# AUTOMATIC SUBMERGED ARC SURFACING OF STRUCTURAL STEELS WITH TRANSVERSE HIGH-FREQUENCY MOVEMENTS OF ELECTRODE

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Transverse oscillations of the electrode in automatic submerged arc surfacing are one of the ways of decrease in penetration depth and share of base metal in deposited one. These oscillations can be created by generating of high-frequency transverse pulsed movements of electrode wire using a specially designed electromechanical generator. The aim of this work is to evaluate the effect of high-frequency low-amplitude transverse pulsed movements of electrode wire on geometry of deposited bead and efficiency of the surfacing process. Deposition of beads was made on plates of low-carbon structural steel with electrode wire Sv-0.8A of 2 mm diameter under flux AN-348A. The pulsed electrode movements at 0.25–5 kHz frequency were generated along the surfacing direction. It was found that with increase in frequency the penetration depth of base metal and bead width are decreased, while the height of bead is increased, in addition the surfacing efficiency is also changed. The nature of change in the mentioned parameters depends on mode of pulsed effect on electrode wire, i.e. the presence or absence of resonance. The most significant change in geometry of the deposited bead is observed in the region of frequencies of the first resonance (0.55–0.75 kHz), namely depth of penetration and share of base metal in deposited one is 3 times decreased. The maximum increase in efficiency is occurred in the region of the second resonance (3.75–3.85 kHz), the coefficient of electrode melting is increased by 10–20 % as compared with surfacing without a pulsed effect. 10 Ref., 1 Table, 4 Figures.

***Keywords:*** *automatic arc surfacing, low-carbon structural steels, high-frequency pulsed movement, mechanical generator, geometry of deposited bead*

The repair of worn-out parts of ship machines and mechanisms is often performed using the automatic submerged arc surfacing (ASAS) which provides, alongside with high efficiency, the required quality and homogeneity of the deposited layer. However, the depth of base metal penetration is increased and its share in deposited one amounts as a rule to 30–50 % [1]. The reduction of the mentioned characteristics of ASAS technology, preserving the high efficiency of the process, is a very urgent problem. To solve this problem, different methods of effect on the processes of electrode metal arc transfer or formation of weld pool are used allowing control the geometric parameters of the deposited bead and, consequently, the share of base metal (SBM) in the deposited layer. The most widely spread are the electric (pulsed-arc welding), mechanical (vibro-arc surfacing) and magnetic methods [2, 3].

It should be noted that the electric method envisages the application of complicated and expensive welding current sources with programming of condition parameters [4], magnetic method has some limitations connected with magnetic properties both of base metal and also electrode metal [5].

The listed drawbacks, in our opinion, are not typical of the mechanical method, characterized by simplicity in realization using the serial welding equipment. It is known that the pulsed feeding of electrode [6] or generation of transverse low-frequency (up to 150 Hz) oscillations of electrode [7] increase the arcing stability, improve the weld geometry and structure. High-frequency (500–1000 Hz) low-amplitude (about 130 μm) transverse pulsed movements of electrode contribute to reduction in penetration depth and SBM at ASAS as well [8]. In the latter case the effect is attained due to periodic forced removal of liquid-metal layer from electrode end at vibration effect allowing control of metal drop mass, transferred through the arc.

The aim of the present paper is to investigate the effect of transverse high-frequency pulsed movement of electrode on geometric characteristics of deposited bead and technological characteristics of process in single-arc ASAS of structural steels.

Generator of transverse high-frequency movements of electrode wire (EW) represents a mechanical drive (Figure 1), easily mounted on welding tractor with a wide range of pulsed effect frequency [8].

