Seam Tracking during Electron Beam Welding in Air

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We study methods of beam positioning at the joint during Electron Beam Welding in air. Traditional methods of automatic beam positioning at the joint are unacceptable during the Electron Beam Welding in air because of the significant dispersion of electrons and the impossibility of the beam deflection inside the electron beam gun due to presence of an airlock. For joint tracking, we propose using magnetic fields of the current in the welded parts created by the beam's current. It is established that the vertical component of the magnetic field of the current in the welded parts is proportionate to the beam deflection at the joint. Differential flux gate meter is used as a tracking device. We outline the functional diagram is of the joint tracking device and address issues with error prevention methods.

Следене за процепа при електроннолъчево заваряване на въздух (Владимир Я. Браверман, Владимир С. Белозерцев, Валерий В. Богданов, Николай В. Успенский, Александър Е. Бенияш). *Ние изучаваме методи на позициониране на лъча върху съединението при електроннолъчево заваряване в атмосферата. Традиционните методи за автоматично позициониране на снопа върху процепа между съединяваните детайли са неприемливи при електроннолъчево заваряване във въздух, поради значително разсейване на електроните и невъзможното отклонение на снопа извън пушката, поради присъствие на ефект на аеро-заключване. За следене на заваръчния процеп ние предлагаме използване на магнитните полета от токовете във заварените части, създадени от тока на лъча. Намерено е, че вертикалната компонента на магнитното поле на токовете в заваряемите детайли е пропорционална на отклонението на лъча от заваръчния процеп. Диференциален поток-метър се използва като следящо устройство. Приведена е функционална диаграма на следящото процепа устройство и адресираме данните по метода на избягване на грешки.*

Introduction

Recently, the industrial use of Electron Beam Welding in air has grown significantly. However, issues with precise positioning of the electron beam at the joint of the welded parts, are the same as in the Electron Beam Welding in the vacuum.

Traditional methods of automatic beam positioning at the joint are unacceptable during the Electron Beam Welding in air because of the significant dispersion of electrons and the impossibility of the beam deflection inside the electron beam gun due to presence of an airlock. For seam tracking we propose using magnetic fields of the current in the welded parts created by the beam's current. It is established that the vertical component of the magnetic field of the current in the welded parts is proportionate to the beam deflection along the seam. Differential flux gate meter is used as a tracking device. We outline the functional diagram is of the seam tracking device and address issues with error prevention methods.

Several aspects of this subject are covered in this work [1]. We describe a method of determining the beam's position along the seam and provide a functional diagram of the device to help apply this method in the Electron Beam Welding in air.

The method to determine beam's position at the joint

The proposed method is based on identification of a magnetic field of the welding current (I_B) and the beam's coordinates. The main idea of this method is that when a beam deflection from the joint occurs, a redistribution of welding current components and the current-induced magnetic fields follows [2], [3].

The electron beam current I_B is divided into two components I_1 and I_2 (*Fig*. 1) with the help of current collectors.

When the electron beam is located right above the joint then the magnetic-fields' strengths H_1 and H_2 have equal values and opposite directions (*Fig.* 1, *a*). In this case, the resulting magnetic field is defined by current I_B, and the vector of the magnetic-field strength is located in the horizontal plane. With the beam deflection (-ε) from the joint (*Fig* 1, *b*), the current I_2 flows from the beam to the current collector through the welded part, and the magnetic-field strength produced by the current I_2 is changed by the value of H_V. The resulting magnetic field above the welded part of the joint is defined by the vertical component of the magnetic field strength H_V from the current I_2, flowing through welded part of the joint, and the horizontal component of magnetic field strength from the beam current I_B.

