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CRYO F—PHR AUTOMATED CRYOGENIC PLANT FOR CERTIFYING THE CHARACTERISTICS OF OPTICAL FILTERS AND PHOTODETECTORS

Introduction. *Defense technology industries rapidly growing, the problem of certification of optical filters and photodetectors becomes very relevant.*

Problem Statement. *Certification of the characteristics of optical filters and photodetectors at the metrological level is complicated by the fact that measurement results obtained in a series of consecutive experiments are practically incomparable.*

Purpose. *An ideal solution of the whole complex of problems is to create an automated cryogenic plant for certifying the characteristics of optical filters and photodetectors within the temperature range from 2.5 to 300 K, in single experiment.*

Materials and Methods. *The material of this research is a design of the cryogenic part of the plant. Its efficiency is determined by analyzing the thermal balance of modules and by the method of certification of filters and photodetectors in single experiment.*

Results. *CRYO F—PHR plant has been proposed, its cryogenic part consists of a functionally completed fully rotating cassette module with a holder of photoelectric sensors and a module with fully rotating cassette with filters. Each module has shields and is equipped with its own system for cooling and maintaining the desired temperature, as well as with current collectors and identifiers of the number of photodetector and filter in the operating position.*

Conclusion. *The plant design and the corresponding research methodology provide a solution to the whole complex of problems related to certifying the parameters of optical filters and photodetectors in the temperature range from 2.5 to 300K, at the metrological level, in single experiment and simulating their real operation in normal conditions. Due to advantages of the design and efficiency of certification in a single experiment, the proposed plant significantly surpasses the known analogs.*

Keywords: optical cryogenic plant, certification of the parameters of optical filters and photodetectors.

Research in the field of cryogenic instrument making for the creation of devices and testing of experimental techniques for studying the properties of optical materials and the development of optical filters and photodetectors made of them is of significant importance for the formation of science-intensive high-tech products. Studying the characteristics of optical materials and products made of them at cryogenic temperatures is one of the most complicated physical experiment problems.

Designing of cryostat configurations is based on a series of studies [1, 2]. It is essential to develop a method for calculating and creating integrated plants and cryostats with a long service life, which have been described in [3, 4].

The world leading institutes and corporations have designed and created many different configurations of liquid nitrogen and helium cryostats with controlled temperature for the study of

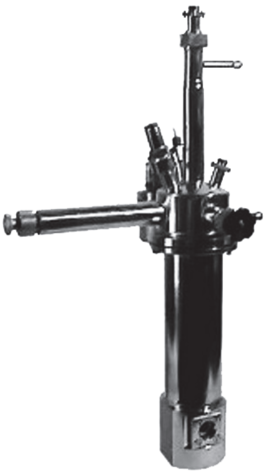

Fig. 1. Appearance of cryostats of *Cryostat KP* series

the characteristics of optical filters, photodetectors, as well as for laser and Mössbauer studies.

The development of small continuous-flow cryostats and the corresponding experimental technique was a decisive and significant stage; the subsequent breakthrough was the creation of small-size cryostats based on close-loop microcryogenic systems.

Thus, the three lines of studying and certifying the characteristics of optical filters and photodetectors have been subsequently formed in the cryogenic instrument making, in particular:

+ Plants based on liquid nitrogen or helium cryostats;
+ Plants based on small continuous-flow nitrogen or helium cryostats;
+ Plants based on close-cycle microcryogenic systems.

The majority of them has been developed by world leading companies and Ukrainian R&D institutes: *Oxford Instruments Limited*, *SHI Cryogenics* (USA-Japan), *JANIS RESEARCH COMPANY, INC.* (USA), *CryoMech* (USA), *Sumitomo Cryogenics Group* (Japan), Verkin Physical-Technical Institute of Low Temperatures of the NAS of Ukraine (Kharkiv), Institute of Physics of the NAS of Ukraine (Kyiv) and Galkin Donetsk Physical-Technical Institute of the NAS of Ukraine. Their developments have been described in [5—10], as well as in catalogs and on the official websites of the institutes.

