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INVESTIGATION OF THE RESISTANCE SPOT WELDING OF Fe-Ni-Co ALLOY AND COPPER

Irina Boyko
Alexander Filipov
Riga Technical University, Mechanical Engineering Institute
Ezermalas 6-426, LV-1006, Riga
Latvia

ABSTRACT
This article is devoted to investigation of the resistance spot welding of Fe-Ni-Co alloy and Cu wires by the method of analog modeling. Welding is a complicated object to research: integrated investigation and description of characteristics of welding by existing mathematical methods not achieved at this time. The application of system analyses by logical functions allows to describe the causal and effect relationships between large number of parameters of the technological process.
For the logically verified original solution development, the analog model of resistance welding of Fe-Ni-Co alloy and Cu wires was elaborated. On the basis of this model the generalized solution, that provides the welding joints of high quality, was developed.
Keywords: analog modeling, resistance welding, generalized solution

1. INTRODUCTION
Up-to-date instrument engineering demands new technological solutions. It must be noticed that applying of traditional procedures for elaboration of new solutions such as intuitive method, statistical approach, fragmentary logic analysis, and optimization on the basis of the system analysis can take the significant time and capital inputs and may be unsecussful.
That's why for investigation of resistance welding of Fe-Ni-Co alloy and Cu wires we decide to use the method of the analog (non-discrete) modelling which was proposed by R.B.Rudzit [1] and was successfully used by authors and other researches [2-5]. The main advantage of this method is that the application of system analysis by logical functions allows describing the causal and effect relationships between large numbers of parameters of the welding technological process.
Using described in [1,4,5] main principles of analog modelling the analog model of resistance welding of Fe-Ni-Co alloy and Cu wires was elaborated and is offered below.

2. PHYSICAL MODEL OF RESISTANCE SPOT WELDING
The physical model of resistance welding of Fe-Ni-Co alloy and Cu wires which contains physical and geometrical parameters of welded components and influences parameters is shown on Figure 1, where $\rho_{e_1}, \rho_{e_2}, \rho_w, \rho_t$ – specific resistance of the upper and bottom electrodes, Cu wire and Fe-Ni-Co tube; $\lambda_{e_1}, \lambda_{e_2}, \lambda_w, \lambda_t$ – thermal conductivity of material of the upper and bottom electrodes, Cu wire and Fe-Ni-Co tube; m_{e_1}, m_{e_2} – mass of the upper and bottom electrodes; d_{t_1}, d_{t_2}, d_w – outer and inner diameters of Fe-Ni-Co tube, Cu wire diameter, correspondingly; α_t, α_{gl} - linear expansion coefficient of material of tube and glass (in our case in investigated electrical device the tube was hermetically fixed in glass).

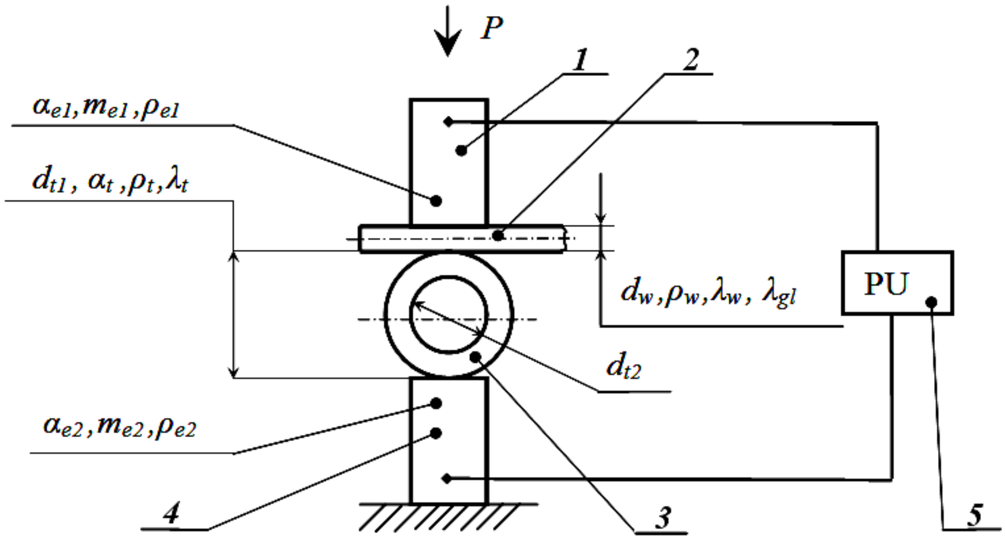

Figure 1. The physical model of resistance spot welding:
1 – upper electrode; 2 – Cu wire; 3 – Fe-Ni-Co tube; 4 – bottom electrode; 5 – power unit; P – static pressure.

