OPERATION OF SCANNING IRRADIATION SYSTEM AT NIRS-HIMAC

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Abstract

Three-dimensional scanning irradiation system has been utilized for treatment since 2011 at Heavy Ion Medical Accelerator in Chiba (HIMAC), in the National Institute of Radiological Sciences (NIRS).

The scanning irradiation requires strict checking for beam position, size, range, and spill shape, because any changes in the scanned beam will cause a significant impact on the irradiation dose. Therefore, the operators perform the regular quality assurance (QA) checks for the therapeutic beam according to daily, monthly and half-yearly reviews.

Daily QA: Before starting patient treatment, the reproducibility of the beam should be checked. Therefore, daily QA procedures require not only adequate but also simple to not skilled operator.

Monthly QA: It is important to periodically acquire a reference data for daily QA checks. Once a month, we perform additional beam QA to measure the characterization of beam in detail.

Half-yearly QA: After the scheduled half-yearly shut down of HIMAC, we check the condition of the scanning system in detail. Additionally, we newly measure the characterization of beam to determine a reference for daily QA and monthly QA and re-tune the current of magnets from the measured results.

In this paper, we report periodic QA as an operation of scanning irradiation system at NIRS-HIMAC. Improvement in daily QA procedures and relevant progress are described.

INTRODUCTION

The carbon-ion therapy has been continued at Heavy Ion Medical Accelerator in Chiba (HIMAC) since 1994 [1]. The total number of patients is more than 7000 in 2013. Figure 1 shows two synchrotrons in HIMAC, which we call the upper synchrotron (USYN) and the lower synchrotron (LSYN).

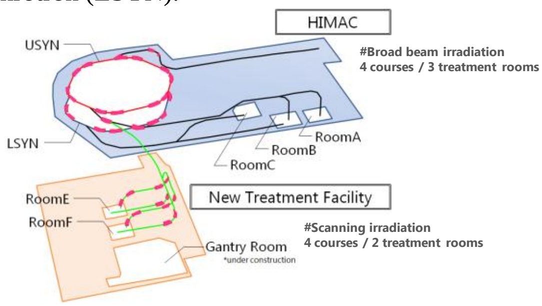

Figure 1: Layout of HIMAC and new treatment facility.

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As part of efforts to upgrade the irradiation system, a new treatment facility was recently constructed as an extension of the existing HIMAC as shown in Fig. 1. The new treatment facility is equipped with three-dimensional (3D) scanning irradiation system and the carbon-ion beam is provided from the USYN in HIMAC. The 3D scanning irradiation has been utilized for treatment since 2011 [2]. Both synchrotrons in HIMAC mainly supply the carbon-ion beam for patient treatment during the daytime from Monday to Friday. While the LSYN is utilized only for a part of the existing treatment rooms, the USYN is utilized for both new and existing ones. In the morning, the USYN provides the beam to the new treatment rooms. Thus the time to carry out QA for the new treatment facility is limited. Additionally, in the scanning irradiation method, since the 3D dose distribution is achieved by superimposing doses of individually weighted pencil beams, the scanning irradiation requires strict checking for beam position, size, range, and spill shape, because any changes in the scanned beam will cause a significant impact on the irradiation dose. In this paper, we report periodic QA as an operation of scanning irradiation system at NIRS-HIMAC.

OPERATION OF SCANNING IRRADIATION SYSTEM

The periodical QA of scanning irradiation system is divided into half-yearly, monthly and daily, three categories by a purpose. These periodical QA items and connection is shown in Fig. 2. Three categories of the periodical QA is described below.

In HIMAC, there is the scheduled half-yearly shutdown for a month two times a year, and beam supply from HIMAC stops during the scheduled shutdown. During the shutdown of HIMAC, periodical maintenance, version up of the hardware and software, and the replacement of the apparatus is performed. Therefore, after the scheduled shut down, we check the reproducibility of the extraction beam from USYN and the condition of the scanning system and compare to a former condition. Furthermore, we newly measure the characterization of beam to determine a reference for daily QA and monthly QA and re-tune the current of magnets from the measured results.
Once a month, we perform additional beam QA to measure the characterization of beam in detail. It is important to periodically acquire a reference data for daily QA checks.