Naturally, the configurations of cryostats in each area and the corresponding experimental techniques have both advantages and disadvantages and specific fields of application where they are successfully used. The author's research is focused on the development of small-sized cryostats for certifying the characteristics of optical filters and photodetectors. In this case, it should be noted that the experience gained while creating integrated plants based on liquid cryostats with a controlled temperature, as well as while conducting optical studies in the magnetic field of superconducting solenoids, the most notable of which have been presented in the abovementioned studies is of paramount importance in terms of elaborating the configurations and experimental methodology and improving the respective software. An unusual option of the combination of liquid and continuous-flow cryostat configurations for optical studies in the magnetic field of superconducting solenoid has been considered in [11]. This modular principle for creating an integrated plant has become widely used while forming many basic laboratories for research in longitudinal or transverse magnetic field. Each laboratory is created on the basis of a cryostat with a long service life, has an open-end warm hole with a built-in cryomagnetic system with a conventional solenoid or solenoid in the form of Helmholtz rings. Also, all laboratories are equipped with a small continuous-flow cryostat with several variable sample holders. In fact, the small continuous-flow cryostat of this type is an independent functional module that is freely inserted into a cryostat through the open-end warm hole. For replacing the sample, there is no need for defrosting the whole cryomagnetic system, since it is enough to defrost and to disassembly the continuous flow cryostat only, which is very convenient for users. In this case, the sample holder that is mounted on heat exchanger and mechanically fixed to it, can be replaced, if necessary. From the author's point of view, the approbation of methodology for measuring temperature during the dynamic process of temperature control [12—14] was a useful issue. The complete experiment automation was facilitated by the development of a device for measuring the level of liquefied helium based on a superconductive level sensor [15] and a microcomputer-based device for measuring and controlling temperature [16],

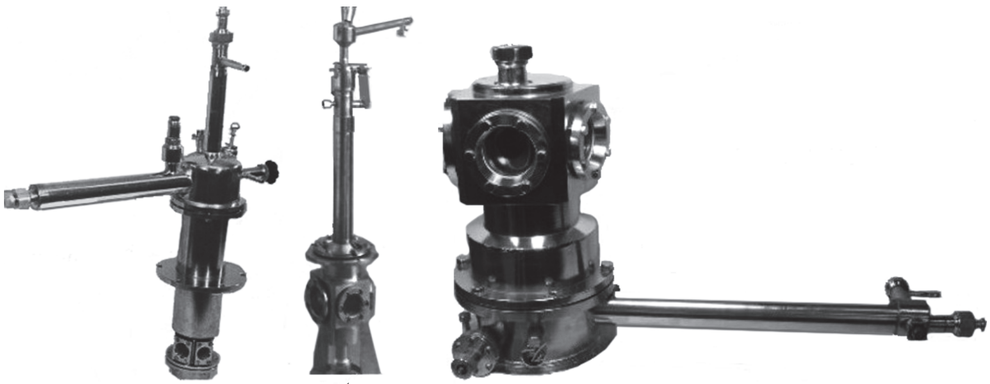

Fig. 2. Appearance of cryostats: *a*, *b*, and *c* models

which was further improved by the use of built-in microprocessor board.

When designing configurations for any of the specified types, to ensure the reliability of measurement results in terms of comparing similar optical characteristics of filters and photodetectors made of identical and, especially, of different materials, using similar technologies at different enterprises, has become a problem of particular relevance. The problem is that measurement results obtained in a series of successive experiments on one cryostat, on different equipment by different researchers, with the use of different techniques are difficult to compare, since in sequential experiments, the temperature of filters and photodetectors is measured based on the temperature of their holders. In precision measurements, it is very important to prevent a "light-shorting" of the photodetector from the surrounding structural elements. In such experiments, it is crucial to ensure a high vacuum that prevents depositing cryo-sediments on the surfaces of filters and photodetectors.

The first fundamental development of Galkin DonPTI of the NAS of Ukraine was the *Cryostat CP* series of cryostats protected with copyright certificate [17]. The appearance of the *Cryostat CP* cryostats is shown in Fig. 1.

The cryostats enable studying the transmission coefficient of filters in the range of temperatures from 2.5 to 300 K using liquefied helium or from 65 to 300 K using liquefied nitrogen. The cryostat has become the basis for equipping research facilities with serial optical spectrophotometers. On its basis, several structural modifications of cryostats have been designed to study the characteristics of single round and wedge filters, photodetectors, and radiating elements.

A significant progress in studying the characteristics of filters and mirrors within one experiment was to create small-sized cryostats with a controllable temperature, equipped with several warm windows on the outer casing and with a mechanism of partial rotation of the holder with a sample. A series of cryostats of this configuration has been presented on the website of *Oxford Instruments Limited*.

