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Metrological support of satellite-borne UV-spectrometry using a backscattering technique

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Abstract. Methods and physicotechnical facilities for examination, calibration and metrological testing of the main power spectral characteristics (total spectral sensitivity, scattered stray radiation, dynamic range) of the vehicle-borne ozone UV spectrometers in the spectral range 250-350 nm are considered.

Keywords: spectrometer, space ozonometry, power spectral sensitivity, metrological workbench, standard UV source.

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1. Introduction

Optical and physical schemes of ozonometers for planetary mapping of the total content and vertical profile of ozone in 250-350 nm spectral range by backscattered dissipation method are double diffraction monochromators on spherical diffraction gratings. Such spectrometers were operating at “Kosmos”, “Meteor”, “Meteor-Nature”, “Resource” series of the Earth artificial satellites [1–3]. Peculiarities of their positioning and gauging (verification) as non-typical measuring tools [4, 5] were described elsewhere [6].

Measuring of central wavelengths and spectral separation power of spectrometer were performed by constructing involution contour of apparatus function of spectrometer with close to delta-function contour of spectral line with variable wavelength:

$$I(x')=\int_{-\infty}^{+\infty} w(x)A(x'-x)dx, \tag{1}$$

where $I(x')$ is illumination distribution at S_{out} plane along dispersion line; $w(x)$ is illumination distribution in the contour of spectral line at the output aperture; $A(x'-x)$ is the apparatus function.

If $w(x)$ is delta-function, then involution contour coincides with apparatus function. Narrow spectral interval was formed by bench-monochromator SDL-1 from continuous spectrum source. Spectral separation power of spectrometer is determined as half-width of apparatus function. Block-diagram of the bench metrology complex facility is shown in Fig. 1.

Apparatus function of ozonometric spectrometer, half-width of apparatus function of the latter is the difference between half-width of the contour and half-width of SDL-1 apparatus function.

Energy spectral sensitivity (ESS) is measured by way of recording output voltage which is the response of electronic circuit of spectrometer to radiating its Sin from UV source with continuos spectrum and with known spectral density of energy brightness (SDEB). ESS is defined as a proportion coefficient in relation to each spectral channel (j = 1, ..., 12):

$$U(\lambda)=SjB(\lambda), \tag{2}$$

where $U(\lambda)$ is voltage of the output signal of spectrometer; $B(\lambda)$ is SDEB of the radiating surface of test source overlapping the vision field.

Spectral brightness value $B(\lambda)$ is obtained by interpolation of values $B_{at}(\lambda)$ of the lamp TRU-1100-2350 given in meteorological certificate for average brightness of its strip.

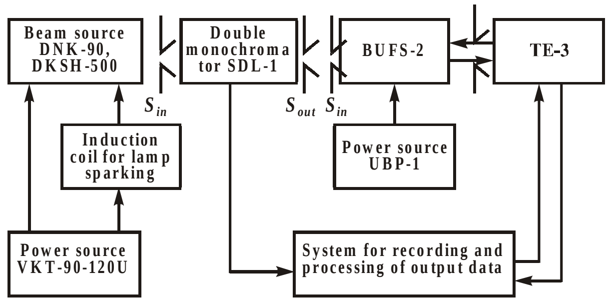

Fig. 1. Block-diagram of complex facility for research and measurement of central wavelength, spectral separation power, energy spectral sensitivity of UV spectrometer. PU DNK, CNP-40, UBP-1 – power sources for lamps DNK-90, TRU-1100-2350 and spectrometer recpectively; TE-3 – special control-verification equipment.

2. Absolute energy spectral sensitivity (AESS)

For AESS calibration at small radiation there were used certified “point“ gas tube lamp DNK-90 and tungsten strip filament lamp [7, 8]. With the method of remote drawing source there were used dissipating plates made of milky glass MS-20, ONS-1, or metal plates covered by barium sulfuroxide.

At calibration based on point source, relation between output spectrometer signal voltage and operational radiation source is determined by the formula in which vision field sensitivity is considered:

$$Uout(\lambda,\phi,\psi)=B(\lambda)\frac{\sigma_\partial}{r^2}\tau'(\lambda)P(\lambda,\phi,\psi), \qquad (3)$$

where ϕ, ψ are angular coordinates of the source within spectrometer vision field; $B(\lambda)$ is spectral density of energy brightness of radiating body of the source; σ_∂ is the area of radiating body surface; $\tau'(\lambda)$ is transmission coefficient of spectrometer. Transmission function of spectrometer $P(\lambda)$ describes its spectral sensitivity and is determined by the formula:

$$P(\lambda)=S_1 h_1 \tau(\lambda)\delta\lambda S_a(\lambda)K(U_a), \qquad (4)$$

where S_1, h_1 are the width and height of input aperture, $\delta\lambda$ is spectral discrimination power of monochromator; S_a is spectral anode sensitivity of photoelectric multiplier; $K(U_a)$ is amplification transfer coefficient.

