Control of electron beam welding parameters based on the gap scanning system data during the welding process

A N Kasitsyn, R Yu Agafonov, A V Leonov, G V Grigoriev

Material science dept., Russian space systems, JSC, 53, Aviamotornaya ave., Moscow, 111250, Russia

E-mail: contact@spacecorp.ru

Abstract. Influence of the gap between the welded edges when sealing the case of electronic devices on the magnitude of the electron emission sensor signal in the process of electron beam welding (EBW) is studied. The impact of electron beam current variation at a constant value of the focusing system current on the penetration depth with the increasing gap between the welded edges is determined. The dependence of the length of the weld at different electron beam currents on samples with an increasing gap between the welded edges is studied. The possibility of controlling the process of electron beam welding by electronic emission from the weld pool is presented. A sensor for electronic emission registration is proposed, which includes an electron collector and an electron current data record system as a part of the EBW installation. The efficiency of the electronic emission sensor directly in the process of sealing under precision welding modes is shown.

1. Introduction

When sealing the cases of electronic devices using EBW in a vacuum chamber the required penetration depth should be provided. The design features of the device case may not provide for the minimum gap between the welded edges of the device case and its cover. Therefore, in the sealing process the non-fusion of the welded edges may occur due to a change in the welding gap size. At the same time, the elimination of such a defect leads to an increase in the penetration depth and, as a consequence, to a violation of the requirements for a welded joint.

In the process of the electronic devices cases sealing by EBW, it is possible to control the beam current, as well as its focus position and shape, using the information from various sensors to ensure the necessary penetration depth. Optoelectronic and X-ray sensors, as well as charged particle sensors based on electron collectors [1–3] are widely used to control the EBW process. The existing joint tracking systems are designed for the electron beam positioning in the direction of the welded parts joint and do not allow an assessment of the gap size between the welded edges in order to adjust EBW modes.

During EBW, due to beam electrons interaction with the welded edges, electrons kinetic energy transfers to thermal energy, causing metal heating and melting, as well as the appearance of various types of charged particles radiations. A certain part of electrons is reflected after the interacting with the metal surface. These electrons, which may have high or low energy, can give useful information about the processes occurring in the welding bath, and can be used in tracking systems and control.
systems for EBW. To register such information the electron collectors [4] are widely used. They are usually based on an electrode, which is grounded through current-measuring resistance and installed directly above the welding zone or close to it.

Using of electron collectors in EBW became widespread and is often used to find the joint of welded parts and adjust the position of the electron beam focus [5, 6]. Typically, a highly focused low-power electron beam is used in these systems to obtain information about the welded edges position by scanning them along different trajectories just before welding. In addition, several methods of EBW process control using plasma plume as a current conductor are applied [7], however, the sensors of such systems are located close enough to the weld pool and can be affected by significant thermal effects, which reduce the reliability of EBW process automatic control.

Before studying the influence of welding parameters on the penetration depth, the signal, which contains the information about the gap width, was singly researched. The signal was investigated using an electron emission collector under the influence of an electron beam on the welded edges. We also investigated the nature of the weld formation at different sizes of the joint gap.

2. Materials and methods
The system of electron current data record [8] consisting of a personal computer (PC) and an electron emission sensor based on an electron collector was used for the research. The schematic diagram of the electron current data record system as a part of the EBW installation is presented in figure 1.

![Figure 1](image)

**Figure 1.** Schematic diagram of the electron current data record system as a part of the EBW installation: 1 - electron beam gun; 2 - vacuum chamber, 3 - electron beam; 4 - plasma plume; 5 - case; 6 - electron collector; R1, R2 - resistance for matching the measured signal; MUX – multiplexer; ADC - analog-to-digital converter; MCU – microcontroller unit; PC – personal computer; CNC - computer numerical control; I_b – beam current; I_s - signal current;

In the proposed scheme the electron collector 6 is an anode relating to the sealed case 5. A positive charge is supplied to the electron collector, so that the electrons emitted from the welded edges surface are attracted by collector 6. The generated electron current is determined by the sum of the thermionic current (thermal electron emission) and the current of reflected electrons (secondary emission), negative ions and positive ions.

Registration of electron current is performed by the electrode, which has the positive voltage of 5 V for its appropriate operation with the ADC. Electron current collected by the electrode passes through
the 20 kohm resistance that connected to the ground (GND). The maximum current recorded by the proposed system is 350 µA at an electron beam current of 11 mA.

Thin samples with a length of L = 150 mm and a thickness of 1.3 mm were produced to perform an experiment to study the signal level and the electron current amplitude depending on the gap size. From one of the sides, the welded edges were tightly fixed in a snap without the gap. From the other side, the gap between the welded edges was provided by insertion of the 1 mm thickness plate. The gap sizes along the samples length was measured using a STEMI 2000-C stereo microscope. Welding was carried out at electron beam currents of 9, 10 and 11 mA. During welding, an electronic current was recorded using the electron emission sensor. The depth of penetration was estimated using the stereomicroscope on fragments, which were cut out from welded samples by machining and prepared for the research.

3. Research results and discussion
The graphs of electron current amplitude with the electron emission sensor during EBW of samples without gaps and with various gaps sizes were obtained. The analysis of these graphs allows noticing differences in signals from the electron collector, which could be useful for electron beam welding process control. In all cases, a moving average filter was used to reduce noise and highlight the signal [9]. During EBW without gaps the electronic current does not change significantly in time (see figure 2).