The appearance of cryostats developed by Galkin DonPTI of the NAS of Ukraine (models *a* and *b*) is shown in Fig. 2.

The next step in improving the configuration was developing the model *c* of small cryostats of the *Cryostat CPO* series (Fig. 2), which has been presented in the author's certificate [18] and in publications [19, 20]. These cryostats are equipped with input and output windows for leading beams and with a mechanism for partial rotation of the sample holder. This enables to study the coefficient of probe beam reflection by mirror at the three fixed angles: 12, 45, and 60°. At the same time, if a filter is fixed in the holder, it is possible to study both the transmission coefficient and

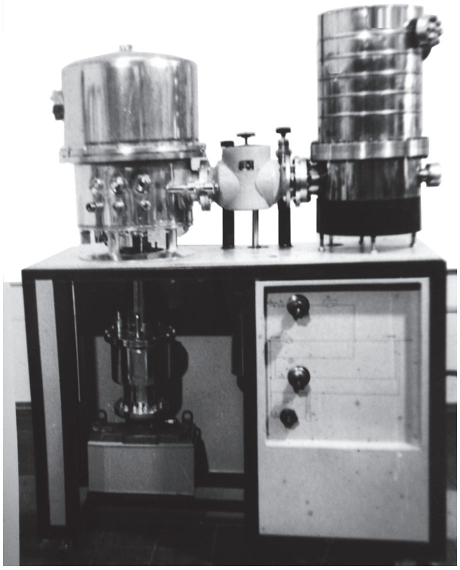

Fig. 3. Appearance of the cryogenic part of automated plant for spectrophotometric studies

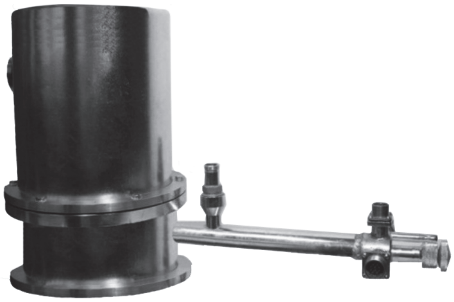

Fig. 4. Appearance of the cryogenic part of *CRYO F–PHR* plant

the coefficient of mirror reflection by probe beam filter within one experiment. This makes it possible to obtain important information for the development of relevant materials and to improve the technology for manufacturing optical filters made of these materials. The cryostats give means to study optical characteristics at sample temperature ranging within 65—300 K, with the use of liquefied nitrogen or within 2.5—300 K, with the use of liquefied helium.

In experiments using the cryostats of both series, the incident beam re-reflection is prevented by installing the incoming window at an angle of more than 10° to the beam axis. An important aspect is that a non-metallic filter with a relatively low thermal conductivity is installed in metallic holder and pressed to it with a moderate force. As a result, under a long-term irradiation of even a small filter, along its thickness and radius, there appear a few-degree temperature gradient. To reduce or to eliminate this effect, a shutter that is open only while irradiating the sample is set in the aperture of the protective screen. These problems have been thoroughly discussed in [20].

The development of a unique cryogenic automated plant for spectrophotometric studies [21] has marked a progress in this field. The cryogenic part of this plant is shown in Fig. 3. It should be noted that its properties are very important, inasmuch as the plant enables to measure within one experiment the filter's transmission or mirror reflection coefficient and the indicatrix of probe beam scattering by the samples (filter or mirror) for angles ranging from 0 to 90° (in both directions).

Despite the obvious advantages of the above developments, all of them are designed to study the characteristics of individual samples in a series of successive experiments in which the samples are replaced when the cryostat is depressurized.

The next step towards studying the characteristics of filters and photodetectors within one experiment was the creation of FPU cryostat. Its design has both many advantages and significant drawbacks. For instance, the holder of photodetector is cooled down with the help of a cold conductor and is not protected from heat released by neighboring elements, with its temperature not dropping below 10 K. Similarly, the filter cartridge is not protected from heat released by surrounding elements and is cooled by a cool conductor from its own cooled heat exchanger that, in its turn, is cooled by a reverse flow of a coolant from heat exchanger of the photodetector, with cartridge temperature not falling below 30 K.

