the resistivity of the contact layer in individual welds. It was assumed that both the power supply and earthing were symmetric (see Figure 4; the areas marked with black lines depict areas of the same imposed potential) and that the resistivity of the contact layer changed. The initial resistivity of all layers amounted to 10 μΩm (electric conductivity was 0.1 MS/m). In turn, in subsequent cases (which could be regarded as equivalent to subsequent moments

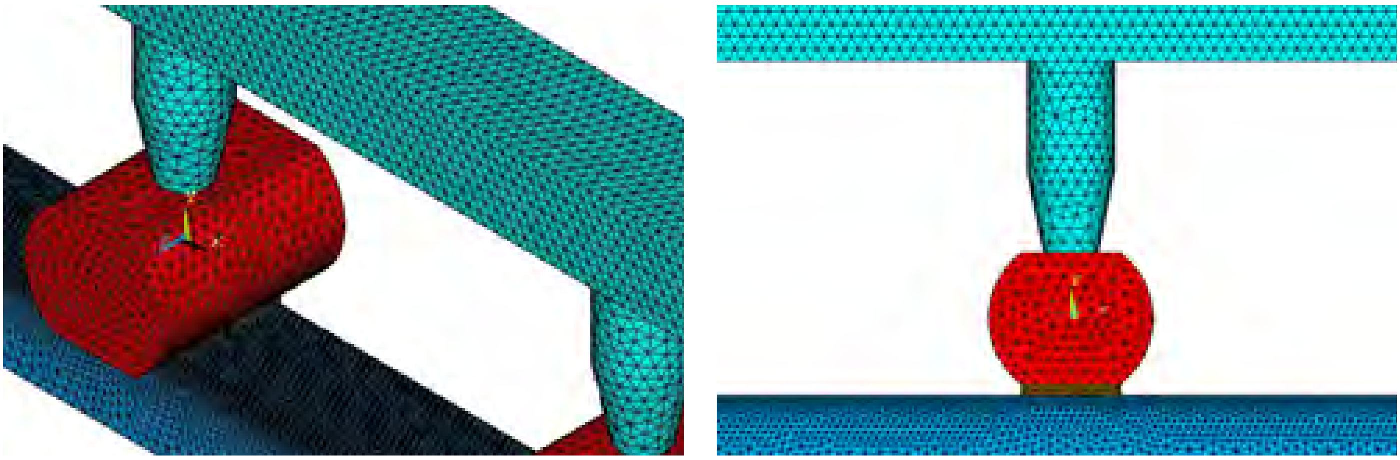

Fig. 3. Fragment of the mesh of finite elements in the 3D ANSYS model

of the welding process), the resistivity, first, of one weld and, next, of two welds decreased to 8.33 μΩm (i.e. by 20%) as a result of the partial melting of the resistance layer.

The results of calculations are presented in Table 1. The calculations aimed to determine power emitted in the contact area between the bars and the percentage fraction of power of individual branches. As can be seen, in the first case the power was emitted symmetrically, whereas the change in resistivity led to asymmetry. A decrease in the resistivity of a given branch resulted in an increase of power emitted in that branch by approximately 10%. At the same time, a change (decrease) in the resistivity of branches combined with the constant value of current forced in the three-spot welding system led to a decrease in total power emitted in the system and also in power emitted in relation to a given weld. A decrease in resistivity of 20% in one branch resulted in the reduction of power by approximately 5%. A decrease in resistivity in two parallel branches led to the reduction of power by approximately 10%.

The modelling process indicated that a change in resistivity in individual branches of the welding machine circuit led to slight asymmetry in the flow of current. However, it should be noted that the analysis was performed in relation to ideally symmetric power supply (which is nearly unobtainable in reality). To assess the effect of the manner of connecting power supply to the circuit of the multispot welding machine it was necessary to perform analysis presented in the subsequent section of the article.

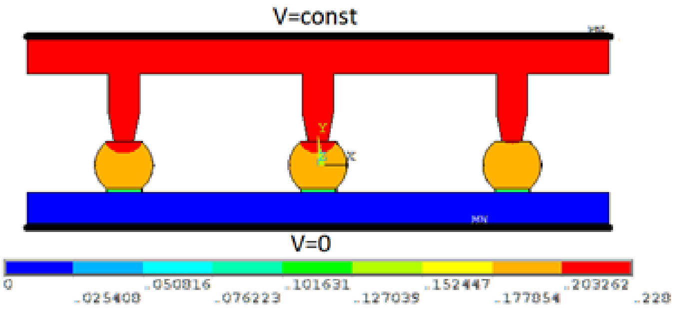

Fig. 4. Voltage drop in the system of symmetric power supply and lower resistivity of one line

Analysis of system properties in relation to various methods of power supply connection

The analysis of the method of connecting the power supply source to the circuit of the multispot welding machine was performed for four variants, forcing the equality of potentials (in relation to a current of 4 kA) on specific areas of the model (see Figure 5). The welding area-related power values are presented in Table 2.

