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

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□ 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



Near to Busan (IPAC2016)

### Site Plan

 Accelerator Tunnel
 Experimental Hall
 Ion Beam Facility 4 Utility Building 5 Substation **Cooling Tower** 6

(7)

 $(\mathbf{6})$ 

- 7 Water Storages
  8 Main Office Building
  9 Regional Cooperation Center
  10 Dormitory
  11 Information Center
  12 Sewage Plant

PEFP Proton Engineering Frontier Project

### Accelerator Building & Experimental Hall,



### 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



### 20-MeV Linac

□ 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 trasported 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

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Seoul (

### **Accelerator Installation**



□ Installed inside tunnel at March, 2012





□ Magnet Installed inside experimental hall at May, 2012

#### 20-MeV Beam line hall

#### **100-MeV Beam line hall**





## **PEFP Control System**

□ Large proton accelerator has many devices

- distributed control system
- integrated operation

#### □ Adopt EPICS toolkit http://www.aps.anl./gov/epics/index.php

- a set of open source software tools, libraries, and applications
- network-based server/client model
- cost-effective and high reliability





□ Introduction

#### □ Control System (20 MeV linac)

□ Control System (100 MeV linac)

**U** Summary

## Configuration of 20-MeV Control System

□ Purpose : 20-MeV Operation and 100-MeV Control System Test

**Timing & Interlock** 

**Data Management & Visualization** 



### 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



#### **Operator Interface**

PMC Board



VME CPU Board



### 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

- MVME5100 and VME multi-serial IO board
- EPICS device/driver
- vxWorks operating system



OPI



**VME Serial IO Board** 

**Multi-Serial** 





### 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 multi-serial board
- EPICS device/driver
- vxWorks operating system



#### **Operator Interface**



#### VME Serial IO Board

### **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



**Control Network** 



RCCS IOC



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

Fabricated water pumping skip

### **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

v ]j	home/pefp/PEFP_OPI/sub/microion1.edl		- 0 X
<b>2</b>	Microwave Ion Source	EX	Т
	High Voltage	-0.011	
Monitors	Voltage	Current	
Magnet	0.007	-0.659	
	Forward RF	Reflected R	F
Directional coupler	0.0	0.0	
	Forward RF	Reflected R	F
Magnetron	0.0	0.0	
Controls			
Magnet 0.001	0.000 Magnetron	0.0	0.0
			- 1
0 save rest	100 0	save rest	5
0.000		0.000	

#### Operator Interface

EPICS Channel Access



## 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



## ALH & Data Storage

#### **Alarm Handler**



#### IFT ON TY WORK Welcome to Accelerator Control Home II 2.5e-9 08: 40 cavity.tet 94: 9458 EH, 2008 E 2,2544 21: 1474148.00 \$700 A25 0± **Real-Time Monitoring** Vacuum Status No. Feb 08 1413947 Download Process Variable(PV) Gauge Statu Ion Source **RFO** Cavity 4.88e-08 **REO East Window** 1.11e.06 **REO West Window** 1.290.06 Search Data Begin Time End Time ▼ - ≝ ▼ - ≌ ▼ 00 ▼ : 00 ▼ : 00 ▼ Data Plotting \$4:00 \$4:00 \$5:00 \$5:00 \$6:00 \$6:00 TPE (5 hours) \$2100 \$2100 \$3100 \$3100