Before starting patient treatment, the reproducibility of beam should be checked. Therefore, daily QA procedures requires not only adequate but also simple to not skilled operator.

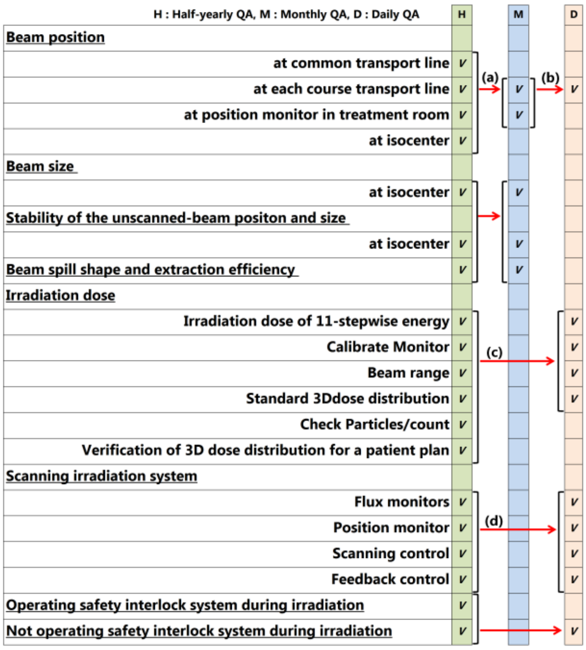

Figure 2: The items of periodical QA.(a) After the shut down, check the reproducibility of the extraction beam from USYN and the condition of the scanning system. (b) Once a month, periodically acquire a reference data for daily QA checks. (c) The measurement same as daily QA checks. As a result, determine a reference for daily QA checks. (d) After the shut down, check the soundness of the system.

Daily QA procedure

Figure 3 shows a typical daytime schedule of treatment in HIMAC.

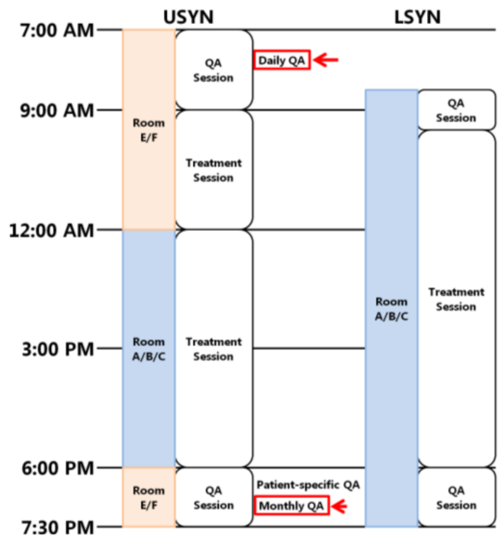

Figure 3: A typical daytime schedule of treatment.

At night-time from 7:30 p.m. to 7:00 a.m., all periodic QA isn't performed. Because HIMAC supplies many kinds of ion beams with various energies for R & D works. In the new treatment facility, the beam utilization relevant to the treatment starts from 7:00 a.m. The reproducibility of the beam should be checked before starting patient treatment from 9:00 a.m. Therefore, in short limited time, the operators efficiently perform the daily QA procedures for the therapeutic beam changed from experimental conditions in two treatment rooms with two fixed beam delivery systems (the horizontal and vertical directions). To realize a quick change of the extraction beam energy, a multiple-energy operation of the synchrotron has been utilized [3]. Multiple-energy operation is able to supply carbon-ion beams with various energies in a single cycle of the synchrotron. At present, 11-stepwise energy operation ranging from 140 to 430 MeV/u is routinely used for the treatment [4]. Therefore, the constancy checks for all energies must be performed. The periodic QA procedure is designed to check the overall readiness of scanning irradiation system consistently within certain reference tolerances. First of all, we check a beam position at a position monitor in all courses. Layout of the scanning irradiation system is shown in Fig. 4. It consists of the scanning magnets, main and sub flux monitors, position monitor, ridge filter and range shifter.