Distributions of voltage presented in Figure 5 were obtained in relation to a forced current of 4 kA and the same basic resistivity of welded joints. Because of the constant value of forced current, the drop of voltage (difference of potentials) was proportional to power supplied to the system. By referring the aforesaid power to values of power supplied to the welding area (presented in Table 2) it was possible to determine the efficiency of such a multispot system (supplying energy to the welding area).

The analysis of the results presented in Figure 5 indicated that asymmetry in current distribution in individual lines of multispot welding was significantly higher in relation to various power supply connection methods than

Table 1. Preset welding cycle parameters and characteristic parameters of the welds

P1, W	P2, W	P3, W	P1%, %	P2%, %	P3%, %
Resistivity of joints, identical in each branch					
274.40	274.27	274.39	33.34	33.32	33.34
Resistivity in branch no. 3, reduced by 20%					
246.42	246.31	279.03	31.93	31.92	36.16
Resistivity in branches nos. 2 and 3, reduced by 20%					
222.53	251.85	251.98	30.64	34.67	34.69

Table 2. Preset welding cycle parameters and characteristic parameters of the welds

P1, W	P2, W	P3, W	P1%, %	P2%, %	P3%, %	Uz, V
Power supply on the left side and symmetric earthing of the lower busbar						
351.0	259.4	220.5	42.2	31.2	26.5	0.301
Symmetric power supply of the upper busbar and earthing on the left side						
416.7	247.3	183.0	49.2	29.2	21.6	0.350
Power supply and earthing on the left side (“lateral”)						
489.3	234.1	158.6	55.5	26.5	18.0	0.403
Power supply on the left side and earthing on the right side (“diagonal”)						
246.4	234.2	349.5	29.7	28.2	42.1	0.419

