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STABILIZATION OF WELDING CURRENT OF RESISTANCE SPOT WELDING MACHINES AT MAINS VOLTAGE FLUCTUATIONS

Yu.N. LANKIN, V.F. SEMIKIN and **E.N. BAJSHTRUK**
E.O. Paton Electric Welding Institute, NASU
11 Kazimir Malevich Str., 03680, Kiev, Ukraine. E-mail: office@paton.kiev.ua

The paper deals with the approaches to development of open-loop systems of welding current stabilization in resistance spot welding machines at mains voltage fluctuations. A microcontroller regulator of resistance welding is described, which provides automatic determination of the initial angle between full-phase current and voltage of the machine, as well as welding current stabilization at mains voltage fluctuations. System of angle determination and current stabilization is implemented as finite state machine with digital model of the object of control, presented in the tabulated form. This enabled application of a simple general purpose eight-bit microcontroller for the regulator. 7 Ref., 1 Figure.

Keywords: *stabilization, welding current, mains voltage, resistance welding*

Under production conditions, the process of resistance spot welding is exposed to numerous disturbances, leading to appearance of defective joints. The principal disturbances are as follows:

- mains voltage fluctuations;
- increase of electrode contact surface at their wear in operation;
- increase of impedance of machine welding circuit as a result of addition to it of considerable ferromagnetic masses in welding of large-sized parts;
- shunting of welding current and force applied to the electrodes, through earlier welded spots, located in immediate vicinity of welding point.

More or less considerable fluctuations of mains voltage are always found during resistance welding in reality, and, therefore, elimination of their influence on welded joint quality is required first of all. The adjustable variable in resistance welding usually is the effective value of welding current and much more seldom this is the interelectrode voltage or power, evolving in the welded spot.

To eliminate the influence of external disturbances, open-loop automatic control systems (ACS) with disturbance control, or closed-loop systems with negative feedback by adjustable variable, or combined ones are used. Historically, open-loop ACS with disturbance control were the first to be developed for resistance welding. They stabilize welding current only at mains fluctuations. Next came ACS with negative feedback, stabilizing welding current, irrespective of the kind of disturbance.

Open-loop ACS are simpler and more reliable than the closed-loop ones. Therefore, they have become the most widely accepted systems. Already the early, still ignitron welding current circuit breakers of PIT and PISh type (Electric Plant, Leningrad) with electronic valve control circuits provided automatic stabilization of welding transformer voltage at mains voltage fluctuations. Stabilization circuit was rather complicated and thorough adjustment was required at variations of resistance machine cos φ. Presence of a filter in control voltage circuit led to certain inertia of the stabilizer, so that short-term mains fluctuations could not be compensated at hard welding modes.

First transistor circuits for current control in resistance welding machines, developed at PWI in the 60s, provided practically inertialess stabilization of current at mains voltage fluctuations [1], stabilization of mean value of voltage in welding transformer at fluctuations of mains voltage and machine cos φ [2]. At the same time, the staff of the Institute of Cybernetics of AS of Ukr.SSR (V.N. Nikulin, V.I. Skurikhin), together with PWI, developed a completely digital system of program control of power evolved in the welding zone, with regulation by disturbances, namely by fluctuations of mains voltage, ohmic and reactive resistance of machine welding circuit [3, 4]. For the first time, general principles of construction of such devices were developed, a number of issues of designing digital control, measuring and converting devices for resistance welding machines controls were solved. The system was built as an automatic machine with finite number of internal states. All the states are presented in the form of tables, containing a matrix of reciprocal object model and measuring and computing matrix, from which the value of the angle of switching-on the contactor power valves is read for each period of mains voltage, depending on set power value, mains voltage and load resistance. This system was ahead of its time for dozens of years. Digital systems of resistance welding control, usually being functionally inferior to it, were developed only after appearance of microcontrollers.

All the modern microcontroller regulators for resistance welding are fitted with the function of «parametric» stabilization of welding current at mains voltage fluctuations. Change of effective value of current of not more than ±3 % at mains voltage fluctuations of 0.9 to 1.05 of the nominal value is claimed. To ensure the accuracy of stabilization in some regulators, for instance, RKS-601, RKS-14, RKS-22, it is necessary to manually enter the value of machine power coefficient cos φ. Now, in the majority of regulators, for instance, RKM-511, RKM-812, RKM-1501, RKS-502, RKS-801(K155), RKS-807, RKS-901, automatic adjustment for power coefficient is performed. In the most perfect regulators RKM-802, RKM-804, RKM-805, RKM-806, KCU KS 02 a combined regulation principle is implemented. They simultaneously contain a closed-loop circuit of regulation by welding current deviation from set value and open-loop circuit for regulation by external disturbance (mains voltage).

Apparently, the most popular algorithm of current stabilization at mains voltage fluctuations for microprocessor regulators for resistance welding was developed by VNIIESO specialists [5]. According to it, current stabilization is performed in each half-period, starting from the second one, by setting angle α of thyristor switching-on in keeping with expression $\alpha = IU/b_1 - b_0/b_1$, where I is the set current value, referred to current of full-phase switching at nominal mains voltage; U is the measured mains voltage, referred to nominal voltage; b_0, b_1 are the parameters of regulation characteristic, represented by second degree polynomials of power factor of full-phase switching of welding circuit. Value of cos φ required for calculation of b_0 and b_1 is automatically determined in the first half-period by measured value of the angle of conduction λ at certain angle α_0, knowingly less than φ, from expression $\cos\varphi = C_0(\alpha_0) + C_1(\alpha_0)\lambda$, where $C_0(\alpha_0)$ is the second degree polynomial of α_0, $C_1(\alpha_0)$ is the third degree polynomial of α_0 [6].

