ENERGY CHARACTERISTICS OF THE PROCESSES OF FLASH-BUTT WELDING AT ALTERNATING AND DIRECT CURRENTS

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Main energy parameters of flash-butt welding machines are considered. It is shown that a.c. machines have higher values of main parameters.

Keywords: *flash-butt welding, alternating and direct current machines, energy parameters*

Selection of equipment for flash-butt welding is one of the main issues in development of the technology of welding various structures. There exist a large number of flash-butt welding machine types, using different principles of electric energy conversion [1, 2]. Therefore, it is rational to compare the currently available power sources for flash-butt welding machines. Some of these issues are considered in study [3].

At present single-phase (two-phase) power sources for power supply from 50 (60) Hz a.c. mains and three-phase sources with the following circuits have become the most widely accepted for powering flash-butt welding machines:

- from frequency converters and number of phases;
- from rectified voltage of commercial frequency;
- from higher frequency rectified voltage generated by an inverter;
- from an inverter of 40–60 Hz frequency.

Effectiveness of application of these sources (mainly by energy parameters) is assessed using the following parameters: efficiency η, power factor k_m, coefficient of utilization of machine power χ.

Efficiency η is equal to a ratio of active power P_c, released in the welding contact, to active power at welding machine input P_{in}. For a.c. machine

$$\eta = P_c/P_{in} = R_c/(R_c + R_{sh.c}), \quad (1)$$

and for a machine with rectification in the secondary circuit

$$\eta = P_c/P_{in} = R_c/[(R_c + R_{sh.c}) + \Delta U(I_w)/I_w], \quad (2)$$

where R_c, $R_{sh.c}$ are the resistance of parts being welded and ohmic resistance of machine short-circuiting; $\Delta U(I_w)$ is the voltage drop on the rectifier; I_w is the welding current.

Welding machine power factor

$$k_m = P_{in}/(UI) = (R_c + R_{sh.c})/Z, \quad (3)$$

where U, I is the effective value of voltage and current at welding machine input; Z is the impedance of the machine and parts being welded.

When at the input of electric energy receiver (welding machine) voltage is sinusoidal, and current is not sinusoidal (at phase regulation), active power consumed by the machine is determined only by the fundamental harmonic

$$P_{in} = U_1 I_1 \cos \varphi_1,$$

where U_1, I_1 are the mean-root-square voltage and current at welding machine input, and $\cos \varphi_1$ for the first harmonics.

It is obvious that $U_1 = U$, as voltage at machine input is sinusoidal and

$$k_m = U_1 I_1 \cos \varphi_1/(UI) = \nu \cos \varphi_1, \quad (4)$$

where $\nu = I_1/I$ is the coefficient of distortion, as current at welding machine input, may be nonsinusoidal.

Coefficient of utilization of machine power is

$$\chi = P_c/(UI) = P_c/(P_{in}/k_m) = \eta k_m. \quad (5)$$

From expressions (1)–(5) it is obvious that

- η is independent on the angle of valve switching on and is determined by the ratio of resistances of secondary circuit and parts being welded;
- with increase of the angle of valve switching on that leads to increase of current curve distortion, power factor drops compared to full phase switching on and coefficient of machine power utilization drops, accordingly;
- η, k_m and χ values of the flash-butt welding machine can be improved by lowering the machine short-circuiting resistance $R_{sh.c}$, $X_{sh.c}$, $Z_{sh.c}$ at optimization of machine circuit dimensions and shape, as well as lowering of power source frequency.

In resistance and flash-butt welding a.c. and d.c. (rectified) power sources are mainly used [4–7].

PWI developed and manufactured d.c. machine for flash-butt welding based on K-724 machine to determine the main energy characteristics of processes in a.c. and d.c. welding. Used as the power source was three-phase rectifier of «RoMan» Company containing three single-phase transformers, the primary windings of which are connected in a triangle circuit. A full-wave two-arm rectifier is assembled on the base of each transformer. Three diodes are connected in parallel in each arm. Thus, the rectifier has 18 diodes (Figure 1).

