Monitoring of a Photon Beam

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Abstract—The characteristics of systems based on Cherenkov counters for monitoring the intensity of a bremsstrahlung photon beam at the S-25R Pakhra accelerator of the Lebedev Physical Institute are presented.

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INTRODUCTION

A quasi-monochromatic electron calibration channel based on a bremsstrahlung photon beam has been created for testing and calibrating detectors and electronic equipment at the Pakhra electron synchrotron of the Lebedev Physical Institute (LPI). The monitoring of the photon beam, including measurements of the beam intensity and profile at various points of the beam transport line from the internal target of the accelerator to the converter in front of the main SP-57 spectrometric magnet, should be performed using Cherenkov counters based on solid-state radiators [1].

Monitoring of photon beams in a similar way was carried out earlier in [2–4]. Hodoscopic systems containing thin optical fibers based on SiO2 were used to monitor high-intensity photon beams with energies of tens of megaelectronvolts.

The specific features of the application of Cherenkov radiation for monitoring a photon beam are:

1. the low efficiency of the interaction of photons with matter in comparison with the interaction of electrons (less by ~10^3–10^4 times), which makes it possible to use a Cherenkov counter for monitoring photon beams in a wide range of their intensities of 10^6–10^10 γ/s (this is a non-disturbing monitoring system with which the photon beam is practically unchanged [4]);
2. the short time of Cherenkov-pulse formation in a radiator, e.g., relative to a scintillation pulse (by ~3–5 times), which is necessary at a high beam intensity;
3. the higher radiation hardness of a fused silica or Plexiglas radiator in comparison with a scintillator (polystyrene).

The most important issue is the proportional dependence of the number of Cherenkov photons on the number of e^-e^+ pairs converted in the counter substance, which makes it possible to compare the number of detected e^-e^+ pairs to the number of photons transmitted through it and to the total intensity of the photon beam [5, 6]. The estimate shows that when a photon beam with an intensity of ~10^9 γ/s passes through a 1-cm-thick Plexiglas layer, the number of Cherenkov photons N_{CP} is from ~5 × 10^7 to 5 × 10^8 photons/s (in view of the passage of two particles, i.e., an electron–positron pair), which is fully acceptable for creating a monitoring system [4, 6, 7].

TOTAL-INTENSITY MONITORING

The investigations were carried out on the bremsstrahlung photon beam line of the Pakhra LPI accelerator, using which a calibration quasi-monochromatic beam of secondary electrons is produced (Fig. 1). The bremsstrahlung photon beam produced by a spill of electrons in the ring onto the inner target is formed by lead collimators K₁–K₄ and the SP-3 cleaning magnet after it leaves the accelerator chamber 1. The beam is then transported in air to the converter 7, which is located directly on the SP-57 magnet. The magnet separates the electrons that are escaping from the converter according to their momenta. The secondary electron beam is formed at angle ϕ = 36° relative to the initial photon trajectory using collimators (auxiliary collimator 9 and K₄) and scintillation counters S₁–S₄, and А (anticoincidence counter).

The system for monitoring the photon beam is divided into two subsystems: the first subsystem (the beam monitor 4) determines the total photon-beam intensity at the beginning of the transport beamline in front of collimator K₃ by means of a 30-mm-diameter hole; the second subsystem, which includes the scin-
ator directly in the beam behind collimator
in the second experimental hall of the Pakhra acceler-
the beginning of the transport beam line. It is located
counter, monitors the intensity of the photon beam at
the horizontal plane in front of the converter
determines the photon-beam intensity and position in
located at the edge of the SP-57 magnet poles [1].
that have detected the conversion of an
tors

tomultiplier tubes (PMTs)
which is viewed from its two ends by two FEU-85 pho-

ard Pulse Counter unit of the CAMAC system for
itor the photon-beam intensity, or to the input of a stan-

The coincidence signals from the monitor arms were
fed to a frequency meter, which was used to visually mon-
tor the photon-beam intensity, or to the input of a stan-
dard Pulse Counter unit of the CAMAC system for
record the signals into the computer memory.

The photon-beam monitor made it possible to
control both the intensity of each electron-beam spill
onto the internal target of the accelerator and the total
beam intensity over a preset time.