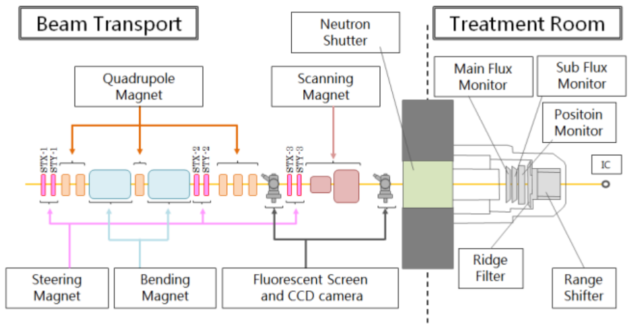

Figure 4: Layout of the scanning irradiation system and a part of the high energy beam transport in the new treatment facility.

The beam position is automatically tuned by the two pairs steering magnets (STX-2, STY-2, STX-3, STY-3 in Fig. 4) with the measurement at two fluorescent screen monitors every morning [5]. In addition, after the adjustment we check the set points of the steering magnets may gradually get closer to the upper limit or the lower limit by daily adjustment. If the electric current of steering magnet get closer to the limits (±12 A), we adjust located more upstream of one pair steering magnets (STX-1, STY-1 in Fig. 4). Figure 5 shows the electric current trend of steering magnets. In case of a set points get closer to the limit, after treatment session it is necessary to assist by a steering magnets (STX-1, STY-1 in Fig. 5) located more upstream of two pairs steering magnets to decrease electric current.

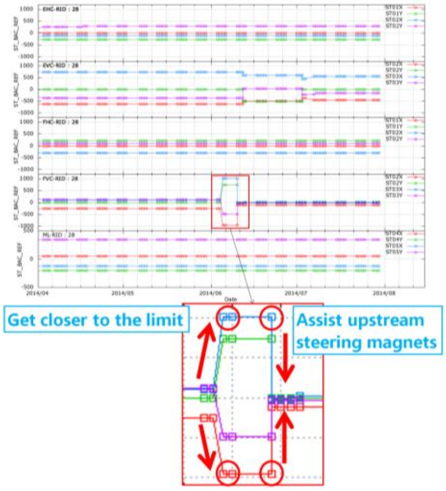

Figure 5: Set points trend of the steering magnets.

The scanning delivery system uses a position feedback control system consisting of scanning magnets and position monitor in order to keep the beam position stable. For tuning the beam position more effectively, new method uses in combination with the feedback control system. The using electric current for feedback control convert into an electric current of one pair steering magnets (STX-3, STY-3 in Fig. 5) and create a setting file of magnets. Figure 6 shows the electric current of scanning magnets for position feedback control. By using the new method, we are able to decrease unexpected adjustment in the morning and checking the set points since the current of the steering magnets are more stable than old method. For comparison, Fig. 7 shows the trend of steering magnets of old method and new method. Furthermore, we are able to shorten check sequence time. The check beam position method will evolve with the goal of making 201-stepwize energy irradiation without range shifter plate from 11-stepwise energy irradiation in near future.

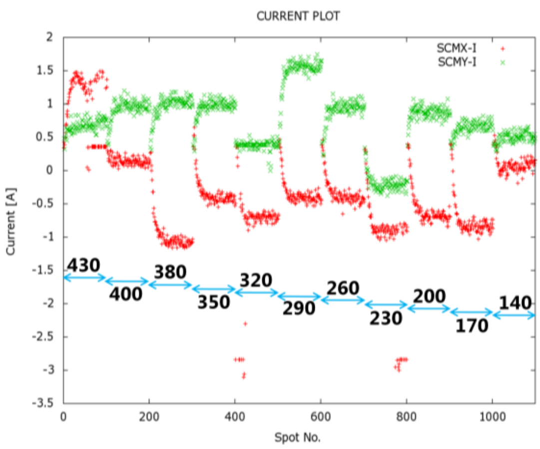

Figure 6 : The electric current for position feedback control.