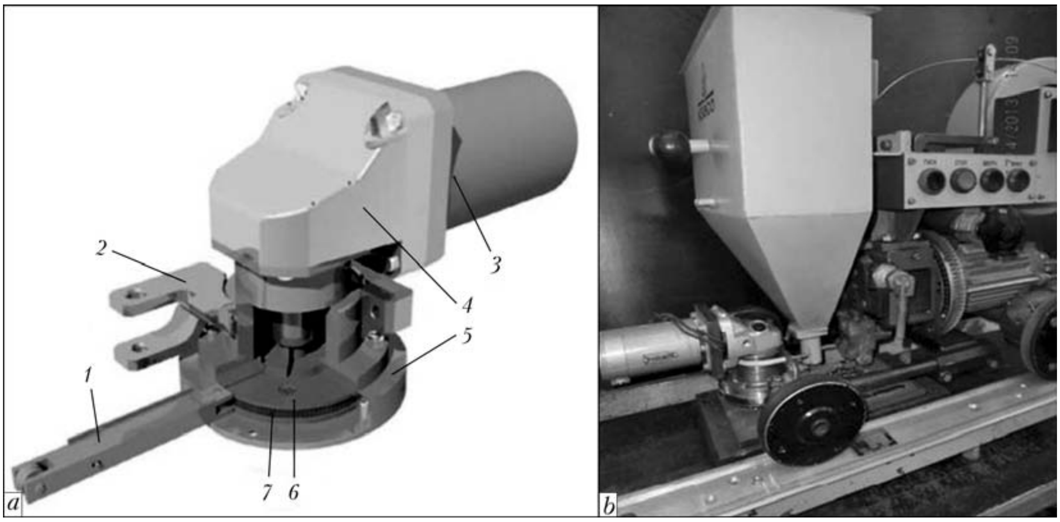



**Figure 1.** Design of generator of high-frequency pulsed movements of electrode (*a*) and its mounting on welding tractor (*b*): *1* — striker; *2* — fastening bracket; *3* — electric motor; *4* — reduction gear; *5* — body; *6* — driven washer; *7* — set-up rollers

The pulsed effect on EW leads to transverse oscillations of its end in two modes: interresonance and resonance. Within the region of frequencies close to resonance, the amplitude of oscillations is abruptly increased, due to which the geometry of deposited bead can significantly change. The resonance frequency, at which the frequencies of pulsed effect and natural oscillations of EW coincide, can be presented in the form of [9]

$$f_{oi} = \frac{d_e}{8\pi}\left(\frac{E}{\gamma}\right)^{0.5}\left(\frac{p_i}{l_s}\right)^2,$$

where $d_e$, $E$, $\gamma$ are the diameter, elasticity modulus and density of EW metal, respectively; $p_i = kl_s$ are the roots of frequency equation determined by nature of fixation of rod end subjected to oscillations, i.e. by scheme of EW fixation in current conductor; $l_s$ is the stickout length; is the Krylov function.

The current conductors, mostly widely used in serial tractors for ASAS, can be conditionally combined into two calculation schemes, realizing hinged (Figure 2, *a*) or rigid (Figure 2, *b*) fixation of electrode. The values of the first two roots of the frequency equation, respectively for the scheme presented in Figure 2, *a* are equal $p_1 = 3.9266$ and $p_2 = 7.0685$, and for scheme in Figure 2, *k*, $p_1 = 1.8751$ and $p_2 = 4.6941$ [10].

It is possible to control the resonance frequency according to above-given equation by change in stickout length or nature of electrode fixation in current conductors. Thus, in the range of 100–1000 Hz frequencies the resonance oscillations for electrode diameter $d_e = 2$ mm take place at stickout length $l_s = 25$–$80$ mm, and for $d_e = 5$ mm, respectively, at $l_s = 40$–$150$ mm. In this case the increase in stickout length and rigidity of electrode fixation in current conductor leads to reduction in resonance frequency.

The drawback of method of metal arc transfer process control with applying the resonance phenomenon is the discrete change in resonance frequencies.

In the interresonance mode of pulsed effect it is possible to control smoothly the amplitude of electrode end oscillations in narrow range (1–3 mm) either by increase in stickout length $l_s$ or by decrease in arm $h_f$ of force applying $F(t)_p$. However, the length of electrode stickout is determined, as a rule, in selection of parameters of surfacing conditions and cannot be freely changed, and arm $h_f$ is limited by value of bending moment, causing the plastic deforming of EW [8].