Rectifier specification

Rated power, kV·A .... 180 at 50 % duty cycle
Primary voltage/frequency, V/Hz 400/50
Secondary alternating voltage, V 5.55
Constant output voltage, V 7.4
(at rectifier powering from 380 V mains
constant output voltage is 7.1 V)

The rectifier is designed as one module. Transformers and diodes mounted on heatsinks have water cooling.

Thyristor contactors controlled by the local computer system KSU KS [7] and industrial computer of upper level system CS for control of the welding machine as a whole are connected in series with transformer primaty windings (Figure 2). Sensors of the main electrical parameters: voltage at rectifier output U_r and machine grips U_{gr}, welding current I_w and currents in phases I_A, I_B, I_C are connected to input of ADC built into control system CS. Signal converters with galvanic insulation PSA-01.01.14.18.03 of PROMSAT, Ltd. (Kiev) were used for voltage measurement. These converters have measurement range from 0 up to 10 V at input signal frequency from 0 up to 1 kHz. Current transformers were used as phase current sensors. A rectification circuit was assembled for welding current measurement, with phase current transformer outputs being connected to its input.

Rectifier output voltage is determined by mean value during the repeatability period $T_{rep} = \pi/3$, which is equal to the time interval of simultaneous operation of a pair of valves in each arm:

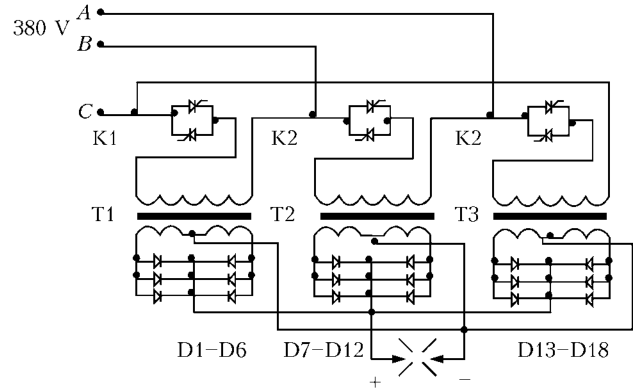

Figure 1. Electric diagram of d.c. flash-butt welding machine

$$U_{d0} = ((3\sqrt{3})/\pi)U_{2l} = 2.34U_{2ph},$$

where U_{2l}, U_{2ph} are the linear and phase voltage, respectively.

Regulation of secondary rectified voltage is performed by changing the angle of connection of thyristor contactors α.

Phase regulation leads to increased ripple of secondary voltage. Coefficient of rectified voltage ripple is determined as the ratio of first harmonic amplitude to mean voltage value:

$$K_{rip} = U_{m1}/U_d = (2/m^2 - 1)\sqrt{1 + m^2 \text{ tg}^2\, \alpha},$$

where $m = 6$ is the number of pulsations for a three-phase full-wave rectifier.

For $\alpha = 0°$ $K_{rip} = 0.057$, and for $\alpha = 30°$ $K_{rip} = 0.2$.

Design features of mechanical part of K-724 machine and rectification module with power transformers, powerful diodes and thryistors did not permit placing this module in immediate vicinity of welding machine grips. As a result, ohmic resistance and in-

