TECHNOLOGY AND NEW GENERATION OF EQUIPMENT FOR FLASH BUTT WELDING OF ADVANCED HIGH-STRENGTH RAILS FOR CONSTRUCTION AND RECONSTRUCTION OF HIGH-SPEED RAILWAY LINES

S.I. KUCHUK-YATSENKO, V.G. KRIVENKO, A.V. DIDKOVSKY, Yu.V. SHVETS, A.K. KHARCHENKO and **A.N. LEVCHUK**

E.O. Paton Electric Welding Institute, NASU, Kiev, Ukraine

Presented are the technology and a new generation of equipment for flash butt welding of high-strength rails for construction and reconstruction of high-speed railway lines, based on the use of the pulsed flash butt welding process.

Keywords: *flash butt welding, pulsed flashing, computerised control system, technology and equipment, rail string, continuously welded rail track*

In the last decade the majority of industrialised countries have been intensively reconstructing their railroads, this being caused by increase in their traffic density and speed. For this the use is made of increased-strength rails with higher wear resistance. Specification requirements to the precision of a rail track determined by permissible deviations from its specified sizes have substantially grown. Meeting of these requirements motivated to a considerable degree the development efforts conducted in the world leading countries and aimed at improvement of the rail welding technology.

Rails laid down in main lines are welded primarily by the flash butt method under factory conditions for manufacture of long-length (200–800 m) rail strings, or under field conditions for their laying down and repair of continuously welded rail track.

For over 50 years the E.O. Paton Electric Welding Institute has been active in development of the technologies and equipment for flash butt welding under factory and field conditions. The world-first mobile machines of the K155 type for flash butt welding of rails were developed by the E.O. Paton Electric Welding Institute and successfully applied in railroads of the USSR as far back as the early 1960s. Commercial manufacture of the machines based on the developments of the Institute was mastered by the Kakhovka Factory for Electric Welding Equipment (KZESO). This cooperation continues to advantage up to now. By 2000, KZESO had mastered several generations of mobile rail welding machines of the K255L, K355A-1 and K900 types, as well as stationary rail welding machines of the K190 and K190PA types. Design of these machines is based on the use of the continuous flash butt welding technology with program control of the main process parameters [1].

The technology developed by the Institute is based on the new principles of control of the flashing process during flash butt welding, which allowed a 2–3 times decrease in power consumption, 1.5–2 times reduction in the welding time compared to the resistance heating welding process, as well as a stable and uniform heating of the rails across their sections. Several hundreds of such machines manufactured by KZESO have been successfully operated up to now not only in the CIS countries but also in many countries all over the world.

With use on the railroads of high-strength rails KF («Azovstal», Ukraine), E76F and K76T (Nizhnetagilisky (NTMK) and Novokuznetsky (NKMK) Metallurgical Works, Russia, U75V (PIETC, China) and BS113A (Corus British Steel), Great Britain), the need arose for substantial upgrading of the welding technology and the equipment required to implement it. Strength indices of metal grew by a factor of 1.3–1.5 (Figures 1 and 2), whereas requirements to ductile properties remained at the previous level according to the specification values.

As established in the course of the investigations conducted by the Institute [2], the required quality of the welded joints on high-strength rails can be achieved by using a highly concentrated heating in welding and a strictly balanced energy input (Figure 3). It should be noted that comparatively small deviations in heating from the optimal distribution of temperature lead to deterioration of indices in mechanical tests.

Decrease in energy input and, therefore, temperature in the near-contact zones of the weld (see Figure 3, fragment 1) leads to formation of fine oxide structures along the welding line. An increased energy input (Figure 3, fragment 2) causes coarsening of grain

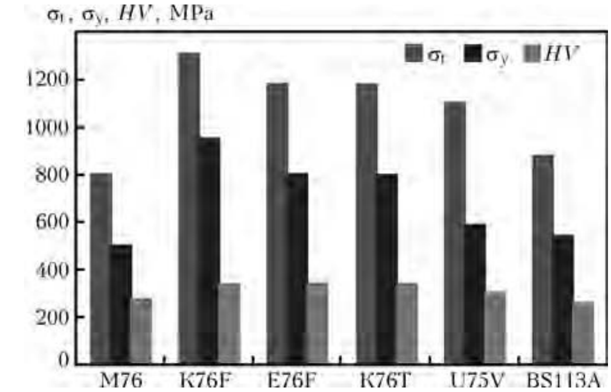

Figure 1. Strength properties of new rails

and formation of solid ferrite network along its boundaries.

