Enhancing an arc welding technology by the methods of adaptive pulsed control of energetic parameters

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Abstract. The work scrutinizes the main directions of improving conventional methods of arc, plasma and electroslag welding and cladding that are based on the algorithms of adaptive pulsed control of energetic parameters of the process. The deliverables demonstrate that the adaptive pulsed technologies feature a range of undeniable advantages against conventional methods that implement a strictly specified program for changing main energetic parameters of the process. The treatise justifies the main principles of adaptive technologies that ensure stability of heat and mass transfer and production of permanent joints of demanded quality under various disturbances affecting the system: power source, arc, weld pool, product.

1. Introduction
The emergence of pulsed welding and cladding technologies in world’s industry has conceptually changed the perception of what conventional arc, plasma and electroslag technologies are capable of in formation of critical permanent joints [1]. The main strong points of pulsed technologies are controllable melting and transfer of each electrode metal droplet, controllable seam metal formation in different spatial positions, shrinkable structurally nonuniform regions, diminishable after-welding stresses and strains. However, the practice shows that fusion welding is accompanied by a plethora of disturbances that impose negative effects on the reliability of permanent joints in manufactured critical structures. This often reduces their performance, especially in extreme conditions and low climatic temperatures [2]. The disturbances are frequently caused by the characteristics of heat and mass transfer accompanying the formation and transfer of electrode metal into a weld pool [3]. Liquid metal formation itself on the edge of continuously fed electrode is stochastic, which finally causes instability that increases sputter during welding and general labor intensity of manufacturing, raises the number of faulty products and total cost of installation and welding [4].

The experience in elaboration of the theory of melting and formation of metal during consumable electrode welding shows that the most effective methods that reduce the impact of disturbance factors on the heat and mass transfer stability are the methods of adaptive pulsed control. As of today, these methods are widely incorporated in modern installation, welding and repair enterprises [5–6]. The developed method is based on strict dosage of energy for melting and transfer of each electrode metal droplet [7]. The whole technological complex (power source, electrode wire feeder, arc, weld pool, welded part) is considered as an integrated closed automatic control system [8]. The system during the
whole welding cycle performs continuous control of heat and mass transfer stability, changing instantaneous values of the majority of technological parameters responsible for the operational indicators of welded connections. The specificities above require additional comprehensive theoretical and experimental studies covering the processes of heat and mass transfer of electrode metal during subprocesses of melting, transfer and crystallization of the seam metal from the melt. Such studies should deliver formulated principles for improving electric arc welding and cladding that ensure long life and high durability of critical engineering systems working in extreme operating conditions and low climatic temperatures [9].

**Research goal:** Find ways to improve conventional technologies of arc welding and cladding based on the methods of adaptive pulsed control of processing energetic parameters in installation and welding works, including those performed at low climatic temperatures.

### 2. Main operation principles of closed and open systems for automatic control of arc fuse welding.

The developed direction of works is performed with due account for the main statements of the automatic control theory developed for arc welding and cladding as the most widely spread industrial method for manufacturing of various metal structures and articles. There is a huge variety of automatic systems featuring different functions for controlling physical processes that can be implemented both directly in welding instruments and in technologies involving them. Such systems combine various designs of mechanical and electrical devices that integrate into a sophisticated complex of interacting constituents.

The examples of automatic systems of controlling arc welding processes are:

- thermal protection of welding power source;
- engagement and disengagement of the power source and electrode wire feeder in the beginning and in the end of the process;
- system for monitoring and aligning the welding head along the joint of a welded part;
- adjustment of the electrode wire feeding depending on the electrode stick-out both before and during welding;
- programmable displacement of the welding head along the welded joint;
- automatic arc length preservation regardless of changing position of weld pool and other parameters.

Almost all automatic control systems can be divided into two categories:

1) systems for single or multiple operations: switching welding equipment on and off, setting electrode wire feeding rate, setting parameters of a power source, etc.;

2) systems that during welding change (or retain) physical values, for instance, coordinates of a moving object, welding rate, arc voltage, stabilize supply voltage, dose energy necessary for melting and transfer of each droplet of electrode metal, control thermal cycles and control seam metal formation in different spatial positions, etc.;

The second type of automatic control systems is the most sophisticated, though more versatile. Such systems can be closed or open. The first principle is used almost in all conventional supply systems (Fig. 1).

![Open automatic control system](image)
The scheme in Fig. 1 is an elementary automatic control system when the power source is controlled by a man. A characteristic feature of open automatic control systems is that its operation has no effect on the result of object control. Therefore, a natural improvement of an automatic system is closing its output with the input of a controllable power source via a feedback unit, which allows adjusting its operation during welding. Besides, the inputs of the controllable power source are connected with the channels that conduct signals proportional to the disturbances that tend to destabilize the system. The structural scheme of an open automatic control system is depicted in Fig. 2.

**Figure 2.** Closed automatic control system

Evidently, a closed automatic control system features a complete interdependence of all constituents. Such design of closed systems is the principle discrepancy from open ones and makes them irreplaceable for creating welding instruments.

### 3. Directions and methods for designing closed automatic control systems.

The practical implementation of such approach requires solving a number of elaborated technological and electromechanical problems [10].

**First group of problems:** droplet formation control, transfer of electrode metal, crystallization of weld pool, controllable main welding parameters (arc voltage, welding current, instantaneous arc power) by welding equipment [11].