The ideal solution to the problem of research and certification of the characteristics of optical filters and photodetectors was the creation of

CRYO F—PHR automated cryogenic plant. It was designed to solve the complex of problems related to improving the characteristics of existing and creating new optical materials, upgrading the technology for making filters and photodetectors, researching and certifying their parameters at the metrological level, within the range of temperature from 2.5 to 300 K, in the visible and infrared region of the spectrum, within one experiment. The plant has a modular structure and is based on the advantages of the aforementioned cryostat designs [22, 23]. This model has the final version of configuration and method of experiment for studying, within one experiment, the similar parameters of filters and photodetectors made of identical or different materials with the use of similar technologies, at different enterprises. Below, there is a description of the design of the cryogenic part of the plant and the method of experiment using the plant. The appearance of the cryogenic part is shown in Fig. 4.

The electronic part of the plant is made of universal details produced by various manufacturers and is completed at user's discretion. The software is also selected individually. However, it should be noted that both electronic and software parts have a two-level structure. The first level is a basic computer of the upper level, in which the program of experiment is formed and research data are accumulated and analyzed. The second level is the devices and their software for accepting and executing the upper-level computer commands. The scheme of the cryogenic part is shown in Fig. 5.

In general, these are two interconnected functionally completed modules with adjustable temperature, assembled in a single sealed housing with a variable, warm input window. The module (*1*) is a cartridge with a holder of photodetectors, which has its own drive (*12*) and are fully rotatable. The cartridge is surrounded by a split-design screen (*17*) kept at almost fixed temperature with the help of its own built-in passive heat exchanger (*8*, by reverse flow of coolant from the outlet of the cartridge heat exchanger (*18*). The

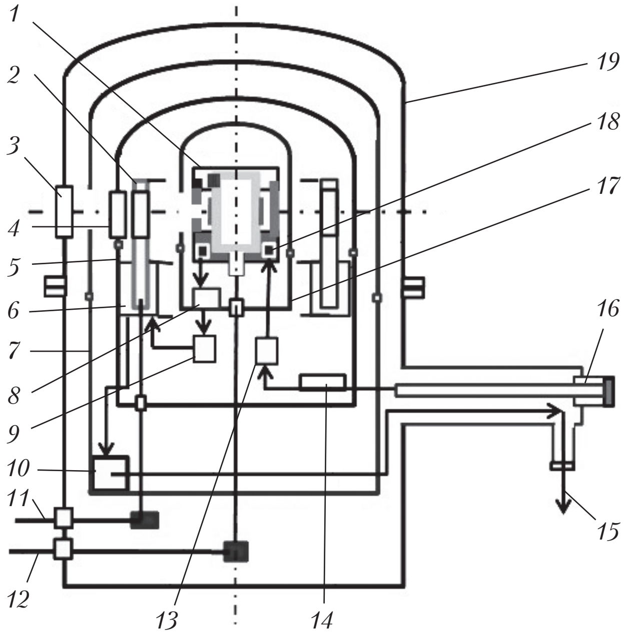

Fig. 5. Configuration of the cryogenic part of the plant: *1* — photodetector cartridge; *2* — filter cartridge; *3* — input window; *4* — shutter; *5* — bearing screen of the filter cartridge; *6* — heat exchanger of the second-stage of filter cassette; *7* — protecting shield of the filter cartridge; *8* — heat exchanger of the third-stage of photodetector cartridge; *9* — heat exchanger of the first-stage of filter cartridge; *10* — heat exchanger of the filter cartridge protecting shield; *11* — filter cartridge rotary drive; *12* — photodetector cartridge rotary drive; *13* — heat exchanger of the first-stage of photodetector cartridge; *14* — cryosorption pump; *15* — steam release duct; *16* — coolant feed duct; *17* — screen of the photodetector cartridge; *18* — heat exchanger of the photodetector cartridge; *19* — removable enclosure

module (*2*) has fully revolving filters and its own thermostat system with screens. The input window, photodetectors, and filters are replaced when the cryostat is depressurized.