To achieve the optimal thermal cycles, the Institute developed the welding technology called pulsed flash butt welding, which was patented in Ukraine [3] and in the world leading countries, such as Russia, USA, Great Britain and China. Multiple-factor regulation of the spark gap existing between the parts in contact during flashing, as well as of instantaneous values of voltage, provides intensification of contact heating, at which the metal losses for flashing are decreased and the efficiency is increased compared to the canonical processes of continuous flashing or intermittent resistance heating. The time of heating and allowances for flashing are reduced by a factor of 1.5–2.0. Production of sound joints is ensured at a smaller width of the HAZ metal (Figure 4).

The automatic system was developed and algorithms of multiple-factor regulation of main parameters of the flashing process were determined, thus allowing the preset level of energy input to be maintained during welding independently of changes in service conditions of the machines (quality of preparation of rails for welding, fluctuations of mains voltage, ambient temperature, etc.). The set program of regulation of the parameters is automatically corrected (adapted) if operational conditions of the machines change. As seen from Figure 5, the use of the optimal parameters (Figure 5, *I*) and automatically corrected parameters (Figure 5, *II*) in fluctuations of the mains voltage provide the specified temperature field and the required quality of the welded joints.

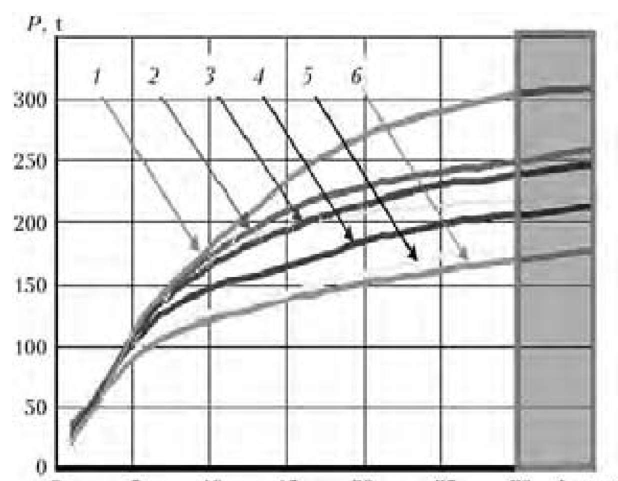

Figure 2. Dependence of load in static bend tests on sagging of rail (minimal permissible value of sag — 30 mm): *1* — NKMK, NTMK E78KhSF (Russia, 2006–2012); *2* — NKMK, NTMK E76F, K76F (Russia, 2006–2012); *3* — NKMK, NTMK E76F, K76F (Russia, 2003); *4* — Azovstal KF (Ukraine, 2011–2012); *5* — U75V (China, 2003–2012); *6* — Azovstal M75 (Ukraine, 1985)

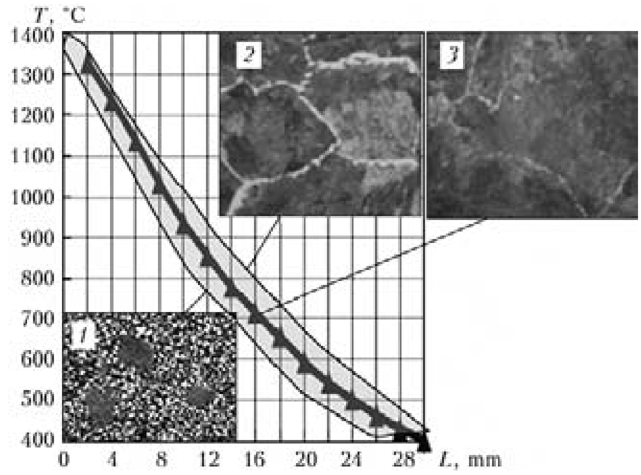

Figure 3. Distribution of temperature in welding of rails R65: *1* — zone of formation of oxide inclusions along the welding line; *2* — zone of overheating (coarse grain with ferrite precipitations along its boundaries); *3* — optimal structure

The problem of automation of some auxiliary operations accompanying production of continuously welded rail tracks was also solved in development of the systems for automatic control of the pulsed flashing process. In repair of the continuously welded rail tracks it is necessary to weld two fixed strings of an unlimited length. According to the accepted technology, an insert of rather big length (not less than 6 m) was welded to the strings with a preliminary bend required to compensate for shortening during welding. This operation is labour-consuming, and upon its completion it is necessary to restore the preset temperature-stress state of a string and geometric dimensions of a track. The calculated range of variations in the ambient temperature (60–90 °C) for a period of operation of the tracks is used in the majority of the

