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COMPUTER DESIGN OF PRECISE SPECTROMETRIC EQUIPMENT WITH INNOVATIVE COOLING SYSTEMS

КОМПЬЮТЕРНАЯ РАЗРАБОТКА ПРЕЦИЗИОННОЙ СПЕКТРОМЕТРИЧЕСКОЙ АППАРАТУРЫ НА ОСНОВЕ ИННОВАЦИОННЫХ СИСТЕМ ОХЛАЖДЕНИЯ

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Abstract: *The small and efficient Stirling electrical coolers, which recently appeared on the market, are opening the wide perspectives for the development of precise spectrometric equipment based on semiconductor detectors for nuclear radiations cooled by innovative cooling systems. The development of such equipment is impossible without efficient computer software packages, intended for the equipment design, simulation of different solutions and preparation of design drawings and/or technological documentation. The greatest problem at the development of cooling systems based on Stirling electrical coolers is their acoustic vibrations, which impact the spectrometric performance of semiconductor detectors. Recent results of computer design of precise spectrometric equipment with Stirling electrical coolers for laboratory, field and space applications are presented.*

KEYWORDS: SPECTROMETRIC EQUIPMENT, DESIGN SOFTWARE, COOLING SYSTEMS, NUCLEAR APPLICATIONS.

1. Introduction

High Purity Germanium (HPGe) detectors for nuclear radiations require cooling till liquid nitrogen temperature to provide the best performance [1]. The small and efficient Stirling electrical coolers, which recently appeared on the market, are opening the wide perspectives for the development of precise spectrometric equipment based on semiconductor detectors for nuclear radiations cooled by innovative cooling systems [2]. Such systems can be build based on Stirling electrical coolers with different cooling power and allow to create precise spectrometric equipment for different applications without liquid nitrogen.

The development of the precise spectrometric equipment at the present is not possible without application of the modern Computer-Aided Design (CAD). Modern application software packages provides not only the reduction of the development terms for the design and technological documents, but also lower the expenses for the prototypes manufacture up to their complete exclusion in the development process.

The objectives of the present work was to design a modern spectrometric equipment based on innovative cooling systems for HPGe detectors using modern computer software package for design and simulations.

2. Equipment Functional Structure Features

The precise spectrometric equipment [3,4] generally comprises the HPGe detector of X- or gamma-radiation, vacuum cryogenic system for the detector cooling based on liquid nitrogen, passive shielding and collimation system, electronics for the detector signals processing, computer with analytical software for the calculations and results display. All these systems have own design-technological peculiarities, which should be taken into account during computer simulation and design:

- vacuum-cryogenic system for detector cooling – it requires the development of the cryostat which could provide the effective cooling for the detector up to liquid nitrogen temperature, low inleakage of the residual gases in vacuum volume over the operation process. The development requires simulation of the gas inleakage processes from the cryostat materials and detector holder as well as heat transfer due to heat conductivity of materials, gas convection and infrared radiation. Applied materials are stainless steel, aluminium, copper. The weight of the details could be varied within several to hundreds grams. The details are made on CNC machines which provide the surface purity of Ra1.6. The further technological processes are the clean welding, vacuum annealing and vacuum pumping. The designer-technologist makes the calculations for strength and gas-dynamic in the documentation development as well as analysis of design processability.

- system for passive detector shielding and collimation - comprises the development of effective radiation shielding and collimators set. Only radiation pure certified materials such as lead, tungsten, copper are applied in the production process. The weight of the shield elements and collimators could be varied within several to hundreds of kilo. The machining process is made with turn/mill equipment. The designer-technologist makes the strength calculations, analysis of design processability, optical calculations for optimal radiation shielding and effective collimators set.

- electronics for detector signals processing - comprises the design of the printed circuit boards topology, design of radioelectronic units and assembly of radioelectronic equipment (REE). The designer-technologist creates the model with volumetric assembly and apply it for the further heat calculations, as well as solves the tasks of the optimal cooling for REE. The same way electromagnetic calculations are made.

- various accessories – in dependence of the type of the developing device.

The manufacture technologies of semiconductor detectors, circuit engineering solutions of low noise electronics and analytical software for the calculation and results display are rather specific products of not design features and are not discussed in the present paper.

3. Choice of Design Software Package

It's impossible to develop innovative product without innovative computer-aided design. Each of the listed system is a functionally completed one with its design-technological features and, usually, is developed in the projects by a various designers, specialized particularly in such developments. Alongside, the designed documents of the device should present the unified documentation set made in the accordance to the international standards as the result of the development and ready for the production. That is why it's very important to choose the soft package optimally

feasible for the design of all systems of the developed spectrometric equipment.

Market analyses shows that among the design software packages the most popular today are Solidworks, Autodesk Inventor, KOMPAS-3D, ADEM CAD/CAPP/CAMM, Solid Edge [5]. And the first two are the absolute market leaders. Both software Solidworks and Autodesk Inventor maintain Unified Standard for Design Documents and comprise the base of the most widely spread world standards: ANSI, ISO, DIN, JIS, BSI, ГОСТ, GB. Both software packages are widely used in the design and their advantages and drawbacks are well known [6]. Nevertheless we have carried out rather large volume of the practical test for various applications of both software packages in the different systems and assemblies of the analytical equipment. As the result of the analysis of all advantages and drawbacks of all studied packages as well as their separate units on the specific systems and assemblies of our equipment, the choice was made for Solidworks [7]. The main reason in that choice was the presence of analytical modules in Solidworks, which allow to simulate different technological processes and to design virtually different variants of device designs without prototyping. The present advantage is highly imperative when scientifically advanced analytical equipment which requires various physical technological processes is under development.

