MACHINE PROTECTION SYSTEM FOR THE KOMAC 100-MeV PROTON LINAC

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Abstract

A Machine Protection System (MPS) is one of the important systems for the 100-MeV proton linear accelerator of the Korea Multi-purpose Accelerator Complex (KOMAC). The MPS is required to protect the very sensitive and essential equipment during machine operation. The purpose of the MPS is to shut off the beam when the Radio-Frequency (RF) and ion source are unstable or a beam loss monitor detects high activation. The MPS includes a variety of sensors, such as beam loss, RF and high voltage converter modulator faults, fast closing valves for vacuum window leaks at the beam lines and so on. The MPS consists of a hardwired protection for fast interlocks and a software protection for slow interlock. The hardware-based MPS has been fabricated, and the requirement has been satisfied with the results within 3 μs. The Experimental Physics and Industrial Control System (EPICS) control system has been also designed to monitor and control the MPS using a Programmable Logic Controller (PLC). This paper describes the design and implementation of the MPS for the 100-MeV proton linear accelerator of the Korea Multi-purpose Accelerator Complex (KOMAC).

KOMAC FACILITY OVERVIEW

The Korea multi-purpose accelerator complex (KOMAC) 100-MeV proton linac has been developed and has been installed at the Gyeong-ju site. Figure 1 shows a schematic layout of the KOMAC 100-MeV proton linac and beam lines [1].

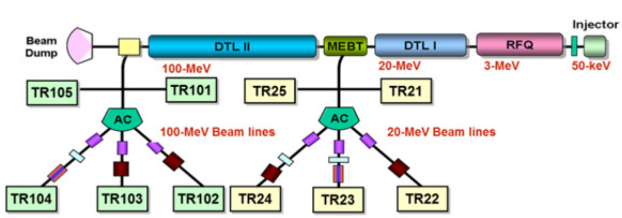

Figure 1: KOMAC proton linac consists of an ion source, a Low-Energy Beam Transport (LEBT), a Radio-Frequency Quadrupole (RFQ), a Draft Tube Linac (DTL), a Medium-Energy Beam Transport (MEBT), beam-lines, and a Target Room (TR) for 20-MeV and 100-MeV beam.

The KOMAC consists of low-energy components, including a 50-keV ion source, a low-energy beam transport (LEBT), a 3-MeV Radio-Frequency Quadrupole (RFQ), and a 20-MeV Drift Tube Linac (DTL), as well as high-energy components, including seven DTL tanks for the 100-MeV proton beam. The KOMAC includes 10 beam lines, 5 for 20-MeV beams and 5 for 100-MeV beams. The peak beam current and maximum beam duty of the 20-MeV linac are 20 mA and 24%, respectively. The peak beam current and maximum beam duty of the 100-MeV linac are 20 mA and 8%, respectively. There are 4 high-voltage convertor modulators. Each modulator drives 2 or 3 klystrons. The peak output power is 5.8 MW, and the average power is 520 kW with a duty of 9%. The pulse width and the repetition rate are 1.5 ms and 60 Hz, respectively.

MPS OVERVIEW

The radiation from the beam loss and faults of the linac components can cause substantial damage to the devices. The KOMAC active protection system needs to minimize the beam loss radiation and ensure the safe operation of the machine [2]. The purpose of a machine protection system (MPS) is to turn off the beam and the sub-systems when an interlock occurs. The MPS consists of two parts: a hardwired-based fast interlock system using an analog circuit and a software-based slow interlock system with a Programmable Logic Controller (PLC). The interlock systems are designed as main unit for machine protection and are fabricated with analog circuits. The PLC includes software logic that checks the result of the machine protection system on an interlock signal and also turns off components related to the interlock. Figure 2 describes a flow chart of machine protection using hardwared and software based interlock system.

