Beam Interlock System for Medical Accelerator Complex HIMAC

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Abstract

A beam interlock system of HIMAC has been in operation since 1993. The system functions not only for radiation safety but also for treatment beam control. It must deal with the accelerator complex as a whole. The design feature and operational experience are described in this paper, together with connection to control systems of each accelerator sub-system.

1. INTRODUCTION

HIMAC complex consists of an injector system (ion-sources and linacs), two synchrotron rings (called the upper ring and the lower ring), high-energy beam transport lines, and an irradiation system for cancer therapy [1]. Each sub-system has its own control system; the injector system [2], the main accelerator system [3], the high-energy beam transport system [4], and the irradiation system. There is also a system for overall coordination; the supervisor system.

In the operation of HIMAC, it is indispensable to stop the beam irradiation on a patient when a radiation dose reaches a planned value, or when a device trouble is observed that may harm a patient due to disturbed quality of irradiation. In order to realize the function an interlock system was established, in which a few signals of the radiation safety management system [5] of the HIMAC building are also involved. The interlock system is called a global interlock system (abbreviated to GI hereafter).

2. FUNCTIONS OF GLOBAL INTERLOCK SYSTEM

Main functions of the system, GI, are as follows:

(1) GI must closes beam shutter and prohibit it from opening to stop the irradiation when GI receives the signal indicating that the radiation dose reaches the planned value.
(2) GI must prohibit a beam shutter from opening when a serious trouble occurs in a device, which could compromise a beam quality.
(3) GI must close a beam shutter and prohibit it from opening when a door of the area of a beam destination is not closed.

This report mainly describes the both functions of (1) and (2).

The GI realizes its works by prohibiting beam shutters from opening or not. Principal response of the GI to a request for stopping irradiation of a beam includes the following aspects:

(A) When a beam interlock signal is received, the GI must find the beam shutter that locates closest to and upstream to the room or the hall, and must issue interlock signal to it.
(B) When the treatment dose reaches the planned amount, the GI not only prohibits a beam shutter from opening, but also reduces power supplies for magnets that are in use for beam extraction from synchrotron rings.
(C) When the beam shutter is not closed within a few seconds after the interlock direction, the GI prohibits another beam shutter from opening, which locates upstream of the former beam shutter.

3. SYSTEM ARCHITECTURE

3.1 Hardware

The hardware of GI is mounted in a 19" standard rack and installed in the accelerator control room. The input signals include; (i) the open/close state of shield doors of the therapy rooms and the experimental caves, (ii) the state (as defined by ID card and key switch system) whether anyone stays in the beam area, (iii) the open/close state of beam shutters, (iv) treatment dose full for stopping irradiation, (v) the state of host computer in sub-systems, and so forth. The signals of (i) and (ii) are provided by the radiation safety management system [5]. The signals of (iii), (iv), (v) are provided by each sub-system. A programmable logic controller (PLC) processes these signals. The GI outputs signals to relevant devices such as beam shutters and power supplies. Cables and logic circuits for the important signals are dualized for reliability, through an electrical cable and an optical fibre. LEDs on the GI panel display the state of the signal, for monitoring purpose.

3.2 Logical Sequence

There are five beam shutters controlled by the GI; FCN4, FCN8, FCN101, FCN12 and FCN15, where FCN is the HIMAC-wide acronym for the beam shutter. FCN4 locates between ion-source and linacs. FCN8 interrupts beam from injector to main ring, while FCN101 stops

beam to a medium energy cave. FCN12 blocks a beam path from the lower ring. FCN15 corresponds to the upper ring. The beam shutter of FCN12 and FCN15 consists of two parts; A-part is made of 20 cm thick aluminium, and can completely close in less than 100 ms. B-part moves slower than A-part but completely stop beams. The high-energy beam transport lines are composed of horizontal beam lines and vertical beam lines. The upper ring provides the latter lines with beams. The lower ring can provide the former lines and latter lines with beams as shown in Fig.1.

