CONTROL SYSTEM OF THE C-BAND STANDING-WAVE ACCELERATOR FOR THE MEDICAL APPLICATION*

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Abstract

A control system has been developed for the 6 MeV C-band accelerator which will be used for the medical application. It is built in the PXI platform and implemented for the operation and the monitoring of sub-components by the LabVIEW programs. To communicate with components in the RF noise environment and to send/store the various monitoring data to the storage server, the interface based on Ethernet is used and it allows the real-time monitoring and the safe and fast feed-back system. In order to achieve the beam stability < 3.3 %, the automatic frequency controller for the magnetron is implemented by the feed-back scheme using the frequency waveform data and the constant cavity temperature is controlled by the real-time monitoring and interlock. In addition, the dose rate and flatness are controlled by a monitor chamber. The interlock system is also designed to protect the patients and also linac components against the improper operation, largely radiation, the misbehavior of monitoring parameters, etc. The architecture and main features are described and operation results are reported

INTRODUCTION

The 6 MeV C-band linear accelerator using a bi-periodic on-axis coupled structure was designed to operate in the π/2 mode standing-wave. It accelerates the electrons with 2.5 MW RF power up to 6 MeV and produces the electron beam and X-ray beam by selecting the target mode remotely [1,2]. This kind of RF linacs are popularly used for modifying a variety of plastic and rubber products, sterilizing medical devices and consumer items, preserving foods, reducing environmental pollution, and also the medical application.

The radiotherapy provides the energetic beam to treat the cancer and consists of a gantry including the medical linac, a treatment couch, a control system, and other diagnostics [3]. The control system is designed for the proper and safe linac operation. For the medical purpose, it should be concerned for the stable beam performance and safe and accurate beam delivery to the patient. It also can contain the extended functions of directing the radiation head of gantry to the tumor position, controlling the couch, and monitoring/analyzing the data. We built it in the PXI (PCI eXtension for Instrumentation) platform which has grown to become one of several modular electric platforms for test, measurement, and control system. The operation and monitoring are implemented by the LabVIEW which has benefits of easy programming, powerful performance and flexible interface. In this paper, we describe the overall design and the implementation of the control hardware and software systems. And the performance results and future plan are discussed.

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DESIGN

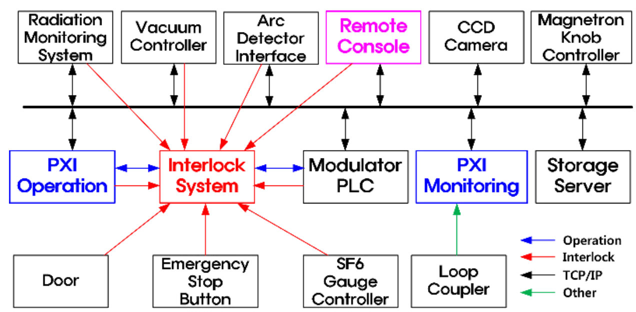

Figure 1: Block diagram of the linac control system for operation, interlock, and monitoring.

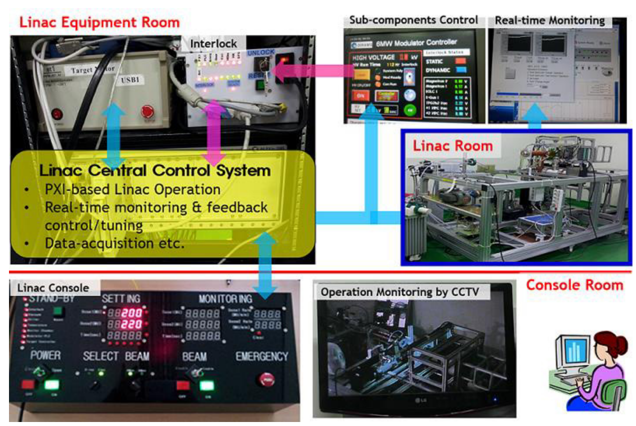

Figure 2: Implemented control system. It is communicated with sub-components in the linac equipment room, the linac room and the console room.

As shown in Figure 1, the linac control system contains operation, interlock, monitoring, and interface with sub-components. It also supervises the sub-components operation and stores the linac environmental parameters and the beam quality data of RF power, pulse information, the dose rate, etc. There are two PXI machines (NI PXIe-8135) for operation and monitoring, resulting that the data transmission process for monitoring and analysing does not interfere with the critical operation. The PXI machine for monitoring also is assigned to analyse the data of incident/reflected RF waveforms, drive the magnetron knob motor and then tune the RF frequency. The interface with sub-components is based on TCP/IP over Gigabit Ethernet to communicate with them in the RF noise environment. Some of sub-components also are available with the RS-232 serial interface.

