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Present Status of HIMAC Synchrotron Control System

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Abstract

HIMAC synchrotron has been in operation since late 1993. Daily operation for irradiation of clinical trial have been executed satisfactorily. Present status of HIMAC synchrotron control system is summarized.

INTRODUCTION

As a medically dedicated accelerator, Beam must be supplied from HIMAC for treatment quite reliably. Requirements for beam energy and intensity can vary from patient to patient. Research programs which have been carried out nights and weekends also widens the variety. Under these circumstances, HIMAC synchrotrons have been operated to deliver beams for clinical trial and basic research experiments in a rather stable manner.

Of course, the individual hardware (magnets, power supplies, etc.) must be able to perform very well in order to realize stable operations. In achieving the reliable beam supply, however, synchrotron control system plays important part because it integrates the functioning of synchrotron components. Design plan and preliminary results were presented in the previous reports.[1,2] Operational experience and improvement plans are described in this report.

INITIAL TRACKING CONTROL

Synchrotron control system of HIMAC has been in operation since fall, 1993, when commissioning began. During commissioning,[3] the most crucial task of the control system was to assure tracking of BM and QF/D magnets excitation, because the scheme was to set current pattern precisely matched and to converge actual output current pattern to the preset one via repetitive, or 'self-study', control. Mechanism is an iterative application of the following procedure: The control system sets the current and voltage pattern of desired excitation to a power supply, then the system detects deviation ΔI at 1,200 Hz, or each firing pulse of thyristors, and, after averaging over several cycles, it calculates modified voltage pattern to correct current deviations. The calculation involves the presumed response characteristics of the magnet & power-supply system, and tuning was done in cut and try method prior to the beam test. Even with the pre-tuning, two aspects remained to be answered by the beam; to find an appropriate current setting pattern and to assure effective convergence of the iteration.

Although we had started from the desired values of magnetic field and the approximate expression of the current .vs. magnetic-field relation from actual field measurement, it turned out that simply applying "proportional" current setting among BM and QF/D magnets apparently suffice. Here, flat base and flat top values of currents are given and the ramping between them are adjusted in such a way that the ratio of current value to flat top value in terms of surplus from flat base value at each point is kept across BM and QF/D. This is certainly less accurate than the case from magnetic field, but more straightforward and practical in operation's viewpoint.

It was later tested with higher excitation than original 230 MeV/u or most used 290 MeV/u level, e.g., 600 and 800 MeV/u, and results were quite successful, even the field saturation effect contributes non-trivial extent at these higher excitation. Thus, semi-empirical method worked well on the first aspect of the problem: finding appropriate current

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setting pattern.

The second part was much more complicated and not yet fully understood, because the power supply itself has its own built-in voltage regulation circuitry and thus the result is a mixture of two mechanism. However empirically, convergence is obtained for each operational patterns without re-adjusting parameters for iterative "self-study" procedure. Further study is expected to exploit the feature.

STABILITY AND REPRODUCIBILITY

After the commissioning, priority of the control was given to stable and reproducible beam supply.

Clinical irradiation is scheduled weekly from Tuesday to Friday with accompanying dose measurements, and beam condition should be kept constant during the period. A patient is usually treated with 18 fractions that spans six weeks, although each fraction is normally 3-5 minutes irradiation. Since the adjustment and fixation of the patient takes typically as much as 20 minutes, beam irradiation is required to start and complete immediately after these preparatory procedure.

In this context, it is an essential performance for HIMAC that the accelerator complex keeps overall tuning for a long time and delivers beam of same conditions without re-tuning. The observation at the early stage of operation was that when the accelerator devices were kept turned-on without beam, which is stopped right after the extraction from ion source, beam was immediately delivered to the final focus when the beam stopper at ion source was opened after an overnight break.

It is also confirmed that a "file" of actually tuned operation parameters enables reproduction of the beam, thus once parameters were well-tuned, simply recalling filed parameters and setting those values secure beam delivery.

At present, carbon beams of 290, 350, and 400 MeV/u are in daily use for clinical irradiation, while other beams such as helium, neon, and silicon have been studied and provided for experimental research. For these beams, we have files of 6 MeV/u (flat base level), 100, 230, 290, 350, 400, 600, and 800 MeV/u for charge-to-mass ratio $\varepsilon = 0.5$, with basically well-adjusted parameters. Essentially, no fine tuning is necessary for different ion species, as far as $\varepsilon = 0.5$. For argon and other ions with $\varepsilon < 0.5$, one or two energy points have been studied and filed. New energy point can be developed from the existing files using the above mentioned procedure, which takes several hours.