When the beam deflection is in the opposite direction, the current I_1 flows through the welded part of the joint and the magnetic field strength produced by current I_1 is changed by the value of ($-H_V$) (Fig. 1, *c*). The resulting magnetic field over the welded part of the joint is defined by vertical component of magnetic field strength ($-H_V$) from the current I_1, flowing through welded part of the joint, and horizontal component of magnetic field strength from beam current I_B. Therefore, the vertical component of the magnetic field over the welded part of the joint carries the information about the beam's position at the joint. If a magnetic field sensor (for example, fluxgate meter) is used in such a way that its sensitive axis is vertically placed, then it is possible to measure the vertical components (H_V) and ($-H_V$), which carry the information about the beam's position at the joint.

Theoretical analysis

Analytical definition of the magnetic field strength dependence on the electron beam's deflection from the joint is carried out with a 3D model, which simulates the welding process based on the electromagnetic properties of air restricted in the plane of the welded parts with coordinates determined by the two-dimensional model analysis. This dependence is defined by the following equation:

$$H_V = F(x, y, h_\partial, I),$$

where H_V – vertical component of the magnetic field; x, y – beam coordinates; h_S –height of the flux-gate meter's position; I – welding current.

The simulation is based on Maxwell equations' calculation [1].

Two parameters were modeled – the direct current in conducting medium and the electromagnetic field. The equations were solved with the finite elements method.

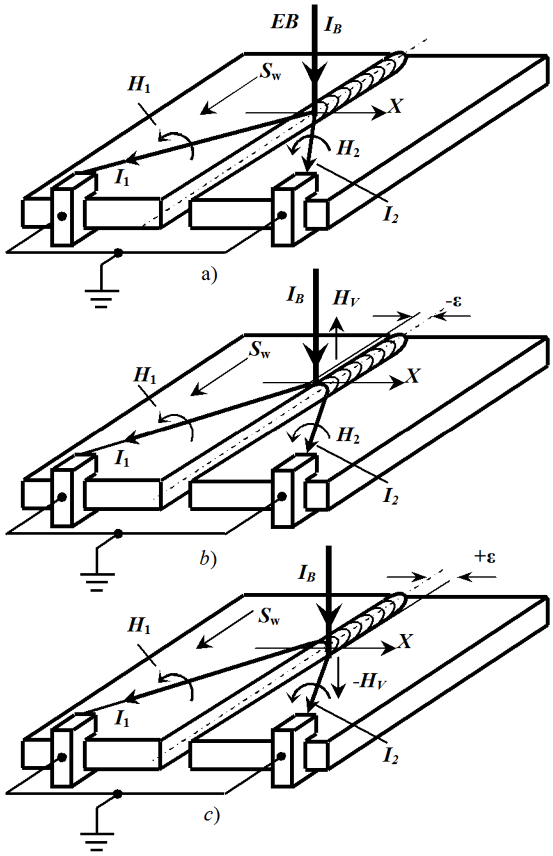

Fig.1. Dependence of the magnetic field vertical component on the electron beam position relative to: a) – X=ε=0 (no displacement); b - X=-ε (left displacement); c – X=+ε (right displacement)

The calculations were produced for aluminum alloy and steel materials under beam deflection variations.

The calculation results for the process of welding the parts made of the aluminum alloy with thickness of 10 mm with the I_B = 250 *mA* and the welding process speed of S_W = 0,5 *sm*/*s* are presented in Fig. 2. The lines represent currents and the shaded areas represent the magnetic field distribution.

This shows that when there is no beam deflection, the distribution of welding current components I_1 and I_2 and the magnetic fields produced by them are symmetrical relative to the joint (Fig. 2, a).

When there is deflection from the joint, the symmetry is disturbed (Fig 2, b), and some current created by the part with the beam deflection passes through the welding area. The larger the beam deflection is, the higher the symmetry disturbance is. The same effect is observed in the simulation described above.

As a result, the parity of the currents I_1 and I_2 no longer exists and the vertical component of the magnetic field H_V appears. The value of H_V depends on the value and the direction of the beam deflection from the joint (Fig. 2). The calculation results have shown that beam deflection from the joint converts to deviation of vertical component of the magnetic field.

The calculations have shown, that magnetic field strength H_V is almost proportionate to the beam deflection from the joint.

