Research and Development of Irradiation Linacs in Tsinghua University and NUCTECH

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Accelerator Laboratory of Tsinghua University
Outline

- Application of irradiation linac
- Backward traveling-wave linac
  - Linac tube development
  - Irradiation system
- Projects Overview
- Research Projects
  - Traveling-wave linac
  - Beam breakup effect study
Accelerator Laboratory of Tsinghua University

accelerator technology for irradiation & sterilization

Apply to irradiation processing of food, medical product, quarantine treatments and etc.

- Damage to the molecular of the harmful organism. To control insects, parasites and pathogens, reduce spoilage.

- Inhibit sprouting, delay ripening and extend self-life for certain farm produce.
• Low Energy
  – <300keV
  – E-beam curing
• Middle Energy
  – 0.3-5MeV
  – Cross-linking of polymers, for cable / rubber …
• High Energy
  – 5-10MeV
  – Sterilization …Food irradiation
Application fields

Medical products, Medicine, Mails......Sterilization
Application fields

Food irradiation
Irradiation phytosanitary treatment
Excellence of E-Beam system

- No environmental pollution.
- Quick processing, high efficiency.
- Do not open the packing case, so it can get across quickly and safely.
- No toxicity or remains. Do not add any chemical reagent, so no original element and quality of products is influenced.
Linac

- Irritation E-beam facility
  - Dynamitron
  - Linac
  - Rhodotron
  - Ridgetron
  - Fantron

- LINAC
  - Standing wave/Traveling Wave/Backward Traveling Wave
• Common structures
  – Disk-loaded waveguide (traveling wave)
  – Bi-periodic standing wave
  – BTW type (Traveling wave)
Introduction of BTW structure

- **BTW structure**
  - High-shunt impedance (~ Optimized shape)
  - Short filling time (~Traveling wave)

<table>
<thead>
<tr>
<th></th>
<th>Shunt impedance</th>
<th>Filling time</th>
<th>Need AFC?</th>
<th>Reflection from input</th>
<th>Peak surface field</th>
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<tbody>
<tr>
<td>Diskloaded</td>
<td>Low</td>
<td>Short</td>
<td>No</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Bi-periodic SW</td>
<td>High</td>
<td>Long</td>
<td>Yes</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>BTW</td>
<td>High</td>
<td>Short</td>
<td>No</td>
<td>Low</td>
<td>High</td>
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</table>
BTW structure

- Cells coupled through coupling holes
  - Beam-pipe cut off
  - Easy for tuning a structure
  - RF focusing
- Power flow opposite direction to the beam
  - High efficiency
  - Easy for cooling the input coupler
16MeV BTW linac

- Energy: 16MeV
- Dose rate: 12000cGy/min@1m
- Beam spot: <φ2mm
- Peak current: 115mA
  - RF power in (peak): \( P_m = \frac{P_e}{40\%} = 4.6\text{MW} \)
  - Beam power (peak):
    \[ P_e = 16\text{MV} \times 115\text{mA} = 1.84\text{MW} \]

- Developed in 2000.
  - First BTW linac
Design parameters

- **Ebeam:**
  - Energy: 10MeV
  - Peak current: 300mA
  - Average power: 20kW

- **Accelerator tube:**
  - BTW type
  - Length: 1.5meter
  - Bunching cells: 11 cells

- **RF source:**
  - 5MW/45kW klystron @ 2856MHz
Beam dynamics

- Efield on axis
- Energy v.s. injection phase (30% captured)
Power dissipation (45kW)

- Accelerating cells
  - Total power
    - 9kW
  - Hottest cell:
    - 580W (40#)
- Output coupler
  - 5kW
- E-beam power
  - 31kW (designed)
Cell design

- CST Microwave suite
  - Frequency
  - Cell-cell coupling
  - Input/output couplers
Thermal analysis

- ANSYS simulation
  - RF field -> RF heating -> temperature distribution
  - -> deform -> frequency detuning

Frequency detuning v.s. temperature rise, and power loss/cell

60KHz/1degree, +41degree/kW, 1MHz/kW (single cell)
Final picture

- Cooling jacket, Solenoid, Pumping port,
- vacuum flange for e-gun and scan system
System integration (Nuctech)
First prototype at Nuctech
First product

