Intellectualization of the technological processes of permanent joints formation at the rocket-space enterprises

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Abstract. The paper deals with the problem of improving the quality of the technological processes of permanent joints formation at rocket-space enterprises. In the course of the study, an analysis of modern technologies for the permanent joints formation of spacecraft elements at the enterprises of rocket-space industry in Russia was conducted, as a result of which the main problems were identified. The analysis made it possible to set the tasks of intellectualization of such production processes as induction soldering, electron-beam welding and diffusion welding. As an algorithmic solution to the assigned tasks, the use of modern intellectual methods is proposed, which allows solving the problem of control in the context of incomplete information on the parameters of the technological process, as well as its complete absence.

1. Introduction

Currently, space technology is becoming more and more widespread in all areas of human activity. The growing demand for the use of space technology in various fields of activity requires the creation of more and more advanced spacecraft (SC) capable of solving various tasks.

At the same time, the production technology of spacecraft elements also does not stand still. With the development of the elemental base of spacecraft equipment, the requirements for manufacturability, accuracy and quality of both production as a whole and the formation of permanent equipment in particular are growing. Even 20 years ago, in many technological processes, the method of argon-arc welding was widely used. Now, at many production stages, more accurate and high-tech methods of diffusion and electron-beam welding, as well as induction soldering, are used. [1-8]

The method of induction heating for the formation of soldered joints has proven itself in the production of antenna-feeder devices waveguide paths [9, 10]. The introduction of such a method allows to improve their radio-technical characteristics (RTC), reduce weight to 40%, reduce production costs by 2–2.5 times, compared to welded analogues. The use of soldered thin-walled waveguide paths in the structure of the spacecraft allows us to reduce the inter-block distances between the elements of the payload, placing it more compactly. This, in turn, allows to reduce the size and mass of the spacecraft by 15-20%, or increase the capacity of the spacecraft for a given weight limit. [3, 11-13]

The method of diffusion welding is actively used in the production of the small-sized elements assemblies of spacecraft equipment, allowing to obtain durable welded joints. The advantage of this type of welding is uniform heating and cooling of the welded parts, which allows to remove all internal tensions in the metal and retain the original electromagnetic characteristics of the product. [14]

Electron beam welding (EBW) has already entered the technological cycle of production of various types of equipment. In aerospace engineering this method is widely used due to minor thermal deformations of the parts to be connected because of the short duration of heat exposure and the small volume of the cast metal. Large technological capabilities of EBW are achieved through flexible process control. [15]

The use of such highly technological methods of forming permanent joints is complicated by the presence of a number of external factors, the greatest complexity of which are [3, 6, 11]:

- Low repeatability of non-automated (manual) soldering/welding process.
- Complexity and sometimes the inability to visually control the heating of parts.
- Distortion of the equipment electromagnetic fields, due to its interaction with various conducting bodies located near the heating zone.
- Imposition of interference on the measurement tools used in the automation of welding/soldering processes, due to the action of powerful radiation sources near the process.
- Large economic losses in case of early termination of the technological process due to a hardware or software failure.
- Influence of the human factor.

The above problems of controlling modern processes of creating permanent joints can be solved as a result of the introduction of intelligent information processing technologies and decision making under uncertainty, which will allow assessing the reliability of information obtained from the heating zone, assess the errors of measuring instruments and form an adequate process control to increase its accuracy and repeatability.

2. Proposed approach

Conducting research covers the solution of three integrated tasks:

- Creation of methods for processing information from sensors.
- Intelligent algorithms development for controlling thermal soldering/welding processes.
- Implementation of a decision support system under uncertainty.

Situations when measuring devices during the operation of technological systems for forming permanent joints provide the control system with unreliable information that can be divided into 4 groups [16, 17]:

- Failure of the sensors when the signal disappears.
- Undocking of the contact sensor (for example, thermocouple) due to the high temperature of the product.
- Appearance of an object on the line of a contactless sensor sight.
- Imposition of interference due to the action of powerful sources of electromagnetic and radiation, accompanying the processes of induction heating and electron beam welding.

All this causes the control system to form influence on the control means of the technological process, which are inadequate real situation. To identify such errors in measurements, as well as their quantification, it is proposed to develop a method for assessing the reliability of information from sensors and a method for estimating the value of errors in measuring instruments under conditions of inaccurate information. [18-21]

The development of such methods is carried out using the model-algorithmic apparatus for calculating thermal processes (for each type of connected elements), the apparatus of the theory of intelligent systems, the theory of probability and mathematical statistics. As a result of such methods use, it becomes possible to:

- Obtaining probabilistic assessment of the information quality used by the process automation system to form a control.

