LEAF ECR Ion Source Control System

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Abstract. FECR ion source is replaced with LAPECR ion source temporarily for other components performance testing in LEAF. LAPECR ion source can afford intense low charge state or medium charge state ion beams. This paper introduces the control system which comprises software, hardware and the interlock system. The control system is based on EPICS and the device supports are developed in Linux. CSS is utilized as the Operator Interface. Commercial controllers and PLCs are adopted to control devices, acquire experimental data and create interlock system. At present, LAPECR ion source has provided beam (150 μA, $^4H^{1+,}$ 0.5Mev) for RFQ outlet. This control system can work stable and interlock system can effectively protect equipment from damage.

1. Introduction

LEAF (Low Energy intense-highly-charged ion Accelerator Facility) is National Science Foundation of China major scientific research equipment development project. Low energy intense-highly-charged ion beam has strong electromagnetic effect with the material and high deposition rate in materials and can be controlled precisely [1]. Scientists can use LEAF to research origin evolution of elements in the universe, stellar evolution and energy production, the energy of stars counterbalance gravitation and the unique mechanism of cosmic heavy nuclide synthesis. Other scientific frontier research and major applications such as high charge state atomic physics and micro-nano processing also needs intense-highly-charged ion beams. LEAF ion source technology and linear accelerator technology are pre-research for HIAF (High-Intensity Heavy Ion Accelerator Facility) [2]. LEAF also innovatively proposes a cocktail beam. LEAF includes four major systems: superconducting ion source, high-voltage platform and beam line, RFQ (Radio Frequency Quadrupole) accelerator and experimental terminals. The ion source is very significant and its quality affects the performance of the entire system.

LAPECR (The Lanzhou All Permanent magnet Electron Cyclotron Resonance) [3, 4] is a temporary ion source instead of FECR which is the final ion source of LEAF. Beams produced by LAPECR can verify the performance of LEBT (Low Energy Beam Transmission line), RFQ and MEBT (Medium Energy Transmission line).
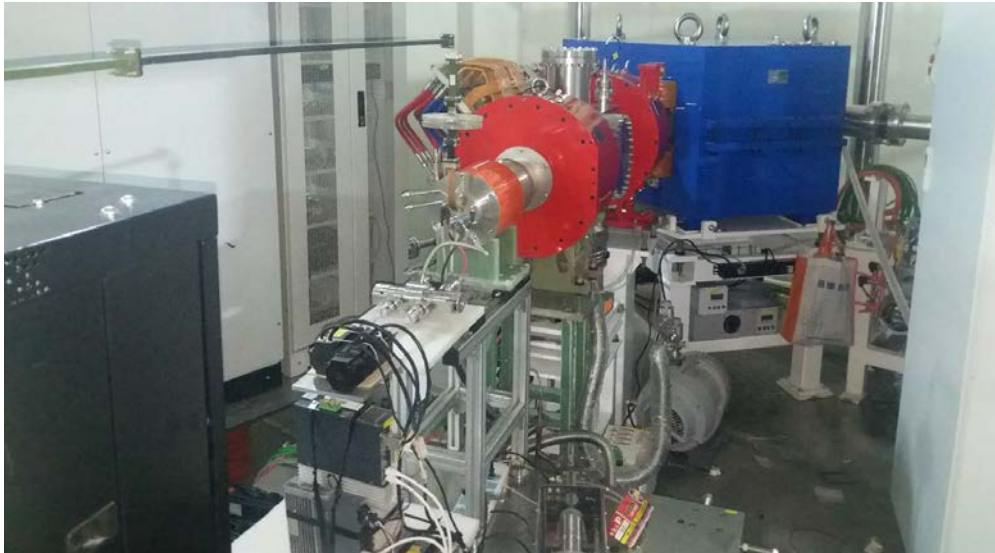
LAPECR has produced ion beams as shown in Table 1 below.

Table 1. LAPECR Ion Source Beams

Typical Ion Beam	Beam Intensity	Extract Voltage	Time Structure
$^4He1^+$	5 (mA)	15 (kV)	Continuous wave
$^4He^{2+}$	1.5 (mA)		

The $^4H^{1+}$ beam with 150µA intensity and 0.5MeV energy has been accelerated by RFQ. LAPECR ion source is shown in Figure 1.
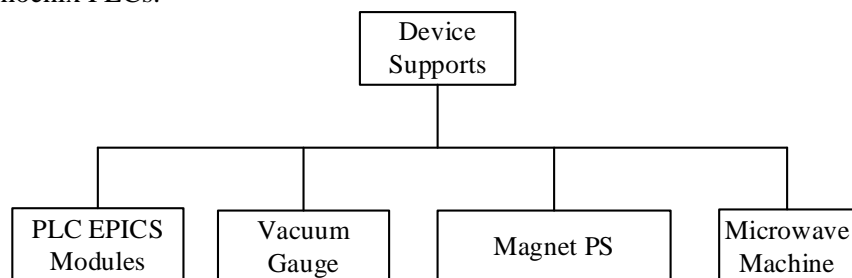