#### □ 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



#### Web Viewer

## **Operator Interface (OPI)**

📤 Applications Actions 😪 🍩 🚷 Fri Mar 25, 2:39 PM 🛛 🔇 mesl.stp 0 mesl.stp TEMPERATURI CAVITY WALLTEMPERATURE RFO LLRF CONTROL OPI CLOSEDOOP EXIT HVCM Inside-Temp Outside-Temp DTL-Kly-Inlet VALUE OF OR TANK FANK : TANK TANK 4 MODULATOR VOLTAGE MONITOR MODULATOR CURRENT MONITOR SETPOINT Gauge:0:01E32 26.69 26.98 34.88 46.19 18.0 1.7 37.5 OPEN CLOSED LOOP 0.400 SETPOINT MODULATOR VOLTAGE (F9 0.38 kV 0.32 A CLOSED ENIT 100 kV +CAP BANK VOLTAGE MONITOR CAP BANK VOLTAGE MONITOR 120000 SETPOINT CAL IANK VOL TAG (F10) 0.003 kV -0.003 kV net Power Sup 0.0 kV EXIT SCR BUS VOLTAGE SCR BUS CURRENT MONITOR Current (A) 9 25.30 27.35 23.03 27.67 33.86 36.14 45.09 46.35 Beam Off SETPOINT SCR BUS CURRENT LIMIT (F11) -0.008 kV 0.2 A EXIT OL 1 50 A EQUIPMENT FAULT FAULT Beam Current (mA) 165.0 2.4e-06 1.4e-06 OK -0.01 Accelerator Ready Qa MP 1 Disconnect 2.629 mA 2.2e-06 Amp 1.4e-07 Target Room Status MP 2 MODE CAP BANK VOLTAGE STATE OPERATION STATE 1.000 MP 3 eam Count : 🛛 👖 STANDBY LOCAL IN RANGE MP4 WHEN POSLPSIZ CALCZZ mas.sta Status ON 154.9 MP 5 Beam Conditi No Request VHEH POSLPSID:CALCZ2 LOUT 157.92 Beam Approval WHEELSPOSLPSELCALCZZ nber of Pulses - O MP 6 OFF V\_OUT ON MERI-POSLPSIS:CALCZ2 2.00 MP7 Not Approved No. WHENT-POSLPSIK:CALCO am Ou/Off 50.00 SOL 2 VINEER POSILPSET CALCER 1 SFT 1.0 Hz NEET POSLPSERICAL C72 Beam Off Status ON VMERZ POSLPBRI (CALCZZ arget Room Access LOUT 180.89 Run / Stop 57 61 OFF V\_001 29.2 EB2 POSLPS82:CALC2 Approved ON 0 14:39:01 May 25, 201 MPS StripTool Control Better EXIT +++++++ scalhost 🗍 RFQ-VACUUM:s 🗍 DTL\_Vacuum:stp 🗍 mps.stp Graph 🖉 Alarm Handler 🗮 Alarm Handler 📷 aph III [petpiPlocalhest] StripTool Graph V III [pet Microwave Ion Source CC DTL ION PUMP High Voltage **Beam Off** PEFP 100 MeV PROTON LINAC -0.011 0.004 DTL LLRF CONTROL OPI CLOSEDOOF EXIT Current -0.659 Magnet 0.007 DTL1 HV1 Reflected RF 0.400 OPEN CLOSED LOOP D VACUUM LLRF BEAM RCCS Directional coupler 0.0 0.0 20 MeV VACUUM STATUS CLOSED ENIT D Magnet P/S HPRF Cooling KLY-INLET Forward RF 120000 Magnetron 0.0 0.0 Pump Statu Tank Wall Temp ION SOURCE EXIT Control ION Sout **RFO** Cavity 2.40e-06 save rest 100 save rest 8F9-Cavity (2.27254-85, 2.31748-85) W4-2.4e-85 8F9 Cavity pressure 8F9 Cavity pressure (1.5384e-65, 2.11156-65) V94-2.1e-85 REG-VACUUM.st 2.10~06 **RFQ East Winde** 0.000 0.000 0 **RFQ West Window** 2.18~06 117.0 RFG West Wester (2.02795e-06, 2.19195e-06) WiL-2.10e-08 COMPANY THE COMPANY OF THE OWNER OWNE 1.53e-06 DTL 21 Tank ENIT 1011-Saurce (-0.00016975, 0.00019125) VWL-0 DTL 21 Window 2.62e-06 DTL 22 Tank -2 14:33:61 Miler 25, 2011 **Beam Status** ENT (Handes) DTL 22 Window -0. Phase Amulitude DTL 23 Tank Beam Off DTL-21-Tank (9e-08, 5e-06) WL-1.53 DTL 23 Window DTL-22-Tank (3e 08, 5e 06) WiL-6.64 DTL 24 Tank DTL-23-Tank (9e-00, 5e-06) W4L-1.33 DTL 24 Window DTL-24-Tank (3e-00, 5e-06) W4-1.2e 011-21-Westerw (3e-00, Se-06) W4L-2.61 STOP Confirmed 011-22-Wedaw (3e-00, 5e-06) W4L-5.18 14:35:52 Mar 25, 2011 011, 23 Wedaw Mar 25, 2011 011, 24 Wedaw (\$e-08, \$e-06) W4L-2.47 Approved EXIT Beam-Off State Flag +++++H+ X+0+ 2 4 SCROLLING

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PEFP Proton Engineering Frontier Project



□ Introduction

□ Control System (20 MeV linac)

□ Control System (100 MeV linac)

**U** Summary

### Configuration of 100-MeV Control System,



PEFP Proton Engineering Frontier Project

### **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





**IOC Test Stand** 



#### **Operator Interface**



#### MPC7457 PowerPC



#### VME Carrier Board IP-ADC & TR Board



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## **Timing System**

□ Programmable timing system (EVG, EVR)

- Iow 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



### **Machine Protection System**

PEFP
Proton Enginee
Frontier Project



### **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







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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)

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# Thank you for your attention