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Investigation of vacuum-tight cooled assemblies for FPAs

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An investigation of the properties of vacuum-tight brazed joints produced by induction brazing for use in components of vacuum cryogenic assemblies of cooled focal-plane arrays (FPAs), specifically in their cold fingers. The specific design features and operational conditions of these joints in micro-cryogenic FPA cooling systems were taken into account. To monitor the helium leak rate, dedicated tooling was developed, which significantly enhanced the ultimate sensitivity of the helium leak detector. The measured helium leak rate of the fabricated assembly samples is 5×10^{-13} Pa·m³/s.

Keywords: induction brazing; vacuum cryogenic housing; focal-plane array.

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Many types of matrix photo-receiving infrared devices require cooling of the photosensitive element (PSE), including to cryogenic temperatures. To solve the problem of providing the necessary operating temperature of PSE, microcryogenic machines are often built according to the Stirling reverse cycle which can be created both in integral design and according to the Split-Stirling system [1]. The structurally cooled photoreceiver is a microcryogenic machine integrated with a sleeve holder on a cold finger which is equipped with cooled PSE. Sleeve holder acts as a functional element of the body of microcryogenic machine inside which the regenerator with a displacer type piston moves. The inner cavity of the machine and, accordingly, the sleeve holder is filled with a working gas (usually, helium) under high pressure (from 20 to 50 kgf/cm²). At the same time, the sleeve holder is simultaneously a part of the body (cryostat) of the photodetector (usually, evacuated or, less often, gas-filled).

Thus, based on the functional feature of the sleeve holder, the following basic requirements apply to:

- leak-tightness;
- freeze-thaw resistance;
- low levels of heat input;
- corrosion resistance of materials used for

the manufacture of sleeve holders, as well as special requirements for their thermal coefficients of linear expansion (TCLE): to ensure geometrical stability of the device they must be small, and the material of the PSE placement site, additionally, must have a TCLE as close as possible to the TCLE of the PSE material to avoid temperature stresses in their connection.

The listed requirements are best provided in the typical design of the sleeve holder shown in fig. 1.

Such a sleeve holder consists of the basic sleeve 1 made of stainless steel, which is directly connected to the body of the microcryogenic machine, a bush 2 is connected to the basic sleeve which is made of thin-walled stainless steel to minimize heat flow. End cell 3 of sleeve holder

on which the cooled PSE is directly mounted is a disk made of material with a normalized TCLE value, for example, covar or invar. Shape and

dimensions of sleeve holder can vary depending on the parameters of specific PSE and used microcryogenic machine.

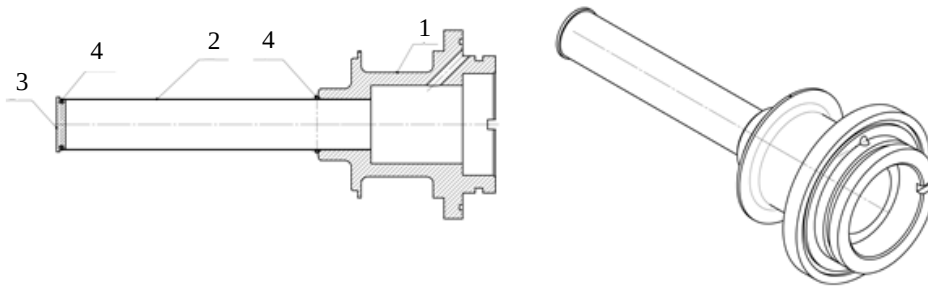


Fig. 1. Design of the sleeve holder: 1 – basic bush; 2 – sleeve; 3 – end cell; 4 – brazing alloy

One of the important technological tasks when manufacturing the sleeve holder is ensuring reliable connection of sleeve holder components to each other which guarantees meeting the conditions of leak-tightness and geometrical stability under cryogenic temperatures. As usual, this can be reached by using welding or soldering. Fig. 1 shows the sleeve holder the components of which are connected by soldering. The locations of alloy brazing are indicated in fig. 1 by pos. 4.

Induction heat is often used in industrial practice to connect metal parts by smoldering [2]; such heat is provided by the occurrence of thermal effect in the connected parts and alloy brazing under the influence of electromagnetic field (Foucault vortex currents).

At the same time, during the heating process, if it is conducted in an air atmosphere, accelerated oxidation of the surfaces of parts and solder invariably occurs, which is not unacceptable for sleeve holder due to the specification of its application, moreover, it can lead to a violation of the tightness of the brazed seam.

Specialists of JSC “SPA “Orion”, as part of solving the problem of manufacturing sleeve holders, tested the creation of vacuum-tight brazed joints by induction brazing which does not lead to oxidation of the connected parts.

Induction heater is used for brazing; its structural diagram is shown in fig. 2.