3. ANALOG MODEL OF RESISTANCE SPOT WELDING

The goal of the present technological task is the quality assurance of process Q_p. So, at the first step of analysis the characteristic of quality assurance of process Q_p is described as analog logical function of two nearest common parameters: parameter of quality of welding Q_w and parameter of negation of crack formation in glass (in the place of tube fixing) $\overline{Q}_{gl}$: $Q_p = f\left|Q_w, \overline{Q}_{gl}\right|$. The kind of analog logical function is defined by tabulation and analysis of the truth-value tables. In this case parameters are related to each other by analog conjunction: $Q_p = f\left|Q_w / \cdot / \overline{Q}_{gl}\right|$. Then each of the characteristics Q_w and $\overline{Q}_{gl}$ are described as analog logical functions of two nearest common parameters and etc. The scheme of the analysis and synthesis of model you can see on Figure 2.

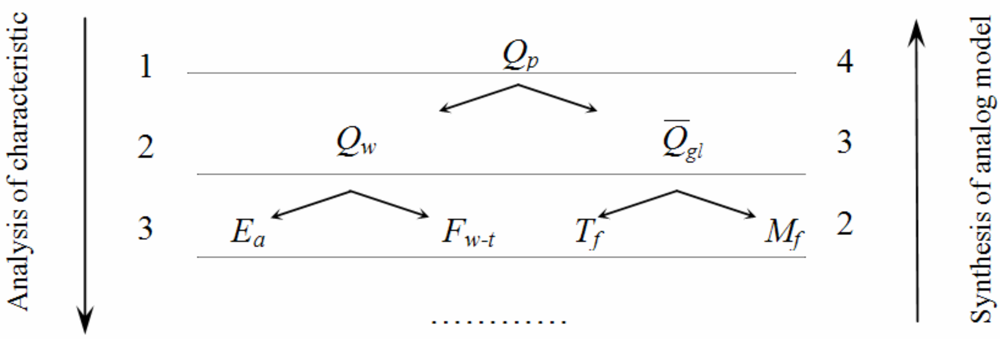

Figure 2. The scheme of the analysis of the characteristic of quality assurance of process Q_p and synthesis of it's analog model (fragment).

After the analysis of the characteristic of welding process the analog model synthesis is executed by consecutive substitutions of parameters-arguments of the subsequent step of analysis in directly determinated by them parameters-functions of the previous step of analysis. Complicated multiparametric process considered as system of elementary physical phenomena combined by the causal and effect relationships. After all substitutions the formula of characteristic of welding quality parameter Q_w is determined:

$$
\begin{aligned}
Q_w = f\Big(& \Big|^{1}_{8}\Big|^{1}_{7}\Big|^{1}_{6}\Big|^{1}_{5}\Big|^{1}_{4}\Big|^{1}_{3}\Big|^{1}_{2}\Big|^{1}_{1} \overline{P}_{st} /+/ \underset{\overline{P}_{st-1}}{\underbrace{\exists}} \overline{F}_{u.e} /+/ \overline{L}_{K_1}\Big|_{1} /+/ \rho_{e1} /+/ \rho_{w} /+/ S_{cond}\Big|_{2} /\cdot/ I_{e1-w} /\cdot/ t_w\Big|_{3} /+/ \\
& /+/ \Big|^{2}_{3}\Big|^{2}_{2}\Big|^{2}_{1} d_w /\cdot/ \rho_w\Big|_{1} /+/ \underset{(1-2)-1}{\underbrace{\exists}}\Big|^{3}_{1} \overline{P}_{st} /+/ \underset{\overline{P}_{st-1}}{\underbrace{\exists}} \overline{F}_{u.e} /+/ \overline{L}_{K_1}\Big|_{1}\Big|_{2} /\cdot/ I_w /\cdot/ t_w\Big|_{3} /+/ \Big|^{3}_{3}\Big|^{3}_{2}\Big|^{4}_{1} \overline{P}_d /+/ \overline{F}_{u.e}\Big|_{1} /+/ \\
& /+/ \rho_w /+/ \rho_t\Big|_{2} /\cdot/ I_{w-t} /\cdot/ t_w\Big|_{3} /+/ \Big|^{4}_{3}\Big|^{4}_{2}\Big|^{5}_{1} d_{t1} /\cdot/ d_{t2} /\cdot/ \rho_t\Big|_{1} /+/ \underset{(1-5)-1}{\underbrace{\exists}}\Big|^{6}_{1} \overline{F}_{b.e} /+/ \overline{L}_{K_2}\Big|_{1}\Big|_{2} /\cdot/ I_t /\cdot/ \\
& /\cdot/ t_w\Big|_{3} /+/ \Big|^{5}_{3}\Big|^{5}_{2}\Big|^{7}_{1} \overline{F}_{b.e} /+/ \overline{L}_{K_2}\Big|_{1} /\cdot/ P_d\Big|_{2} /\cdot/ I_{t-e2} /\cdot/ t_w\Big|_{3}\Big|_{4} /\cdot/ \Big|^{2}_{4} \overline{\lambda}_{e1} /\cdot/ \overline{m}_{e1} /\cdot/ \overline{t}_w\Big|_{4} /\cdot/ \Big|^{3}_{4}\Big|^{6}_{3} \overline{\lambda}_{e2} /\cdot/ \overline{m}_{e2} /\cdot/ \\
& /\cdot/ \overline{t}_w\Big|_{3} /+/ \Big|^{7}_{3} \overline{F}_{b.e} /+/ \overline{L}_{K_2}\Big|_{3}\Big|_{4}\Big|_{5}\Big|_{6} /\cdot/ \Big|^{2}_{6}\Big|^{2}_{5}\Big|^{4}_{4} P_t /\cdot/ \overline{m}_{m.e}\Big|_{4} /\cdot/ \Big|^{5}_{4} \overline{P}_d /+/ \overline{F}_{u.e}\Big|_{4}\Big|_{5}\Big|_{6}\Big|_{7} /\cdot/ \Big|^{2}_{7} P_d /+/ F_{u.e}\Big|_{7}\Big|_{8} \Big),
\end{aligned} \tag{1}
$$

