Estimation of the thermal gap when soldering waveguide elements

I V Kudryavtsev, M V Brungardt, E A Goncharova, O A Li and A V Kolotov
Siberian Federal University, 79 Svobodny Pr., Krasnoyarsk, 660041, Russia

E-mail: ikudryavcev@sfu-kras.ru

Abstract. This paper proposes a method for determining the required gap between the elements of the waveguide path during its assembly by soldering. The need for a thermal gap is defined by difference in mass and dimensional parameters of the elements to be connected, due to which a significant non-uniformity of heating and thermal deformations occur. The non-uniformity of thermal deformations leads to jamming of one element in another, therefore, the heating time and the size of the thermal gap are need to be determined. The diameter of the solder wire is determined according to the size of the thermal gap and the required fillet of the soldered seam. The performed numerical calculations of the stress state of the obtained soldered seam showed the absence of stress concentration. Mechanical tests have confirmed the high strength of soldered seam.

1. Introduction
Soldering of thin-walled waveguide elements is a crucial stage in their manufacture [1-6]. The soldering of the waveguide path is carried out sequentially from one connection of the elements to another. Soldering of aluminum elements of the waveguide structure is carried out by using special microwave equipment with high-frequency currents. With such heating, heat is distributed mainly along two heating circuits, which are shown in figure 1.

![Figure 1. Heating circuits.](image)

The flange and the sleeve are more massive than the thin-walled waveguide. This leads to the fact that when heated, the thin-walled waveguide will heat up and expand faster than the flange. Since some part of the thin-walled waveguide is located inside the recess in the flange, it is possible for the thin-walled element to jam with its subsequent unwanted deformation.
In this paper, a method is considered for calculating temperature deformations during heating of waveguides of various cross-sectional sizes in the process of soldering. Based on the data obtained, the thermal gap was justified and the volume of the solder to obtain a high-quality soldered seam was determined. The strength of the soldered seam is confirmed by calculations and mechanical tests.

2. Statement of the problem

The simplest and most effective solution to the problem of no uniform deformation is a thermal gap between the walls of the brazed elements. A thermal calculation of the joint is necessary to choose the value of the gap.

The solution to the problem consists of the following stages:
1) estimation of the temperature fields of the flange and thin-walled waveguide during heating at selected points in time;
2) estimation of the stress-strain states of a separate flange and a thin-walled waveguide at selected points in time;
3) creation of diagrams of changes in the position of the points under study on the flange and thin-walled waveguide during heating.
4) determination of the required volume of solder and calculation of the required diameter of the welding wire.

The heating of the elements during soldering is carried out according to figure 2. The temperatures of both heating circuits (figure 1) change synchronously.

Figure 2 shows the heating mode: periods of heating alternate with periods of relaxation, i.e. stopping heating, in order to obtain a more uniform temperature field.

The calculation of the elements will be carried out separately, since our goal is to exclude their influence on each other during heating. Having calculated the thermal deformations of the elements, and superimposing them on top of each other, we will find the value of the required gap. This gap will exclude the influence of the elements on each other during heating.
Further, the calculation of the thermo-deformed state of the joint elements during the heating process was carried out and the displacements of control points 1 and 2 were determined (figure 3).

The indices "a" and "b" in the designation of points indicate that the points belong to the thin-walled waveguide and flange, respectively. Having applied the heat load along the heating circuits according to the heating cycle, we determine the position of the control points in time. By converting the absolute displacements of the control points into their displacements relative to each other, we obtain a diagram of the change in the gaps between the flange and the waveguide during the soldering process.

3. Calculation of the gap during the soldering process
The calculation is carried out using Ansys and Nastran software [7-15]. Figure 4 shows a computational finite element model of a thin-walled waveguide and a flange with an applied thermal load.

![Finite element model of the waveguide and flange.](image)

Figure 4. Finite element model of the waveguide and flange.

Figure 5 shows a typical result of calculating the temperature field of a thin-walled waveguide and a flange.

![Temperature field of the waveguide and flange.](image)

Figure 5. Temperature field of the waveguide and flange.

A noticeable no uniformity of heating and temperature values of these elements occur due to the difference in their geometry. Temperature fields for all standard sizes of the waveguide have a similar appearance, differing only in temperature values. We are interested in a very small part of a thin-walled waveguide located near the waveguide heating circuit. The calculation confirms that the heating of a thin-walled waveguide occurs much faster than the heating of a flange and this can lead to its jamming.

We determined the thermal displacements of the control points in the joint and plotted diagrams of the change in the values of the gaps between the flange and the thin-walled waveguide for all the investigated standard sizes of the section. Figure 6 shows a typical diagram for a 15x35 waveguide.
By analyzing the diagrams of changes in the gap, we can determine the moment of jamming and its duration, as well as the size of the required gap. The diagram of the gap change is convenient as it allows us to find the values of the greatest mutual penetration of the control points from the maximum deviation from the horizontal axis to the negative area. The found values represent the required thermal gap between the elements; this gap prevents the mutual influence of elements during heating.

The value of the thermal gap, determined for different standard sizes of the section, varied from 0.11 mm to 0.15 mm. Knowing the perimeter \( p \), depth \( h \) and the size of the gap \( s \), it is possible to determine the volume of the solder \( V \) needed to fill the gap (figure 7). This value must be increased by the size of the fillet. Let us consider the example of a fillet in the form of a right-angled triangle with the length of the legs 1 mm.

The required volume of solder is:

\[
V = p \cdot (h \cdot s + \frac{b \cdot b}{2}) .
\]  

For solder in the form of a round wire, the required diameter is:

\[
d = 2 \sqrt{\frac{V}{\pi p}}.
\]
The calculation results were taken into account when developing the technology of soldering waveguide elements and this let us improve the quality of the soldered joints. Figure 8 shows the result of calculating the stress state of a soldered seam with a fillet; one can see a uniform stress state without areas with stress concentrations.

![Figure 8. Strength of the soldered joint.](image)

Mechanical tests of the brazed structure of the waveguide confirmed that failure occur outside the zone of the soldered seam.

4. Conclusion
In this work, the study of thermal deformations of the elements of the waveguide is carried out. The proposed approach to the study of the thermoelastic state of the assembly in the process of soldering let us substantiate the thermal mode of heating and the size of the thermal gap in order to avoid jamming of the brazed elements. Studying the stress state of the soldered seam using calculations and tests showed its high strength.

Acknowledgements
The reported study was funded by Russian Foundation for Basic Research, Government of Krasnoyarsk Territory, Krasnoyarsk Regional Fund of Science, to the research project no. 20-48-242914: "Development of methods of calculation of a thermoelastic state of waveguide system of the spacecrafts of communication at operation".

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