PROSPECTS OF INCREASING ENERGY CHARACTERISTICS OF FLASH BUTT WELDING (Review)

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Developments aimed at increasing energy characteristics of flash butt welding are reviewed, and possible investigation trends in this area are analysed.

Keywords: *flash butt welding, technology, equipment, power supply, direct current, alternating current, low-frequency current, secondary circuit, circuit resistance, energy characteristics*

Power of the equipment used for flash butt welding (FBW) amounts to tens and hundreds of kilowatts. One of the problems of current importance is to find ways of uniformly loading the three-phase mains at a single-phase load in the welding circuit, which is characteristic of resistance heating. Non-uniform loading causes a higher drop in the distribution mains, this leading to unfavourable conditions for operation of other equipment connected to this mains. While selecting power supplies for single-phase FBW machines, producers have to orient themselves to increased phase loads and, accordingly, total capacity of a power supply.

Most standard FBW machines use the technology that provides for repeated short-time resistance heating of parts, when a load changes from zero to its limiting value, this also having a negative effect on consumers of power in the general mains.

Power factor of standard FBW machines is 0.5–0.6, and thermal efficiency is no more than 30 %. This is attributable to the fact that resistance of the welding circuit of the machines is commensurable with and, in many cases, higher than resistance in contact between the parts during heating [1, 2].

Various control systems for power circuits of FBW machines, intended for splitting the single-phase load into three phases, have been developed in the last decades [2, 3]. As to their operation principle, the power components used can be subdivided into two categories. In the first category, switching of the electric currents takes place in primary windings of a welding transformer, the decreased-frequency (5–30 Hz) current, compared with 50 Hz in the power mains, being maintained in the secondary loop of the welding circuit. In the second category, secondary windings of the welding transformer comprise rectifiers installed there to provide flow of the direct current in the welding circuit. Detailed analysis of converters of the first category is given in studies [2, 3]. Such converters find application in spot and capacitor-discharge welding machines with a capacity of up to 100–150 kW.

The first frequency and phase converter for FBW was developed by the E.O. Paton Electric Welding Institute in the early 1960s [4]. Later on, similar converters were developed by other companies, e.g. «Sciaky». The converter (Figure 1) consists of six thyristors (the first machines used ignitrons).

High-power machines for spot and projection welding still use this type of the «Sciaky» low-frequency converters. Their utilisation for butt welding was limited to production of single specimens and did not receive further development. This was caused, first of all, by substantial complication of design of a low-frequency welding transformer, considerable increase in its weight, dimensions and, hence, cost.

New generations of high-power FBW machines supplied by leading manufacturers of this equipment in the last decade have used converters of the second

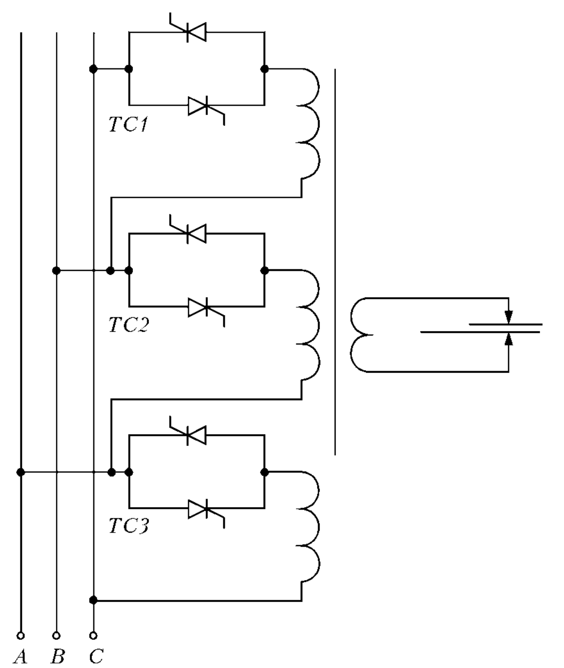

Figure 1. Circuit of frequency converter with four-winding transformer (*TC1–TC3* — thyristor contactors)