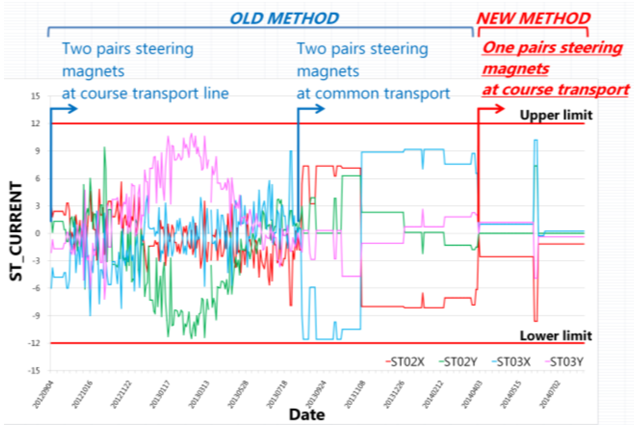

Figure 7: Comparing old method and new method.

Check beam position method		
	Old method (Called BAC)	New method (Called PRNCHK)
Place to check beam position	Two fluorescent screen monitors	Position monitor in treatment room
Magnets to adjust	Two pairs steering magnets (STX-2, STY-2, STX-3, STY-3)	One pair steering magnets (STX-3, STY-3)
Position check sequence time	6 ~ 10 minutes	1 ~ 2 minutes

Table1: Check beam position method.

After checking beam position, we carry out regular irradiation pattern and confirm that irradiation dose and beam range. (see irradiation dose items in Fig. 2). Figure 8 shows the typical results of the daily measurement. (a) 11-stepwise energy irradiation dose, (b) Calibrated MU constant of the flux monitor, (c) Beam range, (d) Standard 3D dose distribution in the reference volume (60 × 60 × 80 mm^3, 1Gy).

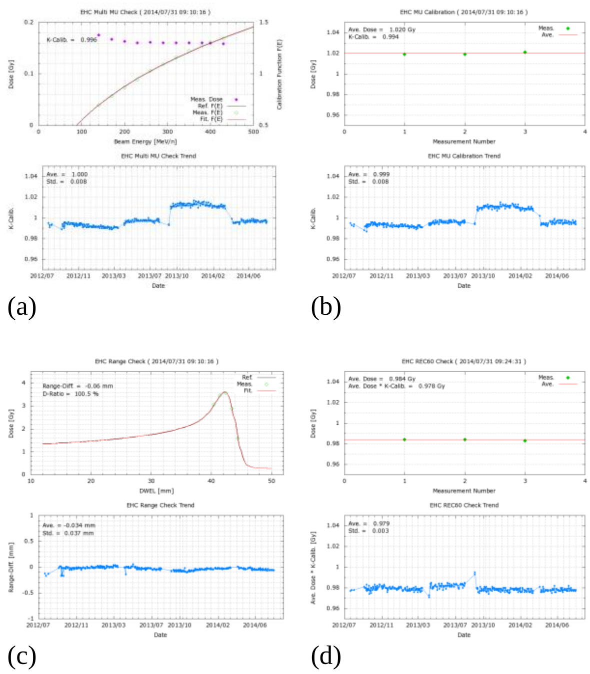

Figure 8: Typical results of the daily measurement.

In addition, we confirm the scanning irradiation system such as a flux monitor and a position monitor can work during irradiation normally (see scanning irradiation system items in Fig. 2). Figure 9 shows the typical oscilloscope display during measurement irradiation, and Fig. 10 shows the display of position monitor measurement. At last, we analyze the result of scanned irradiation and confirm the beam position is less than the tolerance of 2 mm. Figure 11 shows the difference of the beam position at position monitor during scanned irradiation.