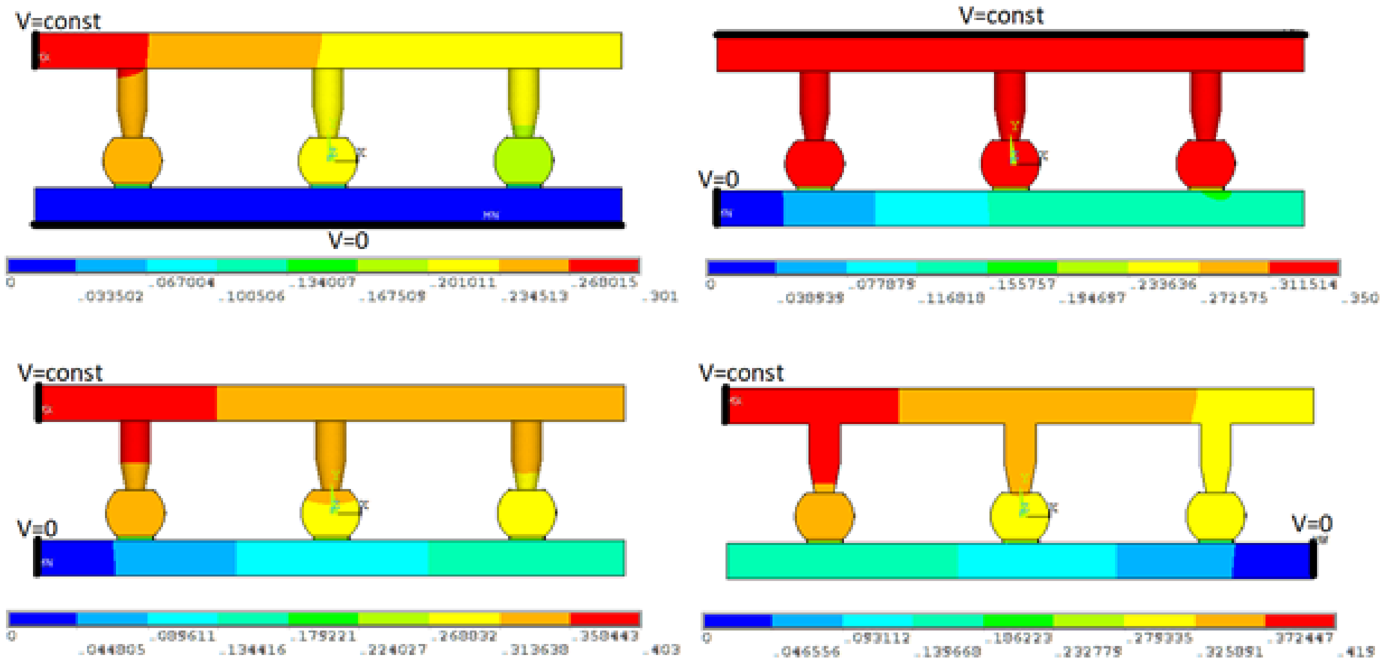

Fig. 5. Distribution of potentials in the asymmetric power supply system

changes in the resistivity of the welded layer itself. The highest variability of supplied power was characteristic of the system with one-sided power supply (because of the adopted left and right-sided power supply of the system). In turn, the system with the left-sided power supply and right-sided earthing was characterised by the greatest total voltage drop, translating into the lowest efficiency of the energy supply system. The foregoing resulted from the low resistivity of the lower busbar made of the structural material. For this reason, a favourable solution could including adding (in such a system) a lower busbar (made of, e.g. copper), in parallel to the welded busbar.

In addition, the lack of symmetry in the power supply connection could trigger changes in the propagation of current in the welding area and, consequently, changes in the welding energy generation area. Figure 6 presents distributions of current in the welding line in relation to the symmetric power supply and the diagonal power supply. Figure 7 also presents the distribution of power losses in the model.

The analysis of the distributions presented in Figures 6 and 7 indicated that the flow of current near the welding area was inhomogenous and that the density of current was higher on the right side (which resulted from the flow of current towards earthing located on the right side of the lower busbar). The asymmetry of current resulted in the asymmetry of emitted power (clearly visible in Figure 7 – in relation to the welding area under the right electrode).

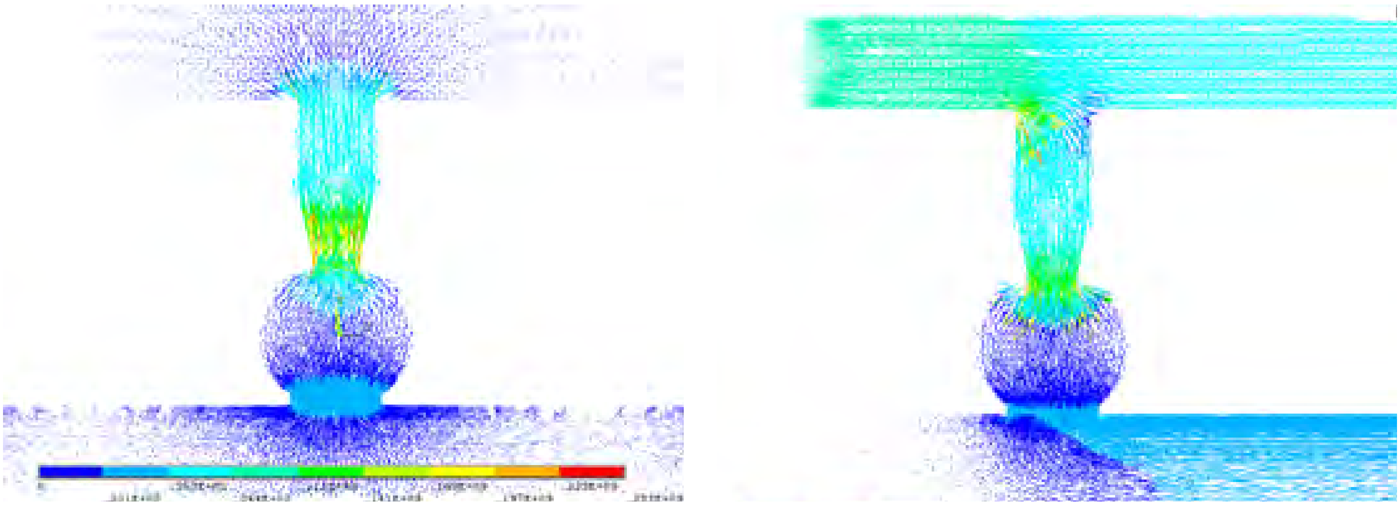

Fig. 6. Distribution of current density in relation to the symmetric power supply and “diagonal” power supply

Such situations could have a significantly unfavourable effect on the shape and strength of welds. Therefore, it is of great importance to ensure the uniform and symmetric power supply in multispot welding systems.