4. Computer Design of Equipment with Stirling Electrical Coolers

Stirling electrical coolers of different cooling power allow to design modern precise spectrometric equipment with innovative cooling systems without liquid nitrogen. At the beginning in development we design Solidworks computer general model and then make a full detailing.

Fig.1. *Laboratory HPGe gamma-spectrometer with shield: 1- with liquid nitrogen cooling and 2 - with cooling system based on Stirling electrical cooler LSF9340-02 (Thales, France).*

Fig.1. shows laboratory HPGe gamma-spectrometer with shield for analysis of radionuclide pollutions in liquids, powders, gas and solid samples, the most widely used in environment monitoring practice. Fig.1.1. shows the spectrometer with HPGe, cooled by liquid nitrogen, produced by our company more that 20 years already. Designed spectrometer (Fig.1.2.) has innovative HPGe detector cooling system based on Stirling electric cooler LSF9340-02 (Thales, France) with cooling power 9W at the temperature 80K. The system of the passive shielding (weight ≈ 600 kg) was made from lead with radiation purity less than 50 Bq/kg with copper cylindrical inserts, coated with galvanic nickel. In modern spectrometer detection limit for radionuclide Cs-137 is less than 0.5 Bq/kg at the acquisition time 1 hour. The energy resolution of the spectrometer at present is approximately 10% worse than with liquid nitrogen cooling due to Stirling electrical cooler vibration.

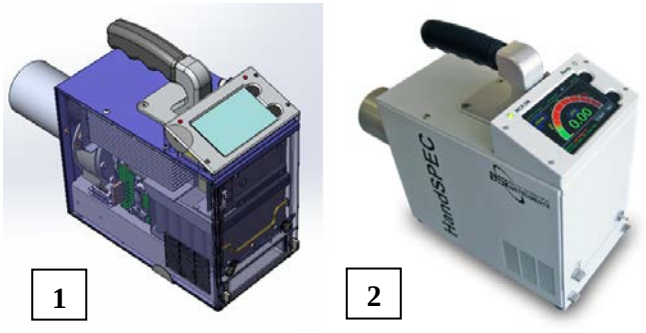

Fig.2. *Portable hand-held gamma-spectrometer HandSPEC with electrical cooling: 1 – computer 3D assembly model in Solidworks; 2 – spectrometer photo.*

Fig.2. presents portable HPGe gamma-spectrometer for field applications - analysis of the radionuclide pollutions on the nuclear enterprises, at the environment monitoring and inspections on the border. The spectrometer has a complicated cooling system for HPGe detector based on Stirling electric cooler SL-400 (AiM, Germany) with cooling power 4W at the temperature 80K [8]. Weight and overall parameters of the spectrometer has important value for portable device and its inner assembly has been modeled several times to get the optimization. The optimization has been carried by Solidworks Professional + attachment Solidworks Simulation (machine dynamics for strength, stability, deformation systems dynamics, thermo elasticity). The weight of spectrometer is 12 kg. Energy resolution of spectrometer is less than 1.0 and 2.0 keV on energies 122 and 1332 keV correspondingly. Worsening of energy resolution of spectrometer, compare to equipment with liquid nitrogen cooling, generated by acustic vibration of Stirling electric cooler.

Fig.3. *Miniature HPGe gamma-spectrometer for space applications*

Miniature gamma-spectrometer for space applications is presented on Fig.3. Spectrometer is designed based on N-type HPGe detector with 30% efficiency registration, cooled by miniature Stirling electric cooler K508 (Ricor, Israel). Miniature electric cooler has cooling power 0.5W at the temperature 80K. The spectrometer weight is 2.9 kg, consumable power is less than 10W. We obtained energy resolution ~ 4 keV on energy 1,33 MeV, when Stirling electric cooler was switched off and ~ 5,9 keV when it was switched on. Energy resolution on energy 122 keV was found to be ~2,0 keV when electric cooler was switched off and ~ 4.0 keV when it was switched on. Testing results demonstrated significant influence of electric cooler Ricor K508 vibrations on developed spectrometer performance.

5. Conclusion

As result of computer design modern precise spectrometric equipment with innovative cooling systems for laboratory, field and space applications were developed. Innovative cooling systems were designed based on Stirling electrical coolers of various cooling power produced by different companies. Such innovative cooling systems can be the bases for creation of wide range of spectrometric equipment with HPGe detectors for many nuclear applications. Acustic vibrations of applied Stirling electrical coolers worsening energy resolution of HPGe detectors remain the biggest problem of precise spectrometric equipment based on such cooling systems until now. The next steps of development should lead to significant decreasing of such vibration influence. Solidworks application results in our project have demonstrated its optimal feasibility for the design of all systems of the developed spectrometric equipment.

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