Figure 1. LAPECR Ion source

The technologies discussed in this paper are control system software, analog power supply controllers, digital power supplies, vacuum gauge controller, programmable logic controllers (PLCs) and interlock system logical strategy with the examples based on actual implemented equipment.
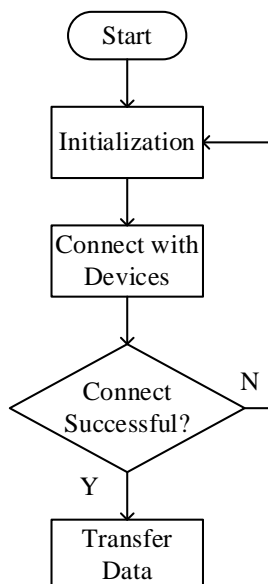
2. Control system software

EPICS (Experimental Physics and Industrial Control System) is a set of Open Source software tools, libraries and applications developed collaboratively and used worldwide to create distributed soft real-time control systems for scientific instruments such as particle accelerators, telescopes and other large scientific experiments [5].

IOC (Input Output Controller) is developed in Linux environment. For a variety of ion source devices, the author developed a custom type of record support named "vcmstringout" in which we add multiple of field names. Device Supports are developed for vacuum gauge, magnet power supplies, micro-wave machine and Phoenix PLCs.

Figure 2. Device supports

The vacuum gauge and microwave interface are RS232 serial ports and need to be converted to a network interface using a serial server. In this way, the TCP/IP protocol can be used uniformly in device support. Program flow chart is shown in Figure 3.
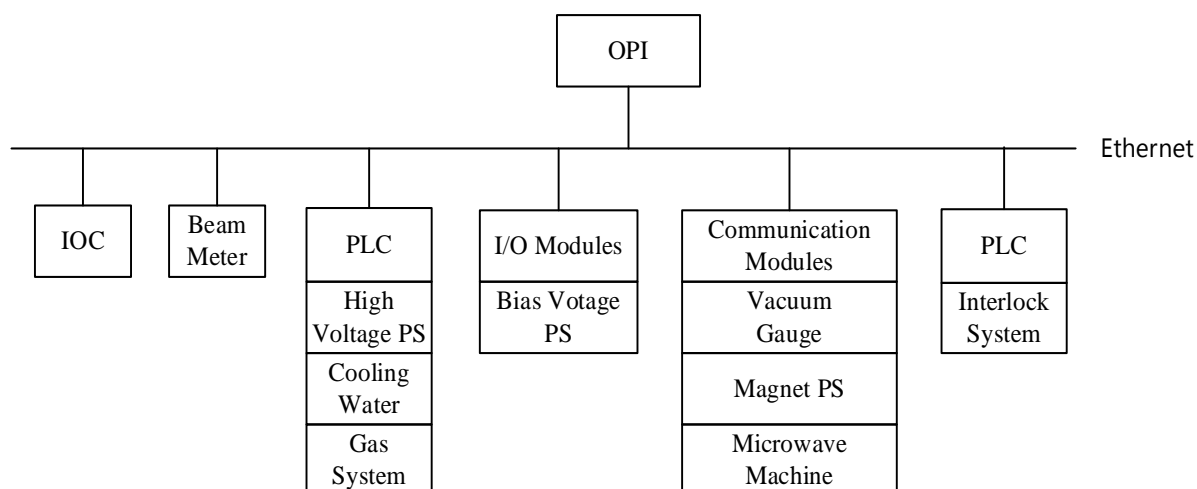

Figure 3. Program flow chart

Analytical magnets in magnet device support require a separate spectrum program. When in spectrum mode, the analysis magnet current rises at a rate of 1A per second. In the non-spectrum mode, the magnet current rise speed is its own default value. Switch between the two modes can be operated through the interface.

The OPI is CS-Studio which is a user interface framework for control systems (EPICS, TANGO, TINE ...) based on Eclipse RCP. Among the features are synoptic/archive/trend/alarm displays [6].
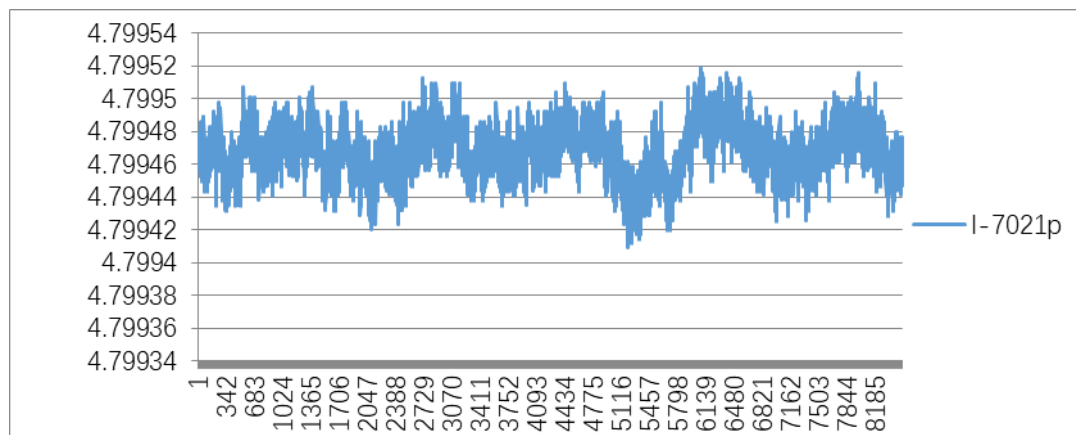
3. Control system hardware