It is sufficiently simply to control the amplitude of EW end oscillation by changing the frequency of pulsed effect. With increase in frequency the speed and acceleration of transmission link (generator striker) are increased, thus lead-

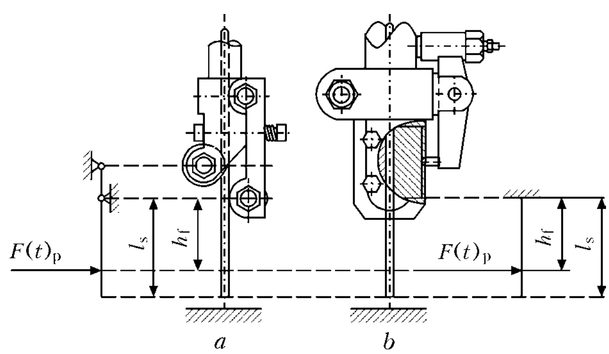
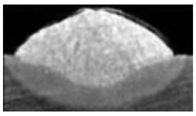
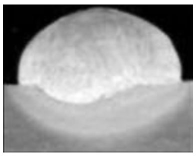
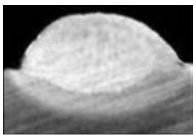
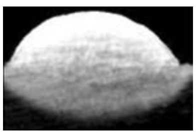
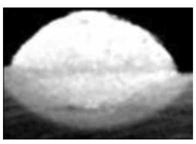



**Figure 2.** Designs of current conductor and appropriate calculation schemes of applying the force of pulsed effect $F(t)_p$ with continuous (*a*) and discrete (*b*) compensation of wear: $h_f$ — arm of $F(t)_p$ force applying

Effect of frequency of pulsed movements of electrode at ASAS on formation of bead, SBM and coefficient of melting

| Frequency $f$, Hz | Macrosection of deposited bead | SBM | $K_m$, g/(A·h) |
|---|---|---|---|
| 0 |  | 0.36 | 15.4 |
| 680 ($f_{r1}$) |  | 0.13 | 16.9 |
| 1295 |  | 0.30 | 15.0 |
| 3820 ($f_{r2}$) |  | 0.22 | 18.6 |
| 5800 |  | 0.25 | 16.1 |

ing to increase in inertial component of force $F(t)_p$.

This assumption was confirmed by the results of a special experimental investigation. During experiments the length of trace, remained on the sample of plastic material, was measured by oscillating sharpened end of EW. It was found (Figure 3) that with increase in frequency of pulsed effect the amplitude of oscillations is increased by parabolic law (see dashed line in Figure). Moreover, at frequencies close to resonance for the given stickout of EW, the abrupt increase in amplitude of oscillations is observed.

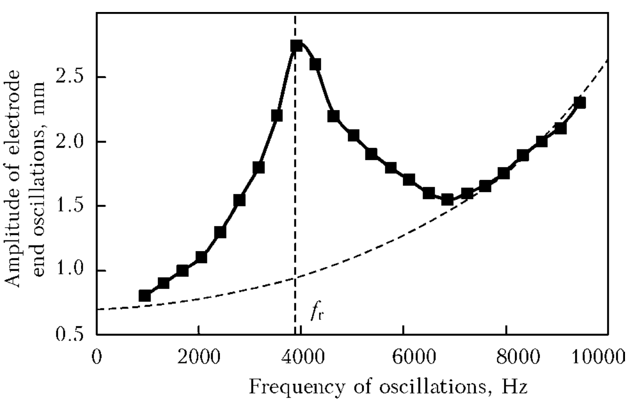



**Figure 3.** Effect of frequency on amplitude of oscillations of 2 mm diameter EW end: $f_r$ — resonance frequency

The amplitude of oscillations of electrode end can be adjusted by two methods: step-wise by change in mass of generator striker or value of its movement in a pulse, as well as smoothly by varying the frequency of rotation of driven electric motor shaft.