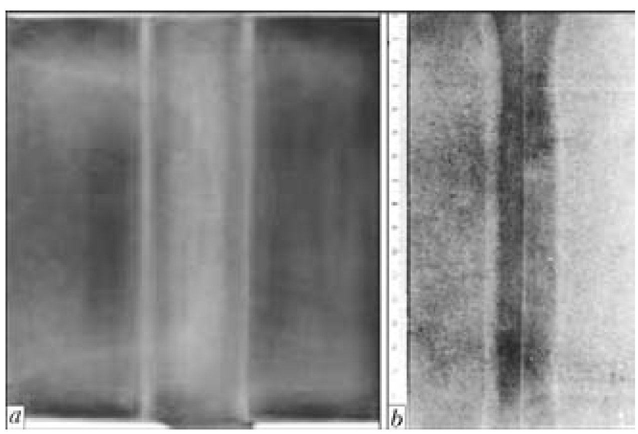

Figure 4. Macrostructure of welded joints on rails E76F: *a* — continuous flashing; *b* — pulsed flashing

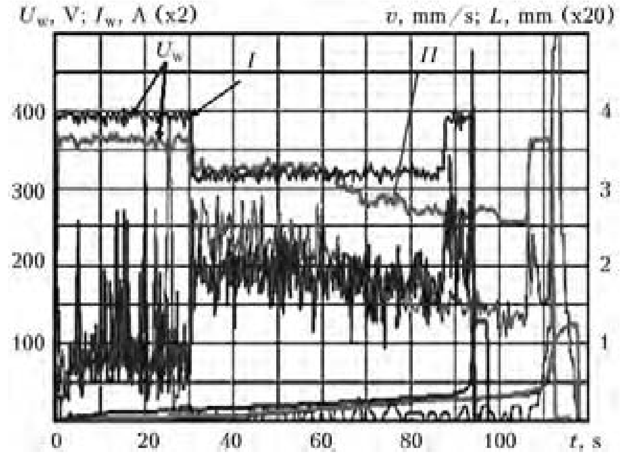

Figure 5. Record of main welding parameters with pulsed flashing: *I* — optimal mode; *II* — adaptive mode

world regions for construction of the continuously welded rails. Accordingly, internal stresses (tensile or compressive, depending on the period of operation) form in the rigidly fixed rail strings. The many years' experience evidences that the compressive stresses causing distortion of geometric dimensions of the rail string or its damage present the most serious hazard.

A new technology for welding of the insert without bending was tested with participation of the Institute. Required shortening in welding is provided due to tension of the string welded, which is freed from sleepers in a limited region (no more than 50 m). After welding the tensile stresses are induced in the string. The value of these stresses can be set precisely by varying the size of the preliminary gap between the ends of the strings prior to welding. Welding of long strings of the continuously welded rail tracks with tension makes it possible to set the most optimal parameters for their service at the ambient temperature changing during operation of the rails. If in repair or construction of the continuously welded rail tracks the value of the tensile stresses is set at a level exceeding that of the probable compressive stresses, the latter will not form in the rails during their entire service life. The similar problem arises in welding of strings of an infinite length in construction of new continuously welded rail tracks. These problems were solved owing to the development of automatic multiple-factor regulation of all parameters of the pulsed flash butt welding process, allowing for the auxiliary operation of tension of the rail strings welded. In welding, in addition to the parameters determining the welding conditions, also the data on the ambient temperature and required level of set tensile stresses in a string welded are loaded into the computer.

The use of the new technology for welding of high-strength rails, combined with their tension, required the development of new generations of the rail welding machines characterised by much higher upsetting forces and equipped with built-in mechanisms for removal of the weld reinforcement in hot state. All of the above innovations of the new technology for welding of high-strength rails and multiple-factor regulation systems were used as a base for the development of a new generation of mobile and stationary rail welding machines. This was achieved by employing the advanced computer facilities, fast-acting hydraulic drives and high-capacity systems for electronic control of welding parameters.