The controlled devices of LAPECR are beam meter, high voltage power supply, cooling water, gas system, bias voltage power supply, vacuum gauge; magnets power supplies and micro-wave.
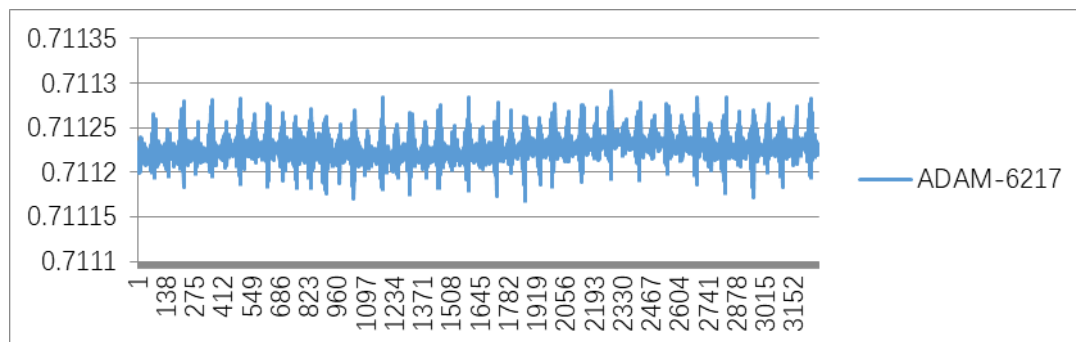

Figure 4. Controlled devices of LAPECR

We placed a slave switch connected with master switch by an optical fiber in LAPECR ion source. Beam meter, PLCs and communication modules are connected with slave switch. The bias power supply is on the high voltage platform, and the rest of the equipment is on the status side. Therefore, the bias power supply and I/O modules cannot be grounded together with other devices. We use optical fiber to connect the controller to the slave switch.

The output controller is I-7021p produced by ICP DAS to provide a 0-10V voltage signal. The I-7021p has ±0.02% accuracy and 16-bit resolution. The input module is ADAM-6217 which is Ethernet-based data acquisition and control module provides I/O, data acquisitions, and networking in one module to build a cost effective, distributed monitoring and control solution for a wide variety of applications.

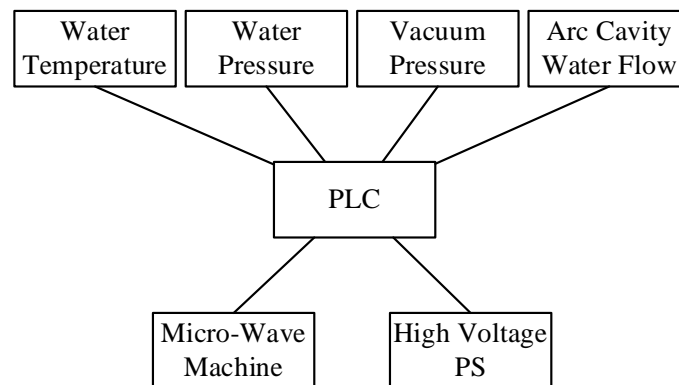**Figure 5.** The stability and accuracy of I-7021p

Figure 6. The stability and accuracy of ADAM-6217

We use Phoenix PLC to control other equipment and build an interlock system which will be introduced in detail in the next part.

4. Interlock system

LAPECR is a high intensity ion source; interlock system must be stable and reliable to ensure that the equipment is not damaged. The water temperature water pressure is 0-20mA analog signal, the arc cavity water flow and the vacuum pressure interlock signal are the dry contact points, which are sent to the operation interface and used as the interlocking input signals after being collected by PLC. The water pressure and water temperature thresholds are set on the operator interface, and the vacuum pressure threshold is set on the vacuum gauge panel. If only one way is triggered, the four-way interlock input signal will start the interlocking mechanism that is to withdraw the high voltage and turn off the microwave power.

Figure 7. The interlock system

A hard interlock wire is connected between magnet temperature and magnet power supply. When the temperature of the magnet is too high, an open contact is output and the corresponding power supply output jumps to zero. All interlock signals are uploaded to OPI via IOC. The operator can reset interlock signals at the operator interface. All interlock input signals provide bypass function.

5. Summary and conclusion

The entire control system uses a distributed architecture. The advantages are high reliability, strong fault tolerance, scalability, flexibility, fast calculation speed, openness and high performance. EPICS control architecture can modularize different devices and make programming simplify. During ion source beam tuning, the control system operates stably and the fault time accounts for less than 1% of the total fault. Interlock system can protect the machine from damage efficiently. Some small bugs have been resolved after beam tuning.

6. Acknowledgement

7. References

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