**The second group of problems** (electromechanical) requires introducing special units (choppers) into the welding equipment that are reliable and capable of switching maximum pulse power, having low inertia and adequate dimensions and weight [12]. Such requirements are hard to meet because they involve switching of huge pulse power (more than 50 kW) over microsecond durations.

Indeed, this approach was put into practice in 1970s-1980s in the Soviet Union as methods of manual shielded metal-arc welding, shielded machine welding in CO₂, Ar and their gas mixtures featuring controllable and uncontrollable transfer of electrode metal by solid and powder wires [13–17]. However, despite the efficiency of existing technologies and instruments, they are not suitable for all the cases of increasing the life, durability and reliability of critical systems working under low climatic temperatures.

**From our perspective, this goal can be achieved by solving three interconnected problems:**

- Development and practical implementation of new-generation welding and cladding materials with submicrocrystalline and nanosized components modifying the zone of permanent joint [18].
- Development and practical implementation of novel methods for diagnosing rapid heat and mass transfer processes accompanying melting, transfer and crystallization of seam metal from melt that have dominating impact on the stress-strain state of critical structures.
- Development of practical implementation of new-generation power sources with high dynamic properties and algorithms of adaptive pulsed control [19].

The first problem of developing and implementing new-generation welding and cladding materials is to be solved by using submicrocrystalline and nanosized powders as modifiers.

In late XX-early XXI centuries, the USA, Canada, European Union, Russia, China and CIS countries have started working on this conceptual problem by applying alloying chemical materials with hard alloys, solid solutions, including those of aluminium, silicon, zirconium and powders of refractory compositions of chrome, titanium, nickel and others. Under pulsed highly concentrated energy fluxes with low pulse duration, they can activate structure, phase and thermochemical transformations, which provide increased physicomechanical and operational properties of coatings [20].

The second problem of developing and implementing novel methods for diagnostics of high-rate processes of heat and mass transfer accompanying melting, transfer and crystallization of seam metal from melt completely depends on the new approaches to diagnosing the micro-metallurgical processes during melting, electrode metal transfer and crystallization of weld pool during formation of a permanent joint.

The most complicated problem is development and practical implementation of new-generation power sources. In principle, it requires creating new sources of pulsed energy for pulsed-arc, pulsed-plasma, pulsed laser, high-rate gas-flame, electro-contact and detonation instruments that would be able to create directed highly concentrated energy fluxes with low pulse duration and using systems of adaptive control to stabilize operational characteristics [21].

Fig. 3 presents a scheme of adaptive automatic control system for shielding welding.

**Figure 3.** Scheme of adaptive automatic control system for welding process: PS – power supply, A – arc, P – product, WP – weld pool, CO – controlled object, PTCU – product temperature control unit, TS – temperature sensor, $T^\circ_S$ – product temperature setting unit, C – comparator, $F_{PS}$, $F_A$, $F_{WP}$, $F_P$ – disturbances.
The technical essence of the power source scheme is in the presence of different intercorrelated units in its structure. The units control the state of the controlled object and play the role of actuating elements in the supply system retaining a preset wire feeding rate, adjusting the operating temperature of the power circuit elements by automatic heating, and changing surrounding air temperature. The most important characteristic of the created power supply systems is the control reaction speed, because modern technological processes frequently require the reaction speed of power supply system to the correction of control algorithm from 0.1 to 0.3 milliseconds.

An important element of the automatic control system is the presence of feedback channels that continuously control the disturbances affecting the object of automatic control. They are processed using the changes in instantaneous values of the main energetic parameters of the process. One of the main elements of presented system in the controllable power source (WPS), which power circuit scheme is presented in Fig. 4.

Based on the experience of creating adaptive pulsed supply systems, we may note that their design now allows eliminating the necessity to control the output voltage of the power source. The necessary arc voltage can be retained during changing electrode feeding rate by using the current pulse duration (arc duration).

![Figure 4. Scheme of the power source power circuit: WPS – Welding Power Source, L1 – Input Series Inductor, L2 – Welding cables self-inductance, R – Current limiting resistor, VT – Transistor Switch, SWD – Switch Driver, CS – Current Sense, AD – Arc Detector, CTRLS – Control System, PS – input terminal for 220 VAC power supply, UI – User Interface, WT – Welding Torch.](image)

Such design allows eliminating the need in conventional smoothing coils on the stage of short-circuit. This allows for 30-40% reduction of lasting short-circuits, which appreciably increases the efficacy of the process and makes it less sensitive to the disturbances at the stage of electrode metal transfer into the weld pool.

4. Conclusion.

1. The method of adaptive pulsed technologies (APT), ensures stable energy parameters of the processes during welding in different spatial positions, capability of programmable introduction of heat into the welding zone, and controllable melting and transfer of each droplet of electrode metal.
Such factors ensure the most favorable conditions for forming highly dispersed structure of seam metal, reducing the heat-affected zone and residual deformations of the welded joints.

2. Considering the efficacy of APT methods in producing critical systems under low climatic temperatures, their application will facilitate the growth of the performance of critical structures. This opens new horizons for achieving the main goals of fundamental investigations: development of mechanical engineering, power engineering, chemical, extraction and processing industries in the Far North and Arctic.

3. Further fundamental and targeted studies in this direction are high on the scientific and engineering agenda. Their success will affect future development of the world's industry.

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