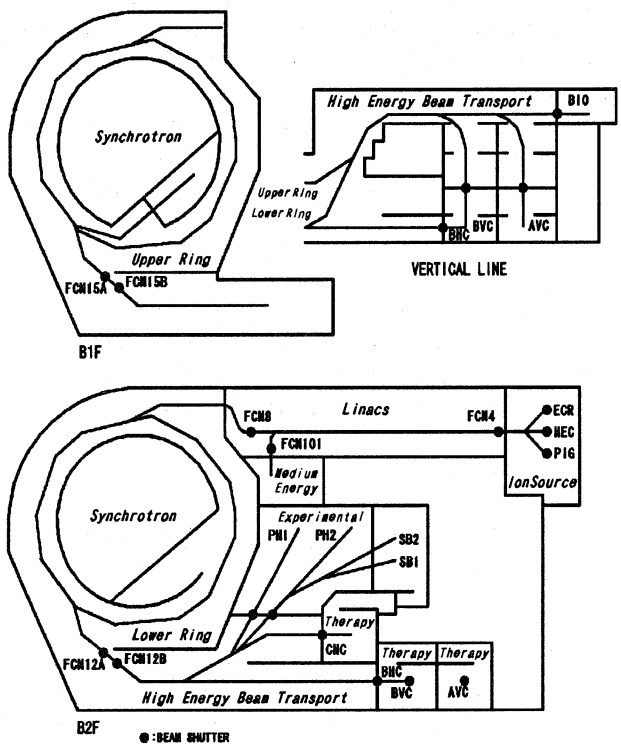

Fig.1 The system layout of HIMAC

The logical sequence of the system to control FCNs is depicted in Fig. 2. Function (C) of the preceding section is realized in the following; the GI examines whether FCN8 has been closed or not 2 seconds later. If FCN8 is not closed, the GI prohibits FCN4 from opening, and examines the state of FCN4 again. If FCN4 is not closed, the GI turns off the power supply for the extraction electrode of the ion-source, which is in use, as the final resort.

The PLC judges which beam shutter, FCN12 or FCN15, should be interlocked, as follows. When the GI receives the demand for stopping the beam irradiation in a horizontal beam line, the GI prohibits FNC12 from opening. For the demand in a vertical beam line, the GI judges which synchrotron ring, the upper ring or the lower ring, provides the beam line with the beam, from the status of the switch magnet. FCN12 is prohibited from opening when the lower ring is in use, and FCN15 is prohibited from opening when the upper ring is in use.

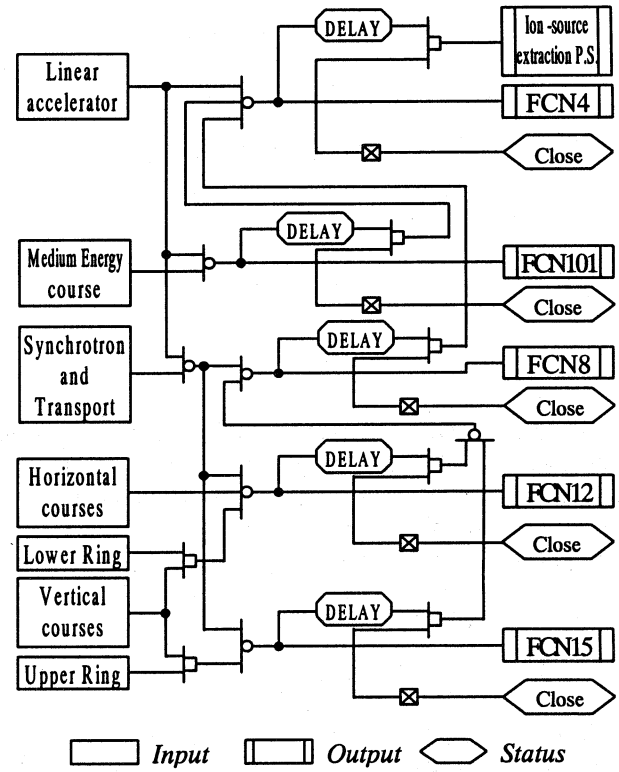

Fig.2 A skeleton of the logical sequence of the GI

3.3 Turn-key Switch interlock for maintenance

Turn-key switches of the FCNs on the GI panel change a control mode from "remote" to "local" or vice versa. There are five key switches. Each key switch corresponds to one beam shutter. When we rotate and pull out a key switch for maintenance of the beam shutter, not only the beam shutter comes to be controlled only locally, but also all the beam shutters locating upstream to the beam shutter come to be prohibited from opening.

