Thermal Modeling of Cooldown Processes In Portable HPGe Spectrometers

O. Yakovlev, V. Malgin and Y. Viba

***Abstract*— The Stirling cycle cryocoolers are usually used for HPGe detectors cooling in γ- radiation portable spectrometers for field applications. The cooling of large size germanium detectors up to cryogenic temperatures by application of low-power cryocoolers makes the topical task of the thermal losses analysis. The equivalent thermal model of detector unit and Stirling cryocooler created by thermoelectric analogies is presented. Thermal modeling is used for analysis and optimization of cooling path from cryocooler to detector can for thermal losses reduction. The calculated cooldown curves of the detector unit as the transition process for the proposed model are compared to the experimental results. It is shown that the proposed model allows simulate the cooldown processes for HPGe detector with accuracy sufficient for the practical applications. The temperature distribution diagrams for the thermal joints obtained by SolidWorks Simulation are presented.**

***Keywords*— Cooldown curve, HPGe detector, Stirling cryocooler, Thermoelectric analogy.**

I. Introduction

Portable gamma-ray spectrometers with High Purity Germanium (HPGe) detectors cooled by Stirling cryocoolers are widely used for the in-situ radioactive monitoring applications [1-4]. To ensure the maximum operating time under field conditions without battery recharging low-power Stirling cryocooler should be used. The low cooling power (typically 1-3 W) limits the permissible heat losses in the chamber defined by the construction of cryostat and level of vacuum. When the detector is cooled, sufficient vacuum is provided by a zeolite (molecular sieve) adsorbing residual gases at operating temperatures which are in the range of 80 K. The operation of portable devices is characterized by long periods of storage or transportation in the OFF state when the detector unit is in warming up state. During that state the zeolite releases the adsorbed gas molecules. Vacuum decrease increases the heat losses in the chamber for cooldown process. In a critical case the cooling power of cryocooler is not enough to provide HPGe detector cooling to the required temperature [2,3].

Therefore, simulation and analysis of the heat losses in the vacuum chamber become to be the most important.

The total heat transfer from the chamber walls is a sum of the conduction through supports and current leads, residual gas conduction and radiation [5].

- Heat transfer through supports and current leads. For the temperatures in range 80K – 300K the thermal conductivity of solids may be considered as constant and heat transfer proportional to the difference between temperatures of outer shell and cooled units.

- Heat transfer by residual gas. As usual the residual gas pressure in cryostat is in range of 10^{-4} – 10^{-3} mbar and molecules free path is more than a distance between surfaces. In according to the Knudsen equation for region of "free-molecule" conduction the heat transfer is proportional to the pressure and the temperature difference.

- Heat transfer by thermal radiation. In according to the Stefan-Boltzmann equation the heat emission from surface of body is proportional to it temperature of degree 4.

It should be underlined that in distinct from conduction through supports and current leads the gas conduction and radiation transfer may be estimated with rather less accuracy. The reason is the difficulty of determining the accommodation coefficient and emissivity, respectively. However, it is usually possible to estimate an upper bond for the heat transfer by these processes and it is sufficient to meet the required demands.

To reduce the heat transfer by thermal radiation a radiation shields are usually used. So, in case of high vacuum, the thermal conductivity of supports contributes mainly to the total sum of heat transfer.

In case of decreased vacuum in cryostat after warming up the molecular conduction of residual gas, the dominating heat load contribution during the cooldown process is introduced. The heat transfer due to thermal radiation should be taken into account but it is not determinative in that situation [6].

The existing dependency of total heat losses in the cryostat during its cooling after heating from temperature difference allows to use the thermo-electrical analogies method for thermal calculation. This method allows to evaluate the thermal characteristics of the spectrometer's cryostat through the analysis of equivalent electrical circuit. The method provides accuracy sufficient for engineering applications, while retaining a clear physical meaning of the processes.

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VI. Thermal Simulation By Solidworks

The equivalent model of cryostat proposed above is useful for the analysis of cooling as a dynamic process. However, it was assumed in this model that the temperatures at different points of the cryostat components, which are modeled as a capacitance as lumped element are the same. But the actual distribution of temperatures on surface of cryostat components has a significant influence to the analysis of heat losses. When parameters of equivalent circuit are determined the evaluation of thermal resistances of joints between elements in cryostat is particularly important [14]. The Solidworks Simulation was used for computer simulation of the temperature distribution in the joints between components of cryostat.

As example, the results of computer simulation of the temperature distribution at the junction between the cryocooler cold tip and tip of the flexible thermal strap are shown in Fig. 8 and Fig. 9. The diagrams for two forms of the tip: flat and cruciform are presented. In real construction, the flexible thermal strap provides the thermal contact between cryocoolers cold tip and detector container, Fig.4. For the simulation, the following parameters were used. The diameter of cryocooler cold tip is 14.2 mm, the area of thermal contact equals 160 mm^2. In numerical simulation, the heat load equals 2 W and was applied to the opposite face of the tip.

Note, that for good thermal contact is necessary to join clean surfaces with as high a pressure as possible. The most common material for thermal contact is copper, which forms an insulating oxide layer. This can be removed every time a joint is made by filing the surface. Pressure is applied by 6 screws for flat tip, Fig.8 and 4 screws for cruciform tip, Fig.9. It is very useful to put a small amount of vacuum thermal grease between the contacting surfaces.