THE CHERENKOV HODOSCOPE

The CH has been designed to monitor the “cur-
rent” intensity and position of the photon beam at the
converter in front of the SP-57 magnet, as well as the
total intensity during the acquisition of experimental
data. The CH is also capable of determining the coor-
dinates of electron–positron pair formation and,
therefore, its points of entry into the SP-57 magnetic
field, so that it would be possible in the future to deter-
mine the exit angle of an electron (a positron) from
SP-57 and its further trajectory using the known char-
acteristics of the magnetic field and counters that
detect secondary electrons (positrons).
The schematic diagram for the photon-beam monitoring in front of a 1-mm-thick 32-mm-diameter copper converter is shown in Fig. 3. The scintillation counter \( S \) with dimensions of 100 \( \times \) 40 \( \times \) 5 mm is located directly in front of the CH and is used as a converter for each of the CH counters and as a trigger counter for the \((S + CH)\) system.

The CH is an assembly of 13 channels, which are transparent 6.5-mm-thick 25-mm-wide Plexiglas plates that are polished on each side (see the inset in Fig. 3). Each plate is turned through an angle of 90° about the vertical axis by heating. An FEU-85 PMT is located at the end of each plate. The length of the part of the plate on which the PMT is placed relative to the turning point is determined so that the PMT photocathode is located in the same vertical plane relative to the photocathode of the first PMT from the top. The length of the parts of the plates before and after the turn, on which the first and last PMTs are fixed in place, are equal to 65 and 70 mm, as well as 570 and 165 mm, respectively.

Whatman paper, metallized Mylar, and metal foil were tested as a reflective surface for wrapping the CH-channel plates. According to the results of the investigation, it turned out that all three materials provided approximately equal results, and metallized Mylar was selected. All faces of each hodoscope plate, except for the face to which the PMT was firmly pressed against without lubrication, were wrapped in metallized Mylar and black paper.

**THE PRELIMINARY CALIBRATION**

The preliminary calibration of the CH was carried out using an \(^{90}\text{Sr}\) radioactive source. The purpose of the calibration was to assess the practical applicability of this method for determining the position of a point source of charged particles, as well as to preliminarily determine the bias voltages applied to the voltage dividers the CH PMTs.

The layout of the calibration is shown in Fig. 4. Electrons from the \(^{90}\text{Sr}\) radioactive source with a maximum energy of 2.2 MeV passed through trigger counters \( S_1 \) and \( S_2 \) (15 \( \times \) 15 \( \times \) 1 mm) and were detected by a CH channel. The signals from \( S_1 \), \( S_2 \), and the CH channel were fed to the leading-edge discriminators \( D_1 \), \( D_2 \), and \( D \) (the thresholds of the discriminators were 10 mV). The signals from \( D_1 \) and \( D_2 \) were fed to the inputs of the coincidence circuit (CC) through delay lines \( DL_1 \) and \( DL_2 \). The Start signal from the CC was a trigger signal of the Pulse Counter unit and was fed to the Start input.

A signal from CH channels from 1 to 13 was sequentially fed to the Analysis input of the pulse counter from discriminator \( D \) through delay line \( DL \). The electron beam from the \(^{90}\text{Sr}\) source was collimated by collimator \( K \), a lead plate with dimensions of 100 \( \times \) 100 \( \times \) 5 mm and a 5-mm-diameter hole at its center, which was placed between the source and the CH.
The selection of the PMT for use in the CH was not carried out; therefore, the CH calibration was performed in two stages. At the first stage, the count rates in each hodoscope channel were sequentially equalized by varying the bias voltage applied to the PMT divider when the $^{90}$Sr ionizing-radiation source, the lead plate, and counters $S_1$ and $S_2$ were located above the corresponding channel. The equalization of the count rates was carried out relative to the count rates of the central channel (channel 7), whose count rate was taken as a basis. The maximum count rate of the central channel was determined from the dependence of triple-coincidence counts for the signals of counters $S_1$, $S_2$, and CH channel 7 on the voltage at the voltage divider of CH channel 7.

At the second stage, the profile of the ionizing-radiation source was determined when the $S_1$ and $S_2$ trigger counters and the $^{90}$Sr source were located at the CH center above channel 7 in the absence of the lead collimator. The result obtained at the second stage of the calibration is presented in Fig. 5. Figure 5 shows that the background count rate of the PMT was $\sim 10$ s$^{-1}$ or less ($U_S = 900$ V).

The bias voltage of counter $S$ was selected so that the maximum count rate of the PMT was $\sim 45$ cps.

The block diagram for the photon-beam detection by the CH is shown in Fig. 7 in (1) the “calibration” and (2) “operation” positions. The signal from the conversion electron–positron pair, which arose in $S$ from the passage of a photon through it, was fed to the fan-out device through discriminator $D$ and delay line $DL$. The signals from the fan-out device then arrived at the second inputs of coincidence circuits $CC_1$–$CC_{13}$, to the first inputs of which the signals from the hodoscope channels shaped by discriminators $D_1$–$D_{13}$ were fed.

