SAFETY INTERLOCK SYSTEM FOR A PROTON LINAC ACCELERATOR

Y. Zhao, Q.Ye, Y.Y.Du, J.He, F.Liu

Division of Accelerators, Institute of High Energy Physics, Beijing 100049, China

Abstract

The C-ADS Inject-I test facility is under construction in IHEP. An interlock system based on redundancy PLC is developed for machine protection and personnel safety. Device status, radiation dose, temperature of cavities and chambers are collected for machine state judge and interlock . A MPS(Machine Protection System) are working together with the interlock system in the control loop, and protect the machine in Four levels for different situations.

INTRODUCTION

The C-ADS linac include two Injectors and a main driver linac. Each injector is designed as a spare of another. The injector I proton linac in IHEP is consist of an ECR ion source, a LEBT (low energy beam transport line), a RFQ (radio frequency quadrupole accelerator), a MEBT(medium energy beam transport line) and superconducting spoke cavities[1]. The interlock system is designed and set up to protect personnel and devices from radiation hazards. It also will be a backup protection of MPS(fast Machine Protection System). The interlock system has permission signal, terminate beam signal and state signals collected from front device. Permission signals have the highest priority to access the Personal protection system, a key to the tunnel door will work together with the permission signals for safety. The state signals from Ion source, Power supply, LLRF (Low Level Radio Frequency) control system of RFQ, Vacuum and so on, indicate the corresponding system state or control "on and off". The terminate beam signals will shut the Ion source down when emergency.

HARDWARE DESIGN

Phoenix RFC (Remote field controller) -460R has been chosen as the main controller for the interlock system. Two RFC can automatically build a high-performance connection to implement redundant through fiber optics for synchronization. Two Profinet interface in the RFC connected the controller into the Profinet ring with RSTP(Rapid Spanning Tree Protocol) to achieve fast ring detection, One LAN interface in the RFC is connected to the control network for. Before each cycle, One RFC which is set as the PRIMARY redundancy role will control the process, and transmits the data to another RFC which is set in Hot Standby mode as BACKUP redundancy role. If one Controller fails, the other will take over immediately [2].

The Axioline modules include bus coupler, I/O modules. The I/O modules complete the function signal in/output are connected to the bus couplers links to the Profinet ring, it's the most fast I/O system in the world by now[2],the update time for each I/O modules is less than 1µs. The bus couplers has two Profinet interface which support PRL(The Phoenix Redundancy Layer), it will help to adopts valid values from I/O modules to the available Profinet controller.

The power supply of controller and Axioline modules are independent to ensure the reliability. Trio-diode modules are fixed for each two power supply units of the same type connected in parallel on the output side for redundancy. Those two power supply units will be isolated from one another. Figure 1 shows the redundancy diagram and Table 1 shows the signals from devices.

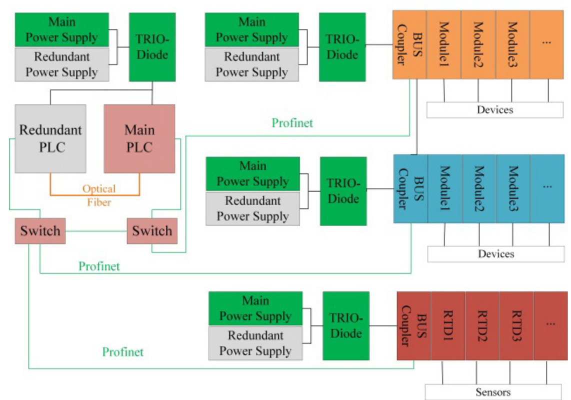

Figure 1: The redundancy diagram of interlock system.

Table 1: The Signals From Devices

Device	Input	Output
Ion Source	1	1
Vacuum	8	1
Personnel Protection	4	3
Power Supply	1	1
RFQ LLRF	1	1
Cryogenic	1	0
Super conductor LLRF	2	2
Bunching LLRF	1	1
MPS	1	6
Temperature	130	4
Flow meter	1	1

The fault tolerance requirements of C-ADS injector I are quite critical. So the reliability of the hardware is also considered. The index R (reliability), MTTF (mean time

ISBN 978-3-95450-148-9

to failures) and λ(the failure rate) are always used to measure the reliability of the control system . The MTTF and λ of each component at 25°C are list in the table in Table 2[2]. As the equipment and cables are located in the stable Power Supply room, the extremely environmental interference can be eliminated.

