The induction heating process modelling of the waveguide paths’ flanges

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Abstract. The article presents mathematical heating model the flange is in process induction soldering of waveguides paths. In the quality of object of research stands out creation process all-in-one connections based on induction heating, or more precisely, patterns distributions energy over time by default flange size waveguide the route. Goal creating a model consists of in the upgrade process quality of management technological equipment process production facilities antenna-feeder devices based on the induction soldering technology. Developed by models can be used for adaptive management technological equipment process induction system soldering when production waveguide paths assemblies.

1. Introduction
A typical waveguide path of the antenna-feeder system of a spacecraft usually consists of a pipe and a Typical waveguide antenna-feeder path space system flying object but how the rule consists of from the pipe and connecting device an element in the form flange either couplings. In the quality of creation method connections often used various methods based on soldering or welding. That's enough frequently used solutions for this task used technological approach the process of induction soldering, based on which one is lying induction heating. When management using these methods on quality issued products provides the impact is as follows negative factors: phenomena, called by vapors materials, change the coefficient non-legal entities material in the result processes oxidation and etc. Negative external and internal links factors, complexity technological equipment process, and also the impact human factor negative affect the quality technological equipment process and issued products.

One of the most popular effective ways to solve the above-mentioned problem is the mathematical models’ creation for working out soldering technology. Research parameter influences inductors on efficiency heating of parts and to the maximum value zone heating with using the following parameters: for modeling systems COMSOL submitted by in the work [1]. Modeling parameters electromagnetic field fields passed in the range the frequency range is 22-100 kHz. Results simulations they showed that the largest heating speed achieved at lower temperatures frequency bands, because in this case penetration depth electromagnetic field fields in the material details above.

In work [2] is presented mathematical model of the temperature sensor fields in rolling stock heat treatment processing with using an induction motor current heating various frequency. Implementation offered models in the form of software the product allows you to define distribution non-stationary ones
temperature sensors fields for hire valke. Given name software software maybe used for a valid reason mode selection thermal power station processing options detail.

Researchers, completed projects job [3], offer combine mathematical approach research apparatus electromagnetic fields and temperature sensors processes for optimizations management source code induction heating heating.

In works [4-7] submitted by results simulations technological equipment process induction heating heating systems in various applications systems computer generated content simulations.

For problem solutions simulations technological equipment process of induction rations at the initial stages very convenient use ready-made software solutions funds, intended use for modeling various technological solutions processes, such as: Simulink as part of the package Matlab [8–10], Comsol [11–14], Ansys [15–18], SimInTech [19–23].

In as criteria choosing software solutions products verifications under development models are offered the following: cost, availability of an academic degree program versions, cross-platform functionality, convenience of graphical display the interface the user, generation software code based on models.

Comparative analysis system analysis simulations submitted by in table 1. Compliance the criteria is set to within the limits of 1 or more up to 5 points, where 1-least likely corresponds to requirements, 5 – the most popular corresponds to requirements.

Table 1. Comparative analysis of verification systems for beam input-output models in the process of electron-beam welding.

| Criteria                        | ANSYS | Comsol | Matlab | SimInTech |
|---------------------------------|-------|--------|--------|-----------|
| The cost                        | 3     | 4      | 3      | 5         |
| Academic version                | 3     | 5      | 4      | 5         |
| Cross-platform                  | 5     | 4      | 5      | 5         |
| Convenience of the graphical interface | 4     | 5      | 5      | 4         |
| Generating program code         | 2     | 3      | 5      | 5         |

How visible from the table, within this framework the works of the most suitable software version modeling tools by all parameters it is a program object product description SimInTech. Its name features that’s enough for modeling technological equipment process of induction rations. Except in addition, the given product is available free of charge academic license with insignificant for the solution delivered issues with restrictions. SimInTech it is cross-platform software the product. Also, SimInTech it is a software application product description domestic production.

Application received mathematical models there will be no models used for development the algorithm adaptive (intellectual) management process induction heating assemblies waveguide systems paths with the goal of achievements uniform heating of soldered items elements for formations high-quality all-in-one connections. Working capacity and applicability offered the algorithm will be investigated as in the case of conducting computing resources experiments, so in the process full-scale projects experiments.

2. General problem statement
For solution of the problem development mathematical model of the induction heating for testing management practices technological process induction soldering waveguide paths must to develop mathematical models for elements waveguide build separately, and for all the Assembly as a whole. Elements waveguide system builds are waveguide tube the road, as well as flange or coupling.

In quality mathematical models heating models’ elements builds with a goal working out technological equipment process of induction soldering of thin-walled aluminum waveguide systems paths used instantaneous heating source in a flat bar (2), (3):
\[ T(x,t) = \int_0^t \frac{Q}{c \rho F \sqrt{4 \pi at}} e^{(-\frac{x^2}{4at} - bt)} \]  

where \( Q \) – amount of heat [J];  
\( F \) – cross section of the pipe [m\(^2\)];  
\( x \) – distance from heat source [m];  
\( c \rho \) - volumetric heat capacity [J / m\(^3\)];  
\( t \) – time [sec];  
\( b \) – coefficient of thermal convection into the external environment from the surface of the rod formula (2);  
\( a \) – coefficient of thermal conductivity;  
\( p \) – section perimeter.

\[ b = \frac{\alpha p}{c \rho F} \]  

where \( F \) – cross section of the pipe [m\(^2\)];  
\( c \rho \) - volumetric heat capacity [J / m\(^3\)];  
\( a \) – coefficient of thermal conductivity;  
\( p \) – section perimeter.

\[ T(x,t) = \int_{i=-\infty}^{\infty} \int_{j=-1}^{1} \frac{Q}{c \rho F \sqrt{4 \pi at}} e^{(-\frac{(x-jl-2iL)^2}{4at} - bt)} \]  

where \( Q \) – amount of heat [J];  
\( F \) – cross section of the pipe [m\(^2\)];  
\( x \) – distance from the left end [m];  
\( c \rho \) - volumetric heat capacity [J / m\(^3\)];  
\( t \) – time [sec];  
\( b \) – coefficient of thermal convection into the external environment from the surface of the rod formula (2);  
\( a \) – coefficient of thermal conductivity;  
\( p \) – section perimeter;  
\( L \) – rod length [m];  
\( l \) – distance from end to source of heating.

