The concept of an electron beam I/O control system to optimize the weld formation in the process of electron beam welding

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Abstract. The processes that occur during the electron beam welding are very complex. The main problem of electron beam welding is obtaining a reproducible cross section of the weld. This place is subjected to rigorous quality control during the welding of thin-walled joints. In particular, it is required to solve the problem of the welded joint optimal formation on the electron beam input/output section. The development of the mathematical models for the electron beam input and output modes, their joint use as a justification for the choice of the latter modes will allow a reasonable approach to the seam optimal formation in the area under consideration. In the framework of this study, the concept of an electron beam input-output control system for a weld optimizing in the electron beam welding process is presented. Within the framework of this concept, it mathematical and algorithmic software have to be developed for electron beam welding of thin-walled aerospace structures in terms of the electron beam input/output. Such approach will improve the quality of formed integral joints, as well as reduce the complexity of setting up the technological process of electron beam welding. It has to be developed and verified the mathematical models of temperature distribution under various modes of an electron beam input and output, models for optimizing input and output modes of an electron beam, and a software system prototype using the obtained models.

1. Introduction

Currently, space technology is increasingly used in all areas of human activity. The growing demand for the use of space technology in various fields requires the creation of ever more advanced spacecraft (SC) capable of solving various problems. At the same time, spacecraft production technologies also do not stand still. With the development of the elemental base of spacecraft equipment, requirements for manufacturability, accuracy and quality of both production as a whole and the formation of permanent connections of equipment in particular are growing.

Electron beam welding (EBW) in aerospace engineering is widely used due to insignificant thermal deformations of the connected parts due to the short duration of heat exposure and the small volume of cast metal.
Electron beam welding is one of the most promising, actively developing, as well as widely used methods of joining parts from various metals. Most often, EBW is used to join refractory, chemically active and heterogeneous high-quality steels, as well as high-strength alloys based on aluminum and titanium. ELS allows us to connect materials with a thickness of 0.1 to 400 mm in one passage, while ensuring maximum ductility and viscosity of welded joints. The small volume of cast metal and the short duration of heat exposure during EBW provides insignificant thermal deformations of the connected parts.

However, with a high level of sophistication of the EBW model-algorithmic apparatus, insufficient attention is still paid to the process of input and output of the electron beam. This causes difficulties in the implementation of EBW systems at aerospace enterprises due to the need of adjusting the technological parameters of the welding process for each specific product. In addition, when thin-walled structures are being welded, increased requirements are imposed on the quality of the welded joint, in particular, uniform penetration depth, which is currently difficult to achieve due to the presence of defects near the weld “zero point”, namely, the input/output point of the electron beam. Currently, this problem is being solved by experimental selection of the EBW process technological parameters, increasing the total cost of product.

Thus, it is urgent to develop mathematical models that describe the input/output process of beam, algorithms for controlling the EBW process, implemented on the basis of the created mathematical models, as well as subsequent testing of the research results in experiments on industrial samples of thin-walled aerospace structures.

2. Literature review
The wide possibilities of electron beam welding make it possible to use this technology for the production of various product types. For example, the authors of [1] use electron beam welding technology to obtain a channel for heating the blades of the inlet guide vane of gas turbines. The work identifies the best options for the structure of the welded joint, depending on the size of the allowance for machining. Electron beam welding has also found its application in the nuclear industry. For example, in the production of thermionic converters for nuclear reactors [2].

Currently, to further quality improve of the electron beam welding process, many authors have carried out mathematical modeling of this process in different modes and with different materials. For example, the authors of [3] considered multicriteria optimization of the electron beam welding process using experimental data obtained on the basis of real technological processes on austenitic steel billets. The methods of statistical data processing allowed us to obtain fairly accurate models of the electron beam welding process, which describe the dependence of the geometry of stainless steel welds on the parameters of the electron beam welding mode.

The authors of [4] studied the processes of the penetration channel formation in electron beam welding with complete penetration of the material. In the framework of this study, a dynamic mathematical model is proposed that allows us to describe the formation of the weld back roll depending on the parameters of the electron beam welding process. The developed model allows predicting the chemical composition of welds in electron beam welding. Verification of the model was carried out by comparing with the results of the chemical composition analysis of the penetration zones in the material.

The authors of [5] developed an approach to modeling, which allows predicting the accumulation of errors in the additive production of large parts. An experimental verification of this model showed its rather high efficiency with a maximum error of 29%. In [6], a simulation of the technological process of electron beam welding using the Taguchi strategy with three levels of input values is presented. The model is used to predict the tensile strength and hardness of products. Both estimates are optimized using gray relational analysis.