Table 2: The Reliabilities of the Hardware

No.	Modules	MTTF/h	$\lambda/(10^{-7}h^{-1})$
1	Power Supply/24VDC	500 000	20.00
2	Trio-diode	10 000 000	1.00
3	RFC 460R	281 627	35.5
4	Bus Coupler	3 950 853	2.50
5	Axioline DI	310 104	32.20
6	Axioline DO	310 104	32.20
7	Axioline RTD	310 104	32.20
8	Switch	2 891 123	3.46

PROGRAM DESIGN

The main control system run in the RFC is designed in PC Works 6.20.327(Phoenix contact) and can be download via Profinet. An EPICS IOC has been developed based on the EPICS driver for RFC 460R to complete the control and data-transfer. The driver is embedded in the main file，the so called "send/receive" protocol is adopted to exchange data block between the PLC and the EPICS IOC[3]. User-defined length data can be transferred during each program circle. The data type or other properties can be defined in the IOC. The IOC has been successfully used online. All operation is completed in the console of control room. The control architecture is shown in Figure 2.

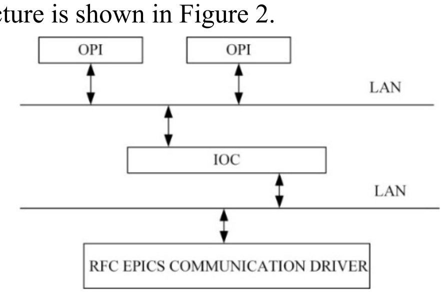

Figure 2: Interlock system control architecture.

PROTECTION LOGICAL DESIGN

The interlock system includes four states: stop, running, emergent stop and debug mode.

Stop mode is the safest mode for machine and personnel, the ion source and power source are disabled when the machine runs at stop mode.

Running mode can only be manual switched to when all the device state and temperatures are normal.

Emergent stop include manual emergent stop and interlock emergent stop. Manual emergent stop is the --- protection level, can be switched on the console panel in the central control room. Interlock emergent mode is automatically switched by PLC programme.

Debug is a special mode, because the whole machine is under construction and phase operation, the RFQ, bunching or the spoke cavities system need non-interlock state. The details of logical control is shown in Figure 3.

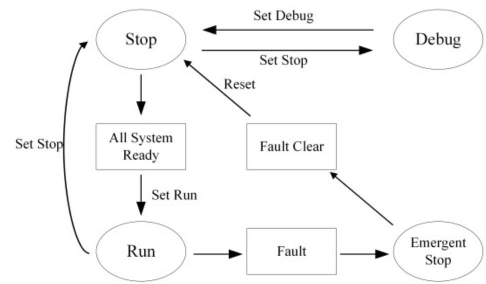

Figure 3: The control logical state.

There are 88 temperature sensors for RFQ water cooling, 12 for bunching cavities, 10 for beam dump, and 20 for vacuum chamber. As the RFQ resonance frequency is nearly linear with the temperature of the cooling water [4], the temperatures are precise to 0.01°C. And if any of the RFQ vanes or the walls temperature is above 28°C, it will trig interlock to stop the power or the beam. The bunching cavities' upper limit is 40°C, the dump and vacuum's upper limit is 60°C. The total state of flow meters for RFQ cooling water is also connected to work together with the temperature sensors.

At present stage, interlock provides 6 protection levels with MPS, for all LLRF state signals are connected to the MPS. According to the different unmoral situations, Interlock will terminate beam or let MPS stop the power source.

The first level - when the RFQ cavities wall, beam dump, vacuum chamber's temperature are higher than the upper limit, the interlock will disable ions source.

The second level – when the RFQ cooling water temperatures are high or the flow meters signal is fault, the interlock will disable the ion source, and let the MPS disable the power source of RFQ.

The third level – when the bunching cavities temperatures are high or the flow meters signal is fault. The interlock will disable the ion source, and let the MPS disable the power source of bunching.

The forth level – when the cryogenic system is not ready, the interlock will disable the ion source, and let the MPS shut the superconductor's power supply and the super conductor cavities' power source.

The fifth level – when the personnel protection system is on alarm, interlock will disable the ion source, and let the MPS shut all power sources.

The sixth level – is used as interlock manual emergent stop. It's the most critical situation, and will shut all the devices once be switched to.

ISBN 978-3-95450-148-9

SUMMARY

The interlock system based on the redundant design, combined with the EPICS control platform is more reliable to protect the machine. The different interlock levels ensure the effective protection and avoid unnecessary loss or operation. As the Injector I start to commission, there will be more various complex conditions, both hardware and software will upgrade to meet the actual demand.

REFERENCES

[1] Tang Jingyu et al. Conceptual Physics Design on the C-ADS Accelerator[R]. IHEP-CADS-Report.2011.
[2] http://www.phoenixcontact.com.cn/products.
[3] Liu G, et al. Epics driver for phoenix contact redundant PLC[C]//Proc of IPAC2013.3176-3178
[4] Xin Wenqu et al., “Resonance Control Cooling System for 973 RFQ at IHEP”, Nuclear Physics Review, 2013.6

ISBN 978-3-95450-148-9