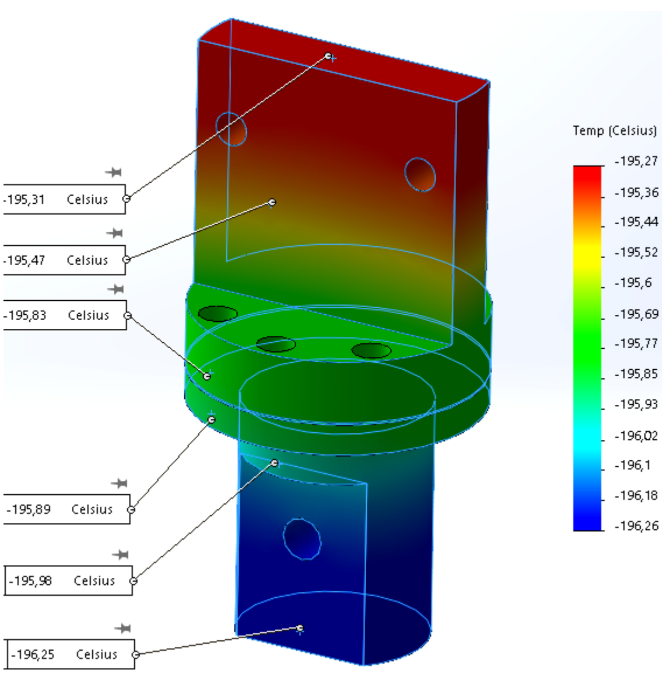

Fig.8. Temperatures distribution on joint with flat tip. Heat load equals 2 W.

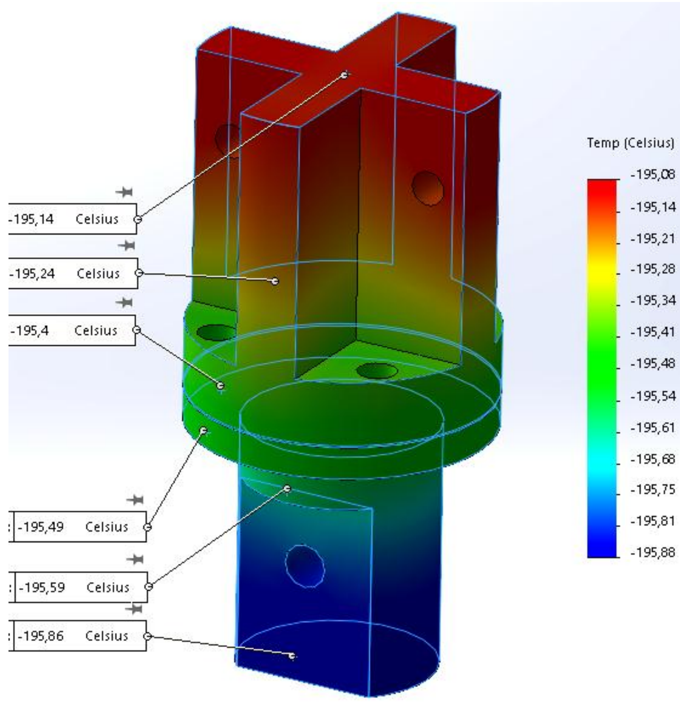

Fig.9. Temperatures distribution on joint with cross-shaped tip. Heat load equals 2 W.

To reduce thermal resistance between contacting surfaces the thermal paste MUNG I (INTIVAC Corp.), consisting of silver powder blended into vacuum grease was applied. A thin layer of thermal paste provides a high coefficient of thermal conductivity equal to 18.2 $Wm^{-1}K^{-1}$. For calculations, the thickness of the thermal paste layer was chosen equal to 0.1 mm. It is a real value, considering the cleanliness of interfaced surfaces and sufficient force of compression by mounting screws. As it is seen from the results of computer simulation, the total temperature drop on the joint is 1.0 K for the flat tip and 0.8 K for the cruciform tip (heat load equals 2 W). Reducing the thermal resistance of the cruciform tip is due to increasing area of its cross section. Careful calculation and analysis of temperature drop on joints may indicate methods of reducing the heat losses reduce heat losses in the cryostat and reduce cryocooler power what is required for the HPGe detector cooling up to a predetermined temperature. Note that this problem is especially important for portable devices in connection with the small sizes of joints and thus the small contact areas between them.

VII. Conclusion

The present article deals with a process of cryostat cooling in a portable spectrometer with a Stirling cryocooler. The simplified thermal model of cryostat as well as equivalent circuit for Stirling cryocooler based on the thermo-electrical analogies method are proposed. The parameters of equivalent circuit can be determined experimentally or calculated from data sheets. By comparing the load characteristics obtained experimentally for various cryocoolers and published in the open press with those calculated by means of the proposed model the sufficient accuracy of proposed thermal model for engineering calculations is shown.

In the framework of proposed model the process of cryostat components cooling as a transition process in equivalent electrical circuit is considered. This approach allows to use a well-known and standard methods from a theory of electrical circuits.

Undoubtedly the application of modern computer programs based on the Finite Element Method as well as network 2-D models with distributed parameters allows to calculate the process of cooling with more accuracy (as example [15], [16]). In this case, it becomes possible to take into account the nonlinear dependence of the specific heat capacity and thermal conductivity of materials from temperature, as well as nonlinear dependence of heat losses from the temperature. However, a simplified approach described in the article is useful for practical engineering applications to provide possibility of quick estimation the thermal performance of a cryostat.

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