The comparison of monochromatic X-ray sources based on X-ray tube and 5 MeV microtron for possible application in medicine

Synchrotron radiation monochromatization in storage rings using crystal diffraction method

1. Source of SR
2. Focusing monochromator
3. Collimatos
4. Goniometer
5. Crystal monochromator
6. Crystal analyser
7. Detector (IP, CCD)
8. Detector (video, films)
9. Detector (video, CCD)

А.В. Забелин и др. //Поверхность. Синхротронные и нейтронные исследования, 2003, №2, с. 56-59

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X-ray sources

- Monochromatization of synchrotron radiation
- XFEL
- Parametric X-ray (electrons, protons, nuclei)
- Diffraction of bremsstrahlung
- Et al.
TO SHOW

• The possibility of creation the X-ray monochromatic source based on compact cheap accelerators
• The application of these systems

TO FIND

• The partners (may be sponsors) *-)}
• Electron accelerator bremsstrahlung monochromatization


<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron energy</td>
<td>5.70 MeV</td>
</tr>
<tr>
<td>Beam current</td>
<td>0.15-0.30 mA</td>
</tr>
</tbody>
</table>

1 - aluminum converter (125 μm), 2 - current sensor, 3 - deflecting magnet, 4 - bremsstrahlung flux, 5 - crystal target fixed on goniometer, 6 - diffractions X-ray radiation, 7 - kapton window (150 μm), 8 - semiconductor silicon detector with a sensitivity region about 13 mm², 9 - lead chamber, 10 - TV-camera, 11 - collimator

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### Crystals parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>C(002)</th>
<th>Ge(111)</th>
<th>W(111)</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear dimensions</td>
<td>20×30</td>
<td>20×20</td>
<td>10×16</td>
<td>mm</td>
</tr>
<tr>
<td>Mosaicisity</td>
<td>~4</td>
<td>~1</td>
<td>~0.3</td>
<td>mrad</td>
</tr>
<tr>
<td>Thickness</td>
<td>350</td>
<td>2000</td>
<td>100</td>
<td>µm</td>
</tr>
</tbody>
</table>
X-ray sources

- Electron accelerator bremsstrahlung monochromatization

\[ \theta = 30^\circ \]
\[ \Delta = 340 \text{ eV} \]

Intensity, ph/\text{el}/sr/\text{keV}

Photon energy \( E_\gamma \), keV
X-ray sources

- Electron accelerator bremsstrahlung monochromatization
- Electron accelerator bremsstrahlung monochromatization

\[ E_{\beta_1} = 9.67 \text{ кэВ} \]
\[ \Delta = 470 \text{ эВ} \]

\[ E_{L\alpha_1} = 8.39 \text{ кэВ} \]
\[ \Delta = 320 \text{ эВ} \]

\[ E_\gamma = 13.61 \text{ кэВ} \]
\[ \Delta = 350 \text{ эВ} \]
- **X-ray tube beam monochromatization**

<table>
<thead>
<tr>
<th>X-ray tube anode voltage</th>
<th>40 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray tube anode current</td>
<td>10 mA</td>
</tr>
<tr>
<td>Anode material</td>
<td>Molybdenum</td>
</tr>
</tbody>
</table>

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X-ray tube beam monochromatization

![X-ray spectrum graph](image)

- Intensity: $10^{-9}$
- Photon energy: keV

Mo peak at 19 keV
- X-ray tube beam monochromatization
- X-ray tube beam monochromatization

\[
\begin{array}{c}
\text{Intensity, Photon/el/sr/keV} \\
10^{-11} \\
1.5 \\
1 \\
0.5 \\
0 \\
\end{array}
\]

\[
\begin{array}{c}
\text{Photon energy, keV} \\
0 \\
5 \\
10 \\
15 \\
20 \\
\end{array}
\]

\[
\begin{array}{c}
(3 \, 3 \, 3) \\
(4 \, 4 \, 4) \\
(5 \, 5 \, 5) \\
\end{array}
\]

\[
\begin{array}{c}
\theta=44^\circ \\
\text{Ge} \\
\end{array}
\]
• X-ray tube beam monochromatization

![Graph showing X-ray spectra with peaks labeled (0 0 4), (0 0 6), (0 0 8), (0 0 10), (0 0 12) at different photon energies. Peaks are differentiated by photon energy, θ = 49° and θ = 44°.](image-url)
X-ray sources

- X-ray tube beam monochromatization

![Graph showing X-ray tube beam monochromatization with peaks at different photon energies and angles.](image)
The application of such source can be realize in radiography and angiography to improve an image contrast and to reduce a radiation dose obtained by patient.

The one image exposure time during coronary angiography is ~ 1 ms.

<table>
<thead>
<tr>
<th>Source</th>
<th>Current (mA)</th>
<th>Energy (keV)</th>
<th>Activity (ph/sr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microtron</td>
<td>0.3</td>
<td>7.29</td>
<td>8.5 \times 10^{-6}</td>
</tr>
<tr>
<td>Pyrolytic graphite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X-ray tube</td>
<td>10</td>
<td>7.9</td>
<td>1.3 \times 10^{-11}</td>
</tr>
<tr>
<td>Spectrum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microtron</td>
<td>0.6 µs</td>
<td>7.29</td>
<td>1.6 \times 10^{10}</td>
</tr>
<tr>
<td>Pyrolytic graphite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X-ray tube</td>
<td>1 ms</td>
<td>7.9</td>
<td>1.5 \times 10^{3}</td>
</tr>
</tbody>
</table>
Purposes

• To carry out research to show feasibility of monochromatic X-ray source construction based on compact pulse betatron

Performance attributes

| The maximum of bremsstrahlung energy | 4 – 10 | MeV |
| Frequency                        | 100 – 300 | Hz |
| Dose rate on 1 m distance        | 1 – 16  | cGy/min |
| Focal point size                 | 0,2 x 2 | mm |
Advantages

• From comparison one may see the DBS photons’ energy while tilting the crystal overlaps approximately one quarter of used in medicine X-ray energies range (ex.: Ge (333) $\Delta \theta \sim 10^\circ \div 80^\circ \rightarrow \Delta E \sim 33 \text{keV} \div 5 \text{keV}$)

• In X-ray imaging using energy of X-ray is vary between 10 and 100 keV (10 – 20 keV in mammography, 40 – 50 keV in thorax radiography, limbs, head, 50 – 70 keV in organography)

• The application of such source in medicine (radiography, mammography, angiography) can be reduce a radiation dose obtained by patient more then two order of magnitude$^1$


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Advantages

• Useful increase of image contrast

• Cheapness of method generation in comparison with synchrotron radiation monochromatization or XFEL

• There is possibility of object dynamics observation in order to reveal its functionality
Thank you for your attention!