![Figure 2. Electron current amplitude during the welding of the sample without the gap at a beam current of 9 mA.](image)

![Figure 3. Electron current amplitude during the welding of the sample with a gradually increasing gap: a – the dependence of the gap width a from the of sample length L; b - a graph of the electron current amplitude I in the welding with the beam current of 11 mA.](image)
During EBW with gap the electron current changes as the gap width increases that is shown in figure 3. The average value of the electron current decreases by 50 µA when the gap width increases to 750 µm. The amplitude of the electron current oscillations is also reduced. This reduction is caused by a gradual decrease in the number of electrons reflected from the edges surface and thermal electron emission from the weld pool. This process is possible because the part of the primary electrons of electron beam does not interact with the welded edges metal, but move into an increasing gap. The gap value becomes critical for the defined parameters of electron beam when a sharp decrease in the current amplitude occurs (approximately at a distance of \( L = 90 \) mm from the beginning). In that moment the fusion process stops and the melting of the welded edges begins separately. Further, as the gap increases, the current recorded by the electron collector continues to decrease. According to the graph “current amplitude – time” it is possible to determine after welding the coordinates of the non-fusion zone at a defined welding speed.

In case of the gap presence, a decrease in the signal amplitude can be observed in the middle of the welded samples, as can be seen in figure 4. It caused by an increase of the number of electrons falling into the gap region.

![Figure 4](image)

**Figure 4.** Electron current amplitude during the welding of the sample with a welding gap in the center: a – the dependence of the gap width \( a \) from the of sample length \( L \); b - a graph of the electron current amplitude \( I \) in the welding with the beam current of 11 mA.

In this case, non-fusion zone was not formed. However, over a long section of 60-120 mm, the average value of the observed electronic current is lower than at the beginning and at the end of the weld sample. This effect corresponds to an increase of welding gap up to 500 µm in the middle of the sample. As the gap decreases, the amplitude of the signal recorded by the sensor also increases.

It was experimentally established that the change in the beam current slightly affects the weldability of the edges with an increasing gap, which is reflected in figure 5. In all samples the non-fusion zones were occurred when the gap between welded edges was about 650-800 µm. Because of the current density distribution over the electron beam radius is Gaussian [10], the increase of power density in the heating spot due to the increase in current is not effective. The most efficient power distribution part of the beam falls into the welding gap and the energy put into the welded edges is not enough to maintain melting.
4. Conclusions
Based on the obtained relations, it can be concluded that the increase in electron beam current slightly affects obtaining of a welded joint with an increasing gap between the welded edges of the case and case cover of electronic devices. Despite the increase in the electron beam current, the power density in the heating spot drops significantly due to the hit of a part of the beam electrons in the gap.

In order to ensure the fusion of the welded edges under these conditions, it is necessary to change the current of the focusing system to increase the area of the heating zone. Together with the focusing current, the electron beam current should be increased to provide the power density required to form the weld pool. As a result of electron current graphs analysis, it is determined that the signal amplitude differs depending on the initial beam current, while the dependence character for determining the gap value is preserved.

To automate the process of controlling the penetration depth when sealing the electronic devices cases, the EBW process control system based on information from the welding zone by using an electronic emission sensor during welding can be used. Comparing the reduction in electron current amplitude during the welding process, the automatic control system makes changes to the parameters of the EBW mode, allowing continuing the sealing process and obtaining a tight connection, satisfying the requirements. The scanning electron beam becomes relevant to use for welding of items with large gaps to ensure the fusion of welded edges.

5. Acknowledgments
The research was performed in the Material science department of "Russian space systems", JRC. Assistance with the literature searches and discussion platform was provided by National Research University "Moscow Power Engineering Institute".

References
[1] Sukach K A, Kutsan Yu G, Kovbasenko S N, Zhadkevich M L, Lankin Yu N and Zubov V V 1989 A method for controlling electron beam welding and a device for its implementation. 4257554/25-27
[2] Druzhinina A A, Laptenok V D, Murygin A V and Laptenok P V 2016 Automatic control of positioning along the joint during EBW in conditions of action of magnetic fields IOP Conference Series: Materials Science and Engineering 155 012009
[3] Bashenko V V, Mauer K O and Mitkevich E A 1974 Using of reflected electrons to control the beam installation on the joint and the parameters of the joint in electron beam welding Proc. LPI 336 pp 97–100

[4] Druzhinina A A 2015 Automatic compensation of the influence of magnetic fields on the positioning accuracy at the joint during electron beam welding (Krasnoyarsk: Siberian federal university Press)

[5] Varushkin S V, Belen’kii V Ia and Trushnikov D N 2014 The use of shielded collector to control the mode of through-penetration in electron beam welding J. Modern problems of science and education 6

[6] Piskunov A L, Lialin A N, Shchavlev V E and Abdullin A A 2012 Review of the results of the use of secondary emission signals to control and control the process of seam formation in electron beam welding J. PNRPU Mechanical engineering, materials science Bulletin 3 p 82

[7] Vinogradov V A, Shershnev N A, Pavlovskii A I and Grigor’ev Iu V 1993 Method of regulating the process of electron beam welding 1133781

[8] Kasitsyn A N, Agafonov R Yu and Grigor’ev G V 2017 Detection system of formation of defects in the process of electron beam welding of instrument housings of radio-electronic equipment of spacecraft Conf. Electron beam welding and related technologies (Moscow: National Research University "Moscow Power Engineering Institute") pp 458-467

[9] Kir’ianov, D V and Kir’ianova E N 2006 Computational physics (Moscow: Polybook Multimedia)

[10] Rykalin N N, Ugllov A A, Zuev I V and Kokora A N 1985 Laser and electron beam processing of materials (Moscow, Engineering Publ) p 496