The new generations of the mobile machines comprise the upsetting drive (Table) that develops the 2–2.5 times higher forces than machines of the previous generations (K900 type). Besides, they are equipped with devices for automatic cutting of flash in the hot state. The rails are kept in the clamped state after welding, which prevents the probability of damage of the weld due to the effect of tensile stresses induced in a string after welding in the heated metal zone. Despite a substantial increase in power of the clamping and upsetting drives, weight of the new machines and their dimensions increased insignificantly, which made it possible to employ them in available

Specifications of stationary and mobile rail welding machines produced by KZESO

Parameter	K900	K920	K921	K922-1	K922-2	K930	K1000	K1100
Rated mains voltage, V	380	380	380	380	380	380	380	380
Maximum secondary current, kA, not less than	18	67	67	67	67	67	84	84
Rated power (duty cycle 50 %), kV·A	150	211	236	210	210	210	300	300
Working pressure in hydraulic system, MPa	100	125	210	210	210	210	160	160
Upsetting force, kN	450	1000	1500	1200	1200	1200	900	900
Clamping force, kN	1350	2500	2900	2900	2900	2900	2000	2000
Stroke of mobile part of machine, mm	70	100	150	100	150	200	100	115
Weight of machine, kg	2700	3000	4100	3100	3100	3450	8800	8800
Time of continuous flash butt welding of rails R65, s	180–220	–	180–220	–	180–220	180–220	180–220	180–220
Time of pulsed flash butt welding of rails R65, s	60–120	60–100	60–120	60–120	60–120	60–120	60–120	60–120

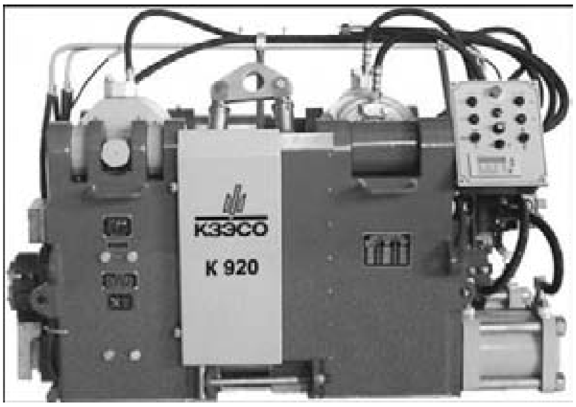

Figure 6. Machine K920

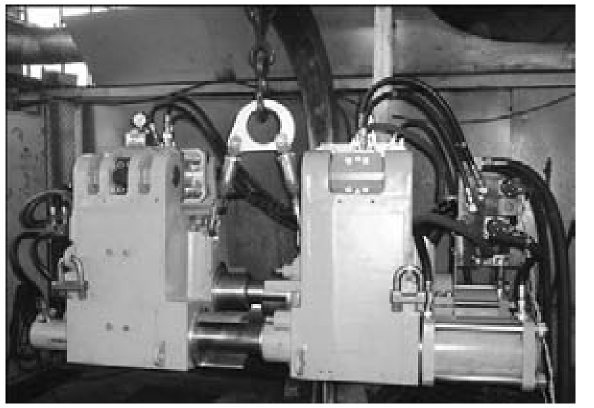

Figure 8. Machine K930 for welding of unlimited-length rails with tension

mobile rail welding systems without substantial reconstruction.

The first machine K921 for pulsed flash butt welding of rails with tension was developed by the E.O. Paton Electric Welding Machine in 2001. It was manufactured by KZESO in cooperation with «Norfolk Southern» (USA). Its application and optimisation of the rail welding technology were performed with participation of the Institute on railroads belonging to this Company. The technology was successfully applied, and different variants of implementation of welding with tension were verified. Over tens of such machines have been operated and efficiently utilised up to now. Flash butt welding of rail strings of an unlimited length, i.e. up to several hundreds of kilometres, without bolted joints was performed for the first time in the world practice. According to the available data, the total length of the unlimited-length rail tacks continuously welded by the Company is over 10,000 km.

In the last decade the Institute has continued working on the developments aimed at upgrading of the equipment for field and factory welding of rails to be used in different world regions.

