Technology of ultrasonic control of gas-shielded welding process

S A Solodsky[1,a], V D Sarychev[2,b] and I S Borisov[1,c]

[1]Cand.Sc, AP. Yurga Institute of Technology (branch) of Tomsk polytechnic university. Russia, Leningradskaya str., 26.
[2]Cand.Sc, AP. Siberian State Industrial University. Russia, Novokuznetsk, Kirova str., 42
[1]student. Yurga Institute of Technology (branch) of Tomsk polytechnic university. Russia, Leningradskaya str., 26.

E-mail: [a]serdgio80@inbox.ru, [b]sarychev_vd@mail.ru, [c]il.borisow2009@yandex.ru

Abstract. A new approach to implementation of electrode metal transfer control under MAG, MIG welding is suggested. The process ensures control of thermal and crystallization processes, stabilizes the time of electrode metal drop formation. The results of the research allow formulating the basic criteria of electrode metal transfer control via ultrasonic exposure, determining the conditions of producing a more equilibrium structure of deposit metal.

1. Relevance

Under rigid and continuously growing requirements to the quality of weld joints designing welding systems capable of controlling electrode metal transfer is currently a priority area of scientific research and practical developments of many companies producing welding equipment for semi-automatic welding [1]. It is evident from significant upsurge in interest to that kind of equipment demonstrated by various industries. The given problem is considered in the works of many authors: Paton B Ye, Dudko D A, Zaruba I I, Potapievsky A G, Dyurgerov N G, Lenivkin V A, Brunov O G, Knyazkov A F, Sarayev Yu N and many others [1, 2, 3].

In the given paper we present a welding system implementing an actual process of controlled transfer. The process is based on exciting resonance high-frequency (10^9 – 10^{12} Hz) mechanic oscillations in the electrode metal drop reducing the size of the drop due to increasing the uniform compression force in the area of the bridge resulting in its faster destruction.

2. Experimental procedure

It is known [4] that magnetic action on ferromagnetic materials makes them change their linear dimensions due to lattice distortion, i.e. magnetostriction effect is observed. Thus, the electromagnetic field may change the linear dimensions of ferromagnetic material placed into it. Subsequently, if we expose ferromagnetic material to variable magnetic field it will induce energy impulses in the material creating surface acoustic waves. In ferro- and ferrimagnetics (Fe, Ni, Co, Gd, Tb and other, some alloys, ferrites) magnetostriction reaches significant magnitude (relative deformation $\Delta l/l \approx 10^{-6} - 10^{-2}$ m). [5].

There are only two types of ultrasonic waves that can propagate in the uniform isotropic indefinite solid medium – longitudinal and shear waves. For the longitudinal waves the movement of particles is parallel to the direction of wave propagation and deformation is a combination of uniform compression (tension) and pure shear. For the shear waves movement of particles is perpendicular to the direction of wave propagation and deformation is pure shear. On the semi-infinite solid-fluid interface Rayleigh surface waves can propagate being the combination of inhomogeneous longitudinal and shear waves with exponentially diminishing amplitudes as they move away from the interface.

The electrode wire applied for machine arc gas-shielded welding, being a ferromagnetic, demonstrates the magnetostriction effect and it is possible to induce the required longitudinal oscillations with specified frequency in it. For this purpose a magnetostriction transducer is applied. It transforms the energy of the magnetic field into mechanic ultrasonic energy.
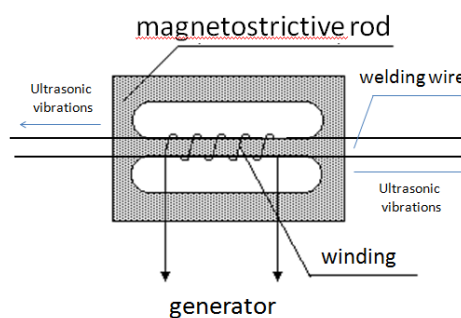

Figure 2.3 Magnetostriction transducer

When considering metal as elastic anisotropic medium we should notice that, under point energy deposition, two types of volume waves: longitudinal waves where particle displacement occurs along the direction of the wave propagation and transverse waves where the particles are displaced in the direction perpendicular to the direction of the wave propagation. It is possible to say that longitudinal and transverse waves are volume natural oscillations.

