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REQUIREMENTS TO TECHNICAL CHARACTERISTICS OF RESISTANCE MICROWELDING MACHINES

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ABSTRACT

Welding of up to 0.5 mm thick parts is usually called microwelding. Resistance microwelding is widely applied in electronics and instrument-making. Thermal inertia of welded parts at resistance welding is proportional to the square of their thickness. As a result of low thermal inertia of the parts at microwelding, the change of their temperature is close to the change in time of welding current of 50 Hz industrial frequency. In order to eliminate the temperature ripple, resistance microwelding should be conducted by direct current pulses or high-frequency welding current. At microwelding, the initial part-part contact resistance is tens of times higher than that of the parts being welded. To reduce the initial splashes of molten metal and to stabilize the welded joint quality, the welding current should increase smoothly at microwelding.

KEY WORDS: resistance microwelding, similarity theory, thermal inertia, welding current frequency, typical welding modes

INTRODUCTION

Resistance welding is the most productive welding process, which covers up to 50 % of welded products in the total volume of all the welding processes [1]. Welding of up to 0.5 mm parts is usually called microwelding. It is widely applied in electronics and instrument-making in manufacture of automotive electronics, sensors, medical instruments, batteries and battery modules, electronic components as well as in manufacture of jewelry [2–4]. Microwelding is often used in assembly of quartz resonators, piezoelectric instruments, capacitors, standard and solid-state resonators, thermocouples, different heating modules, miniature vibro motor, thermobatteries, fuel assembly spacer grills, which operate in the nuclear reactor core, as well as at sealing of the cases of miniature instruments, membrane boxes, and bellows and at installation of electric devices. There are data [4, 5] on replacement of the soldering process in manufacture of electronic instrumentation and jewelry by resistance microwelding, which has a number of serious advantages over it: absence of solders or fluxes, higher electric characteristics of the produced joint, thermal and vibration resistance, minimum impact of temperature on the parts being joined, cleaner manufacturing conditions, etc.

In the majority of the cases the requirements made of the produced welded joint, are limited to the required strength. In welding critical parts, however, in addition to high guaranteed quality and reliability of the joints, it is also necessary to ensure their high repeatability and absence of splashing of molten metal particles. High repeatability is required in manufacture of complex products, when a large number of welds are made, and the finished product quality largely depends on the quality of each of them [7, 8].

FEATURES OF RESISTANCE MICROWELDING

Microwelding has several features, which create additional problems in the technology and design of the equipment. The small thickness of the parts being welded is the cause for low thermal inertia of the spot welds. From the theory of similarity, the thermal inertia of the parts being welded should be proportional to the square of the part thickness. Nobody has performed experimental determination of the magnitude of this inertia, but the analytical solution for nonstationary heating of the spot weld by a source of complex-shaped current is rather complicated, even with considerable simplifying assumptions. Therefore, the inertia was evaluated by mathematical modeling.

At resistance spot microwelding the electrode diameter is much larger than the welded part thickness. It allows assuming that the main portion of welding current flows through a metal column of the diameter equal to that of the electrodes and of the height which is equal to the total thickness of the parts being welded. This simplifying assumption was used when performing modeling of the dynamics of heating by 50 Hz current of spot welds on low-carbon steel of different thickness in an analog computer [9]. While in the first approximation the welded product can be presented as a first order inertia link, the results of modeling the thermal time constants Q of the parts being welded in the thickness range $\delta = 1–0.2$ mm are readily described by equation $Q = 0.0578\delta^2$ s.

Thus, the calculated thermal time constant of the spot weld is approximately proportional to the square of thickness of the metal being welded. As a result, for low-carbon steel at 50 Hz frequency of welding current the temperature ripple, caused by periodical change of welding current in time, are negligibly small in welded thicknesses above 2.5–2.0 mm. At thickness $\delta = 1.0$ mm the temperature ripple in the spot center is equal to < 10 %. In welding of small thicknesses, the spot weld temperature during its formation follows the change of welding current with a slight delay, the rear front of the current pulse actually does not participate in welding, and spot heating (formation) essentially depends on the welding current pulse shape.