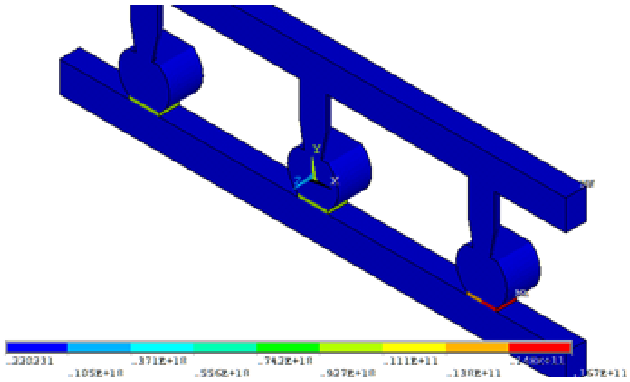

Fig. 7. Distribution of power emitted in the system in relation to the “diagonal” power supply

Modelling based on the ARTAP-AGROS2D software

The numerical modelling results presented in the two previous sections were based on the commercial advanced ANSYS Mechanical software package, i.e. a very efficient tool characterised by extensive computing possibilities, yet also requiring advanced programming. Simple assessment of properties of the current circuit of multispot welding machines could be performed using significantly less complicated tools based on the same computing principles (FEM). One of such tools is the Argos2D software package, being part of the Artap project developed on the “open access” basis by a group of software developers [8]. For comparative purposes, the remainder of the section presents examples of the modelling of a three-spot welding machine based on the aforesaid software programme [9].

The geometry of the system subjected to analysis using the Argos2D software programme was similar to that analysed using the ANSYS software, except that it was based on a 2D model. The structure of the model is presented in Figure 8. The manner of forced current generation was different from that modelled using the ANSYS software. Current in the circuit was generated by supplying a DC voltage of 150 mV, which, in the basic model, corresponded to supply current restricted within the range of 2 kA to 5 kA. In the Argos2D model, two additional layers were applied, i.e. between the electrode and the bar subjected to welding (characterised by an electric conductivity of 27 MS/m) and between (longitudinal and transverse) bars subjected to welding (characterised by a conductivity of 10 MS/m). The geometry of the model did not directly correspond to values typical of such processes, yet it reflected the general structure of the system used in such processes and made it possible to present the method by means of which such a system was modelled.

During 2D numerical modelling, as was the case with the Argos software package, it is necessary to take into consideration simplifications resulting from the modelling and, in particular, the necessity of converting the most commonly provided results (except axisymmetric models) to a length unit (the default depth of the model in the z-axis amounts to 1 m).

Exemplary modelling results concerning the powering of the system from one side are presented in Figures 9 and 10. The manner of forced current generation was similar to that designated as “lateral” in Table 2, except that power was connected to the upper busbar both on the right and left side and the zero potential of the lower busbar was preset only on the right side. The results contain the distribution of potentials in the system in Figure 9 and the distribution of current density in Figure 10 respectively.

The distributions presented in Figures 9 and 10 revealed similar results as during the 3D modelling. The aforesaid results were the consequence of connecting the power supply (or earthing) on one side, which could distort the distribution of power losses in the welding area and, as a result, affect the shape and quality of welds. It should be emphasized that the Argos2D tool features a very comfortable calculator of electromagnetic parameters, making it possible to easily determine and present results in the numerical manner.