IS1020
10MeV
20kW
Second product
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Accelerator Laboratory of Tsinghua University
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ebeam energy</td>
<td>10MeV</td>
</tr>
<tr>
<td>Beam power (average)</td>
<td>20kW</td>
</tr>
<tr>
<td>Pulse width</td>
<td>12μS</td>
</tr>
<tr>
<td>Rep. rate</td>
<td>650pps</td>
</tr>
<tr>
<td>Scan frequency</td>
<td>5 ~ 20Hz</td>
</tr>
<tr>
<td>Scan width</td>
<td>400 ~ 800mm</td>
</tr>
</tbody>
</table>
Applications:

- Shanghai (2013)
- Guangzhou (2014)
- Yangzhou (2015)
- Chongqing
- Huizhou
E-beam irradiation integrated processing center (Shanghai, 2012)
E-beam irradiation integrated processing center (Guangzhou, 2013 on building)

- 10MeV 20kW
- back-wave accelerator
- 8-20 tons/h
- ~300 m²
• 5MeV/2kW mail sterilization
Mail sterilization System (2002)

Mail sterilization system (2008)

Mobile sterilization system (2005)
Accelerator

- **Energy / Power:** 10MeV/15kW
- **Process ability:** 100,000 tons/year
- **Usage:** Fruit fresh & quarantine treatment
- **System occupy:** ~300m²

Background

For usage of the port on the border
Large quantities imported fruits from southeast Asia countries
Quarantine treatment of tropical fruits
Face Vietnam and other southeast Asia countries
The first E-BAEM quarantine treatment system of imported goods in China
Guangxi pingxiang YouYiGuan
10MeV/7.5kW × 2
Disk-loaded traveling wave linac for irradiation
parameters

- Klystron: 5MW, 45kW
- Output: 20kW@10MeV
- E-gun injection voltage: 47~53kV
- RF-beam efficiency > 50%
- Length < 2m
### Parameters

- **Injection voltage**: 50kV
- **Input RF power**: 4.5MW
- **beam energy**: 10/12MeV
- **Peak current**: 280/150mA
- **efficiency**: 62%/40%
- **structure**: constant impedance
- **Phase adv./cell**: $2\pi/3$
Beam Dynamics

[Graphs showing beam dynamics with axes labeled for Energy (MeV), Phase (rad), Magnet (Gauss), and R (cm).]
2-meter linac
Beam break up (BBU)

- **Phenomenon**
  - The tail of pulse will be lost. The beam current is limited.

- **Physics mechanism**
  - The following electron will be deflected by the wake field generated by the previous beam.
  - Collective beam instability.
  - m=1 transverse wake field (HEM11 mode) can be amplified by the beam itself.

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Modes and parameters calculation

- Simulate the eigenmodes of two structures and find the dipole mode.
- Plot the dispersion curve.
- Calculate the parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Travelling wave</th>
<th>Backward wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (GHz)</td>
<td>4.338</td>
<td>4.939</td>
</tr>
<tr>
<td>Phase (degree)</td>
<td>177.8</td>
<td>233.3</td>
</tr>
<tr>
<td>Period length (mm)</td>
<td>35</td>
<td>39.36</td>
</tr>
<tr>
<td>k (1/m)</td>
<td>90.86</td>
<td>103.44</td>
</tr>
<tr>
<td>Phase velocity (1/c)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Group velocity (1/c)</td>
<td>0.001</td>
<td>-</td>
</tr>
<tr>
<td>Q</td>
<td>14158</td>
<td>20100</td>
</tr>
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</table>

The group velocity of backward wave model is very low because of the structural features.
Experiments were done in a 10MeV backward travelling-wave accelerator system.

Different pulse widths and beam current values were scanned to observe and compare the output pulse waveform while BBU.

The beam pulses observed in experiment while BBU (Orange for input, green for output)

Relation of the pulse width and current
Preliminary modelling and simulation

- On the basis of the physics mechanism of beam break up and the beam dynamics, an interaction model for travelling wave accelerating structure has been built.

- A pulse can be considered as a composition of several ten thousand of micro-pulses, being a micro-pulse a bunch. So, the n-th bunch is influenced by the wake field generated by the (n-1) bunches ahead.

- We write a code in MATLAB to simulate the motion of electron in travelling wave accelerator. The maximum transverse offset is nearly in exponential growth with initial current as shown.
Summary

• **BTW irradiation linac:**
  – R&D at University
    • Physics beam dynamics
    • RF structure design / Thermal analyses / Mechanical design
    • Fabrication and brazing / RF measurement and tuning
    • Beam test
  – Industrialization at NUCTECH
    • System integration:
      (controlsyst/klystron/modulator/cooling/building…)
    • Business model

• **Different type:**
  – BTW: main product: 10MeV/20kW
  – SW: 10MeV/5MeV : lower average power

• **Beam break up study on-going**
Thank you!