The role of contact resistances as heat sources grows at the beginning of welding due to relatively small internal resistance of the parts, and small welding forces. So, based on calculations and experiments of V.E. Moravskyi [3] at reduction of the thickness of sheets from low-carbon steel 40 times (from 2.0 to 0.05 mm), the values of initial part-part contact resistances differs 170 times. In the general case, the ratio of contact resistances to internal resistance of the parts being welded is inversely proportional to their linear dimensions. For this reason, at contact microwelding the probability of initial splashes rises abruptly, making it supersensitive to the shape of the leading front of the welding current pulse.

FEATURES OF THE MODES OF RESISTANCE SPOT MICROWELDING

In welding metals of medium and large thicknesses at industrial frequency of welding current, considerable experience has been accumulated on stabilization of spot weld parameters by program and automatic regulation of process parameters during welding. This experience is almost not used in resistance spot microwelding, which is inferior to resistance welding of usual thicknesses, in terms of diversity of the welding modes and stability of welded joint quality. This is caused by a lack of fast-response welding power sources.

Welding of medium and large thicknesses is conducted in welding machines with alternating current of 50 Hz industrial frequency. In keeping with similarity criteria [10], the welding pulse duration is proportional to the square of welded metal thickness. Therefore, while in welding, for instance, of low-carbon steel 1 mm thick welding current time of 0.188 s is set on average, for welding of the same material 0.2 mm thick in a similar mode welding duration should be 0.023 s, whereas for material of 0.1 mm thickness it should just 0.009 s. In this case, it is practically impossible to regulate the welding time at 50 Hz mains frequency. More over, the welding current is also very hard to control.

In welding metals of medium and large thicknesses at industrial frequency, current regulation proceeds by changing the angle of the thyristor switching on. Therefore, after 120^{o} phase of welding current, the spot weld temperature begins to drop following the current and the molten nugget stops growing. The second half-cycle of welding current is ineffective, as it does not lead to further increase of the molten nugget dimensions. Hence it follows that welding of steel of less than 0.2 + 0.2 mm thickness at alternating current of industrial frequency is only possible by one half-cycle of the mains voltage, while the range of phase regulation is equal to 0–90°, calculated from the phase angle of voltage and current of the welding circuit.

For one-half-wave welding, in addition to controlling the current by adjustment of thyristor switching angle, a method was developed to control the current by regulation of the duration of thyristor on state [10, 11]. This is performed by forced blanking of the thyristor, when current has reached the specified value in its rise range.

Both in the first, and in the second case, it is impossible to control the form of the current pulse leading front. Because of all these causes, the so-called capacitor welding machines are used for welding small thicknesses in most cases [3].

Alongside the indubitable advantages, the capacitor welding machines are greatly inferior to alternating current machines as regards welding mode control, for multicycle welding. In capacitor welding machines it is extremely difficult to control the welding current pulse shape, and it is totally impossible to adjust the welding current during welding. Known are rather clumsy attempts to at least somehow change the natural shape of the capacitor discharge current, but all of them lead to an abrupt complication of the welding source, while the possibilities of controlling the pulse shape are extremely limited [3, 11].

Known are power sources with linear transistor regulators [6–8, 12]. They have ideal regulation characteristics, which allow realizing any welding cycles and automatically adjusting the welding parameters. Unfortunately, because of their cost and bulkiness, they will hardly become more or less widely applied, similar to the case of arc welding.

In principle, the resistance microwelding machines will not in any way differ from those for welding medium and large thicknesses at alternating current, if the condition of similarity is met [9]: welding current frequency $f = k_6\delta^{-2}$, welding circuit impedance $Z_k = k_5\delta^{-1}$ and machine mobile part mass $m = k_7\delta^5$. However, at resistance microwelding the influence of relatively high initial contact resistance of the parts being welded is still in place. And this, in particular, is ex-

Table 1. Averaged recommended modes of spot resistance microwelding of low-carbon steels

