Design of a 6 MW Solid-State Pulse Modulator using Marx Generator for the Medical Linac

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Located in Busan, Korea (Southeast Korea)

Commercial linac for patients treatment

- LINAC- ELEKTA (S-band)
- CYBER KNIFE (X-band)

R&D of linac

- Opening 2010, Jul. 16.
- Research for medical use of radiation: medical, biotechnology, chemistry, physics, environment etc.
- Providing medical services and radiological emergency response.

Accreditation KC14-297 : Ionizing Radiation

- Calibration Phantom
- Cobalt-60 Irradiator
- Calibration Stage
- Telescope
- Alignment tool
Design and Construction of 6 MeV C-band (5712 MHz) Linac

- Bi-periodic & on-axis coupled structure, $\pi/2$ mode SW operating.
- Accelerating the electrons up to 6 MeV using 2.5 MW RF power.
- Using the 6 MW pulse modulator which was designed and constructed with the thyratron-switched pulse-forming network.
- We are developing a radiotherapy machine consisting of a gantry, a support stand, a treatment couch, a control console, etc.
For commercial medical linacs

- From marketing data (2013 Jan.)
- Medical linacs (from Elekta, Siemens and Varian) are mostly using the thyratron-switched PFN modulator.
- One solid-state modulator is only used in the TomoTherapy® Hi-Art® Treatment System.
- Still not actively using the solid-state modulator.

**DIRAMS** we’re developing the pulse modulator as follows:

- **Thyratron-switched PFN Modulator**: low power for electron gun
- **Solid-State Modulator**: high power for magnetron

Now we’re here.
Pulse Modulator @ DIRAMS

- **6MW** Pulse Modulator (Average ~ 12 kW)
  - For Magnetron, up to 50 kV & 120 A
  - For Electron gun, up to 20 kV & 1 A
  - Pulse width ~ 4 us and rate up to 250 Hz
  - Using thyratron-switched pulse-forming network
• Developed the low power solid-state pulse modulator based on the Marx generator.
  ✓ Operation for a linac electron-gun
  ✓ Output HV : 5 - 25 kV (P_{peak} = 25 kW)
  ✓ Repetition Rate : 1 - 300 Hz
  ✓ Pulse width : 4 - 10 μs
  ✓ N of Storage-switch stages = 35
• With the same scheme, we propose the high power pulse modulator.
• **Propose of the 6 MW Solid-State Modulator**
  - Operation for a linac magnetron
  - Capacitor-charging PS for input power: 100 - 1000 V, 15 kJ/sec
  - Marx generator (40 storage-switch stages) output: 25 kV and 240 A
  - Pulse transformer (1:2): 50 kV and 120 A
  - Repetition Rate: 1-300 Hz and Pulse width: 4-10 μs
  - Heater isolated transformer: 6.3 VAC and 22 A
Marx Pulse Generator

- A storage-switch stage,
  - Two IGBTs switches for charging and discharging.
  - Gate driver controlled by fiber-optic and powered from the bias power board through the isolated transformer
  - $V_{IN} = 720$ V and switching current up to 240 A
  - Storage capacitor = 25 $\mu$F for the voltage droop of 10 % with the pulse width of 5 $\mu$s
- For operation with the pulse transformer, the tail-clipper (resistors and diodes) is installed at the Marx generator output.
Prototype System

• At a storage-switch stage,
  ✓ For two IGBT switches, IXYN120N120C3 (for discharging) and FGA30S120P (for charging) were chosen.
  ✓ For fast-recovery diode, DSEI2x101-12A was chosen.
  ✓ For storage capacitor, UL3_L256K (25 μF, 1.2 kV) was chosen.
• The prototype system including eight storage-switch stages and the auxiliary boards was designed and constructed.
Test with the resistive load

- The test was performed with the resistive load of 24.36 Ω. It confirms that each stage can drive the switching current of 240 A with the input voltage of 720 V.
- Successfully tested with various voltage amplitudes and pulse widths.
- The voltage droop was measured to be 6% at 4 μs and 12% at 12 μs.
Conclusion & Future Plan

• The 6 MW solid-state modulator was designed.
• The prototype system was constructed and tested. It verified the design and the functional operation of the storage-switch stages.
• The voltage droop \(V_{IN}=720V, 240A, 5\, \mu s\) is measured to <10%.
• This design will be applied for the Marx pulse generator with 40 storage-switch stages and optimized with the pulse & heater transformer for the 2.5 MW magnetron operation.

→ Now producing the stage boards with component assembly.
→ After passing the board-level quality test, they will be integrated.
Obrigada!

감사합니다.

A future of leading radiological & medical science
and a hope of the cancer patients.

[Dongnam Institute of Radiological & Medical Sciences]