CALIBRATION OF X-RAY SPACE TELESCOPES

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In this work the new concept of a source of X-ray beam for ground calibration of next-generation telescopes is proposed. This facility contains a source of a parametric X-ray radiation (PXR). The source would provide a monochromatic X-ray beam and would allow smooth tuning of photon energy and linear polarization direction. The facility is intended for calibration of registration efficiency, polarization sensitivity and angular properties of space telescopes and other X-ray and soft gamma-ray instruments in the energy range of incident photons from several keV up to hundreds keV.

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1. INTRODUCTION

The current astrophysical investigations in the X-ray band are realized mainly by focusing space telescopes up to photon energies of about 10 keV. The currently available installations for calibration of X-ray space telescopes operating in the range of up to 10 keV rely on X-ray radiation sources that are based on powerful X-ray tubes with the use of X-ray monochromator.

Next-generation astrophysical missions are developed to operate in a harder X-ray band. It is supposed the new telescopes will utilize the multilayer mirrors to focus harder X-rays with energies up to of 100 keV and more [1]. For ground calibration of these telescopes new techniques are needed.

The main features of the future installations are:

- X-ray radiation band: from a few keV to 160 keV.
- Monochromaticity of X-ray.
- Smooth X-ray radiation energy variation.
- Possibility to choose the linear polarization direction of X-ray radiation.

Note, the distance between a source of X-ray beam and telescope should be hundreds meters to provide a quasi-parallel X-ray beam at a telescope aperture.

In this paper the parametric X-ray radiation [2] generated by relativistic electrons passing through the aligned crystal target is used as an X-ray beam source. The facility, hundreds of meters in length, can provide calibration of X-ray space telescopes in the energy range from several keV to hundreds of keV. A smooth tuning of both the X-ray spectral peak energy and the linear polarization direction are provided. For the first time use of PXR as source for telescope calibration has been suggested in [3] and more detail description can be found in [4].

2. COMMON SCHEME OF FACILITY FOR CALIBRATION

The present design involves the use of an electron linear accelerator as an X-ray radiation source. This accelerator generates in the aligned single crystal target a parametric X-ray radiation that satisfies the above-mentioned requirements.

Apart from the mentioned main purpose, the installation should also provide the calibration of imaging non-focusing telescopes and their detectors up to energies of ~500 keV. The X-ray radiation in this installation can have a high degree of linear polarization that allows, in turn, the calibration of hard X-ray radiation polarimeters, which are indispensable elements of astrophysical investigations.

The availability of the electron linac makes it also possible to extend the range of electromagnetic radiation to the gamma-radiation region. In this case, a quasi-monochromatic linearly polarized radiation can be obtained in the direction parallel to the electron beam direction with the use of the effect of coherent bremsstrahlung (CB) with energies up to several tens of MeV.

So, the proposed installation will have wide capabilities for calibration of focusing and non-focusing telescopes and detecting apparatus in a wide spectral band partially overlapping the band of telescopes operated on the principle of total external reflection. The main differences of the proposed installation from the facilities in existence are determined by the following considerations:

- the installation must operate in a harder X-ray range as opposed to the previous devices;
- the use of the radiation source based on the electron linac and the goniometer device with a single crystal target.

In view of this, compared to the existing facilities, the installation will have new design features, new constructional units and devices to measure the electron beam and X-ray radiation parameters, and also new elements of the vacuum system.

The general layout of the facility is shown in Fig.1.

The main facility systems are:

- X-ray beam generator composed of linear electron accelerator with electron energy of 100 MeV and goniometer chamber with aligned single crystal target.
- Magnetic system to operate an electron beam.
- Beam control chamber containing instruments for monitoring of electron and X-ray beam parame-

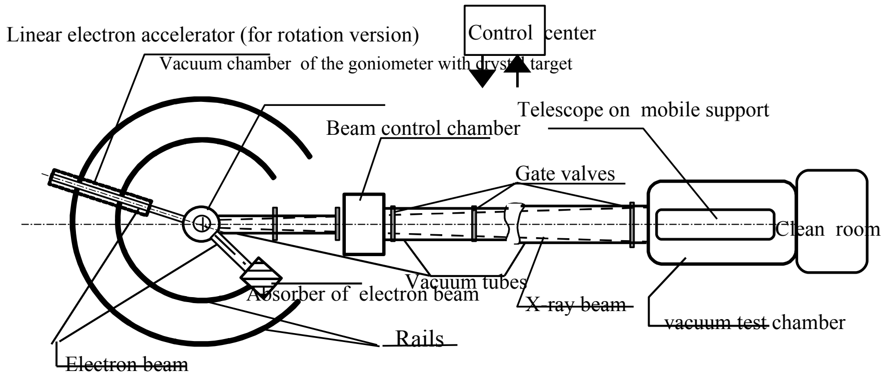


Fig. 1. The general layout of the facility for calibration of the space X-ray telescopes

ters: X-ray detectors, polarimeter, electron detectors.