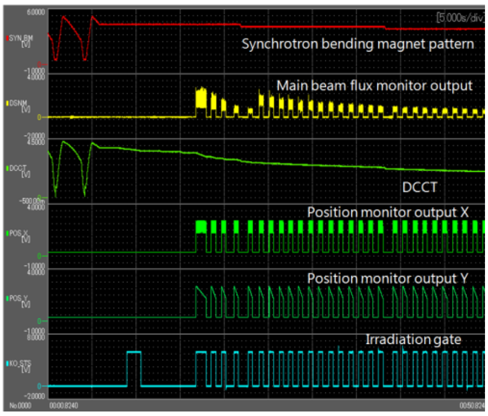

Figure 9: Typical oscilloscope display.

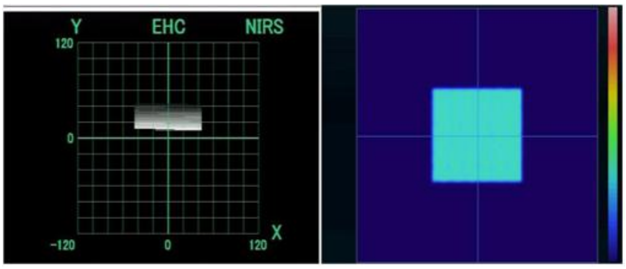

Figure 10: Display of position monitor measurement.
Left: online display of beam position.
Right: measured fluence map for each slice.

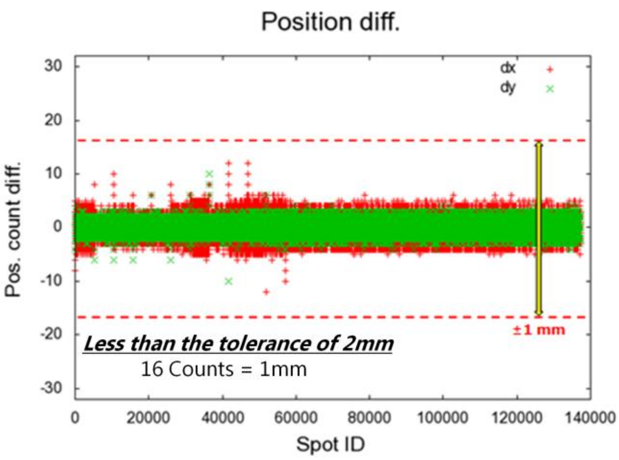

Figure 11: The difference of the beam position at position monitor during scanned irradiation.

Monthly QA

The purpose of monthly QA is the soundness confirmation of the reference of daily QA. Primarily we adjust the beam position at the position monitor on a daily basis, though the reference using by the adjustment is correct or confirm the misalignment of the beam is less than the tolerance of 0.5 mm at iso-center. Figure 12 shows the setup for the checking of beam position [6].

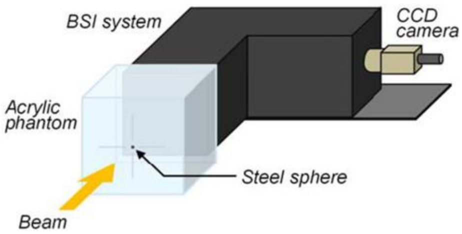

Figure 12: Setup for the checking of beam position.

The confirmation method is utilized by using an acrylic phantom. A steel sphere is embedded in the surface of this phantom, and its position is on the axis of the reference coordinate system (Fig. 12). The misalignment of the beam can be measured by taking an image of the beam spot while setting this phantom. The beam misalignment is calculated by deriving the centres of the beam spot and steel sphere's shadow. Figure 13 shows the typical image of the shadow on beam spot profile and Fig. 14 shows the measurement results.

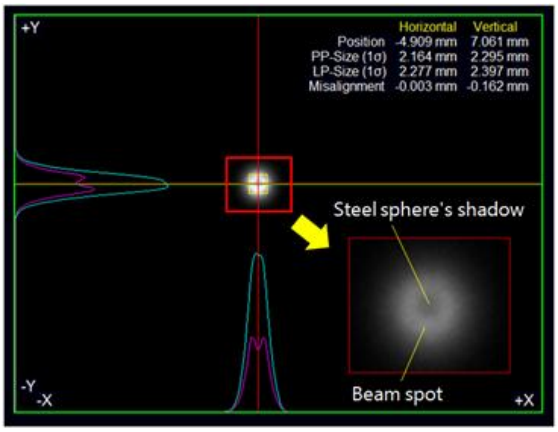

Figure 13: Typical image of the shadow on beam spot profile.