The pulse modulator system has an independent control system based on a programmable logic controller (PLC). It can start and stop the operation in the standalone mode and also in the remote mode. The modulator control system synchronizes the timings of the capacitor-charging power supply (used as the input power source for the modulator) charging/discharging and the thyratron switching, and controls the heater controllers and other sub-components. Because the modulator produces the high voltage pulse and also can give the damage to other system with the improper operation, the modulator interlock system is built independently. The modulator interlock is working for the modulator's sub-component state, the vacuum condition, the temperature, etc.

The main interlock system is designed for three categories: (1) proper operation of the linac central control system and the modulator control system, (2) monitoring of the radiation dose by the monitor chamber, the vacuum level, and the temperatures of the accelerating tube, the magnetron, the electron-gun, and the X-ray target, (3) safety check using the arc-detector, the SF_6 gas level and the door status. It is built using the electromechanical relays and working properly during the radiation.

CONSTRUCTION & OPERATION

Figure 2 shows the linac control system implemented in our laboratory. While the linac is located in the linac room, the pulse modulator, the interlock, the majority of control hardware, and the chiller are located in the linac equipment room. The console box and the monitoring displays including CCTV are in the console room. The console box (the bottom-left in Figure 2) is designed and constructed to be applied for the radiotherapy. It focuses on the clear function and strong interlock for the beam operation.

Operation and interlock

The operation states are defined for stand-by, ready, hv-on, hv-off, beam-on, and beam-off. When all linac components are on and the levels of vacuum and temperature are in the allowed range, it is in stand-by state. After the modulator heating procedures for thyratron, magnetron, and electron-gun are done, the state becomes ready. In the hv-on, the pulse modulator ramps up the high voltage to the set value as the defined time step. And then, the state is changed to beam-on and the beam is generated. When the delivered dose reaches the set value, the state becomes beam-off. However, the operator also can push the beam-off in the operation panel (Figure 3) or the console box. Because of the safety issue for high voltage, the hv-off state is considered with the same state of beam-off.

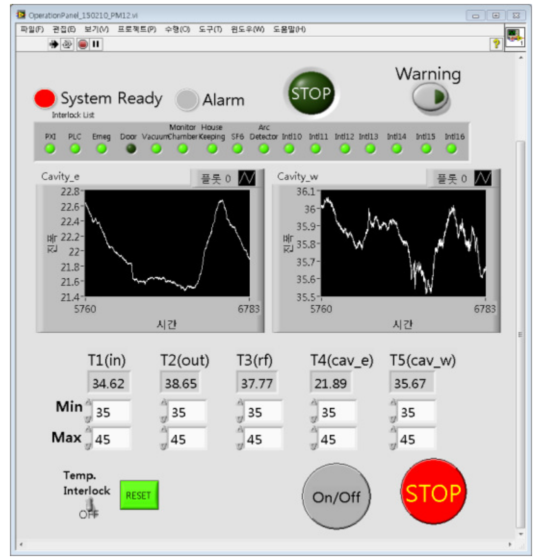

Figure 3: Operation panel in expert mode. (It will not allow for normal operator to use it in the radiotherapy mode.)

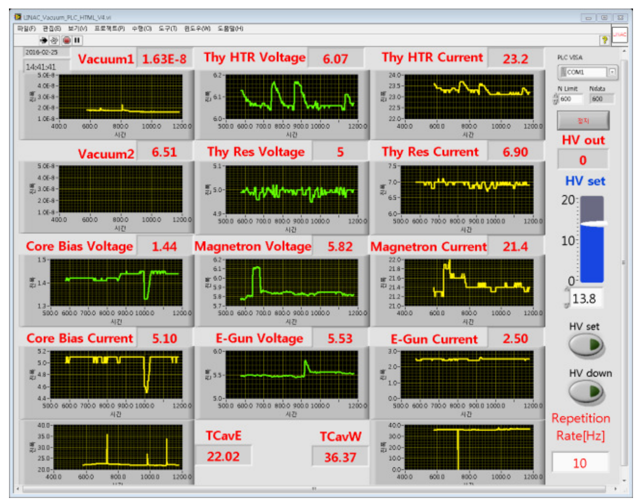

Figure 4: Monitoring panel for sub-components status.

The operation panel programmed by the LabVIEW is shown in Figure 3 and is proposed to be used by expert. It shows the interlock status delivered from the interlock (see white box in the top-left of Figure 2), five temperature sensors which should be monitored for stable beam operation, alarm sign, and beam On/Off button. For example, when the door of linac room is open unexpectedly during the beam-on, the interlock of door is immediately triggered and the beam operation stops. Figure 3 shows that the operation and interlock are properly working for this case.