- Collimators.
- Electron beam absorber.
- Test chamber housing telescopes, instruments of focal plane, instruments for control X-ray beam parameters.
- Radiation shielding.
- Vacuum guide tube with gate valves (tube length is of 100 m, 500 m and 1000 m for three versions respectively.
- Vacuum system.
- Rotating platform supporting whether the accelerator (in a version of the rotating accelerator) or rotating magnets at immovable vertical accelerator.
- Control center.

Clean room next to the test chamber can be installed to mount and operate the focusing telescopes, but it system is not considered in our scientific design. It can be the same as in Marshall Calibration Center [5].

The main problem in any of the versions is the variation of the direction of electron beam incidence in a wide angular range. In the context of the project, we consider two schemes of electron beam rotation around the center of the crystal target relative to the fixed direction of the X-ray beam: a) rotation of the electron accelerator together with the HF power supply system around the center of the goniometer chamber comprising the crystal target rotation of a set of magnets deflecting the electron beam, the vertically located electron linac being immobile [3].

In the case of horizontal arrangement of the accelerator, it is mounted on the rotation platform together with the HF power supply system and the radiation shield.

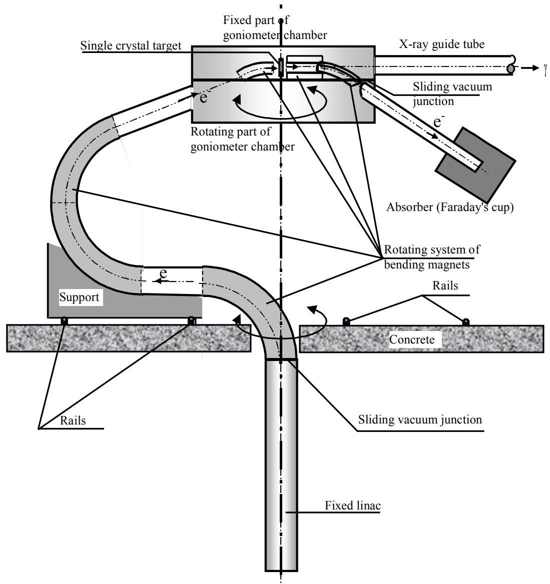
The vertical immobile accelerator (Fig.2) is placed coaxially with the vertical axis of the goniometer chamber that provides the horizontal rotation of the single crystal target at adjusting the X-ray source for the energy needed. The electron beam bending (approximately through twice the angle of crystal rotation) is realized by rotating the whole system of bending magnets around this axis.

3. MAIN PARAMETERS OF X-RAY BEAM GENERATOR

The calculations of principal parameters of the generator and the optimum requirements for the component systems of the generator are presented in [3]. Those components were the PXR source (crystal-radiator), the goniometer, the electron accelerator, and the accelerator's rotating platform. We have considered generator versions with different electron beam energies: 30, 60, 120, 240, 360 and 480 MeV. A detailed analysis was performed to elucidate the influence of multiple electron scattering in the crystal on the PXR spectral and angular characteristics, and on the PXR polarization. The angular differential yield of coherent bremsstrahlung (CB) was calculated, and a possible effect of CB on the production of quasi-monochromatic gamma-ray beams of energies higher than 100 keV was considered [3].

As a result of the calculations performed we have determined the following basic parameters of the X-ray generator intended for ground-based calibration of space telescopes.

Parameters of pulsed electron linear accelerator (linac): 1) Electron beam energy - 30, 60 (base version), and 120; 2) Electron beam current - 100 μA; 3) Pulse



duration - 2 μs; Pulse rate - 50 Hz; 4) Initial electron beam divergence - 1 mrad; 5) Electron beam diameter on the crystal-radiator surface - from 5 to 10 mm; 6) Step of the accelerator's rotating system - 10^{-3} rad.

PXR source as a changeable set of crystalline plates (disks) placed into the goniometer: 1) Crystals in use - silicon, germanium, diamond; 2) Crystalline plate thickness - 14 μm for *Ge* crystals, 58 μm for *Si* crystals, and

Fig. 2. Design version with a rotating magnetic system and immobile accelerator (side view)

87μm for diamond crystals. 3) Working crystallographic planes - <111>, <220>, <311>, <400>, <331>, <422>, <333>. 4) Crystalline plate diameter (inner diameter of the cooling circuit) - no more than 10, 5 and 2 electron beam diameters on the target for diamond, silicon, germanium crystals, respectively; 5) Cooling of crystals-radiators - water; 6) Average crystal-radiator temperature in the region of electron beam passage - no more than 100°C for silicon and diamond crystals, no more than 350°C for germanium crystals; **7**) Number of independent goniometer rotations – 3, range of goniometer rotation - 90 degrees, step of goniometer rotation - 10^{-6} rad;

The basic parameters of the X-ray beam:

1)Energy range from ~2 keV up to about 511 keV (depending on the electron beam energy, the crystal and crystallographic plane types).