- Quantitative assessment of the information distortion from the sensors, which allows us to generate corrective values.

After obtaining estimates of the information quality and its distortion, it becomes possible to develop a model of technological decision-making under failure conditions using intelligent methods for predicting system states for subsequent points in time. In this case, in the event of a long-term failure, the control system is transferred from the on-the-sensor control to the forecast control until the operability of the measuring equipment is restored.

In a general sense, the task of the technological processes intelligent control is reduced to the problem of classification, in which, according to the input parameters of the technological process, it is necessary to choose the values of several output classes of control algorithms. [22-24]

The mathematical formulation of this problem in this case will be as follows. [25]

Let there be:

- At - set of algorithms for controlling the product heating.
- Am - set of workpiece movement control algorithms.
- K1, K2, K3 - sets of control algorithms coefficients.
- Et - set of the mismatch values of the soldered elements temperatures.
- Em - set of the mismatch values of the soldered elements heating rates,
- Apr - set of previously used heating control algorithms for the product,
- Kpr - set of the coefficients values of the previous heating control algorithm for the product.

There is an unknown target dependence y* that maps the set {Et, Ev, Apr, Kpr} into the set {At, Am, K1, K2, K3}, the value of which is known only on the training set. It is necessary to develop a mapping algorithm capable of classifying an arbitrary object from the sets Et, Em, Apr, Kpr.

Various intellectual methods are suitable for solving such classification problem [26-30]:

- Decision trees.
- Artificial neural networks.
- Fuzzy controller.
- Neuro-fuzzy controller.
- K-nearest neighbors method, etc.

The use of intelligent technologies will allow to form a prediction control for various products manufactured at the enterprise under different initial conditions. On the basis of models, it becomes possible to develop a prototype of a decision support system for the implementation of which it is relevant to use a modern object-oriented programming language (C++ or C#) or a web programming language in the case of a web-based software application.

3. The implementation of experimental research

The proposed approach is supposed to be tested when controlling the actual processes of spacecraft elements permanent connections forming. Such approbation can be carried out on the following experimental benches of the laboratory at the Information Control Systems Department of the Reshetnev Siberian State University of Science and Technology:

1. The experimental stand of induction soldering, which includes [9]:

- High frequency generator (66kHz).
- Modernized matching device.
- Control unit for soldering post.

- Manipulator-positioner.
- Set of inductors with working windows of various sections.
- Remote control.
- Ammeter.

The basis of the induction soldering control stand is an industrial computer IPPC-9171G-07BTO, with an PCI-1710 information input/output interface card and 4 RS-232 connectors. Non-contact pyrometry using AST A250 single-spectrometers is used to measure the heating temperatures of soldered elements.

2. The experimental stand of diffusion welding, which includes [14]:

- Inverter generator.
- Matching device.
- Inductor.
- Vacuum chamber.
- Backing pump system.

The basis of the diffusion welding control stand is the industrial PLC-150 controller and the IP320 operator panel. Chromel-alumel thermocouple is used to measure the heating temperatures of the elements being welded.

3) The experimental stand of electron-beam welding, which includes [15]:

- Electron beam gun.
- Electron beam equipment.
- Vacuum chamber.
- MT Turbo 65D/0/8 KF40M MTM turbo-molecular exhaust pumping system.
- ISO63 electromagnetic drive vacuum valve.

The basis of the electron-beam welding control stand is an industrial computer IPPC-9171G-07BTO, with an PCI-1710 information input/output interface card and 4 RS-232 connectors.

4. Conclusion

In the course of the study, an analysis of modern technologies for the formation of permanent joints of spacecraft elements at the enterprises of rocket-space industry in Russia was conducted, as a result of which the main problems were identified. The analysis made it possible to set the tasks of intellectualization of such production processes as induction soldering, electron-beam welding and diffusion welding.

As an algorithmic solution to the assigned tasks, the use of modern intellectual methods is proposed, which allows solving the problem of control in the context of incomplete information on the parameters of the technological process, as well as its complete absence.

Application of the proposed approach will improve the repeatability of the soldering/welding process, reduce the impact of measuring instrument interference on the quality of permanent connections, reduce the impact of human factors, and, consequently, reduce economic losses from hardware or software failures.

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