

LOW DOSE X-RAY RADIATION SOURCE FOR ANGIOGRAPHY BASED ON CHANNELING RADIATION PRINCIPLE

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Abstract

Angiography is one of the most reliable and contemporary procedure of the vascular system imaging. X-ray spectrums provided by all modern medical angiographs are too broad to acquire high contrast images and provide low radiation dose at the same time. The new method of narrow X-ray spectrum achieving is based on the idea of channelling radiation application. The X-ray filters used in this method allows eliminating the high energy part of the spectrum and providing dramatic dose reduction. The scheme of the facility including the X-ray filter is discussed. The results of the spectrum analysis for the channelling radiation source are shown including the data for electron beam trajectories inside the diamond crystal investigation.

INTRODUCTION

Angiography nowadays is the state of the art medical imaging technique used to visualize the inside, or lumen, of blood vessels and organs of the body, with particular interest in the arteries, veins and the heart chambers. X-ray sources in angiography applications are based on X-ray tubes. These sources are well explored and provide high rates of radiation intensity. The main drawback of the tube is wide bandwidth of the generated radiation spectrum. Monochromatic radiation source application can result in better imaging, and, moreover, lower irradiation dose can be applied to a patient.

Large scale accelerators as synchrotrons, storage rings, energy recovery accelerators or LINACs can be only used to produce synchrotron and undulator radiations. Compton scattering needs comparatively smaller accelerator but high power laser and high accuracy control system are strongly requested. Very high CW currents up to tens of Amperes are necessary to excite the characteristic X-ray of La or Ba emitters having considerable photon flux. Channeling radiation source, one of the most powerful radiation emitters by relativistic electrons in crystals is discussed below as a possible alternative of these techniques [1].

For the angiography and radiography procedure one needs a conventional total flux of $2 \cdot 10^7 - 2 \cdot 10^9$ photons/mm²/s and irradiated area about 43x43 cm² [2]. The lower end of photon energy is estimated as 33.2 keV for angiography (the key energy to hit the peak value of iodine contrast mass attenuation). The X-ray monochromatic peak energy can be varied by means of the metal of crystal target variation of electron beam energy tuning. A standard therapy LINAC produced by one of the leading manufacturers can be used. Incoherent bremsstrahlung in a crystal is a serious

problem that results in rather high irradiation dose. Any solution to suppress it is strongly desirable.

X-RAY SOURCE SCHEME

The monochromatic X-ray source based on the channelling radiation generated by the electrons moving inside the oriented crystals is discussed [3]. The principal scheme of the source is presented on the Figure 1. The electron beam (2) is generated in the electron source (1) and accelerated to ultra-relativistic energies in the LINAC (3) that is not considered in the work. After that electrons pass through the aligned crystal (4) placed inside the goniometer (12) and generated the monochromatic channeling X-ray radiation and broadband bremsstrahlung. The deflecting magnet (5) is used to lead the electron beam to the beam dump (11). The X-ray pass through the polycapillary optics (10) and the radiation with energy lower than 40 keV (9) is filtered and deflected to the patient (7), the rest of the radiation is propagated straightforward to the X-ray dump (6). The radiation is then detected with the panel detector (8). The electron beam deflection is done in order to eliminate the possibility of the polycapillary optics damage. The scheme of the polycapillary optics using allows to fix the main problem of such a facility – broadband bremsstrahlung spectrum that leads to unnecessary dose enhancement that is obtained by the patient. The polycapillary optics is the most reliable for filtering of the high energy X-ray radiation with efficiency about 60% at the 17 keV energy level and about 40% at 33 keV level.

RADIATION FROM CRYSTALL

The channeling is the process of the electron movement inside the crystal between the crystallographic planes (in case of the planar channeling) or near the crystallographic axis (in case of the axial channeling). We investigate the planar channeling in the crystal along the <110> plane of the diamond (Figure 2). The electron dynamics in the crystal is evaluated using the BEAMDULAC-CR [4] code. The investigation is held using the classical approach of the electron propagation in the transverse potential field inside the crystal.

