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# Tracking on the joint during the electron beam welding

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**Abstract.** In the article the description of device, which provides automatic positioning of electron beam relative to joint of welded parts during welding, is given. Extremum seeking based on synchronous detection of sensor signal (X-ray or secondary emission) is realized in the device. Measurements are made when beam goes out of the channel following the welding direction.

The application of synchronous detection is possible due to the fact that during joint scanning with electron beam harmonics, carrying data about beam position relative to the joint appear in the joint sensor signal spectrum.

## Introduction

Presently the problems of providing precise positioning of electron beam relative to the joint of welded parts are actual for long joints welding. Such by-effect phenomena as secondary electron emission and X-ray radiation are used as data sources of beam position. In case of welded edges burn-off absence, the dependence of secondary electron emission change and X-ray brems-strahlung intensity on the beam position relative to the joint is equal – extremal. This extremum is minimum which corresponds to the beam and joint coordinates coincidence. This allows applying of unified hardware to build joint tracking devices.

The analysis of secondary radiation under burn-off absence is important. The extraction of data about beam position relative to joint from welding channel is problematic because of high noise level. At the same time necessary data for welding process can be received in the immediate closeness to the channel. It can be realized by, for example, short-time taking the beam out of the channel, making measurements and taking the beam back to the welding zone [1]. It is obvious that maximum time of putting the beam out must provide minimal changing in the weld pool, and speed of beam shifting must provide minimal energy taken out of the weld pool to exclude edges burn-off.

In analyzed device extremum searching based on synchronous detection method of joint sensor signal is realized. The main idea of synchronous detection application is based on the following: under the joint scanning with electron beam in signal spectrum, harmonics with frequencies multiple to scanning frequency appear. First harmonic amplitude of scanning signal is proportional to beam deviation relative to the joint and its phase defines displacement direction.

The appearance of harmonics in sensor signal is connected with the introduction of periodic components into electron beam parameters. For example, mathematical expectation of beam position can be shown as sum of constant component (accidental beam deviation relative to the joint) and periodic component with given amplitude (joint scanning with beam).

**Formalization of the Problem**

Secondary electron emission and X-ray radiation are effect of primary beam interaction with material of welded parts. Therefore if we suppose that electron density of distribution obeys the normal distribution law, then under burn-off absence secondary electron current and X-ray brems-strahlung intensity can be defined with expression [2-5]

$$J(\varepsilon) = KI_b \left\{ 1 - \frac{1}{\sigma\sqrt{2\pi}} \int_{x_1}^{x_2} \exp\left[ -\frac{(x-\varepsilon)^2}{2\sigma^2} \right] dx \right\}, \quad (1)$$

where $J$ – secondary radiation parameter; $I_b$ – beam current; $\sigma$ – root-mean-square deviation of electrons from beam axis; $\varepsilon$ – mathematical expectation of beam position; $K$ – coefficient, characterizing secondary radiation nature; $x_1$ and $x_2$ – joint edges coordinates; $x_1 - x_2 = \delta$ – joint gap.

In Fig.1 the curves built with expression (1) are shown. From the presented expression (1) and curves we can see that extremum coordinate $x$ coincides with joint coordinate $x = 0$ under $\varepsilon = 0$.

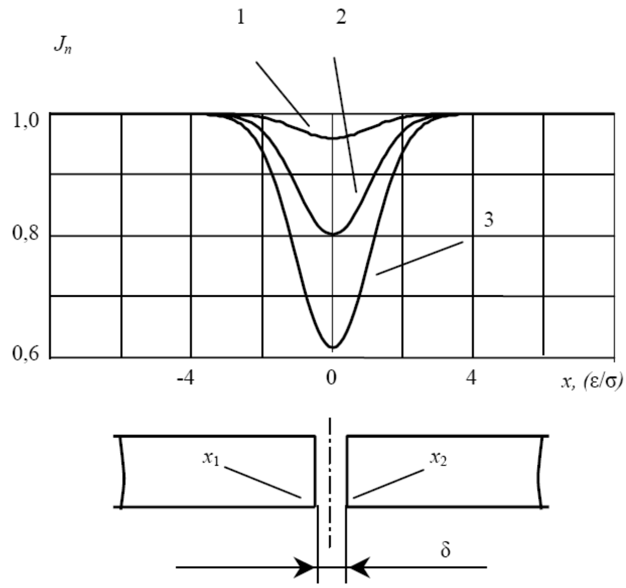


**Figure 1.** Analytical curves showing dependence of secondary radiations intensity on beam position relative to joint: $\sigma = \text{const} = 0.1\,\text{mm}$; $\delta = \text{var}$. Curves: 1- $\delta/\sigma = 0.1$; 2- $\delta/\sigma = 0.5$; 3- $\delta/\sigma = 1$, $J_n$ - normalized parameter $J$

