A quasi-monochromatic electron beam of the accelerator “Pakhra” for calibration of detectors

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Abstract. Characteristics of the calibration quasi-monochromatic beam of secondary electrons of the accelerator “Pakhra” of the P N Lebedev Physical Institute of the Russian Academy of Sciences based on the magnet SP-57 are presented. The energy resolution of the beam from a copper converter in the thickness range of 0.1–5 mm and the interpolar gap in the magnet 6 cm amounted to δ = 10–4.5 % in the energy range of the electron beam E = 98–294 MeV, respectively.

1. Introduction
In experimental work there is often a need for calibration of detectors and equipment or a need for studying new materials. Moreover, creating and testing particle detectors for electron, positron and photon beams of medium energies is often required for solving a number of other problems such as studies of the structure and modification of materials, studies of radiation resistance of electronic components and materials, measurements of cross sections of nuclear processes for civil and military applications, etc. For these purposes accelerators generating beams are usually needed [1-6].

The electron synchrotron “Pakhra” is still an operating accelerator generating electron, positron and photon beams. Synchrotron “Pakhra” of the Lebedev Physical Institute of the Russian Academy of Sciences is located in the city of Troitsk, now South part of Moscow [7].

Bremsstrahlung photon beams on the electron synchrotron “Pakhra” are formed by interaction of an accelerated electron beam with an internal tungsten (W) target with a thickness of 0.22X₀ (X₀ is the radiation length) placed inside the accelerator vacuum chamber. At present time the synchrotron has a repetition rate of 50 Hz and allows to work at energies of accelerated electrons in the range of 300–850 MeV and the beam intensity ~2·10¹² e⁻/sec. A system for stretching the bremsstrahlung beam (while directing the internal electron beam to the internal target of the accelerator) up to 3 msec provides a Duty factor of the bremsstrahlung beam of about 0.15. Thus, the accelerator “Pakhra” can be used to produce gamma quanta with a maximum energy of Eγ max = 300-850 MeV.

An average intensity of the produced photon beam is Iγ ~ 2·10⁹ equivalent photons/sec (γ/sec). The presence of three autonomous channels for bremsstrahlung photon beams and the extracted electron beam makes it possible to conduct several experiments simultaneously [8].
2. The quasi-monochromatic secondary electron beam

Layout of the setup is shown in figure 1. Electrons in the accelerator chamber interact with the tungsten target. Bremsstrahlung photons are transported by air to a copper converter in front of the basic magnet (M2). The thickness of the converter, where photons into electron-positron pairs are converted, was taken from 0.1 to 5 mm. The magnetic field of M2 deflects electrons or positrons to the K3 collimator. Electrons or positrons are then detected by a system of scintillation counters A (veto), C1 - C4. The size of the counters C1 - C3 was 15×15×1 mm³.

The size of C4 could vary depending on the calibration conditions of the detector under study. In current measurements with GAMMA-400 apparatus [4-5] its size was 40×40×5 mm³.

All scintillation counters used FEU-85 phototubes. Trigger was a combination of the timing signals of the counters T=(C1·C2·C3·C4)·A. The total length of the photon channel from the output flange of the accelerator to the converter was about 40 m. The length of the electron channel from the flange of magnet M2 to the converter K3 was about 3 m.

Monitoring of the photon beam was divided into two parts: a system that monitors the intensity of the beam and a system that controls the time interval of the electron beam discharge to the internal target-“stretching”. The energy characteristics of the photon and electron beams were determined using a Cherenkov total absorption spectrometer (CTAS) with the total radiation length about 13X₀.

Horizontal and vertical profiles of the photon and electron beams were determined at key points of its transportation: at the exit of the accelerator, at the inlet and outlet of the cleaning magnet M1, at the entrance to the M2 (SP-57) magnet, and also before the entrance to the K3 collimator.