Another evidence for stability is the fact that rf acceleration without beam feedback signal is routinely realized for a wide range of intensity; 5×10^{2} to 1×10^{10} ppp.[3] In all, this means that the stability and reproducibility of the synchrotron was good enough to meet the requirement of medical application as well as research usage.

SEQUENCE AND FAULT HANDLING

One of the most practiced operation at HIMAC synchrotron is, as seen from the above, setting all devices to a reference value obtained from the file. This procedure can be done with a single set of touch operation. In the early stage of commissioning to routine operation, it sometimes got stranded and the software system of synchrotron hung-up. This was primarily caused by inappropriate handling of the sequence in the device control computers. Although corrective measures were taken, it was realized that momentary load can be larger than expected for some of the device controllers. Therefore, possible upgrade is under consideration for performance improvement.

It is important to locate fault condition that occurred during beam delivery, and to identify the cause quickly. Present control system provides error message with presumed items for each device. Recent recurrent troubles of device level include;

– decreased water-flow at magnet,
– thermo-control error at power supply, and
– rf cavity voltage over.

These were caused by defective hardware, and presumably terminated with correction on the problematic part of the hardware. On the other hand, system problem such as communication trouble happens, although sporadically. It does not seem to be a traffic congestion, but incompatible implementation of the communication protocol that is responsible, although it remains to be identified. Meanwhile, re-setting relevant computer of device control level can be postponed, since each device is set to keep operating as is when link between the controller and higher level computer is lost.

DEVICE CONTROLLERS

VME systems with MVME-147S CPU and FDI/FDO modules function for current pattern control of synchrotron magnets and for event timing generator rather reliably. They are operated with PDOS real-time OS. Additional work station for file management serves also for development and trouble-shooting tool.

In RF/BT system, peak load seems somewhat critical, but routine operation is performed without troubles after system tuning. The rf T-clock frequency was elevated to 50 kHz for smoother transition from B-clock region and thus for smaller beam losses. While it helped, present scheme of memory module operation limits flat top time shorter than needed for 0.3 Hz synchrotron operation, thus it returned to original 10 kHz clock.

MAN-MACHINE INTERFACE

For man-machine interfacing, four VS3100 VAX Stations are used for displaying system status, beam monitor results, current setting patterns, etc. It was found that with original 16 MB memory resource/station is inadequate to respond with operator's request. Therefore, it was enhanced to 32 MB per station and now works basically fine.

Two stations are allocated for two rings each, and interface with operator by accepting touch-panel input or equivalent mouse operation. Among the panels they provide, Pattern Editing, COD, & Tune are the special feature of the synchrotron control, while the others are basically common with other sub-systems, i.e., Linac and HEBT. Those are File List, Device Status, Fault/Not_Ready List, Alarm Message List, Trend Monitors, Vacuum System, System Layout, Profile, and Slit & FCN panels.

MAIN CONTROL

The main control, CS, is VAX4000/300 with 64 MB memory, and is managing all the sequence operations and periodic data taking, as well as individual device control. It has communication with "SV", supervisory node of control system of HIMAC accelerator as a whole. Table 1 shows the processes that are running for these tasks. It is now under performance analysis to improve system throughput further.

IMPROVEMENT PLANS

In addition to what are mentioned above, a few items are considered for improving operationability and control system performance. One of the important change is "stream-lining" of pattern setting sequence, for both with and without synchrotron repetition cycle time change. Another is realization of synchronized switching of magnet and rf patterns. These improvements will enable faster and more independent change of synchrotron operational parameters such as energy, repetition cycle, etc.

Modification to facilitate new functions, e.g., respiration triggered beam control, is in progress, too.

Table 1. Processes at CS (VAX4000/300)

Name	Function
SSMP	System Self Management
MDMP	Master Display Management
FMMP	File and Memory Management
FLSP	File Load & Save
IDCP	Independent Device Control
MDCP	Monitor Display and Control
DOCP	Device Operation Control
SOCP	Sequential Operation Control
TSCP	Timed Sequence Control
RECP	Rotary Encoder Control
TCCP	TCP/IP Communication Control
SVCP	'SV' Communication Control
AEHP	Alarm and Event Handling

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