The temperature control systems of the cartridge holder with photodetectors and that with filters are completely independent structurally and functionally. The temperature control system has a three-stage structure. The first stages are the main heat exchangers (*13*) of the cartridge of photodetector holder and the cartridge of filter with built-in heaters (*9*), which are designed to provide and to stabilize the preset temperature of coolant and to transfer it to the second-stage heat exchangers. The second stage consist of passive heat exchangers (*18*) of cartridges with photodetectors and those with filters (*6*), which are designed to thermostat the cartridges at given temperature. The third stage is represented by passive heat exchangers (*8, 10*) designed to hold the corresponding protective screens at a temperature similar to that of the corresponding working part (filter cartridges and cartridges of photodetector holder). Liquefied helium is supplied to the temperature control system using a feed duct (*16*) through overflow siphon while driving it using a vacuum pump or blowing out using an excessive pressure created in the Dewar vessel. The outlet of the output duct (15) is equipped with a heater that prevents unwanted icing and moisturizing of the duct. The cryostat is pre-evacuated using external equipment. During the experiment, high vacuum in the system, which prevents cryo-precipitation on the surfaces of photodetectors, filters, and windows, is ensured by a built-in cryosorption pump (14) cooled by a coolant flow (liquefied helium or nitrogen).

The filter cartridge module (*2*) shown in Fig. 5 consists of a cartridge with a set of filters located on the inner surface of the bearing screen (*5*) in the housing of its own heat exchanger (*6*) that is temperature-controlled by coolant flow from the heat exchanger (*9*). Each filter to be used in the next experiment is pre-mounted in the holder of suitable size and then into the cartridge. This configuration enables to insert simultaneously several filters of different sizes into the cartridge. The module is equipped with devices for identifying the number of the corresponding filter in the operating position. The bearing screen (*5*) is equipped with a shutter (*4*) and with its own passive heat exchanger (*6*). This screen is used for mechanical fixing of the cartridge with filters, which can be rotated, temperature-controlled, and protected against heat released by neighboring structural elements. At the same time, this screen acts as a shield (*17*) protecting the cartridge with photodetectors from heat released from neighboring structural elements. Filters with different bandwidth can be replaced in the operating position, in the course of experiment, fully rotating the cartridge in both directions with the help of its own drive (*11*). The coolant is fed to the first-stage heat exchanger (*9*) with a built-in heater of the temperature control system of the cartridge with filters through the duct from the output of heat exchanger (*8*) of photodetector cartridge. The screen (*5*) is surrounded by its own shield (*7*) that is temperature-controlled using the heat exchanger (*10*), by coolant reverse flow from the passive heat exchanger (*6*). Having passed through the heat exchanger (*10*), the reverse gas flow is led outward.

The scheme of the cartridge module with photodetector holder is shown in Fig. 6. The module consists of a housing (*6*) with a built-in passive heat exchanger (*7*), its cover (*1*), a built-in reversible holder (*3*) with photodetectors (*4*) and its own temperature control system with screens. The cover (*1*) is equipped with current collectors and devices (*2*) to identify the corresponding photodetector number in the holder in the operating position. The photodetectors are located on the holder flanks. The shutter (*5*) is located at the inlet opening of the cartridge case to adjust the gap for probe beam transmittance. The built-in passive heat exchanger (*7*) is intended for keeping fixed temperature of the holder with photodetectors. The coolant at a required temperature is fed to the heat exchanger (*7*) from the first-stage active heat exchanger of the photodetector temperature control system. The cartridge case acts as a heat exchanger of the holder with photodetectors and its shield that protects them from heat inflows and overheating as well as from light striking from the surrounding elements. This protects the cartridge from heat inflows and the photodetectors from overheating, which ensures that the photodetector temperature is equal to the measured temperature of the cartridge. The full revolution of the holder in both directions is realized using a drive unit (*8*).

Within one experiment, the plant can operate in two interconnected modes — the certification of characteristics of cold filters and the certification of characteristics of cold photodetectors. On the casing, a filter with maximum bandwidth in the range of the probe beam is installed as input window. The filter cartridge contains a set of filters, the characteristics of which are studied. In order to determine the comparative characteristics, the set is advisable to contain filters made of the same material at different times by the same and by different manufacturers using identical technology, several filters from each manufacturer. Also, it is advisable to place nearby a set of filters made of other material, by other manufacturers, at different times, using an alternative technology, several filters of each type. In the cartridge cells, there are installed test filters with preliminarily certified features. In the aperture of the bearing screen of the filter cartridge there is placed a standard shutter. Similarly, a set of photodetectors, the characteristics of which must be certified, are fixed in the holder of cartridge with photodetectors. This set is advisable to contain photodetectors made of identical material, at different time, by the same and by different manufactures, using their own technologies, several detectors from each manufacturer. Also nearby there are placed photodetectors made of other materials, by other manufacturers, using alternative technologies, several photodetectors of each type. At the same time, several test photodetectors with preliminarily certified characteristics, which are suitable for given purpose are installed in the holder. If a cell with a standard shutter is installed in the filter cartridge in operating position, it is possible to consecutively study the characteristics of all photodetectors within the whole bandwidth of the warm input window. The adjustable aperture of photodetector cartridge shutter enables studying the known effect of increasing the sharpness of sight by reducing the optical gap. In addition, the cartridge has a special control position for consecutive installation of photodetectors in such a way as to prevent their exposure to radiation. This enables to study the noise characteristics of all photodetectors and the whole measuring channel.