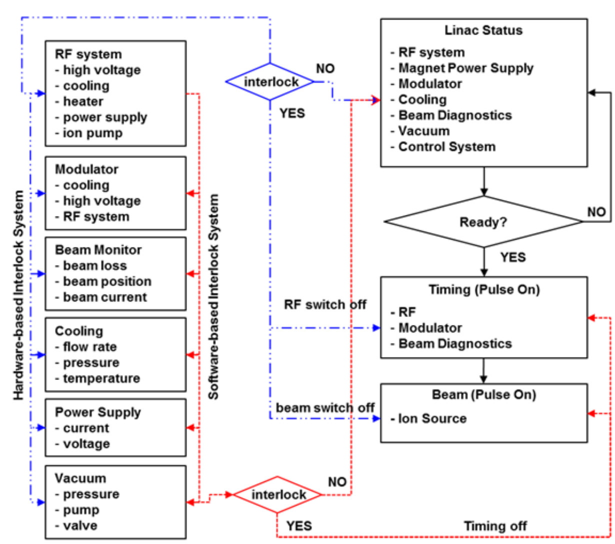

Figure 2: Block diagram of interlock system for machine protection with hardware and software based interlock system.

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The basic concept is that the main interlock system turn off the beam and be connected with distributed local interlock systems for sensitive devices, such as the High Voltage Convertor Modulator (HVCM), the Radio Frequency (RF) system, beam loss, the cooling system, and the beam extraction power supply. A local interlock system collects signals from sensors and report to interlock systems for an RF and an ion source. The RF interlock system acts as the interface to a RF switch system. The beam interlock system also receives input from beam loss and position monitoring circuits. A MPS control screen monitors all interlock signals of the machine components, including the vacuum and the timing systems, as well as sensitive devices, and turns off and prevents a beam.

MPS DESIGN

The MPS is essential devices for machine protection by turning off beam or RF. If the essential equipment is to be protected, an MPS must be designed to identify a variety of device failures around the linac and the beam lines. The machine operation must be done in a reliable protection system. The goal of the machine protection system is to turn off the RF system or the beam of a microwave ion source within a few microseconds when some failure of the RF system or beam loss occurs during the beam operation mode in which the beams are switched to beam lines. Table 1 describes the interlock lists of the machine protection system.

Table 1: List of Interlock Signals for Machine Protection of the KOMAC Linac

List	Interlock signal
High-power RF source	Klystron heater, magnet, and ion pump Low level RF Waveguide circulator and RF window arc
RF cavity	Cavity vacuum, RF arc Cooling water (flow rate, temperature, RCCS, wall cooling)
High-voltage power supply	Equipment fault Personnel fault
Beam	Beam loss, beam position
Beam line	Fast closing valve Safety block

The block diagram of the interlock system, which is developed using a fast-trip direct analog circuit, is shown in Figure 3. The interlock system consists of fast analog interlock modules like comparators and latches, an auto-reset module, a Voltage Standing Wave Ratio (VSWR) module for only the RF interlock unit, and a power supply [3]. The response time of the fabricated interlock system was measured to be within 3 µs. The response time satisfies the requirement for the KOMAC machine protection, which states that the beam must be stopped within a few milliseconds when any device failure occurs during 60 Hz beam operation.

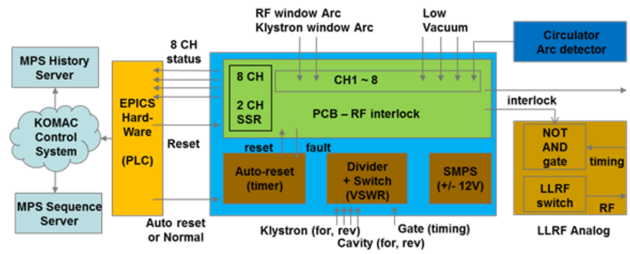

Figure 3: Block diagram of the signal path of interlock system developed by using a fast trip direct analogue circuit.

Local interlock systems are installed into each klystron and RF rack of klystron galley, as shown in Figure 4, to prevent a beam when a device failure is activated. Each local interlock system sends the interlock signal to the interlock system for the ion source, and the beam is shut off by turning off the extraction power supply of the ion source. It is also possible to shut off the RF power of the RFQ to decelerate the beam in the linac. When the interlock signals of the RF system and the HVCM occur, the local interlock systems also send the interlock signal to a switch in the low-level RF system to shut off the RF power to each cavity [4].