In the case of the pile-up of the pulse upon the electrode wire the transverse waves may not be taken into consideration as the point-like pulse is piled-up across the whole diameter and, thus, the transverse waves being excited in every point are mutually absorbed. Let us set longitudinal waves velocity as (c_n). Then the velocity of longitudinal waves propagation in elastic materials with known constants is expressed as follows [1];

$$c_n = \sqrt{\frac{E(1-v)}{\rho(1+v)(1-2v)}},$$ (1)

where ρ – density of material; v – Poisson's ratio; E – Young modulus.

So, surface drift is propagated as an elastic wave along axis x and exponentially damping as it moves inward the wire. This surface wave is called Rayleigh wave R(c) and its velocity equals:

$$R(c) = (2 - m^2)^2 - 4\sqrt{1-m^2} = 0,$$ (2)

where $m = c/c_n$, where c – sound velocity in a material.

Subsequently, if we find the velocity of Rayleigh wave propagation we can obtain the required frequency of the electrode wire as it is known that, under velocities close to R(c), but not exceeding its value the wave becomes concave and under c_n>R(c) it becomes convex.

If we apply electrode wire as ferromagnetic material the piled-up electromagnetic pulses induce a surface wave on it, the wave which propagates in both directions from the center of electromagnetic

pulse application. Under machine gas-shielded welding such electromagnetic pulses are applied to the wire moving towards the welding arc zone. The travel speed of the wire is not taken into account during the calculations as velocity of Rayleigh surface waves propagation is an order of magnitude faster.

Consequently, Rayleigh waves travel by the electrode wire surface towards its end, i.e. up to the bridge of electrode metal drop and on the solid-fluid interface the waves (Love-waves) are excited, they have vertical polarization and their structure and velocity are completely different from those of Rayleigh waves. They consist of a weak inhomogeneous wave in the fluid which amplitude slowly diminishes as the wave moves away from the interface of two strongly inhomogeneous waves in the solid (longitudinal and transverse). Due to this phenomenon the wave energy and motion of the particles are mainly localized in the fluid, not in the solid [6].

These waves continuously radiate energy into the fluid as they propagate forming in the fluid an inhomogeneous wave moving away from the interface. The phase velocity of the given surface acoustic wave equals c_n and the attenuation coefficient for λ wave length is $\sim$ 0.1. Beside the attenuating wave, on the solid-fluid interface there is always a continual wave running along the interface with phase velocity.

Consequently, energy of high-frequency electromagnetic field is transmitted through the wire to the molten drop due to Rayleigh and Love waves. This energy increases the activity of the surface of electrode metal drop, thus, increasing the uniform compression force effecting the bridge and contributing to its faster destruction. Subsequently, the size of the drop able to detach from the electrode wire is reduced.

3. Implementation of the process

In the process of continuous feed welding elastic longitudinal oscillations are piled-up at the wire. Piling-up of elastic longitudinal oscillations is implemented due to magnetostriction properties of electrode wire which allow its application as generator of mechanical longitudinal impulses. Elastic longitudinal impulses appear when longitudinal magnetic field with ultrasonic frequency of $10^9 - 10^{12}$ Hz is piled-up on electrode wire. longitudinal oscillations induce elastic waves in the electrode wire. In the process of welding elastic waves transmit elastic longitudinal oscillations to the drop of molten metal which is at the butt end of electrode wire. When the frequency of longitudinal oscillations of the wire coincide with the frequency of molten metal drop oscillations, it creates resonance of oscillations which causes dramatic increase of forced oscillations amplitude. The effect of mechanical detachment of electrode metal drop is created. of Electrode metal is transferred into the weld pool due to the resonance phenomenon [6].