The electrons dynamics in the crystal shows that electron beam should have the divergence around 10 mrad and energy spread in order of 1% to eliminate the dechanneling (travelling of the electrons from one channel to another) of the electrons. Several calculations were held to estimate the dechanneling effect. The overall amount of dechanneled particles is presented on the Figure 3.

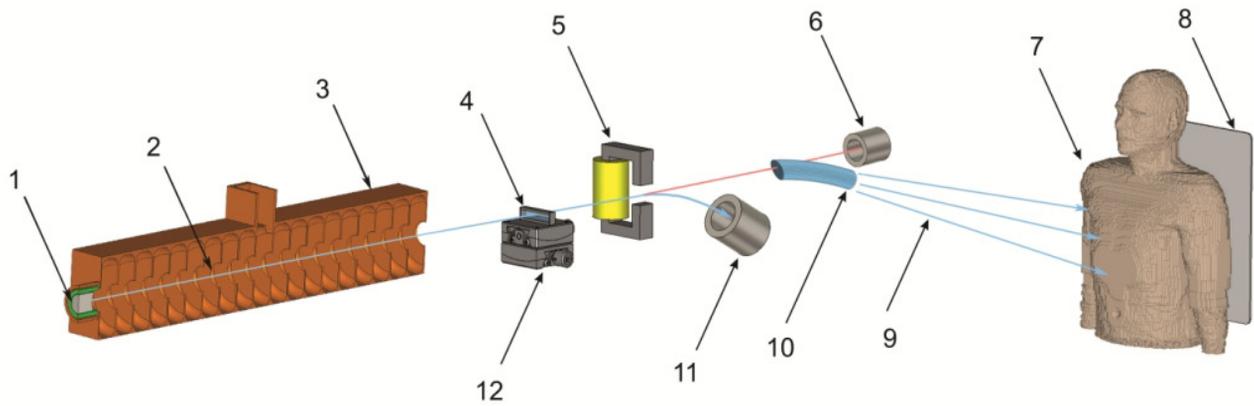


Figure 1: Principal scheme of monocrystal and polycapillary optics based X-ray source.

The dechanneling and channeling processes in the diamond crystal lattice are presented in Fig. 4. The graph is showing the beam traveling in two coordinate systems: r/d (z/d), β_x (z/d) (d is the half potential channel width, z is the longitudinal coordinate, r is the transverse coordinate). The phase trajectories are also presented on the Figure 5. Here the electron beam filling 3 full potential channels is travelling with 3 mrad (a) and with 30 mrad (b) for 23 MeV beam energy. The graphs of transverse coordinates and transverse velocities are showing that the 30 mrad case leads to a large number of particles that start to travel from one channel to another right after crystal surface (zero longitudinal position). The phase trajectories plots are showing that a lot of trajectories are not looped that corresponds to dechanneled particles.

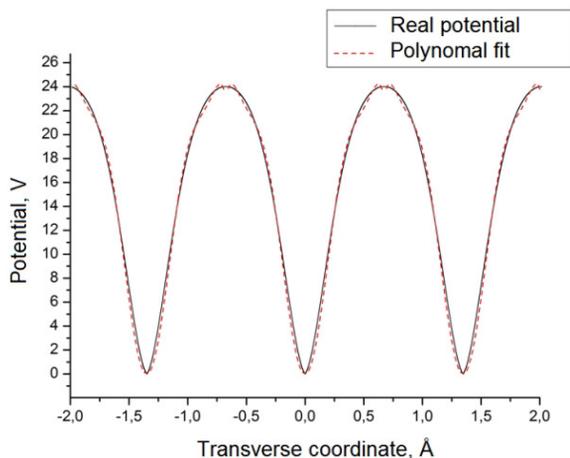


Figure 2: Potential distribution along <110> diamond crystallographic plane.

