ILU industrial electron accelerators.

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Content

• Ordinary ILU accelerators.
  • ILU-8 (1 MeV, 20 kW)
    • Design and Main features.
    • Examples in real industry
  • ILU-10 (5 MeV, 50 kW)
    • Design and main features.
    • Examples in real industry

• New multi-cavity ILU accelerators.
  • Reasons for developing
  • Design
  • ILU-14 (10 MeV, 100 kW)
  • ILU-12 (7.5 MeV, 40 kW)
Compact – Local shielding, RF-triode - cheaper operation, Self-excitation of RF - wide temperature diapason, Pulse – better efficiency

ILU-8 1 MeV 20 kW

Pulse duration 800 mks
Pulse repetition 1-50 Hz
RF frequency 175 MHz
Dim D800x800 mm

RF-triode GI-50A
With 2 MW RF power
4-sided cable irradiation on ILU-8

• Beam extraction device for 4-sided irradiation allows to increase beam usage efficiency comparing with 2 sided irradiation
• No cable twist
ILU-10 5 MeV 50 kW

- Pulse duration 500 mks
- Pulse repetition 1-50 Hz
- RF frequency 115 MHz
- Dim. D1280x1480 mm
Centre of radiation technologies in Novosibirsk.
Centre of radiation technologies in Novosibirsk.

Conveyor load/unload zone.

Entrance to labyrinth.
Sterilization center based on ILU-10 in Semipalatinsk nuclear test site (STS) in Kazakhstan.
ILU-10 in Poland, RadPol SA, 2008

- Treatment of polymer pipes
- Treatment of cables
- Movable accelerator between two conveyors.
Medical sterilization and food irradiation markets required more energy and power.

**Food irradiation requirements**

- 10 MeV E-beam $\rightarrow$ small power

- X-ray 5 MeV $\rightarrow$ huge power (conversion rate $\sim 8\%$)

- X-ray (USA) 7.5 MeV $\rightarrow$ high power (conversion rate $\sim 13\%$)
New multi-cavity ILU accelerator

One cavity

Multi-cavity

\[ P_{\text{loss}} = \frac{U^2}{2R_{\text{shunt}}} \quad \text{and} \quad P_{\text{loss}} = \sum_{n} \frac{U^2}{2R_{\text{shunt}}} \]
New multi-cavity ILU accelerator.

Pulse mode vs CW (Constant wave)

- $P_{\text{losses}}$ does not depend on beam current and depend on U.
- We may achieve required average power and energy by:
  - Short pulse and big pulse current
  - Long pulse and small pulse current or even CW
- Then shorter $t_{\text{pulse}}$ and more $P_{\text{pulse}} = U_{\text{beam}} \cdot I_{\text{beam}}$ then less $P_{\text{losses}}$
- $\Rightarrow$ efficiency of cavity - $\dot{n}_{\text{pulse}} > \dot{n}_{\text{CW}}$

- Pulse Linear Accelerator PLA=ИЛУ (ILU) in Russian
Cavity voltage and beam current for one cavity.

**cw**

- **Accelerating voltage, MeV**
- **Beam current, mA**

**Pulse**

- **Frequency = 50Hz**
- **Duty factor = 2.5%**
- **Pulse duration = 0.5ms**

Energy saving zone

Energy saving zone
New multi-cavity ILU accelerator.

Accelerating structure with 6 cavities
4 RF-triodes – Σ8 MW of RF power
Duty cycle 2.5%
Pulse repetition rate 50 Hz
Pulse duration 500 mks
Pulse edge 50 mks

No need stainless vacuum tank.

RF frequency 175 MHz

Efficiency on pulse duration for different reasons

- Pulse edge
- Duty cycle
- Both
ILU-14 10 MeV 100 kW

<table>
<thead>
<tr>
<th>Operating frequency, MHz</th>
<th>176</th>
<th>Full efficiency, %</th>
<th>26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron energy, MeV</td>
<td>7.5-10</td>
<td>Modulator pulse duration, μs</td>
<td>500</td>
</tr>
<tr>
<td>Average beam power, kW</td>
<td>100</td>
<td>Repetition rate, Hz</td>
<td>Up to 50</td>
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</tbody>
</table>
New multi-cavity ILU accelerator.

In operation from 2014 in Moscow
Shorter version – ILU-12

- 5 MeV 60 kW
- 7.5 MeV 40 kW
- 4 cavities
- Possible upgrade to ILU-14
Conversion rate X-ray/Ebeam power

<table>
<thead>
<tr>
<th>E(MeV)</th>
<th>Ta thickness</th>
<th>60 deg</th>
<th>360 deg</th>
</tr>
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<tbody>
<tr>
<td>7.5</td>
<td>0.9</td>
<td>13.2%</td>
<td>16.9 %</td>
</tr>
<tr>
<td>5</td>
<td>0.7</td>
<td>8.3%</td>
<td>12%</td>
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</tbody>
</table>
As conclusion – features of ILU accelerators

- RF generator with positive feedback – fast start of irradiation, soft requirements to cooling system
- Pulsed beam – High efficiency and multi-window beam extraction
- E-beam and X-ray mode – high profitability of e-beam allows compensate low profitability of X-ray
- Low RF frequency 100-200 MHz – not required high accuracy in manufacture of cavity
<table>
<thead>
<tr>
<th>Accelerator</th>
<th>Production</th>
<th>City, Country</th>
<th>Year of start</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILU-6</td>
<td>Sterilization raw material (medecinal herbs)</td>
<td>Bisk, Russia</td>
<td>2007</td>
</tr>
<tr>
<td>ILU-8 2 Pcs</td>
<td>Wires crosslinking</td>
<td>Cheboksary, Russia</td>
<td>2008, 2017</td>
</tr>
<tr>
<td>ILU-10</td>
<td>Plastic tubes crosslinking</td>
<td>Czluchow, Poland</td>
<td>2008</td>
</tr>
<tr>
<td>ILU-6 (Deep modernization)</td>
<td>Thermo-shrinkable tubes</td>
<td>Czluchow, Poland</td>
<td>2010</td>
</tr>
<tr>
<td>ILU-10, 2 Pcs</td>
<td>Sterilization</td>
<td>Novosibirsk, Russia</td>
<td>2012, 2013</td>
</tr>
<tr>
<td>ILU-10</td>
<td>Sterilization</td>
<td>Kurchatov, Kazakhstan</td>
<td>2013</td>
</tr>
<tr>
<td>ILU-10M</td>
<td>R&amp;D, food irradiation</td>
<td>BARC, Mumbai, India</td>
<td>2014</td>
</tr>
<tr>
<td>ILU-14</td>
<td>Sterilization</td>
<td>Moscow, Russia</td>
<td>2014</td>
</tr>
<tr>
<td>ILU-10</td>
<td>R&amp;D, Sterilization</td>
<td>BINP, Novosibirsk, Russia</td>
<td>2014</td>
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<tr>
<td>ILU-8</td>
<td>Wires crosslinking</td>
<td>Mytichi, Russia</td>
<td>2016</td>
</tr>
<tr>
<td>ILU-10</td>
<td>Sterilization</td>
<td>Almaty, Kazakhstan</td>
<td>2017(under construction)</td>
</tr>
<tr>
<td>ILU-10</td>
<td>Sterilization</td>
<td>S.Korea</td>
<td>2017</td>
</tr>
</tbody>
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Thank you for your attention