The research results provide evidence that it is possible to determine the beam's position relative to the joint by the value and direction of the vertical component of the magnetic fields. Sensor's installation at some distance from the beam does not lead to a systematic error because the vertical component H_V appears when there is a beam deflection form the joint.

The system for joint tracking

Fig. 3 is the diagram of the system for automatic joint tracking with flux gate as a sensor of beam position relatively to joint of welding parts is given.

The differential flux gate is used as a sensor for measuring the beam's deflection from the seam. The signal, proportionate to the external magnetic field, forms in the measuring winding of the flux gate at frequency 2ω, where ω is the frequency of the flux gate excitation. At this frequency (2ω), it is important to differentiate signals for measuring constant and slowly changing magnetic fields.

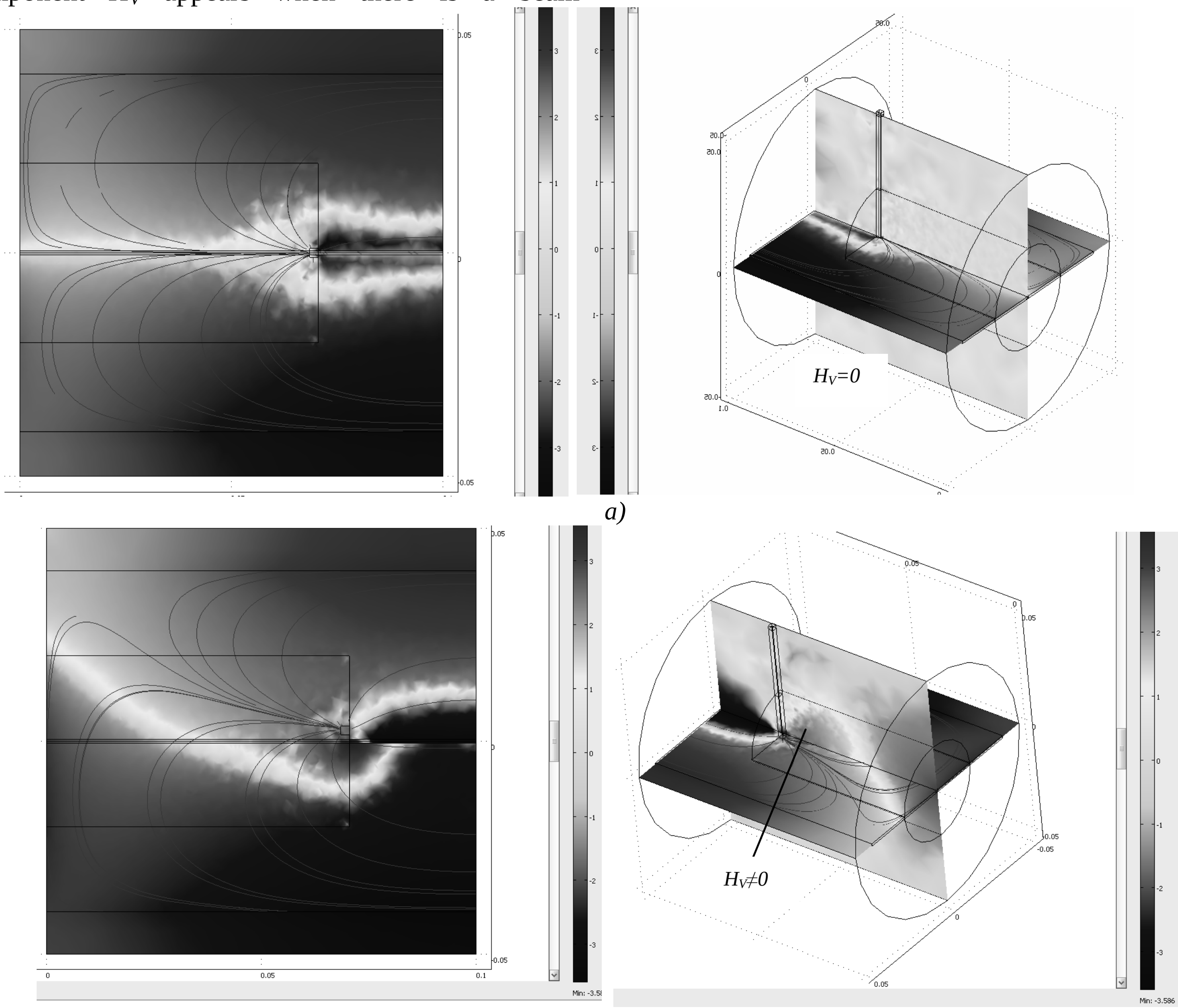

Fig. 2. Magnetic fields distribution: a – ε =0; b – ε =0,1mm (ε – the beam deflection from the joint)

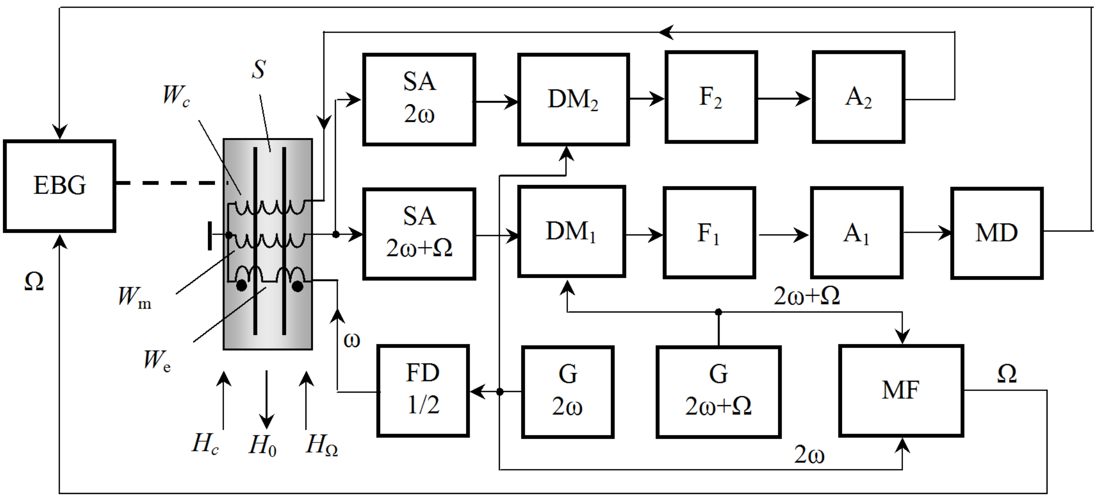