Measurements are made for fixed source positions in coordinates (φ_i, ψ_j) in the plane perpendicular to optical axis. Sensitivity, i.e. transmission function along the vision field for each work channel is determined by the formula:

$$\overline{P}(\lambda,\phi,\psi)=\frac{1}{\frac{\sigma}{r^2}\tau'(\lambda)B(\lambda)}\frac{1}{\Delta\Phi\Delta\Psi}\int_\phi\int_\psi U_{out}(\lambda,\phi,\psi)d\phi\, d\psi, \qquad (5)$$

where $\Delta\Phi$, $\Delta\Psi$ are lamp shifts within vision field in angular coordinates. Similarly to (5) we can put down a formula for drawing source. Using the LLS-07 lamp, calibration could be done only for small radiation flows. In the middle of working spectral interval the DNK-90 lamp is used.

Average vision field sensitivity for drawing source could be measured if brightness distribution of dissipating plate is known along the vision field. Calibration is performed by methods similar to those described in [9;10].

Minimum radiation power which could be measured by spectrometer with established accuracy is called liminal sensitivity. Existence of such lower margin for sensitivity is the result of noise fluctuations in photomultiplier and in electric signal amplification and transfer circuits as well as parasite disipated radiation within a double monochromator. This sensitivity margin is determined by the optic signal value at Sout of monochromator at which signal-to-noise ratio at spectrometer output equals 1. Noise level defines sensitivity margin of the device, precision of measurements and actual spectral separation power. For big values of output optic signal there also exists limitation of signal measurement precision due to volumetric charge formed in multiplier anode proximity; as a result on photocathode liniarity of energy characteristics of photo multiplier is distorted.

To measure dynamic range, between radiation source and input spectrometer aperture a set of certified neutral NF-6, NF-12 filters is installed with the required scale of their transmission coefficients available [10]. Spectrometer output signal series are averaged for a given measurement with assessment of mean square deviation. During measurements of dynamic range, the same as during sensitivity calibration, it is important to provide the unchanged portion of parasite dissipated radiation in spectrometer relative to its total flux.

3. Synchrotron radiation (SR)

Synchrotrons and accumulating rings are radiating in any spectral range. Spectral energy characteristics for SR, same as for absolute black body, (ABB) are estimated very precisely. However in accelerators at particle energies higher than 1 GeV the level of UV radiation is low at the background of powerful X-rays causing fast element degrading which n its turn leads to sharp transmission coefficient decrease. Besides in high-energy accelerators due to the lengthy SR channel, primary SR flow at comparator’s output is low and for near UV does not exceed the radiation power of a 30-Watt Deiterium lamp.

Spectral density of energy brightness of Deiterium lamp in the near UV range was first determined on DESY synchrotron in Hamburg at total mean square deviation of measurement being 4%. Such high precision was ensured by selection of optimum circuit for optic comparator based on relative SR spectrum use with absolute referencing to ABB in optic range. Seven standard facilities were made on SR channels for measurement of absolute spectral characteristics of UV radiation, spectral efficiency of diffraction gratings and mirrors in 10–400 nm range. Standard ambiguity of spectral density unit restoration for illumination power in near UV radiation equalled 0.07%, whereas standard ambiguity for restoration of value of spectral density unit of radiation power for near ultraviolet was 0.3%. Standard ambiguity of transfer of spectral density of energy brightness (SDEB) unit value in 200–400 nm range to secondary standards - Deiterium lamp and filter radiometer - equalled 2% and 1%, respectively. Thus the error of standard secondary sources ceased to be limited by the error of primary standard source and was defined by their own unstability.

It is extra costly to maintain synchrotron solely for spectroradiometry, thus development of inexpensive specialized standard UV SR sources has started with the use of strong magnetic field to generate UV SR at small radius of electron orbits in dozens of mm and low energy of accelerated particles of the order of 60 MeV. Such design provides for radiation safety of laboratory SR source.

To transfer from SR source to standard UV receivers in the SDEB transfer scheme, monochromatic Deiterium lamp serves as an operational standard with miniature monochromator and a set of interferential filters.

The problems of impact of different polarization degrees of monochromatic source and synchrotron are solved by rotating monochromatic source around its optical axis at no vacuum disturbance.

4. Conclusions

Contemporary methods and technical means allow to perform calibration of spectral power sensitivity of spectrometers in near UV range of the spectrum with precision up to 10%.

Specific character of UV spectroscopy essentially differs from the accumulated spectrometric experience in visible spectrum range. All processes are strongly complicated by that UV radiation is dangerous and not visible. It is difficult to create special metrologic stands attested as non-standard complex facilities.

It is possible to increase precision of ozonometric information only if quasi-point sources and drawing plane standard UV sources specially developed for ozonometry needs are available. Existing operational samples of UV emitters require individual examination of their stability.

The most important issue in improving fundamental UV metrology is increase of precision in SDEB reproduction of exemplary sources of first order and their direct comparison with the national standard. To ensure radiation precision of 1–2 % needed in state-ot-the-art UV ozonometry, it is necessary to execute scale referencing with 0.3–0.5 % precision.

Simultaneous increase in precision and spatial separation capacity of ozonometric measurements is possible provided complex solution to problems of elevation in UV sensitivity of UV receivers is found, same as increase of input aperture; creation of multichannel systems; metrologic application of synchronous UV radiation; development of new concepts in spectrometric systems and creation of specialized technological and component basis.

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