BROAD-BAND LONG-FOCUS MIRROR OPTICAL SYSTEM FOR INFRARED DIAGNOSTICS

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Abstract

The characteristics of special optics [1] and their use in experiments with IR synchrotron radiation are exemplified by a diagnostics of ring bunches in the compressor at JINR. For the diagnostics of ring bunches of electrons, which use the IR spectrum of synchrotron radiation, the windows to guide radiation out of the accelerator chamber and two variants of long-focus broadband optical channels to focus IR radiation on the sensitive elements of the detector unit were designed and constructed. The difference between the variants is that lenses are used as an objective in one and as spherical mirrors, in the other.

In our article we describe the Mirror Optics.

If a detector should not be exposed to the electromagnetic and radiation fields of an accelerator (this especially relates to high-sensitive detectors with a filled Dewar flask), a special optical channel with the active reflective elements (spherical mirrors) pro-viding the broadband efficiency of the whole channel and allowing for synchrotron radiation to be recorded in a spectral range of Δλ ~ 0.3–40 μm was designed and constructed.

One of the chief requirements necessary for multi-cell detectors is that they are screened from pulsed electromagnetic and radiation disturbances of an accelerator. The main source of disturbances is a magnetic field of an accelerator. In order to eliminate the influence of disturbances, a position-sensitive detector where the image of a source is focused at a scale of 1 : 1 should be set no less than two meters from this source. This required an optical channel with long-focus elements to be design.

The spectral broadband efficiency of a tract is implemented by using the reflecting elements (mirrors) only. The reflecting elements were made of the optical glass, had the given curvature, and were coated with a layer of silver evaporated in vacuum. As the temperature and humidity in the laboratory is constant, the evaporated metal was not coated with a protective cover, because it would increase the losses in the optical channel. The short-wave cut-off of a spectral range is determined by the quality of the reflecting surfaces and by a material of coating. The long-wave range is limited by diffraction, and the edge depends on the values of an aperture ratio of a system forming the image. In addition, the long-wave cut-off is connected with the limited number of windows to guide synchrotron radiation out of an accelerator and depends on the sensitivity of detectors.

A principal optical diagram of a mirror channel is shown in Figure 1.

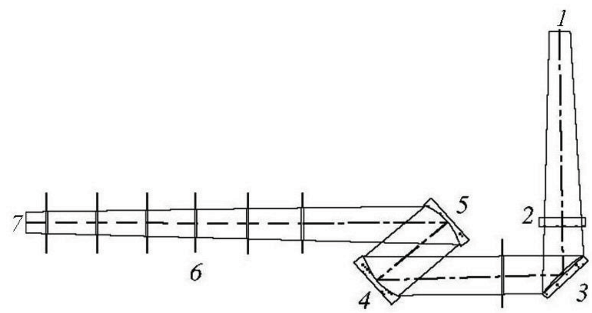

Figure 1: Principal optical diagram of a mirror channel.

As the synchrotron radiation is emit ted into a narrow cone, not all of the electron ring but only its cross section normal to the optical axis of a system is apparent. The synchrotron radiation from the minor cross section (~1/60 part) of an electron ring 1 is extracted from the vacuum chamber of the compressor through IR window 2 in close vicinity to which plane mirror 3 is positioned to deflect the divergent beam of the synchrotron radiation. The first spherical mirror 4 is set so that the object would be in its focus, for the diverging radiation beam would be transformed into the parallel one relative to the optical axis, and thus enabling it to transport it to any distance. The image of an observed object (the cross section of an electron bunch, in our case) is formed in focal plane 7 of second mirror 5 where the sensitive surface of a detector unit is situated. A focal length of both mirrors is the same and equal to 1850 mm. The elements 4 and 5 are concave spherical mirrors, the focal planes of which coincide with the investigated object and its image, which moves along the surface of a position-sensitive multicell photodetector during the compression of an electron ring in an accelerator. Diaphragms 6 limit the influence of glares and stray light.