Connected parts of the sleeve holder 1 and 2 and brazing alloy 3 are placed in the electromagnetic field created by inductor 4. Inductor 4 is connected to the electrical power generator 5 through transformer 6. Inductor 4 together with condenser 7 connected in series to the primary winding of transformer 6 make

oscillation LC-circuit. Depending on the inductance of the coil of inductor 4, condenser 7 capacity, as well as characteristics of the connected parts, the resonant frequency of the LC-circuit may change. This change through the self-excited oscillator 8 keeps the circuit in resonance by changing the frequency depending on the inductance value of the inductor 4. Connected parts 1 and 2 have axially symmetrical shape and are located coaxially to the inductor 4, support 9 contains bearing 10 in which rotary platform 11 is installed, rotation of platform 11 is ensured by drive 12. Seat 13 is installed on platform 11 and it is coaxial to the rotation axis of platform 11. When rotating the connected parts during heating, the installation errors of the connected parts relative to the inductor have a smaller impact on the homogeneity of connection heating.

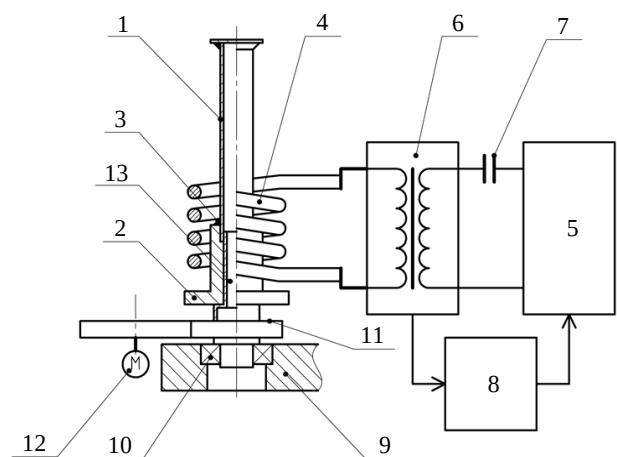


Fig. 2. The diagram of the device for induction brazing of sleeve holders: 1, 2 – components of sleeve holder; 3 – brazing alloy; 4 – inductor; 5 – electrical power generator; 6 – transformer; 7 – condenser; 8 – self-excited oscillator; 9 – support; 10 – bearing unit; 11 – rotary platform; 12 – drive; 13 – seat

The development of induction brazing of sleeve holders was carried out in three main directions:

- obtaining brazed joints under vacuum conditions;
- obtaining brazed joints in the inert gas;
- obtaining brazed joints using protective compounds.

To ensure a vacuum, the inductor and connected parts were placed in a tight chamber from which air was pumped using a high-pressure vacuum pump until reaching residual pressure not exceeding 1×10^{-3} mm Hg. Using a tight chamber also allows to implement the second method by injecting inert gas (for example, argon) in it, replacing air, which allows to create an inert gas environment in the soldering area.

Both in vacuum and inert environment high-quality brazing connections were obtained corresponding to the requirements above. It should be noted that one of the main advantages of soldering under vacuum conditions compared to a gaseous environment is the stable production of brazed joints without voids and cavities which makes the joint vacuum-tight.

However, the use of a tight chamber is unpractical for mass production requiring minimal operating time and minimizing production costs. The thing is that when using a chamber, the access to the connected parts is limited during the soldering process and makes visual inspection over the process more complicated. Moreover, vacuum production or creation of a gaseous environment in the chamber takes significant time and is carried out every time a new set of parts is installed.

One of the solutions to the problem is carrying out induction brazing in the inert gas environment without creating pressurized volume. In this case a setup is used in which inert gas is supplied to the area of brazing joint formation under pressure. With this method, despite the satisfactory quality of the obtained joint and significant reduction in the time of operation, the main disadvantage is the increased consumption of inert gas which makes the process more expensive.

For the mass production of holders, JSC “SPA “Orion” has developed induction brazing in the air environment allowing to ensure high-quality connection and excluding the appearance

of oxide film on the surfaces of connected parts. For this purpose, protective compounds are used during brazing which are applied on the surface of parts and prevent oxidation of these surfaces and simultaneously improve the wetting of the molten solder. Soldering fluxes of certain grades can be used as such compounds.

Soldering process with the use of protective compounds is carried out as follows. Before starting soldering, surfaces of parts and solder are covered with flux for protection against environmental influence and improvement of distribution of molten solder. At the same time, unlike the usual practice of using soldering fluxes, the whole surface of parts is covered in flux, not only sections in the soldering area. Connected parts can be manufactured from stainless or covar. At the same time, it is possible to connect parts from different materials. Solder is used for soldering, which melting point is lower than the temperature of high tempering of steels. In case of connection by soldering of parts made from the materials listed above, silver containing solder is used, and as flux – high-temperature soldering flux based on boron acid. Then the connected parts, solder and flux are heated with an inductor at a set speed to a temperature at which flux has the best wetting – ability to maintain contact with a solid surface due to intermolecular force (the practice shows that the temperature is 420 °C when using the flux). The parts are exposed at this temperature and then heated up to the solder melting temperature (for the example considered 595–605 °C). Then the heating is turned off and the parts cool down to room temperature and the residual flux is removed in a weak sodium hydroxide solution.