δ, mm	$\overline{d}_{el}$, mm	$\overline{F}_w$, kg	$\overline{I}_w$, kA	$\overline{t}_w$, s	*f*, kHz	$\overline{P}_w$, kW	I_w^{min}, kA	t_w^{max}, s
1	2	3	4	5	6	7	8	9
0.05	1.15	12.7	2.2	0.0036	20.0	2.2	1.50	0.01
0.10	1.66	25.6	3.08	0.0090	5.00	3.08	2.09	0.026
0.15	2.05	36.2	3.74	0.0150	2.20	3.74	2.50	0.043
0.20	2.46	47.7	4.29	0.0224	1.25	4.29	2.90	0.065
0.25	2.68	59.0	4.78	0.0300	0.80	4.78	3.25	0.87

actly why expansion of the possibilities for regulation of the welding machine is required.

REQUIRED TECHNICAL CHARACTERISTICS OF AC RESISTANCE MICROWELDING MACHINES

In electronics and instrument-making resistance microwelding is used for welding products in the thickness range of 0.05–0.25 mm. We will extrapolate the data by the modes of welding medium and large thicknesses. The modes of welding low-carbon steel as the most common one are the most fully studied. Statistical treatment of all the accessible data bases of the modes of resistance welding of low-carbon steel in the thickness range δ = 0.5–7.3 mm yielded the following dependencies for averaged welding modes:

$$\left.\begin{aligned} \overline{d}_e &= 5.5\delta^{0.526} \\ \overline{F}_w &= 222\delta^{0.956} \\ \overline{I}_w &= 9.264\delta^{0.478} \\ \overline{t}_w &= 0.188\delta^{1.32} \end{aligned}\right\}. \qquad (1)$$

Welding modes, calculated by (1) for thickness range of 0.05–0.25 mm are given in Table 1.

Table 1 gives the welding current frequencies, required for welding small thicknesses, at which the ripple of the spot temperature will be the same as in welding 1.0 + 1.0 mm thicknesses at 50 Hz frequency.

Analysis of Table 1 shows that welding at averaged modes requires rather high currents and source power. The seventh column shows the power, evolving in the spot weld at 1 V voltage in the spot, which, as is known, almost does not change with the change of the welded part thickness.

In practice, large thicknesses are welded at soft modes to lower the power, medium ones — at rigid modes to increase the productivity. Small thicknesses are also welded in soft modes, so as not to use the difficult-to-ensure short welding time, at which, as shown above, flexible current adjustment is not possible either. At welding at higher frequencies, increase of welding time for small thicknesses is no longer relevant, as the number of welding current cycles, which is increased with increase of frequency, is quite sufficient for current adjustment. However, reduction of the required power of the welding source is highly important, as it simplifies the transistor high-frequency power generator.

Formulas (1) are given for average mode parameters. A weld spot of the same size can be obtained at different combinations of I_w and t_w. Processing of experimental mode data showed that the interrelation of current with welding time can be described by the following complex dependence:

$$I_w^2 t_w^{0.7} = 25.7\delta^{1.8}. \qquad (2)$$

Scatter of experimental data around this regression line is much smaller than that for each of the components taken separately. In keeping with this dependence, welding current I_w decreases with increase of t_w, and vice versa. The variation limits of these parameters are restricted by the following: welding current can be increased with the respective reduction of the welding time, until splashing from under the electrode begins at the start of the current pulse; welding time can be increased with the respective decrease of welding current, until the dent from the electrode does not exceed 15 % of the welded sheet thickness. In the first case, the welding mode is called extremely rigid, in the second case it is the extremely soft. Naturally, the soft modes require lower source power, than the rigid ones.

Processing of welding modes for low-carbon steel 0.9–1.0 mm thick shows that the variation range of admissible current from the average one is equal to ±32 % for extremely modes. Thus, the data from Table 1 can be corrected for soft modes (columns 8 and 9). These data correspond to simply the recommended soft modes, and in no way to the extremely soft ones.

In reality 1–2 mm electrodes are used for microwelding [3], Table 2.