4. STOPPING IRRADIATION FOR CANCER TREATMENT

In treatment, it is required to stop the irradiation as quick as possible to ensure the proper dose. Therefore, the GI not only prohibits the beam shutters from opening, but also reduces currents for a few magnets which are used for beam extraction from the synchrotron rings. Then the beam extraction is aborted in a time of less than an order of milliseconds. It is realized by the logic circuit of exclusive use. At present, GI lowers the output of the following power supplies; two P/S for separatrix-generator sextupoles, one for a bump-magnet, and one for special quadrupole magnets used for adjusting tune. These power supplies become energized again when FCN12 or FCN15 are completely closed. Biology experiments also need dose control and GI provides similar control as therapy. Thus, annual operation of FCN15 is about 10,000 times more frequent than FCN12.

5. SOFTWARE SIMULATION BY SUPERVISOR SYSTEM

The computer of supervisor system has the same functions of interlock as those of the GI for a backup. It also serves as a means by which sub-systems knows the information on GI. All the input signals of the GI are also transmitted to the supervisor system from the GI panel through a process I/O (PIO) interface. A change in any input signal triggers execution of the logical sequence. The supervisor system transfers the resultant outputs to the relevant sub-systems through LAN. For instance, in a case that the GI prohibits FCN8 from opening, the supervisor system demands the injector sub-system to close the beam shutter FCN8, because FCN8 is controlled by only the injector sub-system. Besides, the supervisor system alarms and indicates an alarm message on the computer display. Prohibition of opening another FCN usually occurs due to such as malfunctions of beam shutters or the other devices. In these cases, the prohibition is not cancelled unless the troubles are restored. However, supervisor system gives no alarm when FCN12 or FCN15 is prohibited from opening because the prohibition occurs in a normal procedure of irradiation of a beam in the most cases. Prohibition of opening FCN12 or FCN15 is cancelled when conditions for the beam irradiation are satisfied.

6. MAINTENANCE AND OPERATION

In order to maintain the GI, it is inspected once every year. Two kinds of inspections are performed; (1) the inspection of the GI itself, (2) the inspection of the whole system including the GI and related devices such as the beam shutters and power supplies. The former is performed using simulator that simulates various conditions and outputs the signals to the GI according to the simulated conditions. An examiner can verify the response of the GI on the simulator. In the latter, the GI's responses are examined in same conditions as those of beam irradiation. Examiners manipulate the devices to simulate malfunctions in them or generate conditions, in which a beam shutter is not allowed to be open. The examiners also check the behaviour of the related devices to verify the responses. This inspection needed many examiners. Introducing video cameras to monitor the behaviour succeeded in reducing the number of the examiners.

In the daily operation, a trouble that causes incorrect logic sequence must be fixed urgently. In the 8-year operation, failure had once occurred in a low voltage power supply used for the PLC, which causes all the beam shutters prohibition of opening and turns off the power of the extraction electrode. The power supply was immediately replaced with the spare one. Important parts of the GI are stored for replacement. For improvement of the GI, relays used in the GI has been replaced with the relays with an LED indicator. It helps us fix some troubles easily by checking the status of the relays.

7. SUMMARY

The global interlock system of HIMAC is aiming to control the beam shutters to stop the beam irradiation safely and to prevent patients and those who work in the controlled area of HIMAC building from unwarranted irradiation. The system has been working without any serious trouble since 1993 with performing the daily operation of stopping beam about ten times an hour. The system is maintained by annual inspections. It is planned to improve one of logic circuits to meet an additional new therapy room.

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