The work and the method of the welding process implementation is as follows (Figure 1)
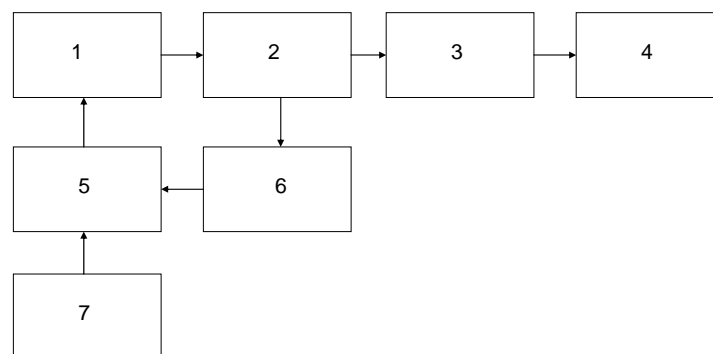

Figure 1 – Flow chart of the welding process implementation: 1 – ultrasonic generator; 2 – inertia-free solenoid; 3 – weld pool; 4 – molten metal drop; 5 – comparing and correcting unit; 6 – resonance indicator; 7 – unit of intended resonance frequency [7]

Ultrasonic generator 1 with variable frequency from 10^9 Hz to 10^{12} Hz feeds pulses of current to inertia-free solenoid 2 inside which electrode wire 3 is passed at a uniform rate. Inertia-free solenoid 2 produces variable longitudinal magnetic field under the effect of pulse current. Elastic longitudinal oscillations with the amplitude of $(4-8) \cdot 10^{-9}$ m and frequency equaling that of the generator are induced in the electrode wire 3 due to magnetostriction effect under the action of longitudinal magnetic field. Longitudinal oscillations move along electrode wire 3 according to the law of elastic waves propagation and Rayleigh waves induced at the butt end of electrode wire are transmitted to electrode metal drop 4. When frequency of Rayleigh waves and longitudinal oscillations of the wire coincide with the natural oscillations of molten metal drop we observe resonance and sharp rise of the amplitude of induced oscillations. The drop of electrode metal 4 is mechanically detached from electrode metal 3. To stabilize the process the control unit includes resonance indicator 6 registering sharp increase of oscillations amplitude. The signal from resonance indicator 6 arrives at comparing and correcting unit 5 where the signal is compared to the signal from resonance indicator 6 and that of the unit of intended resonance frequency 7. If the signals do not coincide the comparing and correcting unit 5 corrects the frequency of mechanical oscillations of the drop changing the frequency of ultrasonic generator 1. The ultrasonic generator is presented in Figure 2.

4. Material and methods of research

The research conducted at the unit allowed experimental determining one of possible resonance frequencies ν_R within megahertz range. The frequency depends on welding conditions and electrode wire material. The current on magnetostriction transducer under the given frequency ν_R is 21 A and it corresponds to field density creating maximum magnetostriction effect for the iron.

Studies of the results of welding with resonance control in CO_2 atmosphere were conducted on the samples produced from sheet metal. To study the welding processes in CO_2 atmosphere with resonance control we applied a welding unit which comprises a magnetostriction transducer with control system designed and produced in Yurga Institute of Technology of Tomsk Polytechnic University under the supervision of AP of Welding Production department, Cand.Sc. Brunov O G, arc welder – welding rectifier VS-300 B UZ, digiscope N338 which two channels were used to obtain oscillograms of voltage and current of the arc. To film the process of metal transfer the unit was placed on the automatic welding head GSP – 2.

For high-speed filming of the welding process and physic models processing we applied high-speed camera "VideoSprint" with camera lens Nikon (maximal filming speed 8000 frames per second). Macroslices were produced by the central laboratory of Yurga Engineering Plant.

On Figure 2 a, b, c the oscillograms of the process are presented. Analysis of the oscillograms showed that under the effect of off-resonance frequencies the process of transfer does not differ significantly from that with classic electrode wire feed (Figures 3 a, b). The oscillograms of the welding process with the frequency of wire oscillations $18 \cdot 10^5$ Hz, i.e. the transfer process is stabilized at the resonance frequency and the size of the transferred drop is reduced.