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Extremal character of these dependences conditions the application possibility of known methods of extremum search for beam position relative to joint defining. One of these methods is synchronous detection method of joint sensor signal (secondary emission or X-ray). For this method realization searching beam shifting – joint scanning with electron beam is introduced. As a result mathematic expectation of beam position can be presented as:

$$\varepsilon = \varepsilon_0 + \varepsilon_m \sin\alpha, \quad (2)$$

where $\varepsilon_0$ – beam shift relative to joint; $\varepsilon_m$ – searching beam shifting amplitude; $\alpha = \omega t$; $\omega$ –

frequency, $t$ – time. Then, expression (1) becomes

$$J(\varepsilon) = KI_b \left\{ 1 - \frac{1}{\sigma\sqrt{2\pi}} \int\limits_{x_1}^{x_2} \exp\left[ -\frac{(x - \varepsilon_0 - \varepsilon_m \sin\alpha)^2}{2\sigma^2} \right] dx \right\}. \quad (3)$$

Having periodical component in parameter $\varepsilon$, sensor output signal (2) can be presented with Fourier series. Let us analyze the dependence of $\varepsilon_0$ on component $b_1$ with frequency $\omega$. This component is defined as Fourier coefficient:

$$b_1(\varepsilon_0) = \frac{1}{\pi} \int\limits_0^{2\pi} J(\varepsilon_0) \sin\alpha \, d\alpha. \quad (4)$$

In Fig. 2 plot showing function $b_1(\varepsilon_0)$ according to expression (3) is given. Thus, in joint neighborhood $b_1(\varepsilon_0)$ is proportional to mismatch of beam and joint positions, and the sign defines the mismatch direction.

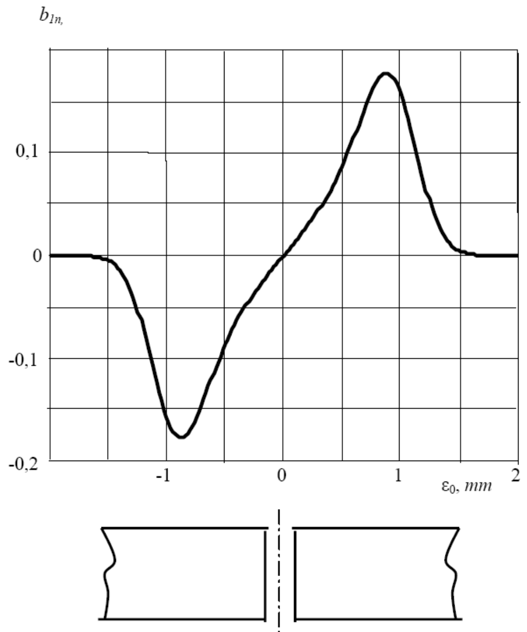


**Figure 2.** Dependence of first harmonic amplitude with frequency $\omega$ of sensor signal on beam position relative to joint: $b_{1n}$ – normalized parameter $b_1$, $\sigma = 0.1$ mm; $\delta = 0.1$ mm; $\varepsilon_m = 1$ mm.

This fact makes data accessing about beam position relative to joint possible due to the application of synchronous sensor signal detection.

## Structural device diagram

Functional device diagram is given in Fig. 3 [6, 7]. With the help of spike generator $G$ and deflection system $DS_Y$ the beam is occasionally taken out of the weld pool following the welding direction. At the same time generator $CG$ and deflection system realize joint scanning with the beam (Fig. 4[430]). Simultaneously generator $CG$ produces reference voltage, which comes to one of the inputs of synchronous detector $SD$, where sensor signals $S$ and reference voltage multiply:

$$[b_1(\varepsilon_0)\sin\alpha]\sin\alpha = [b_1(\varepsilon_0)]/2 - [b_1(\varepsilon_0)\cos 2\alpha]/2 \quad (5)$$

