DEVELOPMENT OF THE CONTROL SYSTEM FOR PEFP 100-MeV PROTON LINEAR ACCELERATOR

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Contents

- Introduction
- Control System (20 MeV linac)
- Control System (100 MeV linac)
- Summary
Introduction

- Project: Proton Engineering Frontier Project (PEFP)
  - 21C Frontier R&D Program, MEST, Republic of Korea

- Objectives
  - To develop a High Power Proton Linac (100MeV, 20mA)
  - To develop Beam Utilization & Accelerator Application Technologies
  - To Industrialize Developed Technologies

- Period: July 2002 – December 2012

- Budget: 307.4 B KRW (~275.0 M US$)
  - Gov.: 176.3B(57.3%), Local Gov.: 118.2B(38.5%), Industry: 12.9B(4.2%)T
  - 66B KRW to Accel. & Beamline (including R&D & personnel expenses)
Project Site: Gyeongju

- Historic city (Capital of Silla Dynasty)
- Conference host city (LINAC2002, APAC2004)
- Easy access (KTX & Express way)
- Near to the light source (PLS) (30min by car)
- Near to Busan (IPAC2016)
Site Plan

① Accelerator Tunnel  ② Experimental Hall  ③ Ion Beam Facility  ④ Utility Building  ⑤ Substation  ⑥ Cooling Tower
⑦ Water Storages  ⑧ Main Office Building  ⑨ Regional Cooperation Center  ⑩ Dormitory  ⑪ Information Center  ⑫ Sewage Plant
### PEFP 100-MeV Linac

#### Features of the PEFP 100MeV linac
- 50 keV Injector (Ion source + LEBT)
- 3 MeV RFQ (4-vane type)
- 20 & 100 MeV DTL
- RF Frequency : 350 MHz
- Beam Extractions at 20 or 100 MeV
- 5 Beamlines for 20 MeV & 100 MeV

#### Output Energy (MeV)
- 20
- 100

#### Max. Peak Beam Current (mA)
- 1 ~ 20
- 1 ~ 20

#### Max. Beam Duty (%)
- 24
- 8

#### Avg. Beam Current (mA)
- 0.1 ~ 4.8
- 0.1 ~ 1.6

#### Pulse Length (ms)
- 0.1 ~ 2
- 0.1 ~ 1.33

#### Max. Repetition Rate (Hz)
- 120
- 60

#### Max. Avg. Beam Power (kW)
- 96
- 160
PEFP Beam Lines

- Designed by reflecting user’s requirements (through User Program)
- Developed components: QM, ACM, DM & beam instruments, Beam window

<table>
<thead>
<tr>
<th>Beam Line</th>
<th>Application Field</th>
<th>Rep. Rate</th>
<th>Avg. Current</th>
<th>Irradiation Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR101</td>
<td>Radio Isotopes</td>
<td>60Hz</td>
<td>0.6mA</td>
<td>Hor. Ext. 100mmØ</td>
</tr>
<tr>
<td>TR102</td>
<td>Medical Research (Proton therapy)</td>
<td>7.5Hz</td>
<td>10µA</td>
<td>Hor. Ext. 300mmØ</td>
</tr>
<tr>
<td>TR103</td>
<td>Materials, Energy &amp; Environment</td>
<td>15Hz</td>
<td>0.3mA</td>
<td>Hor. Ext. 300mmØ</td>
</tr>
<tr>
<td>TR104</td>
<td>Basic Science Aero-Space tech.</td>
<td>7.5Hz</td>
<td>10µA</td>
<td>Hor. Ext. 100mmØ</td>
</tr>
<tr>
<td>TR105</td>
<td>Neutron Source Irradiation Test</td>
<td>60Hz</td>
<td>1.6mA</td>
<td>Hor. Vac. 100mmØ</td>
</tr>
</tbody>
</table>

- Radio Isotope
- Bio-Medical Application
- Semiconductor
- Basic Science

- 100 MeV Beamlines
- 20 MeV Beamlines

- Designed by reflecting user’s requirements (through User Program)
- Developed components: QM, ACM, DM & beam instruments, Beam window

- 33, 45, 57, 69, 80, 91, 100 MeV beam
Operation at KAERI in Daejeon: Linac test and Beam supply to users

- RFQ, DTL: designed (PEFP), fabricated (domestic company)
- Integrated (May 2005)
- First beam extraction (July 2005)
- Operation license (June 2007): Avg. Current 1 μA, 4-hour/week
- User beam service (from July 2007)
- Operation finish (Nov. 2011)
- Installation at project site in Gyeongju (Feb. 2012)
20-MeV Linac Disassembly and Movement

- Disassembly of the 20-MeV linac from Dec. 2011
- Movement from Daejeon to Gyeongju (~200km apart)
- DTL and klystron was transported by using the vibration free truck through express way.
- No notable field distortions in DTL before and after (~ 3%)
- Special supporter with oil jack and caster was used in the tunnel.