3. **Mathematical model of the flange of the waveguide path**

For simulations heating the flange starting from similar considerations. The flange represents by yourself relatively small body, which means, that it's enough it returns slowly heat. Therefore, under certain conditions speeds heating temperature it will be uniform along the cross-section axis. near the zone rations, and, based on from this, consideration of distributions temperatures along this plane you can omit it. However, the flange that's enough thin on the other hand the axis and, obviously, no way be evenly distributed heated by it. The flange is limited from both sides, in contrast to pipes, so necessary consider heat reflection from end users borders of the body. Thus, for the model heating the flange fair enough model limited rod with assumptions, specified higher. In figure 1 presented typical flange in photorealistic mode the presentation.

Calculation formula (4) for the process of heating the flange of the waveguide assembly with reference to a specific standard size has the form:
where $Q$ – amount of heat [J];
$F$ – cross section of the pipe [m$^2$];
$x$ – distance from the left end [m];
$c\rho$ - volumetric heat capacity [J / m$^3$];
$t$ – time [sec];
$b$ – coefficient of thermal convection into the external environment from the surface of the rod formula (2);
$a$ – coefficient of thermal conductivity;
$p$ – section perimeter;
$L$ – flange / coupling length [m];
$j$ – the number of reflections taken into account in the calculation, selected in such a way that for $j+1$ for any $x$ and $t T(x,t) \leq \varepsilon$ for $\varepsilon \rightarrow 0$.

Figure 1. Photorealistic image of the waveguide assembly flange.

Figure 2 shows projections of the flange of the waveguide path assembly with standard sizes.
Figure 3 shows a graph of the heating model of the flange of the waveguide path assembly for different values of the power of the induction heating source.

Thus, this design scheme sufficiently corresponds to the technological process of induction heating for the flange of the waveguide assembly.

4. Verification of the created model by comparing the simulation results with the behavior of a real object in the process of field experiments

At this stage of the study, necessary perform verification received mathematical model models for the item their correspondences the real one process b acceptable values within the limits. For it wasn't there used comparison results experimental data research and modeling. In figure 4 submitted by summary schedule for comparison model numbers charts and real-time graphs technological equipment process induction heating flange waveguide assemblies’ paths spacecraft.

As can be seen from the above graph, as well as the data on the value of the root-mean-square error presented in table 2, the developed model of induction heating of the tube of the assembly of thin-walled aluminum waveguide paths of spacecraft simulates this technological process with a sufficiently high degree of accuracy.

The results of full-scale and model experiments show that the proposed model can be used to test different modes of operation of the technological process of induction brazing of thin-walled aluminum waveguide paths of spacecraft.
Figure 2. Flange projections of the waveguide duct assembly with standard sizes: where $F$ is the flange sectional area; $p$ is the section perimeter.

Figure 3. The graph of the heating model of the flange of the waveguide path assembly: where blue graph - flange temperature 39x11, heating power 11 kW; orange graph - flange temperature 39x11, heating power 5 kW; green graph - flange temperature 39x11, heating power 3 kW.
Figure 4. Comparative graph of the induction heating model and the real technological process of induction heating of the flange of the waveguide path assembly for a standard size of 39 x 11 mm: where the blue solid graph is the flange graph (model), power 11 kW; orange discontinuous graph - flange graph (real process), power 11 kW; green solid graph - flange graph (model), power 5 kW; red intermittent graph - flange graph (real process), power 5 kW; blue solid graph - flange graph (model), power 3 kW; brown intermittent graph - flange graph (real process), power 3 kW.

Table 2. Table of standard deviations of simulation results and real technological processes.

| Standard size | Heating source power, P kW |
|---------------|---------------------------|
|               | 3            | 5            | 10           |
| 22x11         | 16           | 14           | 11           |

5. Conclusion
In under this research solved the problem development mathematical models of induction heating flange Assembly, waveguide tract for testing technological the process of induction brazing thin-walled aluminum waveguide paths space flying devices. For verification developed models were held model and field testing showing developed the flange Assembly, waveguide tract high degree of accuracy meets leakage real technological processes induction brazing thin-walled aluminum waveguide paths spacecraft.

On based on the conducted research assumed:

- Development of models for heating the assembly of the waveguide path.
- Development of a set of adaptive methods for controlling the technological process of induction soldering based on modern algorithms for data mining.
- Implementation of a prototype control system for induction soldering of waveguide paths of spacecraft, using the developed mathematical models and algorithms.
- Conducting a test of the operability, applicability and efficiency of the prototype of the system both during computational experiments and in the process of field experiments.
- Development of a scheme for integrating the proposed prototype of the software system into an existing experimental installation for induction soldering of waveguide paths of spacecraft.
Use and implementation developed models with the inclusion of them into the existing hardware and software control kit induction soldering waveguide paths space flying devices will reduce material costs use these models when working out new modes technological the process of induction soldering waveguide paths space devices on various configurations and sizes waveguide assemblies’ paths.

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