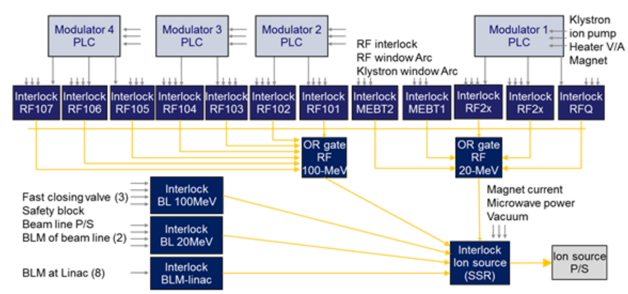

Figure 4: Schematic layouts of the hardware based MPS to protect the linac components from the high-power RF system, low-level RF, beam radiation, and modulator fault. The MPS shuts off the beam-extraction power supply of the ion source.

The interlock systems are essential devices for personnel safety and machine protection by turning off beam. Also, in order to support sequential operation based on interlock signals, software-based monitoring system is designed using the Experimental Physics and Industrial Control System (EPICS) framework and industrial PLC [5]. The PLC collects local interlock signals from local MPSs as well as vacuum and cooling components. The PLC I/O chassis is distributed into the linac gallery and communicated with a main PLC CPU system through ControlNet. An EPICS Input Output Controller (IOC) for the PLC is integrated with the KOMAC main control systems through the EPICS Channel Access (CA). Figure

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5 shows a user interface screen for the interlock status and alarm.

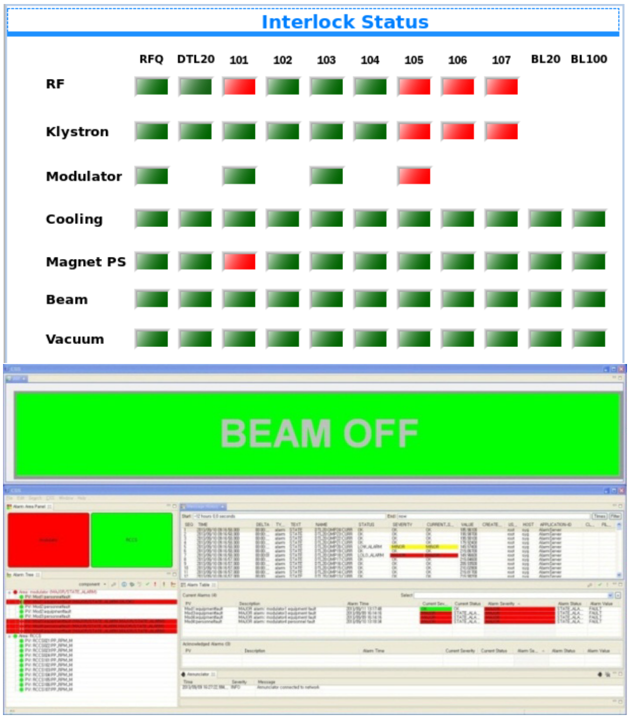

Figure 5: User interface screen for the interlock and alarm status.

The beam permission in the linac and beam lines is controlled by local interlock systems, Personnel Protection System (PPS), and Target Room (TR). One of the failures will activate a beam stop.

There is upgrade plan for KOMAC MPS that is under development using fully programmable system based on Field Programmable Gate Array (FPGA). The new MPS is one module type for all measurements. The interlock sensor interface is totally flexible. The MPS utilizes individual processors which are independent from other hardware.

CONCLUSION

A hardwired based interlock system was developed to protect critical devices from beam-induced damage, such as excessive beam losses and faults at high-power components. The local interlock system for a fast interlock has been fabricated, and its response time was within 3 µs. This response time satisfied the requirement for machine protection. The requirement specifies that a beam must be prevented within tens of microseconds during beam operation. A beam can be accelerated under conditions that protect both machine and personnel using the MPS.

ACKNOWLEDGMENT

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