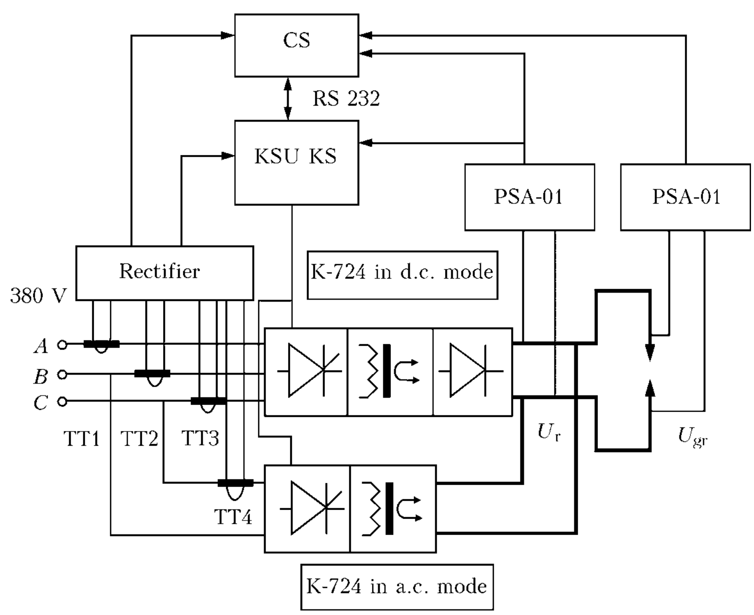

Figure 2. Block-diagram of connection of recording devices and control system of K-724 machine

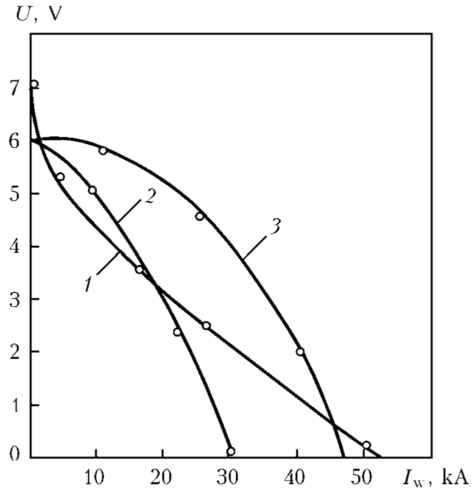

Figure 3. External characteristics of K-724 machine at powering by direct (*1*) and alternating current with standard (*2*) and optimized (*3*) circuit

ductive reactance of the welding circuit turned out to be higher than in some a.c. machines. A.c. power to the machine was supplied by welding transformer of TK-2008-6 type, the design of which allowed connecting it both to the point of rectifier connection (practically standard circuit), and to the point located in immediate vicinity of machine grips (optimized circuit). Parameter calculation was performed for these two variants.

Measurement and calculation results were used to plot external characteristics of the welding machine (Figure 3), as well as dependencies of useful power (active power released in the welding circuit) on load current (Figure 4) for alternating and direct current. The following values were assumed when plotting these dependencies: range of welding current variation I_w = 5–40 kA, voltage drop on diodes of rectifier

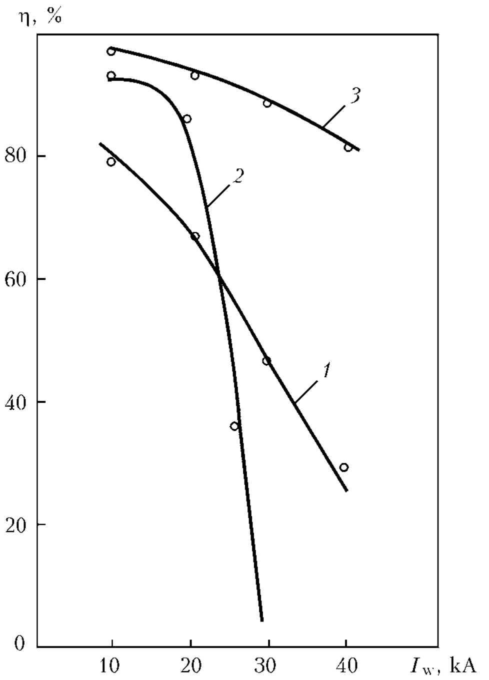

Figure 5. Dependence of efficiency of K-724 machine on welding current value at powering by direct (*1*) and alternating current with standard (*2*) and optimized (*3*) circuit

module of «RoMan» Company (three diodes connected in parallel) ΔU = 0.57 V at I_w = 10 kA, ΔU= = 1.1 V at I_w = 40 kA, circuit ohmic resistance R = = 32 μOhm, circuit inductance L = 0.7 μH, resistance $R_{sh.c}$ = 96 μOhm.

