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# DEVELOPMENT OF A MACHINE PROTECTION SYSTEM FOR KOMAC FACILTY

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*Abstract*

The Korea multi-purpose accelerator complex (KOMAC) 100 MeV proton linac has been developed and installed at the Gyeong-ju site [1]. 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 ten beam lines, five for 20 MeV beams and five for 100 MeV beams. The KOMAC utilizes a high power, heavy-ion linear accelerator to support diverse beam service, including a radio-isotope beam line and provides beams of 100 MeV with a beam power > 100 kW [2]. Therefore, in the event of operating failure, it is extremely important to shut off the beam to prevent damage to accelerator components such as the linac cavities and diagnostic equipment. The KOMAC machine protection system (MPS) is required to protect the high-performance accelerator components. The MPS developed previously with an analog circuit interlock box was upgraded to a digital interlock system [3]. We designed the new MPS to be flexible enough to accommodate both machine study and beam operations. In case of a beam abort, the KOMAC MPS inhibits all relevant devices to protect the accelerator components against beam losses, thereby avoiding damage leading to long maintenance times. In this paper, we present the KOMAC machine protection architecture, technical specification, and performance results of the new machine protection system.

## MPS ARCHITECTURE

The KOMAC linac and multi-beam lines were designed to provide users with a proton beam under various beam conditions. Representative specifications of the KOMAC linac are maximum beam energy of 100 MeV, and peak beam current of 20 mA, and the adjustable repetition rate is up to 120 Hz, as described in Table 1.

Table 1: Specifications of the KOMAC Linac

| | | |
|---|---|---|
| Output Energy (MeV) | 20 | 100 |
| Max. Peak Beam Current (mA) | 1 - 20 | 1~100 |
| 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 |

The maximum beam repetition rate is 120 Hz at 20 MeV, and 60 Hz at 100 MeV. The KOMAC has a plan for increasing the beam power to 160 kW. The accelerator components are protected from damage by a MPS that shuts off the beam within one beam pulse during normal 120 Hz operation. The damage to sensitivity components when operating an accelerator facility comes from beam loss. The machine interlock system uses KOMAC-built hardware with both commercial processor and field programmable gate array (FPGA) chips. The system comprises eleven local interlock nodes covering the 100m machine from the injector to the 100 MeV beam dump. The local interlock nodes are located each 30m in the component gallery of the KOMAC facility, as shown in Fig. 1.

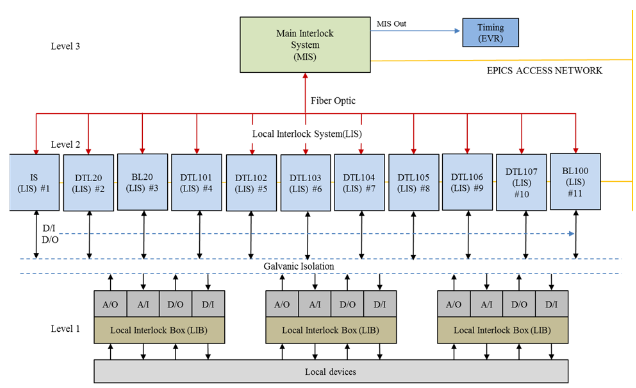

Figure 1: Network overview of the machine protection system.

The local interlock nodes are connected to the main interlock node in a star topology over a fiber connection. The MPS is intended to detect failures of the accelerator components. The components need to be controlled according to beam conditions. An unstable beam can lead to undesirable results such as damage to equipment and long maintenance times.

## MPS IMPLEMENTATION

In order to protect the linac cavities and other accelerator components from beam loss, a fast response time by the interlock system is required. The required global response time of the KOMAC MPS is from 20 to 50 μs for the high power linac that runs at the maximum beam repetition rate of 120 Hz at 20 MeV and 60 Hz at 100 MeV with a pulse length of 0.1 to 2 ms. The KOMAC MPS has been designed in three layers: local interlock box (LIB), local interlock system (LIS), and

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main interlock system (MIS). The LIB is responsible for converting analog to digital signals between local devices and the LIS. The local device currently in use has diverse interlock signal types for itself (e.g., analog, digital, contact signals). The LIB is used to unify the various interlock signal types. The signal transmission between LIB and LIS has been designed to be resistant to external noise at 24 V between isolation intervals, with galvanic isolation of up to 4,000 V. The digital isolator is a digital in/out and has a 100 Mbps transmission speed and 10 ns propagation delay. The analog isolator is an analog in/out and has a wide bandwidth of DC to >1 MHz, 5,000 Vrms voltage isolation, and linear photoconductive output type. The operating time of the D/O relay is 0.1 ms with 170 V switching voltage and 0.5A switching current. The LIS nodes are connected to the MIS using optical cable and a timing system. The fiber optic connection between LIS and MIS has a transmission speed of 50 MBd data rate and transmission distance of 900 m.

The MPS software supports EPICS IOC which communicates via EPICS channel access over Ethernet to the control system [4]. The interlock system is based on a Raspberry Pi processor that runs at 900 MHz and has 1 GB of RAM. The processor uses UART communication and FPGA using the Asyn library [5]. Figure 2 shows a schematic layout of the hardware architecture. The EPICS IOC that is ported in Raspberry Pi is connected with the KOMAC control system. The MPS sets individual device interlocks based on the approved mode, and controls changes to configurations using EPICS client tools. It is possible to set enable or disable for interlock input and output of each channel according to the machine operating mode. It is also possible to set active low or active high for interlock input and output levels.

