The automated system for technological process of spacecraft’s waveguide paths soldering

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Abstract. The paper solves the problem of automated process control of space vehicles waveguide paths soldering by means of induction heating. The peculiarities of the induction soldering process are analyzed and necessity of information-control system automation is identified. The developed automated system makes the control of the product heating process, by varying the power supplied to the inductor, on the basis of information about the soldering zone temperature, and stabilizing the temperature in a narrow range above the melting point of the solder but below the melting point of the waveguide. This allows the soldering process automating to improve the quality of the waveguides and eliminate burn-troughs. The article shows a block diagram of a software system consisting of five modules, and describes the main algorithm of its work. Also there is a description of the waveguide paths automated soldering system operation, for explaining the basic functions and limitations of the system. The developed software allows setting of the measurement equipment, setting and changing parameters of the soldering process, as well as view graphs of temperatures recorded by the system. There is shown the results of experimental studies that prove high quality of soldering process control and the system applicability to the tasks of automation.

1. Introduction

Waveguide systems are widely used in spacecraft, ensuring apparatus and its on-Board equipment. The thin-walled tubes made of aluminum alloy with rectangular cross section are used as a waveguide system in JSC "Information satellite systems" named after academician M. F. Reshetnev (JSC "ISS") of the city Zheleznogorsk, Krasnoyarsk Krai, Russian Federation. The induction soldering is used for production of waveguide systems in JSC "ISS" [1, 2]. However, induction soldering of thin-walled waveguides is a complex process with a set of features [3].

Firstly, the melting temperature of silumin solder is close to the melting temperature of the base material. Secondly, the components of the waveguide systems such as a waveguide pipe and flange are independent systems until solder between them will not be melted [4]. Thus, there is practically no heat between the elements, and their heating occurs independently from each other. Thirdly, it was found that during induction heating of the waveguide paths zones of the maximum heat generation in the sections of elements (maximum density of induced eddy currents) do not coincide with the zones of the soldering [5].
Besides, a large range of brazed products with different mass-dimensional parameters leads to the difference by mass of the same name products to 25%. Also the elements of the waveguide paths do not change their color during heated, which eliminates visual inspection, of brazed products local overheating [6].

Listed factors significantly complicate the reproduction of the waveguide path induction soldering technological process. There are requirements to positioning accuracy, to the inductor form, to the generator equipment parameters and to the highly skilled personnel [7, 8].

The analysis of the above listed features shows the need for technological process automation and led to the development of a hardware-software complex, which allows accurately reproduce the process. Developed automated system produces the control of the product heating process, adjusting the power, which is delivered to the inductor. The control in system is based on the information about the temperature from the soldering zone [9].

2. Software structure and algorithms

The software product of induction soldering process automation, is a Windows application, which can be used in operation systems such as Windows XP/7/8/8.1/10.

Software product developed in C++ programming language using an object-oriented approach, which allows to make a modern and scalable applications [10].

The system works with COM ports, which is realized by WinApi [11, 12, 13], work with the PCI1710 card by implementation of freely distributed library bdaqctrl.h [14].

Structural scheme of software product is shown in figure 1.

![Figure 1. Scheme of the software product](image)

The software system project consists of five source code files:

1. soldering.cpp – contains the main program function WinMain(), which starts the program system;
2. mainform.cpp – contains algorithms of the application main window;
3. pyroform.cpp – contains pyrometers information forms;
4. bdaqctrl.h – contains the PCI1710 card interface, which is used for thermocouple connection and generator control;

5. Pyro_class.cpp contains the description of the pyrometers class, algorithms of interaction with them, as well as algorithms for the pyrometers adjustment.

A single custom class Pyro is implemented to store all information about pyrometers, their connection and parameters.

By using this class, it is possible to produce:
1) the switching on of the pyrometer laser;
2) the switching off of the pyrometer laser;
3) query of the pyrometer laser state (0 - disabled, 1 - enabled);
4) request of the thermometer serial number;
5) request of the minimum temperature received by the pyrometer;
6) request of the maximum temperature received by the pyrometer;
7) request of the current temperature measured;
8) the request of the pyrometer emissivity parameter;
9) the setting of the pyrometer emissivity parameter;
10) the automatic calculation of emissivity parameter.

Figure 2. The block diagram of the software system.
From the block scheme it is obvious that initialization of all data structures, ports and interfaces configurations are made on the first phase. Also, before the application main window occurs, the disconnection of the pyrometers lasers is made, because laser significantly affects the measurement accuracy.

During the application closing all ports will be closed, the PCI1710 card will be deactivated and the inductor will be switched off.

At the initial stage before the form displaying on the screen sequential survey of the pyrometers is conducted and the following information from them is receiving:
- serial numbers;
- the minimum temperature measured pyrometer;
- maximum temperature measured pyrometer;
- coefficient of the material emissivity that is installed on the thermometer.

Further, all information is displayed on the appropriate fields of the form.

When you click on the "START" button the automatic soldering process starts, during which product heating control based on the proportional controller is carried out [15, 16] with aim to maintain the required heating rate [17].