DTL tanks inside vibration free truck

Special supporter inside tunnel
Accelerator Installation

- Installed inside tunnel at March, 2012
Beam line Installation

- Magnet Installed inside experimental hall at May, 2012
PEFP Control System

- Large proton accelerator has many devices
  - distributed control system
  - integrated operation
  - a set of open source software tools, libraries, and applications
  - network-based server/client model
  - cost-effective and high reliability
Contents

- Introduction
- Control System (20 MeV linac)
- Control System (100 MeV linac)
- Summary
Purpose: 20-MeV Operation and 100-MeV Control System Test

**Configuration of 20-MeV Control System**

- **Timing & Interlock**
  - Timing Synchronization
  - Interlock
  - Interlock Network
  - Timing Network
  - Interlock

- **Data Management & Visualization**
  - RDB Server
  - Operator Interface
  - Web Monitoring
  - Channel Archiver
  - CA Gateway

- **Control Network**
  - RCCS
  - Klystron Modulator
  - HPRF LLRF
  - Injector
  - Magnet Power Supply
  - Beam Diagnostic
  - Vacuum Pumping
Control Room (20-MeV Linac)

20-MeV Control Room

EPICS OPI  RF & Beam Monitor  LLRF Control System  EPICS OPI Server
Low Level RF

- RF amplitude and phase requirements within 1% and 1 degree
- Digital RF feedback control system
- Pentek 7142 Four 125 MHz 14-bit A/Ds One 500 MHz 16-bit D/A Xilinx Virtex-4 FPGAs
- Control software: PI implemented in FPGA and EPICS OPI by PEFP
- Digital LLRF was tested at the 20-MeV linac (2010)
  - Monitor amplitude, phase, and waveform
  - Control PI gain, amplitude, and phase
Magnet Power Supply Control System

- Monitor current and status (on/off, local/remote, normal/alarm)
- Control on/off, settings of current, permissible setting range, and knobs
- Connection of Modbus/RTU and RS232
- Using SNL for programming sequential operation on external events
- VME IOC
  - MVME5100 and VME multi-serial IO board
  - EPICS device/driver
  - vxWorks operating system

VME IOC

OPI
Vacuum Control System

- Monitor pressure, current, voltage, and status (on/off, normal/alarm)
- Control HV on/off, settings current, voltage, and start/stop
- Interlock of vacuum pressure with section valves
- VME IOC
  - VME multi-serial board
  - EPICS device/driver
  - vxWorks operating system
Resonance Control Cooling System

- Resonance frequency matched to the HPRF driving frequency
- RCCS used to control the resonance frequency of each DTL tank by supplying temperature-controlled water to draft tubes
- RCCS monitors resonance frequency error measured by LLRF system
- Temperature, flow rate, pressure, motor speed & control, valve status & control, alarm status screen, flow chart screen, AutoSave

### Operator Interface

### Control Network

### RCCS IOC

### Fabricated water pumping skip

<table>
<thead>
<tr>
<th>Items</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case/Slot</td>
<td>19”, 6U USB Backplane Type</td>
</tr>
<tr>
<td>CPU</td>
<td>Intel Pentium, 500 MHz</td>
</tr>
<tr>
<td>Memory</td>
<td>512 MB</td>
</tr>
<tr>
<td>HDD</td>
<td>4 GB Compact Flash Memory</td>
</tr>
<tr>
<td>Ethernet</td>
<td>10/100/1000 Mbps</td>
</tr>
<tr>
<td>OS</td>
<td>Linux (Fedora Core 8 and over)</td>
</tr>
<tr>
<td>Kernel</td>
<td>RT Kernel 2.6.23.1</td>
</tr>
<tr>
<td>Software Tool</td>
<td>EPICS base, sequencer, AutoSave</td>
</tr>
</tbody>
</table>
| Signal I/O modules | Analog Input Board  
                       Analog Output Board  
                       Digital Input Board  
                       Digital Output Board  
                       RTD board              |
Microwave Ion Source

- Control system isolated from high voltage boundary
- VME optical IO board for optical serial link
- IO system of optical to analog transition converter in high voltage boundary
- Monitor forward and reflected RF of magnetron and directional coupler, current of magnet PS
- Control magnetron RF power, PS current
High Voltage Converter Modulator

- HVCM used to drive the klystron
  - 5.8MW peak power with 1.5ms pulse, 60Hz repetition rate
- Soft IOC
  - Linux, Intel Xeon 2.4GHz/4-core
  - EtherNet/IP Driver
- Monitor operation state, voltage, current, equipment fault, personnel fault
- Control settings of voltage and current, limit

Ethernet (Channel Access)

- Intel Xeon 2.4GHz/4-core
- Memory 4GB
- Ethernet 1Gb

Ether/IP

- Soft-IOC
- Linux
- EtherNet/IP protocol (ControlNet over Ethernet)