On the other hand, the following dependence is valid for the extremely soft modes:

$$j_w^{min} = \frac{0.089\sqrt{p}}{\delta^{0.5}}, \qquad (3)$$

where j_w^{min} is the minimum current density; *p* is the specific pressure of the electrodes.

Table 2. Recommended soft modes of spot resistance microwelding of low-carbon steels

δ, mm	d_{el}, mm	j_w^{max}, kA/mm^2	I_w^{min}, A
0.05	1.0	1.056	0.875
0.10	1.0	0.743	0.583
0.15	1.0	0.607	0.477
0.20	1.5	0.526	0.929
0.25	1.5 (2.0)	0.470	0.830 (1.476)

Table 2 gives I_w^{min} values, calculated by (3), which correspond to those of minimum welding current for electrodes used in practice and p = 7 kg/mm^2. As a result, it turns out that the entire range of thicknesses of interest to us, can be welded at approximately 1 kA current.

CONCLUSIONS

The thermal time constant of the welded sheets, is proportional to the square of sheet thickness.

For low-carbon steel, the coefficient of proportionality of the thermal time constant to the square of welded sheet thickness is ≈ 0.06 s/mm^2.

In order for the temperature ripple in welding low-carbon steel of 0.1 + 0.1 mm thickness, which is due to thermal inertia of the spot weld, to be the same as in welding steel of 1.0 + 1.0 mm thickness at 50 Hz frequency, welding current frequency should be 5 kHz.

Low-carbon steel of 0.05–0.25 mm thickness can be welded in soft (as in welding of medium thicknesses) modes, using up to 1 kA welding currents.

REFERENCES

1. Bannov, M.D. (2005) *Resistance welding technology and equipment*. Moscow, Akademiya [in Russian].
2. Ataush, V.E., Leonov, V.P., Moskvin, E.G. (1996) *Microwelding in instrument engineering*. Riga, RTU [in Russian].
3. Moravsky, V.E., Vorona, D.S. (1985) *Technology and equipment for spot and projection capacitor-discharge welding*. Kiev, Naukova Dumka [in Russian].
4. Kolupaev, Yu.F., Privezentsev, V.I. (2003) Peculiarities of capacitor-discharge welding of nichrome in producing of jevellery. *Svarochn. Proizvodstvo*, **11**, 41–43 [in Russian].
5. Paerand, Yu.E., Bondarenko, A.F. (2005) Peculiarities of formation of current pulses for small-size parts. *Tekhnichna Elektrodynamika. Tem. Issue: Power Electronics and Power Efficiency*, Pt 3, 28–31 [in Russian].
6. Paerand, Yu.E., Bondarenko, A.F. (2006) Application of special shape pulses for resistance microwelding. In: *Proc. of 7th Int. Sci.-Pract. Conf. on Modern Information and Electronic Technologies (MIET–2006), Odessa*, Vol .2, SE Neptun, Tekhnologiya.
7. Paerand, Yu.E., Bondarenko, A.F. (2006) Power supply for resistance microwelding with programmable shape of welding pulse. *Tekhnologiya i Konstruirovanie v Elektronnoj Apparature*, **4**, 51–54 [in Russian].
8. Lankin, Yu.N. (1967) Electromodeling of thermal processes in resistance spot welding. *Avtomatich. Svarka*, **7**, 23–26 [in Russian].
9. Lebedev, V.K., Yavorskij, Yu.D. (1960) Application of similarity criteria for determination of resistance welding modes. *Ibid*., **8**, 37–44 [in Russian].
10. Paton, B.E., Lebedev, V.K. (1969) *Electric equipment for resistance welding. Theory elements.* Moscow, Mashinostroenie [in Russian].
11. Paton, B.E., Gavrish, V.S., Grodetsky, Yu.S. (1963) Inertialess diagrams of automatic regulation of resistance welding processes. *Avtomatich. Svarka*, **5**, 7–10 [in Russian].
12. Leonov, V.P., Barabanshchikova, L.A., Grechenkova, A.A., Ataush, V.E. (1990) Controllable power supply SARM-1 for resistance microwelding. *Svarochn. Proizvodstvo*, **10**, 36–38 [in Russian].

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