Parameters of welding transformer of TK-2008-6 type for a.c. machine are as follows: U_2 = 6 V, ohmic resistance of transformer windings R_t = 13.6 μOhm, reactive inductance X_t = 16 μOhm. To create equal

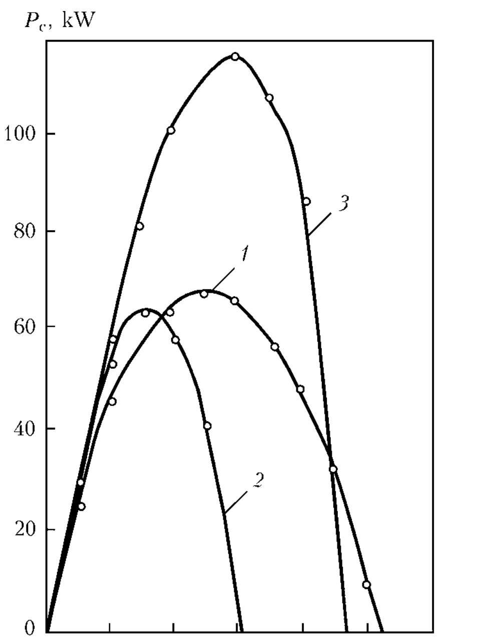

Figure 4. Dependencies of useful power of K-724 machine on load current at powering by direct (*1*) and alternating current with standard (*2*) and optimized (*3*) circuit

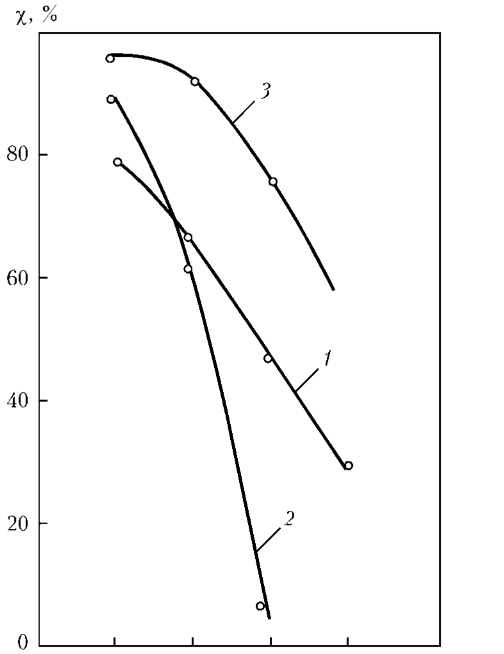

Figure 6. Dependence of coefficient of utilization of K-724 machine power on its welding current at powering by direct (*1*) and alternating current with standard (*2*) and optimized (*3*) circuit

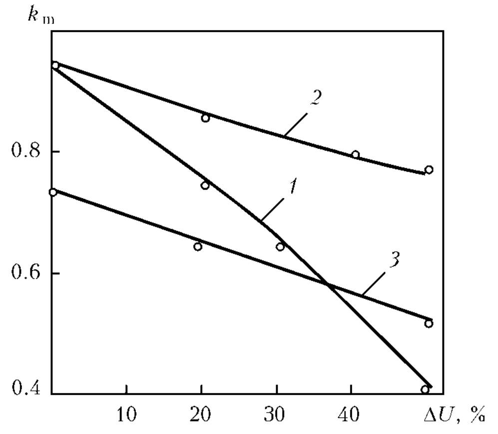

Figure 7. Dependence of power factor of K-724 machine on relative change of voltage at its phase regulation at powering by direct (*1*) and alternating current with standard circuit at welding current of 10 (*2*) and 20 (*3*) kA

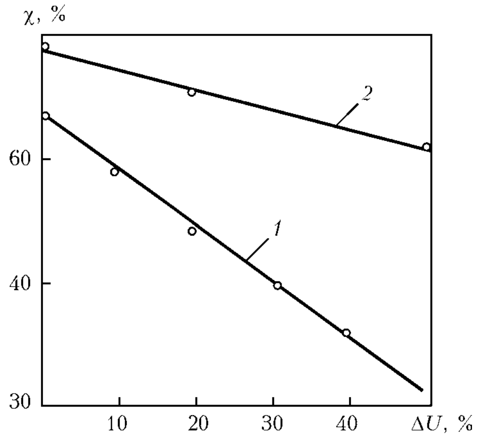

Figure 8. Dependence of the coefficient of utilization of power of K-724 machine at powering by direct (*1*) and alternating current with standard circuit (*2*) and welding current of 10 kA at phase regulation

conditions for source operation, voltage U_2 was decreased by the value of voltage drop on the diodes.