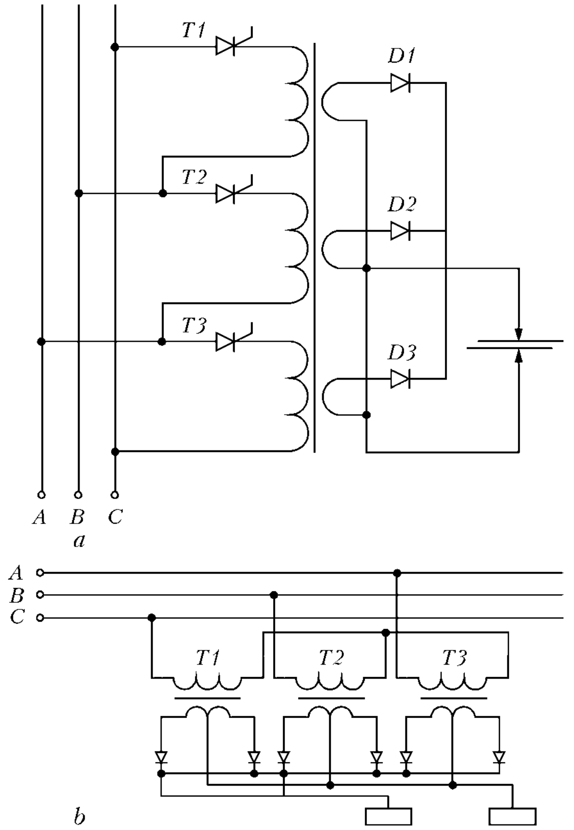

Figure 2. Circuits of three- (*a*) and six-phase (*b*) rectifiers (*T1*–*T3* — thyristors, *D1*–*D3* — diodes)

category, which provide for rectification of the current in the secondary circuit.

Figure 2 shows circuits of the three- and six-phase rectifiers used in modern FBW machines.

Separate transformers with delta or star connection of their primary windings are used most frequently. The primary winding circuit comprises thyristor contactors, which allow adjustment of voltage supplied to the transformer. One- and two-arm rectifiers are included into each circuit of secondary windings of the transformers, the secondary windings being star connected. Physically, a rectifier is a single module. Transformers and rectifying cells have a cooling system. The rectified welding current is practically of the direct type, pulsation factor for the three-phase star rectifier is 25 %, and for the six-phase star rectifier is 5.7 %. Six-phase rectifiers with a delta connection of the primary windings are mainly used for the high-power FBW machines. In the last years, companies «Roman Transformer», «Safco System s.r.l.» and «Dalex Schweisstechnik» have been supplying the above types of the modules for currents of 17 to 100 kA. Emergence of such systems on the world market has substantially widened potentialities for development of new generations of specialised and versatile FBW equipment for different industrial sectors. Application of DC converters allows solving the problem of uniform loading of the mains when using high-power FBW machines, and increasing the efficiency of their utilisation. Moreover, this leads to increase in power factor of such equipment because of decrease in reactive losses in the secondary loop of the welding circuit. Along with the noted advantages, in general the use of the direct current did not allow the total consumed power in the welding circuit to be considerably decreased, compared to the similar indicators with a power supplied from the 50 Hz mains. This is attributable to the fact that in resistance heating of heavy-section parts (5,000–10,000 mm^2) a voltage drop in contact between the parts is 1.5–2.0 V. The voltage drop at modern silicon rectifying cells is approximately the same, and losses of power in the cells are commensurable with the power consumed for welding. In welding of aluminium parts the power losses are even higher. Therefore, the thermal efficiency of the resistance heating process at the direct current is lower than in the case of using the first group of the converters, e.g. low-frequency converters [4]. The Table gives technical characteristics of some modern machines for FBW of rails. They use high-power rectifiers, allowing the currents of 50–100 kA to be provided in the secondary circuit. To compare, the Table also gives similar characteristics of the machines designed for a single-phase load.