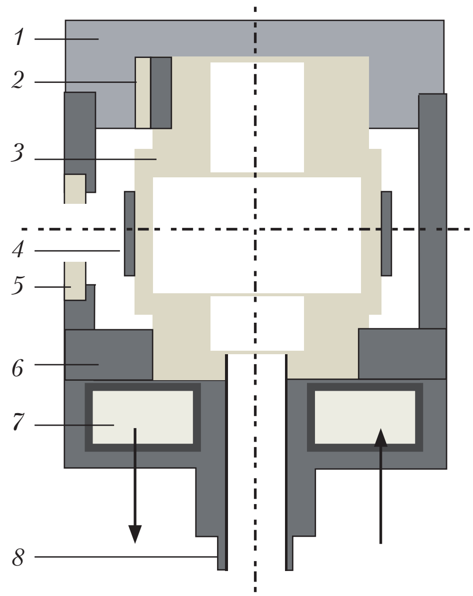

Fig. 6. Configuration of the cartridge with photodetector holder: *1* — cartridge cover; *2* — device of photodetector number indicator; *3* — holder with photodetectors; *4* — photodetector; *5* — shutter; *6* — cartridge case; *7* — passive heat exchanger; *8* — rotary drive

The *CRYO F—PHR* cryogenic automated plant is configured as follows: its cryogenic part has a modular structure. It consists of the functionally completed cartridge module with a movable holder of photodetectors and the fully rotatable filter cartridge module. This configuration enables independent consecutive replacement of filters and photodetectors in the operating position and independent control of their temperature. The method for automated control of experiment that has been implemented with its help makes it possible to carry out longstanding and large-scale studies according to established program. Due to the mentioned properties of the plant configuration and the experiment technique, it is possible to certify, at the metrological level, the characteristics of the filters and ultra-sensitive photodetectors with an ultra-high resolution in identical conditions of one experiment, within the range of temperature from 2.5 to 300 K, for the whole spectral range of the probe beam.

If necessary, the cartridge with photodetectors can be cooled down to 1.5 K. Also, should the need arise, the plant can be reconfigured to run on liquefied nitrogen at a temperature of 65—300 K.

At the same time, the above properties of the plant give solutions to the whole complex of problems related to studying the comparative characteristics of materials and technologies for the manufacture of filters and photodetectors. As a result, it enables the further improvement of materials and manufacturing technology for creating photodetectors and filters with enhanced parameters.

The advantages of the plant configuration and the experiment method are important for addressing the tasks of defense industry in terms of the selection and metrological certification of the parameters of standard specimens of filters and ultra-sensitive photodetectors with an ultra-high resolution. In this aspect, during this experiment, it is important to repeatedly check the characteristics of the filters and photodetectors and to select the most promising filter-photodetector pairs. As a result, it enables to simulate the real operation of both single filters and photodetectors and their selected pair in the regular mode and to form their metrological certificate for the whole range of reception of a useful radiation signal.

It should be noted that for solving more limited tasks, two more modifications of the plants have been designed, with the configuration of cryostats, respective experiment techniques, and software simplified significantly.

Firstly, this is the plant for certification of the characteristics of a batch of filters. The configuration is simplified due to the fact that instead of the rotating holder of photodetectors in the cassette (Fig. 6), only a fixed holder (*3*) with a test photodetector (*4*) is provided. Accordingly, the plant has no rotary drive of the holder of photodetectors and devices for indicating the number of photodetector in the operating position, so the experiment technique and software are simplified as well.

The second one is the plant for certification of the characteristics of the batch of photodetectors. The design is simplified due to the fact that instead of the rotatable filter cartridge (*2*) (Fig. 5), the plant has only a fixed holder with an aperture on the bearing screen (*5*) in the heat exchanger (*6*). If necessary, a test filter may be installed in this aperture. Accordingly, there is no need to rotate the filter cartridge and devices indicating the number of filter in the operating position, therefore, the experiment technology and software are simplified.