It is seen from dependencies $P_c = f(I_w)$ (see Figure 4) that useful power in a.c. welding essentially depends on circuit dimensions. In the main welding current range (10–20 kA) useful power of a.c. machine is higher than that of d.c. machine even with a standard circuit.

Dependencies of efficiencies of d.c. and a.c. machines plotted by formulas (1), (2), are given in Figure 5. Dependencies of the coefficient of utilization of d.c. and a.c. machine power plotted by formula (5) are given in Figure 6. Here also these parameters are higher for a.c. machine in the main range of welding current.

As voltage regulation in welding machines is performed mainly by phase method, it is necessary to assess the influence of the angle of switching on the thyristors on energy parameters. With this purpose, computer simulation using MatLab program was conducted and dependencies $k_m = f(\Delta U)$, $\chi = f(\Delta U)$ with phase regulation were plotted (Figures 7 and 8). The range of regulation by welding transformer current and voltage of 1:2 was considered as the most widely accepted one. It is seen that a.c. machine has higher parameters.

An important characteristic of powerful welding machines is their electromagnetic compatibility, i.e. the ability to function without deterioration of parameters of general mains. In operation flash-butt welding machines have an essential influence on all the quality characteristics of electric power. These are, primarily, fluctuations and drops of mains voltage, asymmetrical load of three-phase mains, harmonic components of current and voltage. Welding machines essentially are a source of electromagnetic interference that has an adverse influence both on welding machines proper, and on other current receivers powered from the same mains. Current sources for welding machines should be selected with a minimum level of electromagnetic interference, the admissible level of which is determined by standards of power quality in general purpose power supply mains [8].

As almost all flash-butt welding machines are fitted with thyristor contactors, then depending on the angle of switching on welding current can have different spectra of harmonic components of current. Thus, these machines are sources of higher current harmonics. Value of current components by different harmonic determines the electromagnetic compatibility of welding machines and is specified in standards.

Dependence of total harmonic distortion K_{THD} on relative voltage at phase regulation is given in Figure 9. At the same change of voltage d.c. machines have smaller total harmonic distortion. In this connection, it is rational to regulate the voltage of a.c. machine using an autotransformer or welding transformer stages.

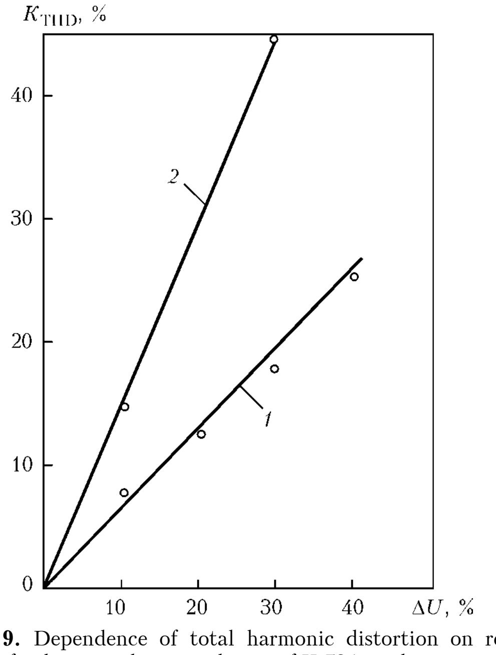

Figure 9. Dependence of total harmonic distortion on relative change of voltage at phase regulation of K-724 machine at powering by direct (*1*) and alternating current with standard circuit (*2*)

CONCLUSIONS

1. Such energy parameters as efficiency, power factor, coefficient of utilization of power in the working range of current and voltage for butt welding are higher in a.c. machines than in d.c. machine.