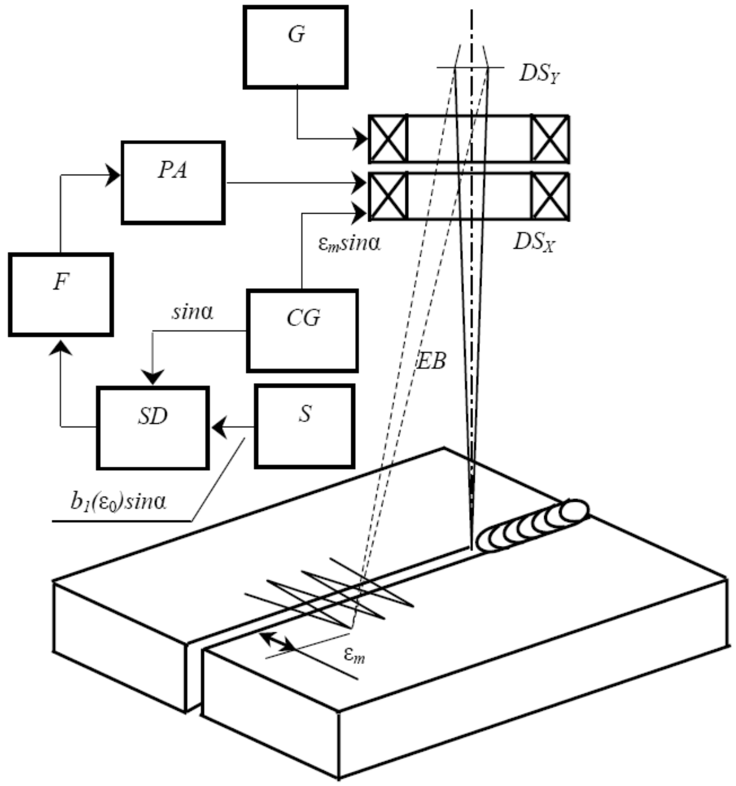


**Figure 3.** Structural diagram of the device for automatic beam control: $S$ – sensor; $CG$ – scanning beam generator; $SD$ – synchronous detector; $F$ – filter; $PA$ – power amplifier; $G$ – generator of spike; $DS_X$ – deflection system for X-axis; $DS_Y$ – deflection system for the Y-axis.

Expression (4) and oscillograms show that if there is beam shift $b_1(\varepsilon_0)$ from the joint, then synchronous detector output signal is a sum of direct component and variable component with frequency equal to $2\omega$ (Fig. 4b). High frequency component is filtrated with pass $F$ and direct current signal, proportional to beam shift through power amplifier, comes into deflection system. Beam position correction is realized. If beam and joint coordinates coincide $b_1(\varepsilon_0) = 0$, synchronous detector output signal is close to 0 (Fig. 4c).

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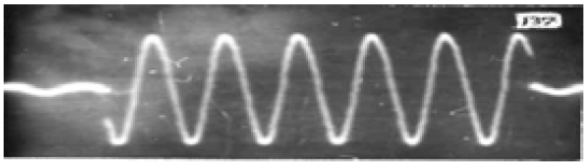
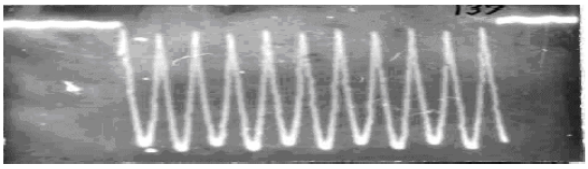


*a)*



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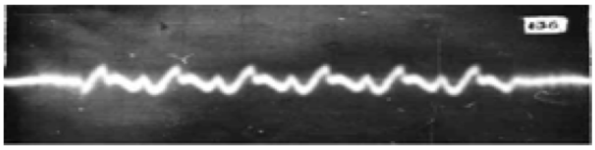

*c)*

**Figure 4.** Signals oscillograms: a) scanning current in deflection system $DS_X$; b) synchronous detector output signal under $\varepsilon_0 \neq 0$; c) synchronous detector output signal without mismatch of beam and joint.

Technical realization of the device is not problematic. Secondary electron collector is used as secondary emission sensor. Scintillation detector with photoelectron multiplier can be used as X-ray sensor (Fig. 5).

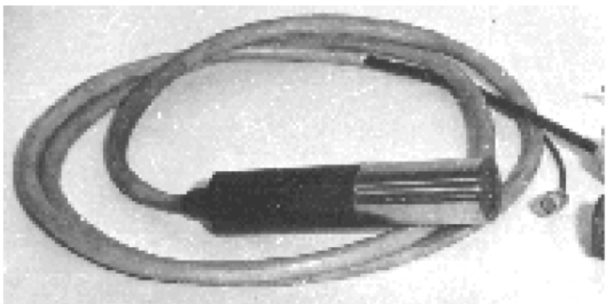

**Figure 5.** Scintillation detector.

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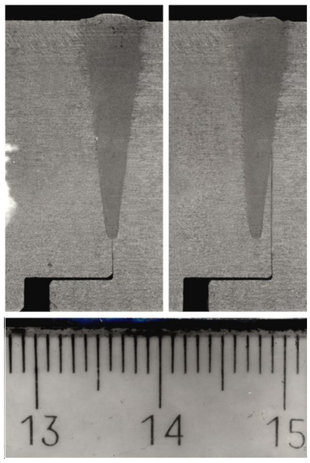


**Figure 6.** Welded joints microsections realized without tracking (on the right) and with automatic joint tracking (on the left).

At Fig. 6 joints microsections realized with electron-beam welding are shown.

Devices, designed in accordance with the given functional diagram, are utilized for electron-beam welding of large-dimension details in aerospace industry. Error of beam alignment with joint is not more than 0.1 mm.

## Conclusion

1. Equal nature of secondary emission and X-ray radiations under electron-beam welding allows application of equal hardware to control welding process.
2. In conditions of electron-beam welding it is preferable to apply X-ray sensors for joint tracking, as X-ray radiation is the least sensitive to different destabilizing factors.
3. Synchronous detecting of joint sensor signal allows improving of device noise immunity due to the fact that interference risk at scanning frequency is low.

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