The signals from coincidence circuits $CC_1$–$CC_{13}$ then arrived at the inputs of the multichannel register unit, which was triggered by the $Start$ signal coming from the fan-out device, after which the signal from the register unit was recorded into the computer memory through the CAMAC crate controller (CC).

In the calibration position, the count rates of each hodoscope channel were equalized by changing the voltage applied to the voltage dividers of the hodoscope counters. The dependence of the count rate in the channel on the bias voltage applied to the PMT voltage divider of this channel was plotted for each CH channel. The count rate, the same for all hodoscope channels, was thereafter selected to be $180 \pm 10$ s$^{-1}$.

**Fig. 5.** The dependence of counts $N$ in the Cherenkov-hodoscope channels ($N_{\text{CH}}$) on the position of the $^{90}$Sr source.

**Fig. 6.** (a) The calibration and (b) operation positions of the CH relative to the photon beam: ($S$) scintillation counter.

The results of the preliminary calibration with a $^{90}$Sr source showed the applicability of CH with this design for charged-particle detection.

**THE BASIC CALIBRATION**

The basic calibration of the Cherenkov hodoscope was performed directly on the photon beam in the “calibration” position (Fig. 6a). To obtain the same detection efficiency of each CH channel for electron–positron pairs produced by conversion of bremsstrahlung photons in counter $S$ that was located in front of the hodoscope, the hodoscope was placed on the path of the photon beam so that the electron–positron pairs were incident on the CH perpendicularly to the 25-mm-wide side and passed through all hodoscope channels.

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After the count rates of all channels were equalized, the hodoscope was put in the operation position (Fig. 6b), in which the conversion electron–positron pairs escaping from counter S were detected by one of the hodoscope channels (Fig. 3). Electron–positron pairs were incident on the CH in this position perpendicularly to the 6.5-mm-wide side. The CH aperture in this position was 90 mm in the horizontal plane and 65 mm in the vertical plane. However, taking the aperture of counter S into account, the working CH aperture was 90 and 40 mm in the horizontal and vertical planes, respectively.

RESULTS

Figure 8 shows the photon-beam profile measured by the Cherenkov hodoscope in front of the converter that was located at the edge of the SP-57 magnet poles (Fig. 1).

The FWHM of the profile was five channels, which, taking the CH channel width into account, corresponds to the diameter (30 mm) of collimator K3 located in front of the SP-3 and CH cleaning magnets [1]. The total count rate in the histogram of the photon beam profile was \( \approx 2 \times 10^5 \) 1/s, which corresponds to the photon-beam intensity of \( \approx 10^9 \gamma/s \) that are incident on the copper converter. The profile shows that the photon beam has a background component of approximately 13% of the total intensity of the main beam (five central channels), i.e., \( \approx 1.3 \times 10^8 \gamma/s \). Hence, it can be seen that the number of events determined by the CH (\( \approx 2 \times 10^3 \)) is significantly less not only than the intensity of the total photon beam (\( \approx 10^9 \gamma/s \)), but also than the intensity of the background component (\( \approx 1.3 \times 10^8 \gamma/s \)).

CONCLUSIONS

The presented system for monitoring a bremsstrahlung photon beam has been designed to form a calibration quasi-monochromatic beam of secondary electrons. It is built on the basis of Cherenkov detectors and is capable of monitoring the intensity and profile of the photon beam at various points of its transport line.

It should be noted that monitoring systems based on Cherenkov radiation have great physical and functional capabilities in experimental practice. As an example, when carrying out an experiment using a
photon beam for studying the cross sections of nuclear reactions, one can determine the photon-beam profile at the entrance to the experimental target upon each spill of the primary beam onto an internal tungsten target and thereby obtain the integral profile over a preset time.

The channels of the Cherenkov hodoscope can act as active converters, i.e., operate without the primary converter in front of the hodoscope. In this case, the hodoscope counters can be used as trigger counters and can independently determine the coordinate of electron (positron) production and, therefore, its entry point into the SP-57 magnetic field.

In the future, it is possible to determine the exit angle of an electron from the magnet and its further trajectory based on the known characteristics of the magnetic field and the geometric parameters of the magnetic system. Knowing the electron trajectory will improve (by a factor of ~ 1.5–2) the energy spectrum width of the secondary electron beam [1].

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