At an identical productivity and power of the welding machines, machines with a three-phase load have a power distributed into three phases. As a result, their installed power decreases three times.

Judging from the experience of operation of such equipment, utilisation of the direct current provides a number of advantages, in addition to improvement

Technical characteristics of «Schlatter» machines for DC and AC FBW of rails

Type of machine	Maximal cross section to be welded S, mm^2	Rated power of welding machine P_r, kV·A	Short-circuit power of welding machine P_{max}, kV·A	Maximal secondary current $I_{2\,max}$, kA
Direct current				
GAAS-80	12000	580	630	80
GAAS-100	20000	580	630	100
Alternating current				
Aa 50/500u	10000	500	1500	90
Aa 50/450s	10000	450	1300	80
Aa 35/400s	8000	400	1000	70
BHVR 43/120	6000	450	–	–

of power indicators. In particular, as noted in promotion materials [5], the use of the direct current provides a more uniform heating of parts over their entire cross section.

The data given apply to the welding technologies at which the main heating of parts is provided by resistance at short-circuits from the ends.

The possibilities of further increasing the thermal efficiency and decreasing the consumed power through using these technologies have been exhausted to a considerable degree, at least for the systems that use modern semiconductor rectifying cells. A more radical improvement of these characteristics is likely if methods are found for increasing the efficiency of resistance heating providing for increase in contact resistance $R_{sh.c}$ or decrease in $Z_{sh.c}$ of the welding circuit.

In the last decades the E.O. Paton Electric Welding Institute has developed several generations of the machines for FBW of parts from different steels and aluminium-, titanium- and chromium-base alloys with a cross section area of up to 100,000 mm^2 or more. They are characterised by a relatively low specific power consumption (15 W/mm^2), high power factor (0.80–0.95) and high thermal efficiency (60–70 %). Design of the machines and control systems is based on the technology of continuous FBW with program control of main process parameters. Modifications of this technology, called pulsed FBW, have found commercial application in the last years [6]. Along with high productivity, the technology provides a considerable decrease (2–3 times) in power consumption, compared to the machines that use the welding technology with resistance heating. First of all, this is explained by the possibility of achieving a highly concentrated heating through automatic control of resistance in contact between the parts welded, $R_{sh.c}$, at a level of $R_{sh.c} \geq Z_{sh.c}$. Implementation of the continuous flashing process requires that the $Z_{sh.c}$ value be decreased 2–3 times, and in specialised machines — more than 10 times, which can be achieved owing to a special design of the welding circuit. Although such machines do not provide three-phase loading of the mains, their power in phase is lower than that of conventional machines with three-phase loading. As most of such machines are made particularly for welding certain parts (pipes, rails), they have individual power supplies (mobile electric stations), when requirements for three-phase loading are not that important. In a number of cases the continuous FBW technologies are used to advantage with versatile butt welding machines, where it is difficult to make substantial reconstruction of the secondary loop. Very effective was re-equipment of versatile standard single-phase rail welding machine MSGU-500 by using a low-frequency and phase converters. Utilisation of the 5 Hz frequency in the secondary loop allowed decreasing its resistance from 280 to 120 μOhm. This made it possible to decrease the voltage required to excite continuous flashing in welding of heavy types of rails from 11.5 to 6.26 V [4]. Application of the continuous FBW technology in this case provided a 2.5 times decrease in power consumption, and 1.5–2 times reduction in welding time and power input.

Considering prospects for further improvement of this equipment, it seems reasonable to develop the first category of the converters designed for medium frequencies of up to 30 Hz, along with finding rational designs of the secondary loop to minimise its resistance.