HVCM Local Control Rack
ALH & Data Storage

- **Alarm Handler**
- **Web Viewer**

- **Two database systems**
  - EPICS Channel Archiver: IOC Real-Time database
  - RDB MySQL
- **Data viewer**
  - EPICS Extensions (EDM/MEDM, etc)
  - Web viewer
- **CSS BOY and channel archiver engine and alarm**
Operator Interface (OPI)
Contents

- Introduction
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Configuration of 100-MeV Control System

20MeV QMP:
- QMP (26)
- MEBT (8)
- LEBT (2)
- Steering (2)

100MeV QMP:
- QMP (23)
- BL (10)
- Dump (4)
- 45 BM (2)

Magnet PS
- RS232 38 ea.
- Ethernet 39 ea.

Multi Serial Controller
- 16ch/ea. (3 ea.)

Server PC
- 20ch/ea. (2 ea.)

DI/DO
- 20ch/ea. (2 ea.)

AI/AO
- (12 ea.)

RCCS
- 20ch/ea. (12 ea.)

HVCM
- (4 ea.)

IS
- (1 ea.)

MPS
- 8ch/ea. * 16ea. (128ch)

LLRF mv5100
- ADC (11 ea.)
- DAC

BPM mv5500
- ADC
- 64ch/ADC (12 ea.)

BPM mv5500
- ADC
- 64ch/ADC

RCCS
- 16ch/ea. (5 ea.)

Multi Serial Controller
- 16ch/ea. (5 ea.)

PLC
- 23 ea.
- EVG 1 ea.
- EVR 7 ea.
- FANOUT

Timing mv3100
- EVG
- EVR

Controll er
- 43 ea.

Controll er
- 43 ea.

20Mev 7 ea.
- 100MeV 16 ea.

Gauge
- 20Mev 7 ea.
- TMP 19 ea.
- IP 47 ea.

Pump
- 20Mev 7 ea.
- 100MeV 16 ea.

CT
- (13 ea.)

FC
- (4 ea.)

BPM
- (14 ea.)

BLM
- (12 ea.)
Beam Monitoring System

- Data acquisition for BCM, BPM, and BLM
- Industry Pack (IP) ADC board
  - external trigger and clock
  - Max. 200KSPS/channel, input ±5/±10
- EPICS and ASYN modules
  - carrier card and IP module driver
- Create raw data, average, and waveform

<table>
<thead>
<tr>
<th>EPICS / Channel Access</th>
<th>Operating System</th>
</tr>
</thead>
<tbody>
<tr>
<td>VME CPU/ADC</td>
<td></td>
</tr>
<tr>
<td>Electronics BLM</td>
<td>Electronics BCM</td>
</tr>
<tr>
<td>Electronics BPM</td>
<td>BPM Detector</td>
</tr>
<tr>
<td>BLM Detector</td>
<td>BCM Detector</td>
</tr>
<tr>
<td>IOC Test Stand</td>
<td>Operator Interface</td>
</tr>
</tbody>
</table>

MPC7457 PowerPC

VME Carrier Board IP-ADC & TR Board

IOC Test Stand

Operator Interface
Programmable timing system (EVG, EVR)
  - low level RF control trigger
  - beam gate generation
  - RF gate generation
  - klystron modulator control trigger
  - time referenced to external clock

MVME3100 (MPC8540)
Vacuum & Magnet Power Supply

- IOC H/W changed from VME IOC to embedded IOC and Soft IOC
- Monitor vacuum pressure, current, voltage, status (on/off, normal/alarm), PS current, voltage, status (on/off, normal/alarm)
- Control pump HV on/off, settings current and voltage, start/stop, PS on/off, settings of current, permissible setting range
Hardwired MPS for the 100MeV Machine
  - will shut off the beam at the ion source and RF power

Connected to EPICS control system to monitor the MPS status
  - Interlock box (8CH, 10V DC) 16 sets (RF 12 sets, Beam 3 sets, IS 1 set)
  - monitoring (8CH * 16 sets),
  - control (remote reset / auto or normal reset: 2CH * 16 sets)
PEFP Control Room

- **Air conditioning**
  - 21 ~ 24°C

- **Double floor**

- **Display**
  - OPI 23” LCD 28 ea.
  - CCTV 40” LFD LED 3 ea.
  - safety status (LED) 4 ea.

- **Console table**
  - U-shaped array
  - console and seating

- **Computers Room**

- **Control Room**
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Summary

- 100-MeV proton accelerator control system
  - developed using EPICS
  - distributed control system

- 20-MeV control system
  - used to operate the linac for 5 years
  - debugged and upgraded for 100-MeV linac control system

- 100-MeV control system
  - extension system of 20-MeV control system
    - (LLRF, RCCS, HVCM)
  - new system
    - (timing system, beam monitor system, MPS, vacuum, magnet power supply)
Thank you for your attention