In 2001–2005, machines of the K920 type (Figure 6) and two modifications of machines K922 (Figure 7) were developed for welding of rails in the CIS countries. Characteristics of these machines (upsetting and clamping forces, dimensions) were optimised with allowance for the existing repair and construction technologies, as well as for the available mobile rail welding systems. In particular, the weight and dimensions of the machines were substantially (1.5 times) decreased compared to the first pilot sample K921. They found wide application for repair and reconstruction of railroads in Ukraine and Russia. The pulsed flash butt welding technology was approved by the standards of railroads of Ukraine and Russia as the basic one for welding of high-strength rails. 18 machines K922-1 and 12 machines K1000 are in operation in Ukraine. Over 50 machines K922 were supplied to Russia. Machines K922 supplied to China (15 pieces) are very efficiently utilised. They were applied primarily for construction of high-speed railway lines. During the last 5 years the range of application of these machines has been considerably widened. Specialists of the Institute render the required consultation assistance in optimisation of the technology for welding of different types of rails and setup of the equipment. Different schemes of arrangement of the work in welding of rails under erection conditions are used. Machine K930 (Figure 8) providing a large length of tension of strings was developed for a more complete stabilisation of the temperature-stress state in unlimited-length rail sections.

Modern mobile rail welding systems manufactured by KZESO are self-propelled machines that are either rail-mounted — KRS5 (Figure 9), or of a combined type — KSM005 (Figure 10), which allows them to

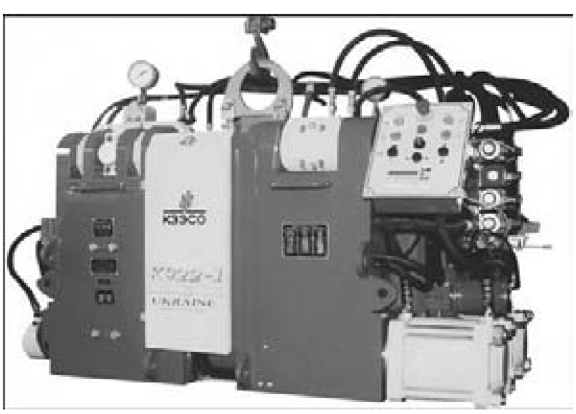

Figure 7. Machine K922-1

Figure 9. System KRS5

Figure 10. System KSM 005

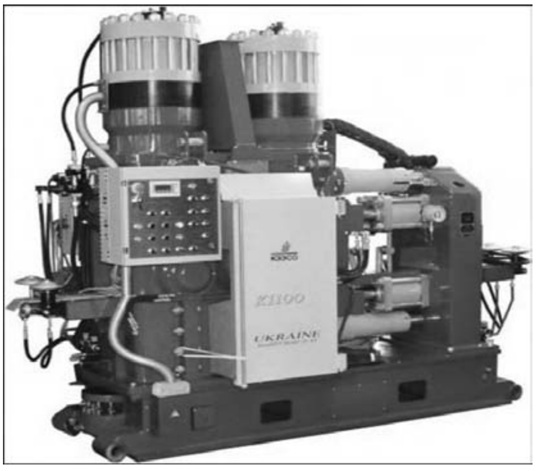

Figure 11. Machine K1100

be moved both on rail tracks and on highways or earth roads.

In addition to rail welding machines, the mobile systems comprise also diesel generators with a capacity of up to 200–300 kW, hydraulic rams, auxiliary equipment for preparation of rails for welding, and non-destructive test systems. Mobile systems of this type, where machines K920 and K922 are used, are employed on railroads of Europe, by Company «Holland» in the USA, Company «Network Rail» in Great Britain, as well as in China, Australia, Brazil, Taiwan, Malaysia, India, Turkey, Saudi Arabia and Thailand.

To raise the productivity of labour in reconstruction and construction of railway tracks, the rails are preliminarily welded into long-length strings from 200 to 800 m long, and then they are transported to the laying-down location. Welding is performed in stationary or semi-stationary shops by using stationary welding machines. In the last decade the Institute has developed a new generation of stationary high-strength rail welding machines K1000 and K1100 (Figure 11), which are based on the use of the pulsed-flash butt welding technology. The machines are characterised by a high productivity (the time of welding the maximal-section rails is no more than 70–120 s) at a power of 250 kV·A, this being almost twice as low as that of the known foreign stationary rail welding machines. The machines provide a high accuracy of alignment of the rails welded, which is especially important for welding of rail strings laid down into high-speed tracks. The machines perform automatic cutting of the weld reinforcement in the welding zone, while the hydraulic drives of the machines provide the increased upsetting forces required for welding of high-strength rails.

The computerised control systems of the machines ensure consistent reproducibility of the preset pulsed flash butt welding parameters and perform operational monitoring of the quality of the joints. The systems estimate the quality immediately after welding. Compared to the known machines, machine K1000 has smaller weight and dimensions, which allows using it in arrangement of semi-stationary shops for welding of rail strings.

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