Using the direct current for continuous FBW allows expecting improvement of energy indicators of the welding process, as an average value of $R_{sh.c}$ in flashing is higher than in resistance heating. This deteriorates operation of the rectifying cells requiring synchronisation of loads. The world practice does not know so far any examples of commercial application of the machines with the DC converters for continuous FBW of heavy-section parts. Experiments on DC welding of plates and thin-walled pipes of heating surfaces 30–50 m in diameter were conducted under laboratory conditions [7, 8]. Resistance in contact between the parts in FBW is higher than in short circuits, which are characteristic of resistance heating. So, it may be expected that relative losses of power in rectifying cells will be lower. In this case it is difficult to determine their values, as resistance in contact during flashing gradually varies from values close to the short-circuit ones to complete breaking of the circuit. It is noted that mostly fine contacts form at the direct current. In this case the process is more stable than at the alternating current, and the flashed surface is smoother. As a result, sound joints can be provided at flash and upset allowances that are lower than 20 %. In general, the authors of the study came to a conclusion that transition to the direct current in FBW of the said parts would give the same technological advantages as decrease in $Z_{sh.c}$ of the machines by reconstructing their welding circuit at 50 Hz, which is less expensive.

The sinusoidal wave form of the voltage supplied to the parts welded is not optimal, because the efficient heating of elementary electric contacts occurs only in the amplitude portion of a sinusoid, the duration of which during a half-period is insignificant.

It is reported that abroad such drawbacks of FBW are eliminated by using inverter power supplies, which consist of a rectifier and inverter. The rectifier provides uniform loading of all three phases of the power supplier and converts the three-phase voltage into the single-phase one, while the inverter converts the single-phase direct voltage into the single-phase alternating one, having a square wave form. Moreover, the presence of the inverter in a new power supply is attributed to the fact that to provide the direct current flashing process it is difficult to solve the problem of commutation of the high direct current power, whereas the square wave form of the voltage is caused primarily by a difficulty of providing the sinusoidal form of the voltage at the inverter output. Study [6] gives data on development and testing of a pilot sample of the inverter power unit. As follows from the data, the highest energy indicators in FBW can be obtained with the machines having a sufficiently low resistance of $Z_{sh.c} \leq 100$ μOhm by using the phase converter in the primary circuit of transformers. Converters designed for frequencies of 20–30 Hz are also used for FBW and provide uniform loading of the mains. Furthermore, standard transformers of FBW machines can be used in this case. While considering the FBW progress trends, it is necessary to account also for the possibility of using this process for highly concentrated heating in solid-state resistance welding. Machines that use the stored energy, and most often these are the capacitor-discharge spot welding machines, are characterised by the most efficient utilisation of energy in welding. At low charging powers, such energy storages generate the currents during welding that are dozens and hundred of times higher than the charging currents. For example, spot welding of aluminium alloys 1.5 + 1.5 mm thick can be performed with AC machine MT-4019 and capacitor-discharge machine MTK-5502. Electrode extension is identical in both cases. The power consumed from the mains by machine MT-4019 will be 300 kV·A, and by machine MTK-5502 — 20 kV·A [3]. The time of welding with the capacitor-discharge machines is tens of milliseconds.

In FBW of parts with a relatively small cross section area (up to 1000 mm^2), the duration of heating is tens of seconds. Building of capacitor-discharge storages for such loads seems economically inexpedient, if we orient ourselves to technical characteristics of standard modern capacitors. Considering continuous development efforts in this area, emergence of such converters in the nearest future is highly possible.