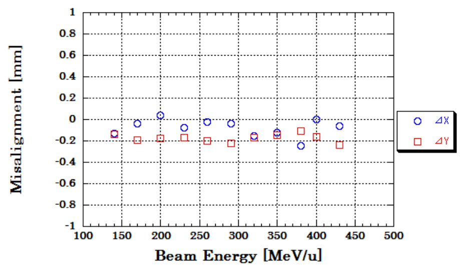

Figure 14: Measurement results of the beam misalignment.

In addition, we confirm the beam size at iso-center, the time stability of the beam position and size, as shown in Fig. 15 and size during irradiation, as shown in Fig. 16, beam spill shape and extraction efficiency, as shown in Fig. 17. These confirmations guarantee the reference of daily QA.

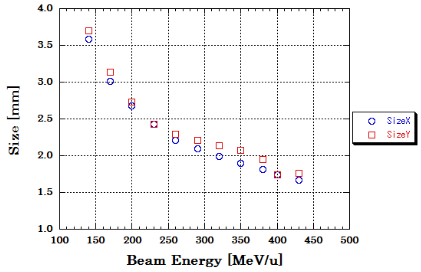

Figure 15: Measurement results of the beam size.

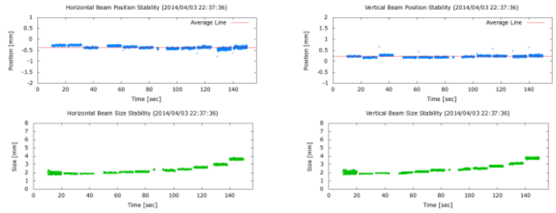

Figure 16: Time stability measurement of the beam position and size.

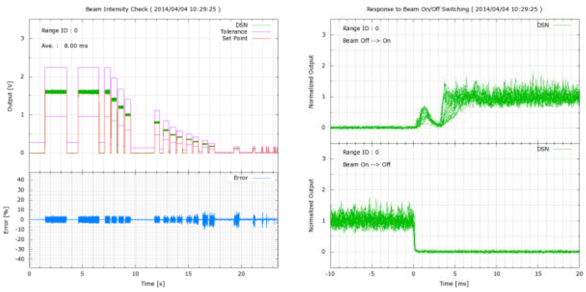

Figure 17: The result of beam spill shape and extraction efficiency.

Half-yearly QA

After the scheduled shut down, we check the condition of the whole scanning system including synchrotron in detail. Additionally, we newly measure the characterization of beam to determine a reference for daily and monthly QA. Conclusively, irradiation is performed in the same manner as in the patient treatment and check the comprehensive scanning system, as shown in Fig.18.

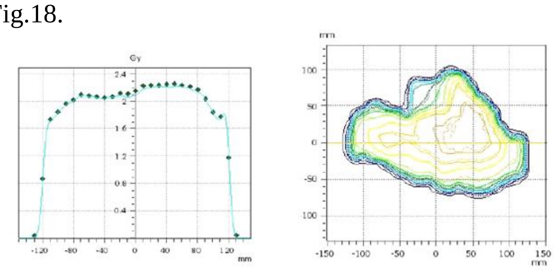

Figure 18: Verification of 3D dose distribution for patient plan.

SUMMARY AND DISCUSSION

We introduced some examples of the current operating. In near future, it shifts from 11-stepwise energy irradiation to 201-stepwise energy irradiation without range shifter. Additionally, rotating gantry and respiration gated irradiation with 3D scanning is starting. Consequently, it is expected the spending time of daily QA increases. Therefore, it is important to efficiently perform the QA checks.

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