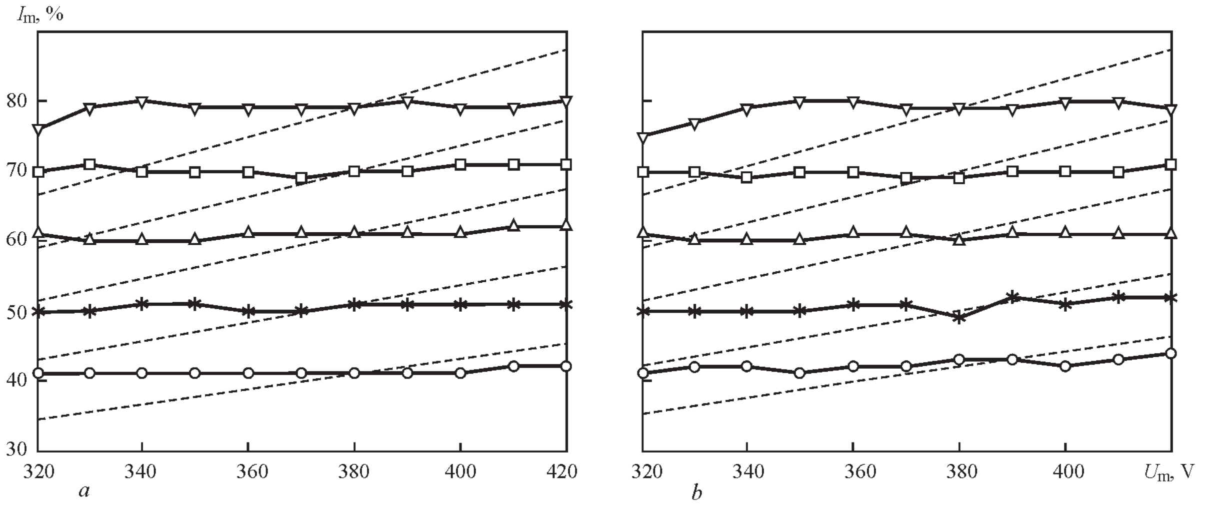
Automatic determination of cos φ, used for current stabilization at mains voltage fluctuations, is even more necessary for automatic limitation of minimum angle of thyristor switching-on in all resistance welding regulators without exception. The point is that if thyristor switching-on angle is set less than angle α, welding contactor will conduct half-wave current of just one polarity, and welding transformer will go into emergency mode with DC bias. To satisfy condition $\alpha > \varphi$, it is more convenient to measure not cos φ, but φ [7]. In this work expression $\varphi = a_0 + a_1\lambda + a_2\alpha + a_3\alpha^2$ is used for φ, where a_1, a_2, a_3 are the constant coefficients.

In the above-described and the majority of other digital current regulators rather cumbersome analytical models of the object of control at mains voltage fluctuations are used, which require real-time mathematical calculations with floating point. They make unreasonably high requirements of regulator microcontroller capacity. In our opinion, it is the most rational to use digital automatic machines with finite number of internal states, presented in table form. Such automatic machines do not require mathematical calculations by complex formulas, thus allowing application of the simplest and least expensive microcontrollers for their realization.

A model of resistance welding regulator is realized in a simple eight–bit microcontroller PIC16F886. Regulator provides adjustment of the duration of standard set of welding cycle positions: compression, forging, current-pulse, pause from 1 up to 99 in mains periods, as well as assigning welding current I_{set} in the range of 25–90 % of full-phase current.

System of current stabilization at the change of mains voltage is designed as table-type finite state machine. Angle φ of full-phase current shift relative to voltage applied to resistance welding machine, is determined at current flowing in the first period of welding pulse. For this purpose sufficiently high fixed angle of thyristor switching-on $\alpha_0 = 0.7\pi$ is set, so that the corresponding current were definitely less that the set welding current. The φ value is determined by measured λ values from φ–λ table for α_0.

Seven tables of I_{nom} dependence on α, at nominal mains voltage U_{nom} are stored in regulator microcontroller memory for different φ values, for which cos φ is in the range of 0.2–0.8. From these tables α can be selected to obtain the assigned values of welding current. However, at mains voltage $U_m \neq U_{nom}$ another table should be used, which is calculated by expression $I_m(\alpha) = I_{nom}(\alpha)U_m/U_{nom}$. To reduce the used memory of microcontroller, just the minimum required part of this table is calculated for α, changing after $\Delta\alpha = \pi/200$ from α_1, for which $I_{nom}(\alpha_1) = I_{set}$, up to α_2, for which $I_m(\alpha_2) = I_{set}$. As here fast operations of program multiplication of single-byte numbers and bitwise shifts are used, calculations take small enough time even in low-capacity controllers. Thus, the angle of thyristor switching-on, required to obtain set current at nominal mains voltage, is corrected in accordance with fluctuations of mains voltage that provides current stabilization.



Static characteristics $I_m = f(U_m)$ at variation of mains voltage: *a* — φ = 0.2π; *b* — φ = 0.35π

The Figure gives experimental static characteristics of the regulator at mains voltage variation for different values of set current and load power factor. $I_m = f(U_m)$ dependencies in absence of stabilization are also shown here by a dashed line. From this Figure it follows that at mains voltage fluctuations from 320 to 420 V, effective value of current changes by not more than ±2 % of the set value. Only for current set at the level of 80 % of full-phase value, current stabilization is limited by minimum mains voltage of 325 V for φ = = 0.2π and 334 V for φ = 0.35π. This is related to the fact that for reliability minimum angle α was program limited to value φ–π/18.

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