The authors of [7] conducted a numerical simulation of the electron beam welding process taking into account the technological parameters of the process. Experimental studies are also presented to verify the latest research in this area on heat transfer, thermomechanical analysis, etc. In [8], the development of the dynamics model of a steam loop in the process of electron beam welding is given.
The study [9] is aimed at determining the optimal parameters of the electron beam welding process to minimize bursts when welding copper plates. Using statistical methods, a correlation was found between input parameters and peak values. Also, the causes of bursts are explained. The optimization problem was solved using the genetic algorithm. Experimental verification of the method on real technological processes showed the consistency of the proposed method.

The authors of [10] developed a mathematical model of scanning electron beam welding, which for the first time made it possible to simulate the dynamics of a technological process, and made it possible to obtain a criterion for optimizing this technological process.

The use of artificial neural networks in [11] made it possible to develop an effective mathematical model of the electron beam welding technological process with high specific power. Models based on artificial neural networks were trained using various algorithms: the error back propagation algorithm, the genetic algorithm, the particle swarm algorithm, and the bat algorithm. Experimental verification showed the high efficiency of the proposed model. To reduce the deformation of the material in the process of electron beam welding, the authors of [12] developed a mathematical model of the distribution of the heat flux on the raster pattern of the material being welded. The effectiveness of the proposed model is experimentally confirmed.

Modern methods for controlling the electron beam in EBW are presented in [13], [14]. In particular, such methods include: pulsed modulation of the electron beam current, oscillation of the beam with a different type of scan at the welded joint, multifocal welding.

3. Control system concept
To increase the efficiency of the electron beam welding process of thin-walled aerospace structures by modeling the input and output of an electron beam and optimizing the parameters of such stages of the technological process, it is required to solve the following tasks:

- Perform a theoretical and analytical review of the approaches used to simulate the thermal processes occurring in electron beam welding. Within the framework of such a review, it is necessary to make an informed choice of the principles and technology of modeling, as well as software for verification of the developed models.
- Creation of mathematical models of temperature distribution under various modes of input and output of an electron beam during welding.
- Development of a model for optimizing the electron beam input mode depending on the geometric dimensions of the product, technological parameters of the process and the required characteristics of the welded joint.
- Development of a model for optimizing the output mode of the electron beam, depending on the input mode, the geometric dimensions of the product, the process parameters used in the welding process, as well as the requirements for the quality of the welded joint.
- Development of a software system prototype that uses the obtained models and control algorithms for input and output of an electron beam.
- Experimental studies on industrial designs of thin-walled aerospace structures.

In general, to solve the problems of scientific research, it is supposed to use approaches developed in the framework of the theory and practice of system analysis, the theory of mathematical modeling of thermal processes, the theoretical foundations of computer science, as well as the theory of automatic control.

During the development of temperature distribution mathematical models for various soldering modes, it is supposed to use a model-algorithmic apparatus for calculating thermal processes to create mathematical descriptions of the temperature distribution, and probability theory and mathematical statistics to assess the adequacy of the proposed mathematical models to both constructed simulation models and the behavior of a real object in the process of field experiments.

The structure of the proposed software system is shown in figure 1.
Figure 1. Structure of the electron beam I/O control system.

The above figure shows a block diagram of an intelligent beam I/O control system, which allows identifying interference, failure of measuring sensors and other measuring instruments and actuators [15], [16], [17], [18]. The use of intelligent methods makes it possible to accurately identify and classify the normative and non-normative errors of measuring instruments [19], [20], [21].

4. Conclusion
In the framework of this study, the concept of an electron beam input-output control system for the optimal formation of a weld in the process of electron beam welding is presented. To implement the presented concept, mathematical and algorithmic support for the process of electron beam welding of thin-walled aerospace structures in terms of electron beam input/output will be developed, which will improve the quality of the formed integral joints, as well as reduce the complexity of setting up the EBW technological process, and, accordingly, reduce the impact of human factor and reduce the cost of product. It also requires the creation of mathematical models of the temperature distribution under various modes of the electron beam input and output during the welding process, allowing to complement the complex of existing mathematical models and conduct more accurate modeling compared to simulation. Optimization models for electron beam input and output modes will allow creating mathematical justification for choosing specific values of technological parameters for such modes depending on the product geometric dimensions, process parameters and required characteristics of the welded joint, as well as implementing the approach proposed in the work within the framework of software control systems. Implementation of the proposed approach in the form of a software system prototype will allow the application of the developed control methods both within the framework of the new automation systems being created, as well as with the modernization of existing electron beam welding systems.

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