| a | b |
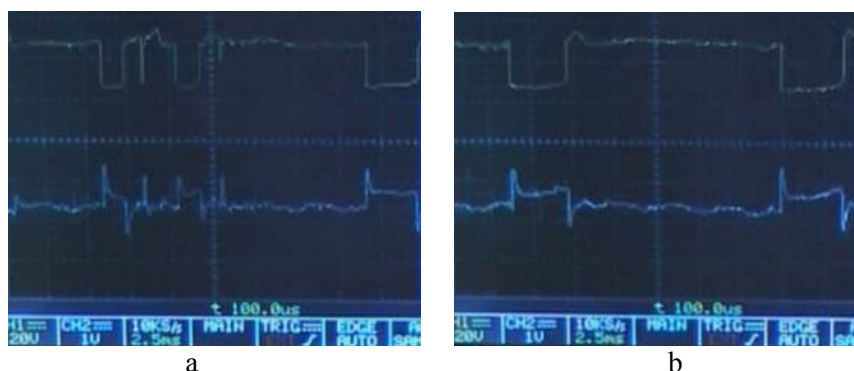
c

Figure 2: a – Oscillograms of the welding process with wire oscillation frequency $7 \cdot 10^4$ Hz. b - Oscillograms of the welding process with wire oscillation frequency $22 \cdot 10^6$ Hz. Frequency of drop transfer is 42 Hz, c − Oscillograms of the welding process with the obtained wire oscillation frequency ν_p

Frames of high-speed filming of the welding process are presented in (Figure 4) (Uд = 22 B, Iд= 180 A).
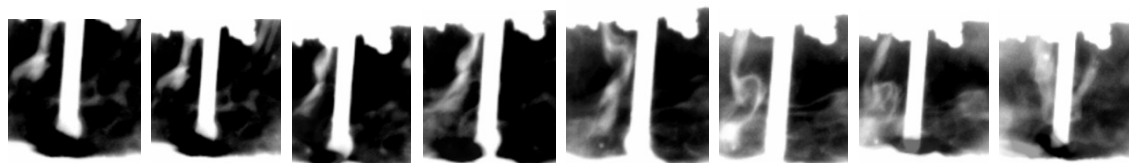

Figure 4. Frames of high-speed filming of the studied process on the resonance frequency (1500 frames per second)

Analysis of the records [8, 9] showed that application of resonance allows increasing stability of the welding process due to introduction of additional force pushing the drop towards the weld pool. The given approach allows reducing oscillation of arc spots, thus, improving stability of the drop, reducing its size, increasing frequency of transfer. All that leads to reduction of spattering and alloying elements burning, improvement of weld formation without application of expensive pulse control systems.

5. Conclusion
The developed welding method is characterized by the following advantages:
   a) transfer of electrode metal drop is realized due to resonance causing mechanical detachment of electrode metal drop from the electrode wire;
   b) control of electrode metal transfer happens without periodic alteration of arc-welding current;
   c) the suggested method of welding for realizing controlled transfer does not require a switched-mode power supply and special means of pulsed wire feed.

References
[1] Saraev Y N Adaptive pulse-arc welding methods for construction and repair of the main pipelines. Proceedings of The 2nd South-East European IIW International Congress "Welding – HIGH-TECH Technology in 21st century". Sofia, Bulgaria, October 21st-24th 2010, p. 174 – 177.
[2] Dyurgerov N G and Lenivkin V A Stability of pulsed-arc consumable electrode welding. Welding Internationa 2016.
[3] Chinakhov D A Study of thermal cycle and cooling rate of steel 30ХГСА single-pass weld joints

// Applied Mechanics and Materials. – Vols. 52−54. – 2011. – p. 442-447. - Mode of access: http://www.scientific.net/AMM.52-54.442

[4] Vonsovsky S V, Magnetism, M. 1971; Belov K P, Elastic, thermal and electric phenomena in ferromagnetic, 2nd ed., M. – L., 1957.

[5] Ultrasonic transducers, transl. from English, under the editorship of I P Golyamina, M., 1972.

[6] Viktorov I A Acoustic surface waves in solids. Publishing house: Nauka, M−1981.

[7] Patent for invention № 2481931 (RF). Method of consumable machine welding with piling-up mechanic nanoimpulses over electrode wire feed. Solodsky S A, Brunov O G, Zelenkovsky A A, Vasilyev D V I priority of invention 4th of May 2012 V23K 9/173. Published 20.03.2014. Bul.№8.

[8] Chinakhov D A and Agrenich E P Computer simulation of thermo-mechanical processes at fusion welding of alloyed steels // Materials Science Forum. – Vols. 575-578 (2008). – Pp. 833-836.

[9] Valuev D V and Danilov V I Reasons for Negative Formation of Structures in Carbon Steel Processing of Pressure // 7th International Forum on Strategic Technology (IFOST − 2012): Proceedings: in 2 vol., Tomsk, September 18−21, 2012. − Tomsk: TPU Press, 2012 − Vol. 2 − p. 151-154.