Due to the induction heating at the junction of soldering parts, the bush surface and holder tube are oxidized which can negatively affect the evacuation of the holder as part of the cryostat. To remove the formed oxide film on the bush surface, washing in a hot aqueous solution of versene is used, the operating principle of which is based on the extraction of cations of insoluble salts that make up the oxide film, in the oxidation degree of +2, +3 and their replacement with sodium cations, practically all salts of which are soluble in water. As versene is not an oxidizing agent, interaction with metal in the zero oxidation

degree does not occur. The complex soluble ferritic salts occurring on the holder's surface are easily removed by flushing in hot water.

The advantage of this method is the possibility of conducting soldering in the open air without using a chamber. This also makes it possible for parts to cool down quicker after heating and shortens the operation time. You can accelerate the cooling process by applying forced air cooling. Due to the convenience of access to the connected parts and inductor, it is possible to ensure a more accurate alignment of parts relative to the inductor.

According to the results of studies and development of the induction brazing method, a patent [4] was obtained for an induction soldering method.

The conducted work allowed to ensure stable mass production of sleeve holders. The appearance of the mass-produced holders is shown in fig. 3.



Fig. 3. Appearance of the mass-produced sleeve holders

One of the most important requirements for sleeve holders is ensuring the brazing joint

tightness. Check of tightness is conducted with the use of special a tool shown in fig. 4. The device reproduces the operation conditions of the holder as part of the ISS and vacuum cryostat at elevated helium pressure ($20 - 50 \text{ kgf/cm}^2$) inside the sleeve holder. Thus, it is the leakage of helium from the holder that is controlled which is specific to its operation as part of a cryogenic system and not the inleakage into the holder as with the traditional method of inspection using a leak detector.

Fig. 4 shows: the inspected sleeve holder 1 which is tightly connected with body 6 using O-ring 3 (solder wiring is used as sealing material) and flange 8. Through the filling valve 4 in the body 6, sealed with a solder disc, the inner cavity of the sleeve holder is filled with gaseous helium with set overpressure. Next the sleeve holder is aligned with bush 9 through fluorinated rubber O-ring 2. The bush has flanges on both sides, one of which 11 (KF standard) is fixed by clamp 5 on the housing 5 ensuring clamping force from the side of bush 9 on the inspected sleeve holder 1; another flange 7 (KF standard) is similarly connected with a helium leak detector.

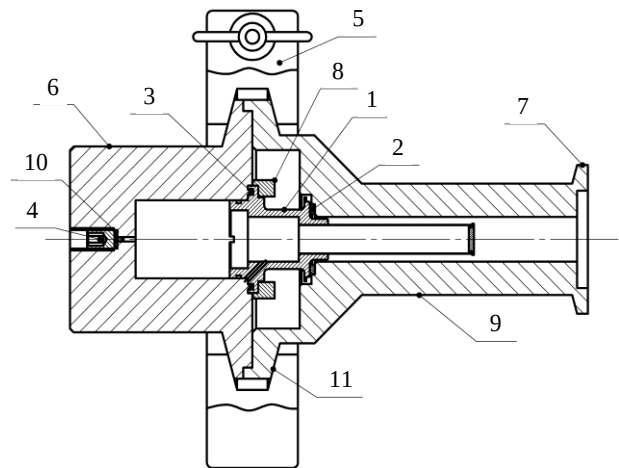


Fig. 4. Design of the device for the tightness test: 1 – inspected sleeve holder; 2, 3 – O-rings; 4 – valve; 5 – clamp; 6 – body; 7 – attachment flange KF; 8 – flange; 9 – bush; 10 – filling hole; 11 – flange KF

Such design allows to search for leaks with greater sensitivity. The registered helium leakage rate is $5 \times 10^{-13} \text{ Pa} \cdot \text{m}^3/\text{s}$ which corresponds to the limit sensitivity of the used helium leak detector.

Conclusions

Results of the conducted studies made it possible to ensure a stable mass production of holders of evacuated cryostatic bodies with high

operational specifications. When checking the tightness, it was confirmed that the leakage rate of the gas (helium) from the holder's working cavity is not more than $5 \times 10^{-13} \text{ Pa} \cdot \text{m}^3/\text{s}$.

REFERENCES

1. Novotel'nov V. N. et al., Cryogenic machines. St. Petersburg, Polytechnica, 1991.
2. Vologdin V. V. et al. Induction soldering. Leningrad, Mashinostroenie, 1989.
3. Lashko S. V. and Lashko N. F. Soldering of metals. Moscow, Mashinostroenie, 1988.
4. Bannikov M. V., Korotaev E. D. and Sharov A. A. Induction soldering method. Patent RU 2824969. 2024.

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