2. Main advantage of three-phase power sources compared to single-phase machines is related to better characteristics of electromagnetic compatibility, here uniform load is applied to mains phases and phase current decreases by 18 % at the same consumed power.

3. Lowering of the reactive component of secondary circuit resistance practically to zero when a rectifier is used in the secondary circuit does not lead to lowering of secondary circuit impedance, because of the features of machine design. Application of diodes introduces additional electrical resistance into the circuit.

4. Cost of power components of single-phase source is at lest 12 times lower compared to the considered rectifier source.

1. Paton, B.E., Lebedev, V.K. (1969) *Electric equipment for resistance welding*. Moscow: Mashinostroenie.
2. (1986) *Technology and equipment for resistance welding*. Ed. by B.D. Orlov. Moscow: Mashinostroenie.
3. Kuchuk-Yatsenko, S.I., Nejlo, Yu.S., Gavrish, V.S. et al. (2010) Prospects of increasing energy characteristics of flash butt welding (Review). *The Paton Welding J.*, **2**, 23–27.
4. Lebedev, V.K. (1992) Effectiveness of application of d.c. machine for resistance welding. *Avtomatich. Svarka*, **11/12**, 3–6.
5. Lebedev, V.K., Pismenny, A.A. (1998) Improvement of power systems of resistance welding machines. In: *Welding and related technologies — to 21st century*. Kiev: Naukova Dumka.
6. Lebedev, V.K., Pismenny, A.A. (2001) Power systems of resistance welding machines. *The Paton Welding J.*, **11**, 28–32.
7. Rudenko, P.M., Gavrish, V.S. (2007) KSU KS 02 system for automatic control and monitoring of resistance spot welding process. *Ibid.*, **11**, 34–36.
8. Zharky, A.F., Palachev, S.A. (2005) Legislative control of emission of current high harmonics in power supply systems of EU countries. *Tekhnich. Elektrodinamika*, **6**, 57–61.

RESEARCH AND DEVELOPMENTS OF THE E.O. PATON ELECTRIC WELDING INSTITUTE IN THE FIELD OF ELECTRIC ARC WELDING AND SURFACING USING FLUX-CORED WIRE (Review)

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The results of works performed by the E.O. Paton Electric Welding Institute in the field of welding and surfacing using flux-cored wire are generalized.

Keywords: *electric arc welding, surfacing, low-alloyed steels, flux-cored wire, production of flux-cored wire*

The flux-cored wire is high-efficient electrode material allowing solution of wide range of tasks connected with manufacturing of welded structures at the modern level.

At the beginning of the 1950s I.I. Frumin offered the application of flux-cored wire for automatic submerged surfacing of mill rolls [1]. The production of surfacing flux-cored wire was organized at Magnitogorsk Metal Wares and Metallurgical Plant.

The idea of application of flux-cored wire as welding consumable appeared to be very fruitful. At the second half of the XX century the investigations of electric-physical, metallurgical and technological processes of welding and surfacing using flux-cored wire were carried out. As a result a large number of different types of flux-cored wires of different purpose was developed, technologies of welding and surfacing and also industrial equipment and technology of production of flux-cored wires were also developed and tested. The materials for welding and surfacing in shielding gases, materials without additional shielding (self-shielding flux-cored wires), flux-cored wires for underwater, arc (electric gas) and electric slag welding with a forced weld metal formation and also for desulphuration and alloying of metal melts were developed.

At present, welding and surfacing using flux-cored wire, widely applied in many countries of the world, are the most challenging arc processes for joining metals, restoration of products or to impart them the necessary properties.

In the present article the review of works of the staff of the E.O. Paton Electric Welding Institute in this field was made.

Development of welding using flux-cored wire. The first industrial samples of flux-cored wire were developed and tested under the industrial conditions in 1959–1961 [2–4]. Their successful tests in welding