Fig. 3. Structural diagram of the device for automatic beam control: S – sensor (differential flux gate); W_m - measuring winding; W_e – excitation winding; W_c - compensation winding; SA (2ω+Ω) - selective amplifier (frequency 2ω+Ω); DM_1 – demodulator; F_1 – filter; A_1 – power amplifier; MD - motor drive; EBG – electron-beam gun; SA (2ω) - selective amplifier (frequency 2ω); DM_2 – demodulator; F_2– filter; A_2 – power amplifier; FD(1/2) - a frequency divider by two; G(2ω) - frequency generator 2ω; G(2ω+ Ω) - frequency generator (2ω+ Ω); MF - frequency mixer; H_Ω - the magnetic field strength is proportionate to the deflection of the beam from the joint; H_c - magnetic field compensation; H_0 - magnetic field disturbance

At the constant electron beam current, the vertical component, H_V of the magnetic field will also be constant. But, under the control principle, it is much smaller than the magnetic fields of the welded parts and welding tools as well as the magnetic field of the Earth. Under those conditions, it may be impossible to get a signal (H_V) proportionate to the beam deflection from the joint. Additionally, significant external fields may lead to the fluxgate core saturation and make the device unusable.

If the electron beam current is included in the variable component with frequency Ω, then a component with the same frequency will be in the range of the measured magnetic fields and components with side frequencies (2ω ± Ω) (Fig. 4) will be present in the signal range of the measuring winding.