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КРІОГЕННА АВТОМАТИЗОВАНА УСТАНОВКА ДЛЯ АТЕСТАЦІЇ ХАРАКТЕРИСТИК ОПТИЧНИХ ФІЛЬТРІВ ТА ФОТОПРИЙМАЧІВ «CRYO F—PHR»

Вступ. Стрімкий розвиток оборонних галузей техніки зумовив суттєву актуальність проблем атестації оптичних фільтрів та фотоприймачів.

Проблематика. Атестація характеристик оптичних фільтрів та фотоприймачів на метрологічному рівні є проблемою, оскільки результати вимірювань, отриманих в низці послідовних експериментів, взагалі порівняти практично не можливо.

Мета. Ідеальним рішенням сукупності зазначених проблем є створення кріогенної автоматизованої установки для атестації характеристик оптичних фільтрів та фотоприймачів в діапазоні температур 2,5—300 К в умовах одного експерименту.

Матеріали й методи. Матеріалом розробки є конструкція кріогенної частини установки, ефективність якої визначається аналізом теплового балансу модулів та методикою атестації фільтрів та фотоприймачів в умовах одного експерименту.

Результати. Розроблено та охарактеризовано установку «CRYO F—PHR», кріогенна частина якої виконана з функціонально завершених модулів касети з тримачем фотоприймачів, здатного до повного обертання, та модуля касети з фільтрами, також можливістю повного обертання останньої. Кожен модуль з екранами захисту обладнано власною системою охолодження та утримання заданої температури, а також струмоз'ємниками й пристроями ідентифікації номера фотоприймача та фільтра в робочому положенні.

Висновки. Конструкція установки та відповідна методика досліджень забезпечують рішення всього комплексу проблем атестації характеристик оптичних фільтрів та фотоприймачів в діапазоні температур 2,5—300 К на метрологічному рівні в умовах одного експерименту та імітацію їхньої реальної роботи у штатному режимі. За наявними перевагами конструкції та оперативністю атестації в умовах одного експерименту запропонована установка суттєво перевищує відомі аналоги.

Ключові слова: установка кріогенна оптична, атестація характеристик оптичних фільтрів та фотоприймачів.

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КРИОГЕННАЯ АВТОМАТИЗИРОВАННАЯ УСТАНОВКА ДЛЯ АТТЕСТАЦИИ ХАРАКТЕРИСТИК ОПТИЧЕСКИХ ФИЛЬТРОВ И ФОТОПРИЁМНИКОВ «CRYO F—PHR»

Введение. Стремительный рост оборонных отраслей техники обусловил существенную актуальность проблем аттестации оптических фильтров и фотоприемников.

Проблематика. Аттестации характеристик оптических фильтров и фотоприемников на метрологическом уровне является проблемой, так как результаты измерений, полученных в ряде последовательных экспериментов, сравнить практически невозможно.

Цель. Идеальным решением совокупности определенных проблем является создание криогенной автоматизированной установки для аттестации характеристик оптических фильтров и фотоприемников в диапазоне температур 2,5—300 К в условиях одного эксперимента.

Материалы и методы. Материалом разработки является конструкция криогенной части установки, эффективность которой определяется анализом теплового баланса модулей и методикой аттестации фильтров и фотоприемников в условиях одного эксперимента.

Результаты. Разработана и охарактеризирована установка «CRYO F—PHR», криогенная часть которой выполнена из функционально завершенных модуля кассеты с полностью вращаемым держателем фотоприемников и модуля полностью вращаемой кассеты с фильтрами. Каждый модуль с экранами защиты обустроен собственной системой охлаждения и поддержания заданной температуры, а также токосъемниками и устройствами идентификации номера фотоприемника и фильтра в рабочем положении.

Выводы. Конструкция установки и соответствующая методика исследований обеспечивают решение всего комплекса проблем аттестации характеристик оптических фильтров и фотоприемников в диапазоне температур 2,5—300 К на метрологическом уровне в условиях одного эксперимента и имитацию их реальной работы в штатном режиме. По существующим достоинствам конструкции и оперативностью проведения аттестации в условиях одного эксперимента предложенная установка существенно превосходит известные аналоги.

Ключевые слова: установка криогенная оптическая, атестация характеристик оптических фильтров и фотоприемников.