Acquired spectrums of the channeling radiation from BEAMDULAC-CR are shown on the Figure 5. The photons number is based on the 10^{12} electrons in the single bunch and the diamond plate thickness of 55 μm . The graphs were evaluated for the 21 and 23 MeV electron energy and correspond to the energy spectrum of the main harmonics 33 ± 2.4 keV (21 MeV) and 37 ± 2.9 keV (23 MeV). The angular dependence of the emitted radiation has narrow peak at 0 degrees relative to

electron beam direction. The peak of radiation angular distribution is characterized by the FWHM value of 2 degrees. The acquired angular dependence reveals the theoretical proportionality of the bremsstrahlung cone opening $\theta \sim \gamma^{-1}$, where γ is the Lorentz factor of the initial electron beam.

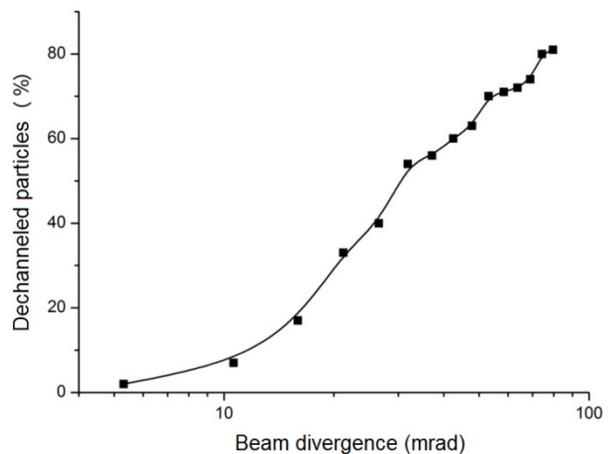


Figure 3: Percentage of the dechanneled particles vs. beam divergence.

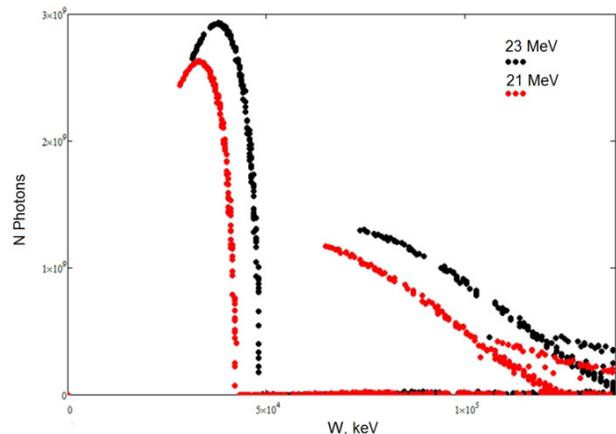


Figure 5: Spectrum of the channeling radiation.