To improve disturbance resistance of this system, the signal for the beam and joint misalignment forms on the side frequency (2ω + Ω), where Ω is the electron beam current modulation frequency. For this, the output of the fluxgate measuring winding (W_m) is attached to the selective amplifier SA_1, which resonates with frequency (2ω+Ω). Then the signal is straightened with the demodulator DM_1 which has a base input attached to the generator G(2ω+Ω). After the filtration (through filter F_1), the constant current proportionate to the beam deflection from the joint goes through an amplifier (A_1) and enters the motor drive (*MD*) of the electron beam gun (*EBG*), which moves with the beam to eliminate the deflection.

The compensation channel of the constant and slowly changing magnetic fields (H_0) in the fluxgate chamber is included in the device. These fields can be caused by the residual magnetism of the welded parts and welding equipment and may lead to the saturation of the fluxgate core. When these fields appear in the measuring winding (W_m) signal range, a component emerges with the frequency 2ω and the amplitude proportionate to the amount of the current and the phase determines its direction. This component is distinguished by the selective amplifier SA_2 tuned in to resonate with 2ω frequency. Then the signal is straightened with the demodulator DM_2 which has its base input connected to the frequency generator *G*(2ω). After that, the signal, as the constant current passing through the filter F_2 and the amplifier A_2, enters the compensating winding (W_c), where the magnetic filed (H_c) is formed, which compensates for the interference of the external fields in the fluxgate chamber.

The electron beam current modulation signal with frequency Ω is formed by the mixer (*MF*), whose inputs receive signals coming from generators with frequency 2ω and frequency (2ω+Ω). The fluxgate excitation signal is formed by the frequency divisor by 2, which has an input connected to the output of the generator with frequency 2ω. The excitation signal is

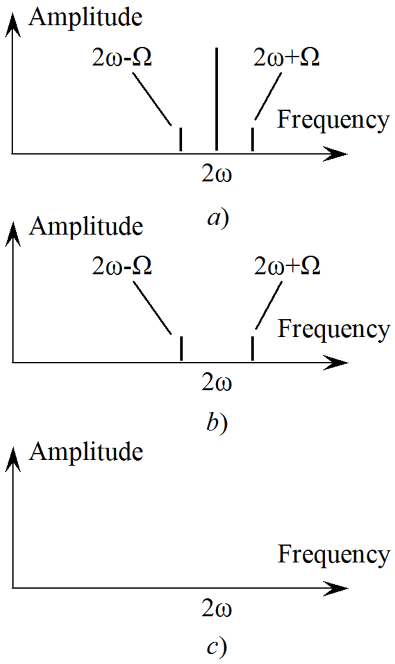

Fig. 4. Spectrum components of the Fluxgate measuring winding signal: a) - $\varepsilon \neq 0$; Spectrum component of the measuring winding signal with uncompensated frequency 2ω; b) - $\varepsilon \neq 0$; Spectrum component of the measuring winding signal with compensated frequency 2ω; c) - $\varepsilon = 0$; spectrum component of the signal with frequency 2ω - compensated.

delivered to the fluxgate excitation winding W_e with the frequency divisor by 2 *FD*.

The device was tested in vacuum conditions. The error of the beam alignment with the joint did not exceed 0.3 mm, which is quite acceptable for the Electron Beam Welding in air.

Conclusions

1. We propose a method of electron beam positioning relative to the joint during the electron beam welding in air. This method is based on identification of the magnetic fields and coordinates of the electron beam.

2. The proposed method allows controlling of the electron beam location and correcting it with the help of the automated system for joint tracking with no errors.

3. The noise immunity of the proposed system is improved, as the useful signal has the frequency different from frequencies of parasite magnetic fields.

4. During electron beam welding of dissimilar materials, when the beam is at the joint, the vertical component of the magnetic field does not have a zero value due to inequality of currents in the parts. This is explained by differences in the materials' conductivity. In this case, the current's strength, proportionate to the strength of the vertical component of the magnetic field, needs to be compensated for at the input of the electron beam gun motor drive.

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