The effect of transverse high-frequency pulsed movements of electrode on geometric characteristics of deposited bead was evaluated from results of investigations made on experimental stand (see Figure 1, *b*), equipped by welding tractor KA-001 with a generator of high-frequency pulsed movements of electrode and power source KIU-501.

Bead depositing was made by EW Sv-08A of 2 mm diameter under flux AN-348A on 10 mm thick plate of low-carbon structural steel St3sp (killed). In experiments only frequency of pulsed effect was varied, remaining other parameters of welding conditions unchanged. Stability of welding process, recorded by electron USB-oscillograph IRIS, was evaluated from oscillograms of arc voltage. Geometric parameters of deposited beads, area of penetration and surfacing, and SBM were determined from macrosections.

Below the results are presented, corresponding to pulsed effect on EW along the surfacing direction. It was found that with increase in frequency of pulses the bead width and depth of penetration of base metal are decreased, and bead height is increased (Figure 4).

The nature of the above-mentioned parameters depends on mode of pulsed effect on EW, i.e. the presence or absence of resonance. At the resonance condition the «extremal» change in bead geometry with appropriate change in SBM is observed (Table).

Maximum effect was attained at main tone (first resonance) of oscillating system within the

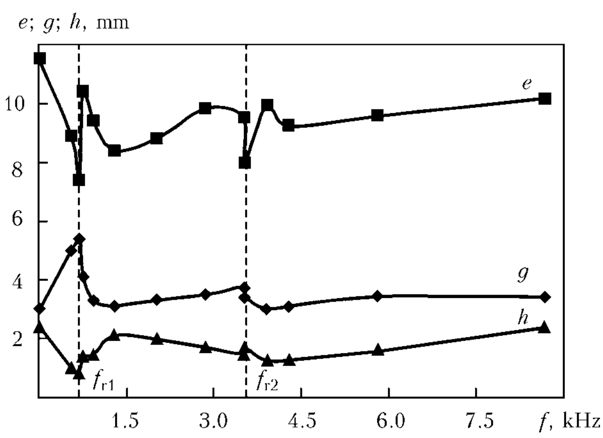



**Figure 4.** Effect of frequency of pulsed movements of electrode on geometric parameters $e$, $g$ and $h$ of deposited bead at $d_e$ = 2 mm, $I$ = 200 A, $v_w$ = 19 m/h, $l_s$ = 48 mm: $e$ — bead width; $g$ — height; $h$ — depth of penetration of base metal

range of frequencies $f_{r1}$ = 560–750 Hz. This is well correlated with resonance frequency $f_r$ = = 630 Hz, calculated using equation abovegiven.

The interresonance mode of oscillations leads to a smooth change in bead geometry. With increase in frequency the force effect of electrode metal drops on weld pool is increased. The depth of penetration and SBM due to it are increased logically.

The high-frequency pulsed movements of electrode have an effect also on the surfacing efficiency. Increase in frequency and amplitude promotes the decrease in thickness of liquid-metal layer at the EW end, increase both in heat transfer from arc to electrode and also in coefficient of electrode melting. Thus, at 3820 Hz frequency of the first overtone the coefficient of melting exceeds the initial value by more than 20 % (see the Table).

**Conclusions**

1. Applying the high-frequency mechanical pulsed effect on EW allows control the metal transfer process, sizes of deposited bead and efficiency of ASAS process.

2. Transverse mechanical oscillations of EW have the highest effect in the region of resonance frequencies of the first tone — on the geometric parameters of deposited bead, and of the second tone — on the efficiency of electrode melting.

3. ASAS of structural steels the mechanical pulsed effect on EW within ranges of frequencies of 600–4000 Hz allows 3 times decreasing the depth of penetration and SBM, and increasing the coefficient of electrode melting by 10–20 %.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