where P_{st} – static pressure; $F_{u.e}$, $F_{b.e}$ – form parameters of upper and bottom electrodes; L_{K1} –length of contact of upper electrode and Cu wire; S_{cond} – parameter of surface condition of upper electrode and Cu wire; $I_{e1-w}, I_w, I_{w-t}, I_t, I_{t-e2}$ – current flows through contact resistance of upper electrode-wire, wire, wire-tube, tube, tube-bottom electrode contacts, correspondingly; t_w – pulse duration of welding current; P_d – dynamic pressure; L_{K2}. – length of contact of bottom electrode and tube; P_t – static pressure un tube; $m_{m.e}$ – mass of moving elements.

The sequence numbers of synthesis steps of braced parameters are shown under brackets. The sequence number of parameter on this step of synthesis is shown above left bracket.

Likewise, the formula for parameter-function $\overline{Q}_{gl}$ is determined as follows:

$$
\begin{aligned}
\overline{Q}_{gl} = f\Big(& \Big|^{2}_{8}\Big|^{3}_{7}\Big|^{3}_{6}\Big|^{3}_{5}\Big|^{6}_{4}\Big|^{8}_{3}\Big|^{6}_{2}\Big|^{8}_{1} P_{st} /+/ \underset{P_{st-1}}{\underbrace{\exists}} F_{u.e} /+/ L_{K_1}\Big|_{1} /+/ \overline{\rho}_{e1} /+/ \overline{\rho}_{w} /+/ \overline{S}_{cond}\Big|_{2} /\cdot/ \overline{I}_{e1-w} /\cdot/ \overline{t}_w\Big|_{3} /+/ \\
& /+/ \Big|^{9}_{3}\Big|^{7}_{2}\Big|^{9}_{1} \vec{d}_w /\cdot/ \overline{\rho}_w\Big|_{1} /+/ \underset{(1-9)-1}{\underbrace{\exists}}\Big|^{10}_{1} P_w /+/ \underset{P_{w-1}}{\underbrace{\exists}} F_{u.e} /+/ L_{K_1}\Big|_{1}\Big|_{2} /\cdot/ \overline{I}_w /\cdot/ \overline{t}_w\Big|_{3} /+/ \Big|^{10}_{3}\Big|^{8}_{2}\Big|^{11}_{1} P_d /+/ \\
& /+/ F_{u.e}\Big|_{1} /+/ \overline{\rho}_w /+/ \overline{\rho}_t\Big|_{2} /\cdot/ \overline{I}_{w-t} /\cdot/ \overline{t}_w\Big|_{3} /+/ \Big|^{11}_{3}\Big|^{9}_{2}\Big|^{12}_{1} \overline{d}_{t1} /\cdot/ \overline{d}_{t2} /\cdot/ \overline{\rho}_t\Big|_{1} /+/ \underset{(1-11)-1}{\underbrace{\exists}}\Big|^{13}_{1} F_{b.e} /+/ \\
& /+/ L_{K_2}\Big|_{1}\Big|_{2} /\cdot/ \overline{I}_t /\cdot/ \overline{t}_w\Big|_{3} /+/ \Big|^{12}_{3}\Big|^{10}_{2}\Big|^{14}_{1} F_{b.e} /+/ L_{K_2}\Big|_{1} /\cdot/ \overline{P}_d\Big|_{2} /\cdot/ \overline{I}_{t-e2} /\cdot/ \overline{t}_w\Big|_{3}\Big|_{4} /\cdot/ \Big|^{7}_{4} \lambda_{e1} /\cdot/ m_{e1} /\cdot/ \\
& /\cdot/ t_w\Big|_{4} /\cdot/ \Big|^{8}_{4}\Big|^{13}_{3} \lambda_{e2} /\cdot/ m_{e2} /\cdot/ t_w\Big|_{3} /+/ \Big|^{14}_{3} F_{b.e} /+/ L_{K_2}\Big|_{3}\Big|_{4}\Big|_{5}\Big|_{6} /+/ \underset{(5-3)-1}{\underbrace{\exists}}\Big|^{4}_{6} L /+/ \\
& /+/ \overline{\lambda}_t\Big|_{6}\Big|_{7} /\cdot/ \Big|^{4}_{7}\Big|^{4}_{6} \overline{N} /+/ \overline{P}_{d.t}\Big|_{6} /\cdot/ \Big|^{5}_{6} \overline{P}_{d.t} /\cdot/ \overline{m}_{unit}\Big|_{6} /\cdot/ \Big|^{6}_{6} \overline{P}_{d.t} /+/ \overline{P}_{unit}\Big|_{6}\Big|_{7}\Big|_{8} \Big),
\end{aligned} \tag{2}
$$