Ionistors, which are also called supercapacitors (SC), are electric devices characterised by an enormous output capacity achieved within a very short period of time. Owing to this capacity, they have received wide acceptance in many fields of electronics and electrical engineering. The latest changes made in their design, as well as new achievements in the production technology make them ones of the most promising electronic devices [9]. SC are superior to other types of capacitors in density of capacitance ρ_C, charge ρ_Q and energy ρ_E. SC can provide operation of different systems at increased pulse current loads. That is why in a number of cases they replace chemical current sources. SC are characterised by a unique combination of important characteristics. Compared to lithium elements, advantages of SC include an order of magnitude higher power density ρ_W, long shelf life (about 10 years), absence of toxic and hazardous components, and a large number of re-charging cycles with no change in capacitance (up to 10 million cycles). Capacitance of modern SC and batteries on their base is 1–10,000 F [10]. Characteristics of SC allow using them as energy storages, e.g. uninterruptible power supplies (UPS), components of pulse power devices, and in other instruments requiring fast energy sources [9]. Widening of their application can be accelerated by finding more perfect processes of contact resistance heating. The E.O. Paton Electric Welding Institute completed investigations [10] that showed the possibility of resistance welding of parts with compact and developed cross sections of 2,000–3,000 mm^2 using a highly concentrated heating. Increase in heating concentration is achieved owing to the use of intermediate inserts having a composite structure. The heating duration in this case was 1.5–2.0 s, and current density — 1.5–2.0 A/mm^2. This process can be implemented by using not only capacitor-type energy storages, but also other storages of the energy, e.g. kinetic energy in mechanical converters.

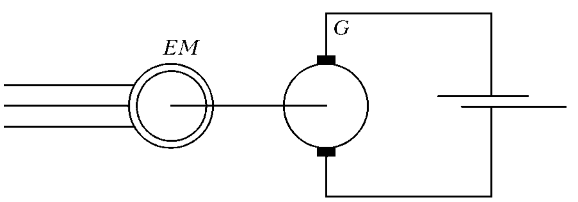

Figure 3. Unipolar generator scheme

In this connection, of interest are the long-time development efforts [7] in the field of a unipolar generator to power the machines for FBW of pipes, the idea of building of which was a subject of many discussions [8]. Here the point is that the unipolar generator designed for low voltage is built into the secondary circuit of the welding machine (Figure 3) instead of a transformer.

Special current conductors feed currents amounting to hundreds of thousands of amperes from a generator collector directly to electrodes of the welding machine, which makes it possible to minimise losses in the secondary loop. Electric motor *EM* of a drive of generator *G* is built into the generator stator casing, which excludes intermediate elements in kinematics of the drive experiencing considerable peak loads. Big mass and sizes of rotating elements of the drive at high rotation speeds provide storing of the substantial kinetic energy in the generator that is consumed for welding. This provides a uniform loading of three phases of the mains, and power of the drive can be decreased tens of times compared to the peak one consumed in welding. This source can be efficiently utilised in repeated short-time operation of the welding machine, where pauses between welding cycles are sufficiently long to restore the required level of the stored energy.

Many years' developments [11] aimed at building different-power unipolar generators were accompanied by looking for optimal technologies for resistance heating of parts with big cross section areas (up to 12,000 mm^2), including the pipes. They were concluded with manufacture of a commercial batch of the systems comprising generators of the machines for welding of pipes with a diameter of 80–320 mm and wall thickness of 8–12 mm [11]. Different-power welding machines use 10–60 MJ energy storages, this allowing the 1.5–9.0 MA currents to be produced in the welding circuit. The heating duration in welding is no more than 3 s, and power consumed from mains of the electric drive is 230–420 kW. Application of high-rate high-concentration heating at current densities of 50–60 A/mm^2 made it possible to produce the high-quality joints on 80–320 mm diameter pipes with wall thickness of 8–12 mm, made from X65 type steels and steels of the austenitic and martensitic grades belonging to the hard-to-weld ones. Along with high strength values, the joints exhibited the high properties in impact toughness tests.

Further improvement of this type of energy storages creates conditions for widening of the application fields for the FBW technologies, especially for hard-to-weld materials.

As noted for the machines for FBW of 114–320 mm diameter pipes, utilisation of a power supply with square wave pulses and frequency of 50 Hz provides a 25 % reduction in the welding time [6].