Deflecting mirror 3 turns the optical axis by 90°. Its surfaces initially had a cylindrical form to correct the spherical mirrors for astigmatism due to oblique beams. Later, in order to obtain optimal image quality, the optical system was analyzed, with the help of computer, frequency-contrast characteristics. It was shown that the best image quality gave plane, not cylindrical, deflecting mirror. The influence of astigmatism seemed to be less

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than that of other aberrations (spherical, coma, etc.) of the optical system. The corresponding frequency-contrast characteristics are shown in Figure 2 and 3.

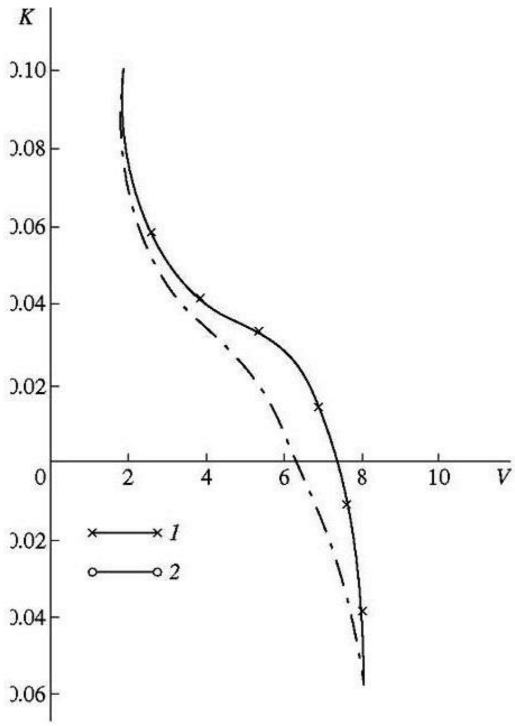

Figure 2: Frequency-contrast characteristic of an optical channel with a deflecting mirror: (1) in the center of the field of view, (2) at the boundary of the view field.

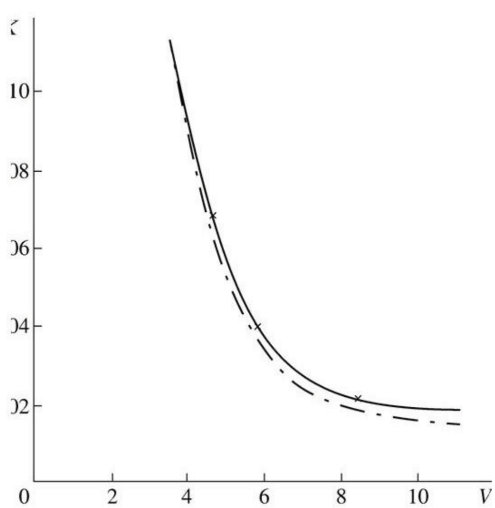

Figure 3: Frequency-contrast characteristic of an optical channel with a deflecting mirror.

Spatial frequency ν, the number of lines per mm in the image, is plotted on the abscissa, and the relative change of image contrast compared with the contrast of object k is laid off as an ordinate. It can be seen from the figures that if a level of 0.02 (the visual resolution) is accepted as the lower limit of the image contrast, the resolution of the optical system in the meridian sys tem plane, the plane of the drawing was 5–6 lines/mm for a cylindrical mirror. The results of computation showed that this is the best resolution of the mirror.

When a plane mirror was used as mirror 3, the resolution was 9–10 lines/mm.

Upper curves (crosses) in Figure 2 and 3 refer to the center of the field of view, the lower ones (dots), to the boundary of the view field.

The photographic resolution of the system is shown in Figure 4.