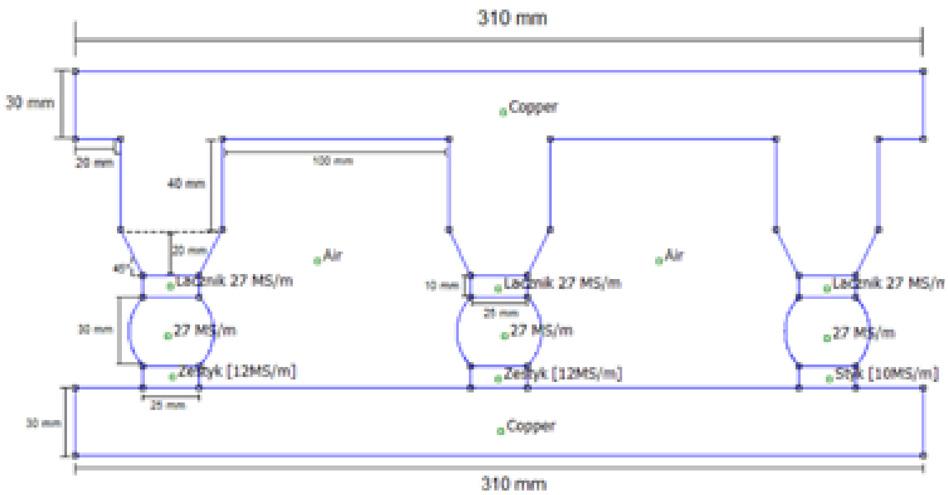

Fig. 8. Geometry of the model of the three-spot welding system in Argos2D [9]

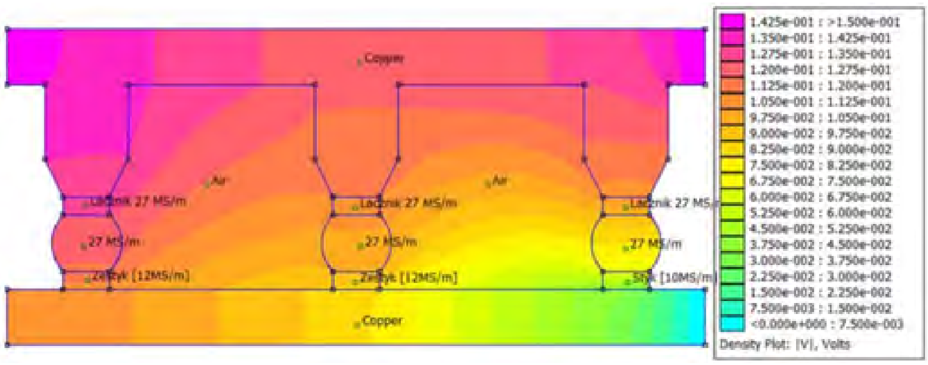

Fig. 9. Distribution of potentials in the three-spot welding system obtained in Argos2D

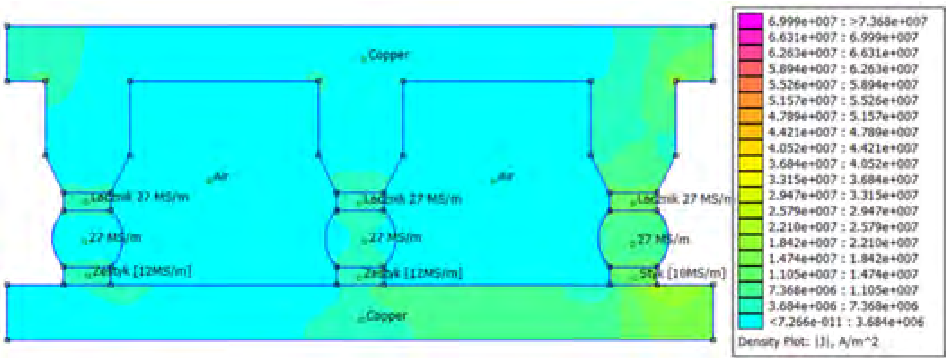

Fig. 10. Distribution of current density in the three-spot welding system obtained in Argos2D

Summary

The simulation tests presented in the article constitute a representative example concerning the modelling of current flow processes in multispot welding systems. The modelling performed using two different computing tools (based on various geometries) made it possible to observe similar phenomena in the distribution of field parameters. The numerical tests were of purely illustrative nature and represented phenomena in a qualitative manner. Nevertheless, the above-presented tests along with their results justified the formulation of the following conclusions:

- 3D numerical modelling of the resistance spot welding process provides the more precise representation of an object, yet it requires significantly higher computing power. Three-dimensional models (even not particularly complex) require the generation of a mesh composed of hundreds of thousands of finite elements;
- 2D modelling requires the conversion of parameters of the system to its actual thickness (depth);
- ensuring the uniformity of current propagation in the multispot welding system requires not only the symmetry of the system geometry but also the symmetry of the power supply connection;
- changes in weld resistance during the welding process trigger the formation of the slight asymmetry (of several percent) of current propagation;
- power supply asymmetry is not only responsible for an increase in the total resistance of the system but also triggers changes in the space distribution of power emitted in the welding area, potentially leading to the formation of welds characterised by improper parameters (shape, strength, etc.).

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