1. Kuchuk-Yatsenko, S.I. (1992) *Flash butt welding*. Kiev: Naukova Dumka.
2. Paton, B.E., Lebedev, V.K. (1969) *Electric equipment for flash butt welding. Moscow*: Mashinostroenie.
3. Smirnov, V.V. (2000) *Equipment for flash butt welding*. St.-Petersburg: Energoatomizdat.
4. Podola, N.V., Kuchuk-Yatsenko, S.I. (1957) Low-frequency current flash butt welding. *Avtomatich. Svarka*, **1**, 63–72.
5. (1985) *Catalogue of Schlatter Company*. Prosp. 2. Schlatter AG.
6. Khomenko, V.I., Pankov, O.G., Sergeev, S.K. et al. (1991) Application of inverter power supplies for flash butt welding in construction of pipelines. *Svarochn. Proizvodstvo*, **9**, 16–17.
7. Bertinov, A.I., Alievsky, B.L., Troitsky, S.R. (1966) *Unipolar electric machines with liquid metal current pickup*. Ed. by A.I. Bertinov. Moscow; Leningrad: Energiya.
8. Haase, P.W., Carries, R.W., Hudson, R.S. (1995) The University of Texas at Austin, Center for Electromechanics. Homopolar pulsed welding for offshore deep water pipelines. *Welding J.*, **5**, 35–39.
9. Shurygina, V. (2003) Supercapacitors. *Elektronika, Nauka, Tekhnologiya, Biznes*, **3**.
10. Despotuli, A.L., Andreeva, A.V. (2006) Supercapacitors for electronics. *Sovrem. Elektronika*, **5**, 10–14.
11. James, C., Wright, P.E. (1999) *Homopolar pulsed welding for pipeline application*: Report of Int. Symp. on Exploiting Solid State Joining. Cambridge.

PORTABLE SYSTEM OF MONITORING AND CONTROL OF RESISTANCE SPOT WELDING PROCESS

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The paper presents the schematic diagram and operative algorithm of system of quality control of welded joints made by resistance spot welding, based on a pocket PC. In addition to real-time quality control, the system also implements functions of expert system for technology selection and production analysis.

Keywords: *resistance spot welding, welded joints, quality control, process control, weld spot nugget diameter, expert system, pocket PC*

The quality of resistance spot welding depends on many factors, mainly on the selected technology, applied equipment and automatic control of process in real time.

A lot of stationary and pocket devices, systems, based on the office and industrial PCs and laptops, designed for control of process of resistance spot and seam welding is known.

These devices and systems allow investigation of process of welding the new and well-known materials and structures, automation of selection of welding condition and its optimization, presetting and verification of acceptable limits of variables of condition parameters, welding quality control in real time. With their use it is possible to perform accumulation, statistical processing and analysis of data, certification of production, calibration of sensors, to realize the technical maintenance of welding machines and electrodes.

As an example of resistance spot welding control systems it is possible to mention the wide nomenclature of devices of Miyachi Uniteck [1], monitors of WeldComputer Corp., ATek Resistance Welding and Dengensha America (USA), pocket tester of TECNA (Italy) [2], measuring systems of VNIIESO (Russia) [3].

The E.O. Paton Electric Welding Institute has also developed the series of devices for monitoring and diagnostics of process (UDK-01 -02, -05) [4] and welding condition control systems with wide package of functions on control of condition parameters and quality of a welded joint (RVK-100, KSU KS-02) [5, 6].

The above-mentioned devices on controllable parameters are differed negligibly. This is in general the welding current or current in primary winding of welding transformer, voltage between electrodes, pressure or compression force of electrodes, movement of electrodes and time of optimizing operations in cyclogram. However they can considerably differ in technical realization. For instance, the series of Miyachi Uniteck includes stationary MG3, MM-370 (of 5 kg weight) with a graphical display, more compact MM-122A (1.9 kg) with possibility of connection to outer PC (e.g. laptop) and printing device, so-called palm MM-380 (0.9 kg) and, finally, pocket devices for measuring of current parameters (MM-315A) and compression forces (MM-601A). At the same time the monitors WeldComputer Corp. are similar to industrial working stations with a full-scale graphical screen with