were L – distance from welding place to glass; N – effort using for tube mounting on upper electrode; $P_{d.t}$ – potential dynamic pressure on tube; m_{unit} – mass of electrical device unit; P_{unit} – effort on device unit after taking off pressure from upper electrode.

Offered model contains all information about changes of level of output (Q_p) during any changes of level of input variable parameters. It should be noted that input variable parameters are easily determined parameters, such us physical properties of materials, welding conditions and geometrical parameters.

4. ELABORATION OF GENERALIZED SOLUTION

At the next stage the choosing of strategic decisions from table of enumeration of possibilities [1,3] was made. In our case only 27 situations from possible situations have levels of characteristics of process different from previous (Fig.3.). However, there is no situation, where levels of characteristics Q_w and $\overline{Q}_{gl}$ simultaneously increased. Therefore, the generalized solution should be elaborated. Since under the technical objective the dimensions and materials of welded details not variable the unique decision is to use coating or intermediate layer from material which have unrestrained or significant mutual solubility with copper and Fe-Ni-Co alloy.

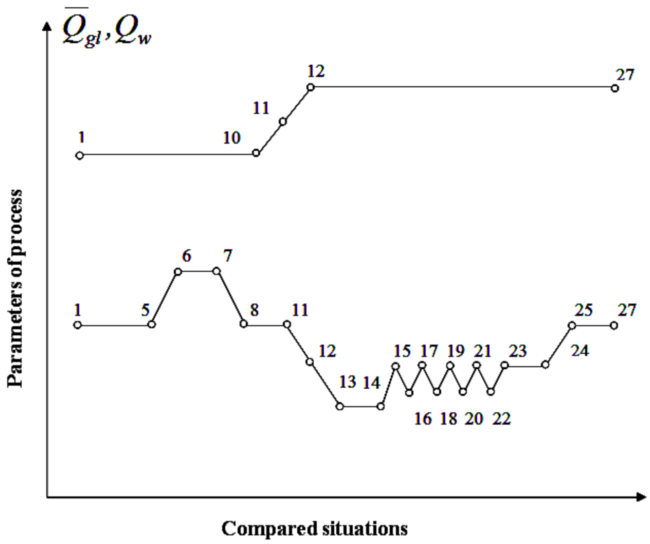

Figure 3. Graph of compared situations.

Generalized solution: preliminarily the Cu wire should be welded with Ni foil, and then foil with another end should be welded with Fe-Ni-Co tube. On the side of Cu wire the Mo electrode should be used, and on the side of Ni foil – Cu electrode. During welding Ni foil and Fe-Ni-Co tube Cu electrodes should be used. Electrodes should have plain working surfaces for Ni foil and should have groove for Fe-Ni-Co tube.

5. CONCLUSION

For the logically verified original solution development, the analog model of resistance welding of Fe-Ni-Co tube and Cu wires was elaborated. On the basis of this model the generalized solution, that provides the welding joints of high quality, was developed. Analog modelling is especially efficient in development of new welding technological processes and in optimization of known processes.

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