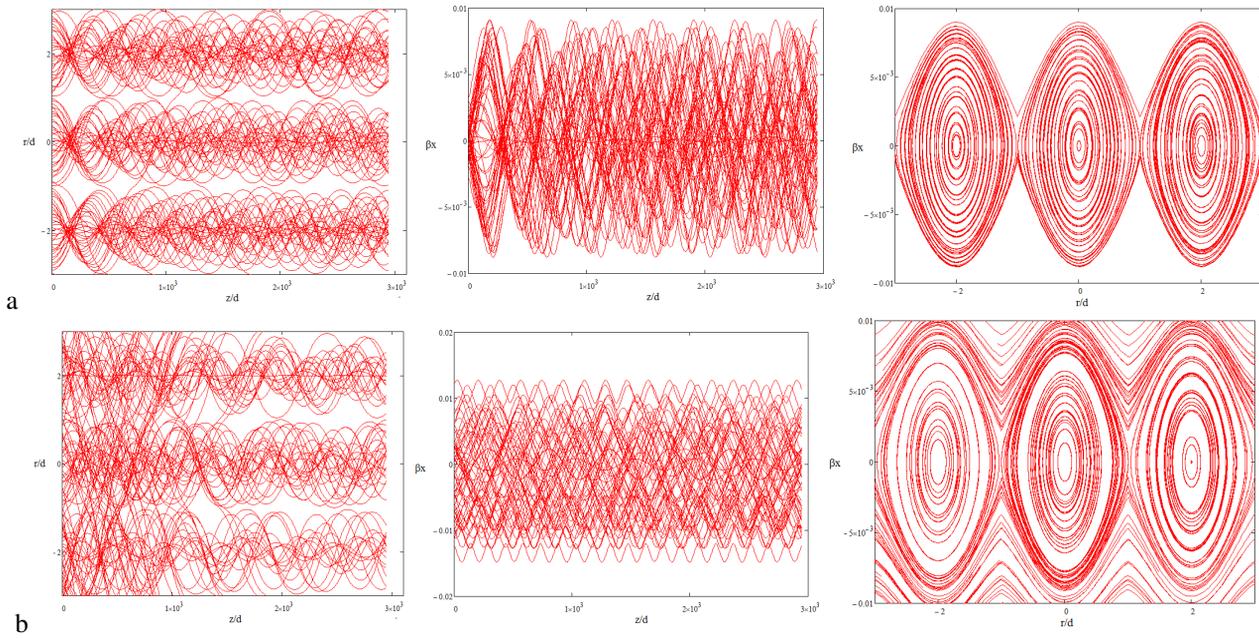


Figure 4: Graphs describing the beam trajectories inside the diamond crystal for 3 (a) and 30 mrad (b) divergence.

DEFLECTING MAGNET

Deflection of the electrons from their trajectory is an important process in the operation of the setup. If this is not foreseen the electron beam will strike the polycapillary optics and for sure will bring it down. The deflection in the discussed case is based on the simple but effective magnetic system. It should deflect the beam for and $\psi=45^\circ$ angle vs. the initial track. Here the magnet with 5x5 cm poles is discussed with application to the 23 MeV beam. To deflect this beam the 24 mT induction is required.

Induction of this field is not a problem, but arising synchrotron radiation – is the one to be investigated. For better interpretation the directivity of the synchrotron radiation is presented on the Figure 6a. The arising radiation has directivity of $\psi+\phi$, but only the ϕ part should be taken into account because all other angles are not coming to the input of the optics. The dependence of the radiation vs. the magnetic field induction is presented on the Figure 6b. So while deflecting the 23 MeV beam the arising radiation has power of 10.72 W and energy of 0.2 keV due to equations for the synchrotron radiation [5]. The parameters of the radiation allow concluding that it can be excluded from the discussion due to low energy that makes it fully absorbable by the air.

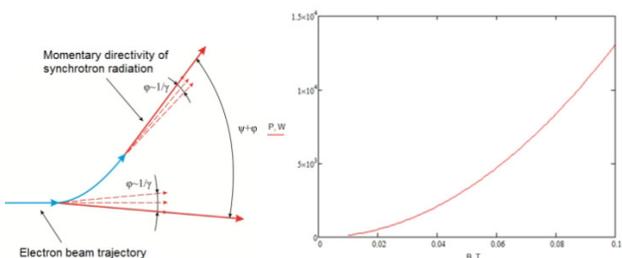


Figure 6: synchrotron radiation directivity (a) and power vs. magnetic field induction (b).

CONCLUSION

Principle of X-ray generation using the electron channelling through the crystal was considered. Possibility of utilizing the principle of electron channelling radiation in crystals for generating X-ray radiation was investigated. One of the possible applications of obtained X-ray radiation – angiography was discussed. Principal scheme of the estimated facility has been presented.

Electron trajectories inside the crystal were estimated and the percentage of the dechanneled particles was calculated. Also the electron beam deflection by the magnetic system was investigated. The magnetic field of 24 mT is required to deflect the 23 MeV beam from its track. The arising synchrotron radiation has low energy and is fully absorbed in the ambient atmosphere.

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