Characteristics of the quasi-monochromatic electron beam of the accelerator “Pakhra” can be summarized as follows:

- the working energy of the bremsstrahlung photon beam  \( E_\gamma \text{ max} = 200 - 500 \text{ MeV} \)
- intensity of the photon beam  \( \sim 2 \times 10^9 \gamma/\text{sec} \)
- thickness of the converter  \( 0.1 - 5 \text{ mm, Cu} \)
- diameter of the K3 collimator  \( 10 \text{ mm} \)
- field of the main magnet M2  \( 0.2 - 0.8 \text{ T} \)
- energy range of the secondary electron beam  \( E_e = 30 - 300 \text{ MeV} \)
- intensity of the secondary electron beam  \( \sim 100 \text{ e/sec} \)
- energy resolution for electrons of 98 -294 MeV  \( \delta = \Delta E/E = 10 - 4.5\% \), resp.

3. Determination of the energy resolution of the secondary electron beam

Quasi-monochromatic beam of secondary electrons is the result of production of electron-positron pairs in the converter by photons and interaction of electrons with the magnetic field. So, all the characteristics of the electron beam depend on the characteristics of the converter and the magnetic field. Illustrations of the dependence are shown in figures 2 and 3.
Figure 2. Dependence of the energy of quasi-monochromatic electron beam from the field of the magnet SP-57 at various thickness of the copper converter: 1 – 0.1 mm, 2 – 1.1 mm, 3 – 3.1 mm, 4 – 5.1 mm.

Figure 3. Dependence of the energy resolution of the quasi-monochromatic electron beam from thickness of the copper converter at various fields of the magnet SP-57: 1 – 0.275 T, 2 – 0.527 T, 3 – 0.767 T.

The energy resolution of the electron beam was determined using the following steps (see figure 4):

- Step 1: The energy of electrons was determined using a CTAS located behind the scintillation counter C4. The converter was a copper converter plus the air in front of the converter.
- Step 2: The copper converter was removed and the energy of electron was determined with the air converter.
- Step 3: From the spectrum (converter: copper + air + CTAS) was subtracted the spectrum (converter: air + CTAS).

Figure 4. Energy spectrum of a quasi-monochromatic electron beam: (a) converter = 0.1 mm copper + air + CTAS; (b) converter = air + CTAS; (c) spectrum difference (“copper + air + CTAS” – “air + CTAS”).

Using GEANT4, a simulation was done of the passage of electrons from the point of conversion in a copper converter with a thickness of 1 mm prior to detection in the counters C1 – C4 and CTAS. The
calculated dependence of the electron beam energy release in the CTAS (assuming that the CTAS energy resolution is zero) and the experimental dependence of the beam energy on the SP-57 field are shown in figure 5 which shows that both dependences within the errors are the same, the difference being about 3%.

![Graph showing the dependence of energy release in CTAS and experimental dependence on SP-57 field.]

**Figure 5.** The dependence of the energy of quasi-monochromatic electron beam from the field of the magnet SP-57. Copper converter of 1 mm. 1 – experiment, 2 – GEANT4 calculation.

4. **Plans for future**

At the present time the quasi-monochromatic beam is used for calibration of detectors and equipment of the astrophysical observatory GAMMA-400 [4] (see figure 6).

![Image of workplace for calibration showing equipment and detectors.]

**Figure 6.** View of a workplace for calibration of equipment and detectors of the astrophysical observatory GAMMA-400 in the Experimental Hall-2.

In the nearest future it is planned to create a calibration beam in the Experimental Hall 1 (see figure 7) on the basis of a high-intensity extracted electron beam. It is assumed that the characteristics of the electron beam will be as follows:

- intensity $10^3 - 10^6$ e/sec,
- $E_e = 200 - 500$ MeV,
- $\delta_e \sim 1\%$. 


Figure 7. The channel of the extracted electron beam of the accelerator "Pakhra";
(a) – a scheme of experimental halls of the accelerator; (b) – a view of the channel of the extracted electron beam in the hall of accelerator.

5. Conclusions
Created on the basis of the accelerator "Pakhra" of P N Lebedev Physical Institute of the Russian Academy of Sciences the calibration quasi-monochromatic beam of secondary electrons has good characteristics and can be used for calibration of experimental equipment and other studies.

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