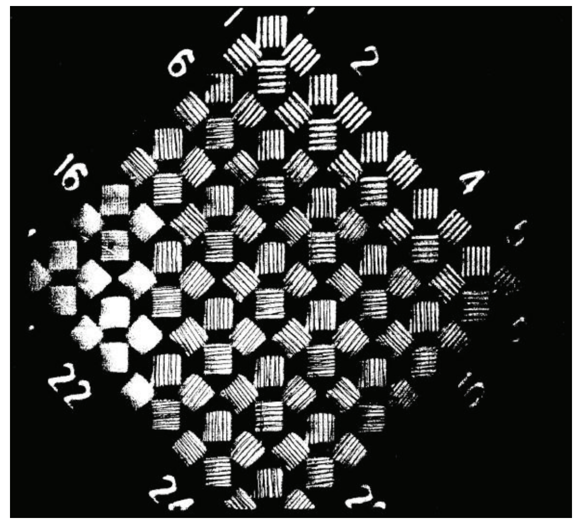

Figure 4: Photographic resolution of the system.

The main technical data and characteristics of the wide-range optical mirror channel are as follows:

The field of application: the systm works in the UV and IR ranges of spectrum (Δλ ~ 0.3–40 μm), which is limited only by mirror coating and diffraction.

Focal length of the spherical mirrors is f = 1850 mm.

Aperture ratio is 1 : 21.

Magnification is 1 : 1.

Photographic resolutions are:

(i) 7^{-1} mm in the focal plane of the tract;

(ii) 7^{-1} mm in points shifted at ±5 mm; 7^{-1} mm, at ±10 mm; 7^{-1} mm, at ±15 mm; and 5^{-1} mm, at ±20 mm.

The field of view in the plane of an object is ∅34 mm.

The overall dimensions in mm are 2000 × 360 × 370.

The spherical mirrors can be displaced along the optical axis of the optical mirror channel by ±70 mm and rotated ±5° around the intersection point of the mirror surface with the optical axis. The plane mirrors can be rotated ±5°. In order that the focal surface of a detector unit (e.g., photographic camera) perfectly coincided with the focal surface of the second spherical mirror, a ±70 mm aligning interval is provided at the optical axis for the photodetector. The absence of chromatic

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aberration allows the channel to be adjusted with visible light.

One of the advantages of the chosen design is a low radiation loss of the optical channel, which is less than 4% owing to the high reflectance of silver in a spectral range of 0.3–40 µm and the absence of protective coating on the reflecting surfaces. The intensity losses of synchrotron radiation are mainly caused by the materials of an IR window (to 40%) and a detector. All the elements and units of the channel construction are made of nonmetallic, nonconducting, and nonmagnetic materials.

A picture of the mirror system is represented in Figure 5.

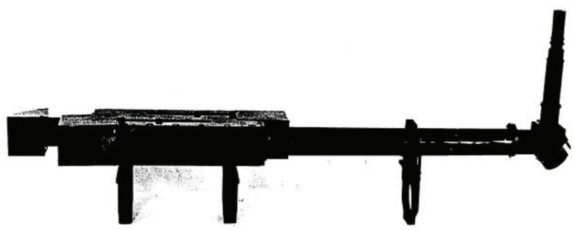

Figure 5: Picture of the mirror system.

The optical tract, in the form of a separate unit, is mounted with tube support to a concrete wall or on a concrete cube, i.e., it is fixed on the rest or base that is free of vibrations.

The channel can be used with various types of IR and non-cooled photodetectors, but mainly with the mosaic photo detectors from silicon, indium antimonide (working temperature of T_w = 77 K), lead selenide (T_w = 250 K), and pyroelectrics. As the mirrors reflect radiation in a wide range of the spectrum, the channel can be also used in the UV and visible ranges of spectrum. The optical channel has the ability to work in the visible and IR ranges of spectrum with a SFR high-speed camera. Photoresistors cooled by liquid nitrogen can be adapted for the channel to record radiation in an IR range. In Figure 5, such a cooled detector is discerned at the exit of an optical tract.

An optical mirror channel was used when synchrotron radiation was first detected and recorded in an accelerator-compressor. The intensity (i.e., the number of electrons) in the first experiments was so low and the spectrum so indefinite that without optical amplification and the ability to record it in a broad range of wave-lengths, the detection of synchrotron radiation would have been impossible.

REFERENCES

[1] A. A. Mal'tsev and M. A. Mal'tsev, Technical Physics, Vol. 47, No. 6, 777 (2002).

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