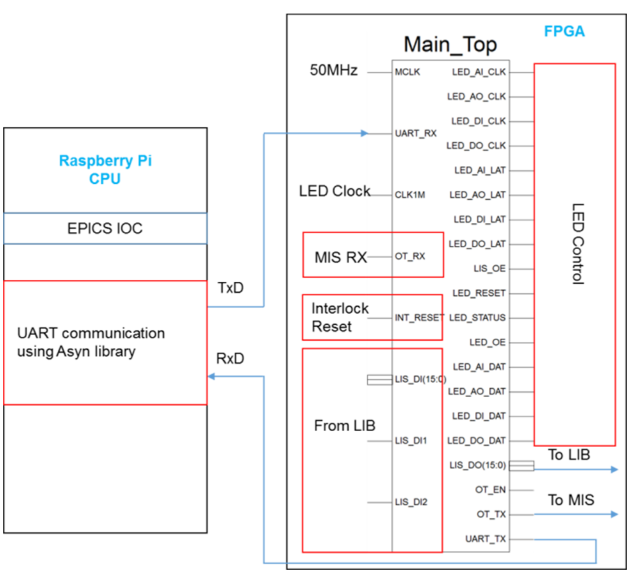


Figure 2: Architecture of MPS hardware.

## PERFORMANCE

The response time of the interlock system should be adequate to prevent excessive radiation and component damage from any abnormal beam loss effectively. The concept of the KOMAC MPS is that the LIS detects component failures and passes this information to the MIS. The MIS sends the interlock signal to another LIS. The system performance has been measured with loopback tests of the local interlock system and main interlock system. The loopback test is used to measure the response time when the interlock system detects equipment failure, as shown in Fig. 3.

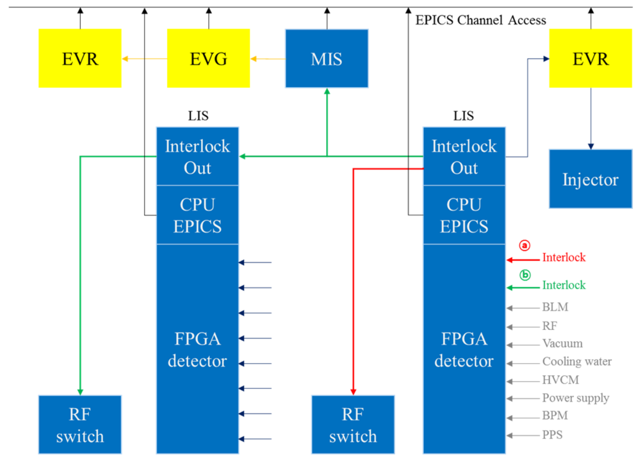


Figure 3: Schematic diagram for loopback test of LIS (ⓐ Red line) and MIS (ⓑ Green line).

The FPGA detects an external signal, and counts the signal for 400 ns to determine whether the interlock signal is noise or not, and if not, approves an interlock signal. The noise is generated in the optical receiver that uses an optical bit pattern of active low and will be improved by photodiode replacement. Since it is not easy to detect the error moment of the bit pattern, we use filtering of 400 ns. After 400 ns delay, the interlock signal is sent to LIS and MIS. The response time of the loopback from LIS to LIB was 25 µs, as shown in Fig. 4.

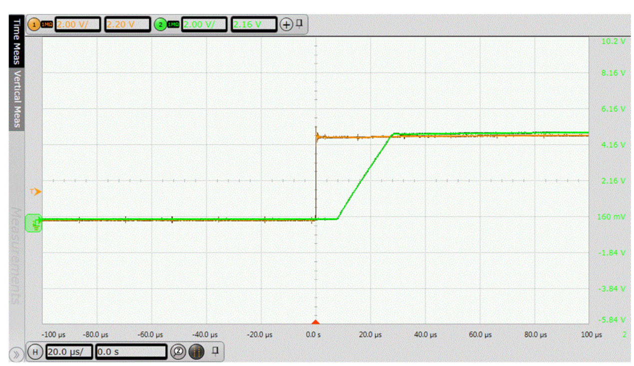

Figure 4: Response time of LIS loopback (Orange: Interlock Input, Green: Interlock Output).

This result shows that the RF switch can be turned off within 30 µs. This response time includes the RF interlock box delay of 3 µs [6]. The loopback test between LIS and MIS showed a response time of about 3.5 µs. During the loopback procedure, the LIS detects

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the interlock signal and transfers it to the MIS, and the MIS sends it to the LIS, as shown in Fig. 5. Including the LIS loopback time of 25 µs, the overall response time is about 30 µs.

Figure 5: Response time of MIS loopback (Orange: Interlock Input, Green: Interlock Output).

## CONCLUSION

In order to protect the linac cavities and other accelerator components from beam-related damage, a rapid response machine protection system (MPS) is required. The KOMAC MPS that was developed using an analog circuit interlock box was limited from covering increasing interlock signals and modifying the interlock logic. These disadvantages have been much reduced with an upgraded to a digital interlock system for more efficient logic modification and interlock management. By selecting hardware that supported our requirements for the machine protection system, and making use of the features available in the machine operation, we were able to provide a powerful tool for protecting the equipment from damage at the KOMAC facility. The MPS has been shown to cut off the beam gates within one beam pulse during normal 120 Hz operation, and to improve the reliability of the equipment used in the high-power beam transport in the KOMAC facility.

## ACKNOWLEDGMENT

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