2)Flux intensity from ~10 to ~5000 quantum/(c·cm^2) (0.2 to 100 quantum /cm^2 per bunch) at ~500 m from the source and at an average electron beam current ~100 mA (depending on the electron beam energy, the X-ray beam energy, the crystal and crystallographic plane types).

3)Spectral resolution *E/ΔE (ΔE* is the energy spread at the radiation spot on the telescope aperture) - from ~5 to ~1000 (without monochromator), depending on the X-ray radiation energy, the electron beam energy and the angular size of the detector (radiation spot size on the telescope aperture).

4)Radiation spot size at ~500 m - from ~0.1 to ~10 m, depending on the radiation energy and the needed energy resolution.

5)The generator can produce both linearly polarized and non-polarized X-ray beams.

4. CONCLUSION

The X-ray generator based on PXR has essential advantages over other radiation sources through the possibility of smoothly varying the spectral peak energy and the linear polarization direction at a small angular divergence of the X-ray beam. In particular, the generator provides the production of quasi-monochromatic linearly polarized and non-polarized X-ray and gamma-radiation beams with a smoothly tunable energy in the range from ~2 keV to ~500 keV.

It is evident that the working range of the X-ray beam energy is strongly dependent on the electron beam energy of the accelerator. If one is oriented to performing the calibration of telescopes and X-ray equipment with the use of X-ray (gamma-) quanta of energies up to 200 keV[1], then the electron beam energy must be 120 MeV. If, however, the quasi-monochromatic gamma beams of energies up to 511 keV must be produced, then the electron beam energy should be increased up to ~500 MeV. On the whole, it is believed that the basic version of the X-ray generator for calibration of space telescopes can rely of the linac with an electron beam energy of 60 MeV and a current beam of 100 μA. This generator would provide the yield of quasimonochromatic X-ray quanta in the energy range from 2 to ~120 keV with a flux intensity from 10 to 1000 quantum/(s·cm^2) at a distance of 518.16 meters[2] from the radiation source. A further increase in the electron beam energy can be realized by stages and parallel with the development of new space X-ray telescopes intended for production of images of X-ray (gamma-) sources with a radiation energy higher than 120 keV.

Note, that the use of the 60 or 120 MeV electron-beam-energy generator version may appear quite sufficient for producing quasimonochromatic gamma-beams in the energy range from ~100 keV up to several MeV. It might be realized if the coherent bremsstrahlung (CB) could be used for energy calibrations. To elucidate this possibility of using the CB when performing calibration measurements, additional experimental and theoretical studies into differential properties of the CB and its possible interference with the PXR must be conducted.

Besides, note a possibility of electron accelerator application for irradiation. For example, it may be used in test of radiation resistance of devises during time, when facility does not work for calibration programs.

The issue may be of interest for specialists in the fields of X-ray astronomy, optics, detectors and new kinds of X-ray radiation.

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[1] At present, the possibility of creating space X-ray telescopes for detection of cosmic X-ray (gamma) radiation of energies up to 180 keV [1] is only considered.

[2] This is the path length in the MSFC facility for calibration of space telescopes [5].

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КАЛИБРОВКА КОСМИЧЕСКИХ РЕНТГЕНОВСКИХ ТЕЛЕСКОПОВ

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Предложена новая концепция источника рентгеновского пучка для наземной калибровки телескопов следующего поколения. Это устройство содержит источник параметрического рентгеновского излучения (ПРИ). Источник обеспечивает монохроматический рентгеновский пучок и плавную перестройку энергии фотона и направления линейной поляризации. Устройство предназначено для калибровки эффективности регистрации, чувствительности к поляризации и угловых свойств космических телескопов и других рентгеновских и мягкого гамма-излучения приборов в энергетическом диапазоне падающих фотонов от нескольких до сотен кэВ.

КАЛІБРОВКА КОСМІЧНИХ РЕНТГЕНІВСЬКИХ ТЕЛЕСКОПІВ

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Запропонована нова концепція джерела рентгенівського пучка для наземного калібрування телескопів наступного покоління. Цей пристрій містить джерело параметричного рентгенівського випромінювання (ПРВ). Джерело забезпечує монохроматичний рентгенівський пучок і плавну перебудову енергії фотона і напрямку лінійної поляризації. Пристрій призначений для калібрування ефективності реєстрації, чутливості до поляризації і кутових властивостей космічних телескопів і інших рентгенівські і м'які гамма-випромінювання приладів в енергетичному діапазоні падаючих фотонів від кількох до сотень кеВ.