Monitoring

The monitoring panel programmed by LabVIEW shows the vacuum level from the vacuum controller, the temperature detected by the thermos-coupler attached at the accelerating column, and the voltage and the current values of heater controllers for the modulator sub-components (Figure 4). These values are displayed in

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real-time and the data are delivered with a few Hz and stored in the storage sever.

The pulse voltages and currents applied for the magnetron and the electron-gun, and the beam current are currently readout by the FADC based on the oscilloscope. For these data with high bandwidth, we are trying to use a ROOT-based data acquisition platform [4] of FADC for fast monitoring.

Dose rate control

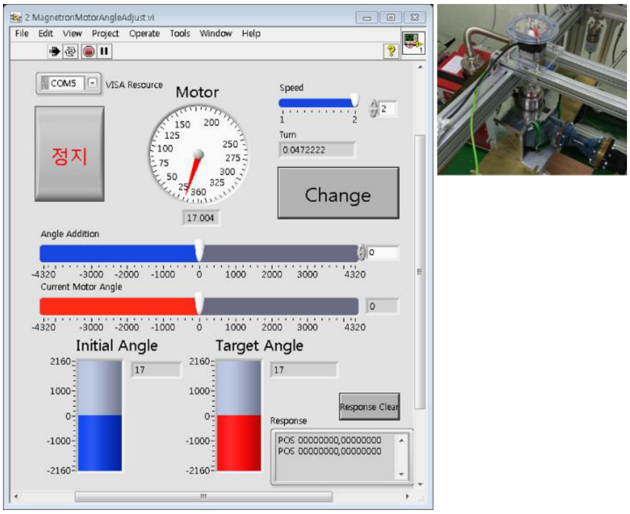

Figure 5: Magnetron frequency knob driving panel (left) and the picture of magnetron tuning shaft with a stepping motor (right).

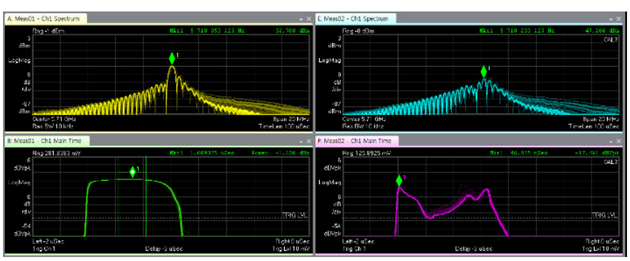

Figure 6: Incident (left) and reflected (right) RF power distribution in frequency (top) and time (bottom) domains taken by the Keysight VSA software.

The temperature change affects the resonance frequency in the accelerating column and this situation also happens in the magnetron. It makes the reflected RF power increase and then the beam dose decrease. With the temperature control and fine re-tuning of magnetron RF frequency (Figure 5), we achieve the stable beam dose rate. For high repetition rate (>150 Hz), the magnetron is easily affected by heat and it requires the fast re-tuning frequency. However, the current method takes about 10 sec. to get the proper frequency and minimize the reflected RF power. The feed-back system analyses the incident/reflected RF data from VSA (Figure 6) and determines the knob rotation angle. It is under development to optimize this decision process.

The monitor chamber was designed and constructed for real-time dosimetry [5]. It has a thin flexible printed circuit for electrodes and is based on a plane-parallel ionisation chamber. It is installed in the radiation head and is used to monitor the dose. Whenever the dose arrives at the pre-set value, the interlock of monitor chamber (Figure 3) is triggered and the beam operation stops. Now the linac can stop by the operation panel and also by the pre-set dose value required by the medical linac.

CONCLUSION & FUTURE PLAN

When the 1st prototype C-band 4 MeV linac was constructed on 2014, it started to operate with the simple interlock system including vacuum, temperature and door safety, and the modulator PLC. When the linac was upgraded into 6 MeV on 2015, the magnetron frequency controller was implemented by the LabVIEW. Also the software of operation and monitoring was programmed. In the beginning stage, the interface with sub-components was based on the serial communication and sometimes suffered the RF noise during the operation. We made an auxiliary interface board for TCP/IP and if necessary, a C code for porting was imported. The half of sub-components are communicated over Ethernet. The last 2016 Feb. linac run showed that the linac control system was working without fatal bug and without any interrupt from RF noise.

Each software was developed with flexible modularity. The next step is to integrate with them. In order to reduce the resource load the PXI machine, some monitoring is proposed to be a web-based display and the time-dependent display also needs to be optimized. Still the beam stability is more efficiently achieved by manual handling. Therefore, we focus on the improvement for the automatic system.

ACKNOWLEDGEMENT

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