Figure 3 shows a block diagram of the soldering process control.
Figure 3. The Block diagram of the soldering process control algorithm
Here:
- \( W_{\text{set}} \) – setting power of the generator in volts. Changes from 2V to 12V, where 2V is 0% power generator, 12V is 100% capacity;
- \( T_{\text{cont}} \) – temperature value obtained from the pyrometer, introduced in the control loop;
- \( T_{\text{stab}} \) – stabilization temperature value, which is required for the solder melting and specified as technological parameter of the process;
- \( V_{\text{heat}} \) – heating rate of the product;
- \( V_{\text{set}} \) – required heating rate, which is necessary to maintain. Is specified as technological parameter of the process;
- \( t_{\text{StartStab}} \) – the time stamp when the system begin the stabilization process;
- \( \text{TimeStab} \) – the time during which is necessary to sustain the product when \( T_{\text{stab}} \) is specified as a parameter of the process.

This management scheme implemented on the base of the proportional regulator, allows effective control for 20 times per second. In a series of experiments, it was found that this controlling actions discretization is sufficient for effective management of the induction soldering process.

3. The automated system description

The system provides two access levels:
- operator access which allows to control the equipment and to view a database of the waveguides brazing technological parameters;
- technologist access which allows to view and edit a database of the waveguides soldering technological parameters and to control equipment complex.

The main window of the automated system in the operator regime is shown in figure 4.

![Figure 4. The Main window of the software system (operator)](image-url)
In this window the user has several possibilities. First, it is the view of the heating process graph.

Also, there are a number of control elements grouped by functionality. They are highlighted in the image frames and marked with numbers 1 and 2. Here, the first control elements group allows to set soldering parameters, the second group – the control buttons for the pyrometers laser.

In the emergency heat mode it is possible to shutdown the system by pressing the button "STOP".

Also, operator has to choose the technological process parameters from the database before soldering.

The technologist additionally has the opportunity to manage database of the soldering technological parameters (figure 5). For this purpose, there is the button “Edit database”, where the technologist can see in tabular form the data of process parameters and manage them: edit, add new or remove the outdated.

![Figure 5. The Main window of the software system (operator)\n
For providing analysis of the soldering results there is the option of logging processes in graphical form (images of temperatures graphs) and in the text.

If it is necessary to check the connection of the measuring devices and to adjust their parameters, user can look at the pyrometers information form (figure 6).
The are two tools to adjust the value of the material emissivity:

1) manual correction – when you click on the button "Change to", value of the material emissivity in the pyrometer will be replaced by the included in the box to the right of the button. This value is expressed in the range from 0 to 1;

2) automatic configuration – when you click on the button "Configure automatically" the selecting process of the best emissivity value will start. This process requires a connection of at least one thermocouple to the system. Average time of the automatic setting varies from 40 to 50 seconds.

4. Experimental study of the automated system effectiveness

To investigate the effectiveness of the developed system a number of laboratory experiments with the experimental equipment with various sizes of pipes and flanges/couplings of waveguides was conducted.

While conducting the experiments we used the information from two pyrometers directed to the pipe and flange/coupling.

The purpose of the first set of experiments was information about the thermal process, which must be entered in the control loop, selections.

Three options were considered:
- using temperature data from the pyrometer directed to the flange/coupling;
- using information about temperatures from the pyrometers directed to the pipe and flange/coupler;
- using temperature data from the pyrometer directed to the pipe.

Disadvantage of the flange/coupling temperature control was solders insufficient flow into the full depth of the joints due to the natural cooling pipe in the aging process. Using of the weighted-average temperature from both thermometers directed to the pipe and flange/coupling has often led to the pipe burn-through.

The pipe temperature process control showed the best results, thus the melting of the parts was pretended and the complete flow of the solder was ensured.

The aim of the second set of experiments was to determine the soldering technological regimes for the following sizes of waveguides: 28.5x12.6 mm; 35x15 mm; 58x25 mm and 19x9.5 mm.

For these experiments the single heating rate 5 deg/sec was implemented. The increasing of the heating rate led to increasing of the temperature difference between the upper and lower surfaces of the flange. The reducing of the speed led to the deterioration of the flux and, consequently, to the solder flow.

Through the experiments the necessary clearances and temperature stabilization were established. The choice of an appropriate gap between inductor and the flange allows to achieve the minimum temperature difference between the joined elements - pipe and flange.

Bank of the waveguide paths soldering technological process was made as the results of experiments.

Examples of the obtained processes graphs are shown in figures 7, 8.

![Figure 7](image.png)

**Figure 7.** The Graph of the soldering process pipe flange 19x9.5 mm, gap 3 mm, the stabilization temperature of 600 degrees
Conclusion
In presented study the automated system is developed, which allows to solder waveguide paths of different structures and to reduce the human factor.
The system has the following basic functions:
1) automated control of the induction soldering process;
2) visualization of the temperature value in the soldering area;
3) setting the parameters of the soldering process;
4) calibration of the measuring devices – pyrometers;
5) maintenance of technological processes database;
6) access rights to the system.
Developed software helps the operator to choose the induction soldering parameters and to provide the reproducible heating modes.
Thus, the application of the proposed automated system will improve the quality of the waveguide paths, reduce human factor and improve the staff working conditions.

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