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Quadrupole Magnet Requirements for Achromatic Operation of DIAC Nano-beamline

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1. Introduction

DIAC (Daejeon ion accelerator complex) is part of KEK's TRIAC (Tokai Radioactive Isotope Accelerator Complex), which was transferred to KAERI in April 2012 and installed [1]. It consists of ion source, RFQ, and IH, and the specifications of each component are shown in Table I [2]. To use accelerated beams, three beamlines are planned to be installed downstream of the accelerator, called Nano, Material, and Micro-beams, respectively. The beamlines are configured as shown in Fig. 1.

Table I: Specifications of accelerator components

Ion source	Type: ECR Frequency: 18 GHz RF power: 1 kW Plasma chamber: 75 mmϕ x 300 mm
RFQ	Type: Split-Coaxial Frequency: 25.96 MHz Charge-to-mass ratio: ≥1/28 Input energy: 2.07 keV/u Output energy: 178 keV/u Norm. emittance: 0.6πmm·mrad Energy spread: 1.03% Duty factor: 30 or 100% Total length: 8.6 m
DTL	Type: Interdigital-H Frequency: 51.92 MHz Charge-to-mass ratio: ≥1/9 Input energy: 178.4 keV/u Output energy: 1090 keV/u Norm. emittance: 0.6πmm·mrad Energy spread: ≤2.8% Duty factor: 50% # of tanks: 4 Total length: 5.6 m

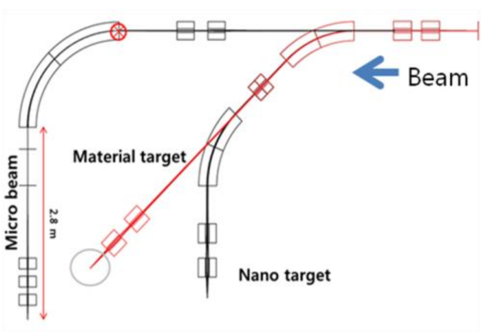

Fig. 1. Layout of planned beamlines.

In the case of the Nano-beamline, two 45-degree bending magnets are installed in the direction of 90 degrees with respect to the accelerator. The specifications of the bending magnets are given in Table II. It is difficult to obtain beam of small size in a beamline composed of only bending magnets because the beam divergence occurs due to the energy spread of the beam from the accelerator. In general, the energy spread of the beam from linac is a few percent. In order to eliminate such beam divergence, the achromatic operation of the Nano-beamline was studied.

Table II: Bending magnet

Bending angle	45 degrees
Bending radius	1,353 mm
Entrance/Exit pole angle	0 degree
Max. magnetic flux density	1.2 T
Pole gap	70 mm

2. Beam Optics

The simplest way to achieve achromatic conditions is to install a single quadrupole magnet between the two bending magnets. These magnet arrays are called Double Bend Achromat (DBA) structures. Since the Nano-beamline already has a quadrupole magnet between two bending magnets, it was examined whether the achromatic operation could be performed using this quadrupole magnet. Table III shows the input parameters for the beam optics calculation.

Table III: Input beam parameters

Reference particle	He
Charge-to-mass ratio	1/4
Energy	1,090 keV/u
Beam current	1 μA
Bunch frequency	25.96 MHz
Emittance (rms)	0.6πmm·mrad (norm)
Energy spread	≤2.8%

2.1 Optics of Chromatic Operation

First, the beam line operation condition that was the baseline at the time of installing the beam line was checked. At that time, beam divergence due to energy spread was not considered, and the beamline operating condition considering beam optics of beam emittance only was obtained. Based on these operating conditions, the result of calculation using TRACE code [3] is shown in Fig. 2. The beam transport considering beam emittance only is good, but beam divergence due to energy spread is not controlled. The beam radius due to energy spread is obtained from the following equation.

$$R = D \times (\Delta E/E) / 2 \qquad (1)$$

where R is beam radius, D is dispersion, ΔE is energy spread, and E is total energy. Due to the energy spread, the increase in the beam radius at the target is expected to be 1 cm.

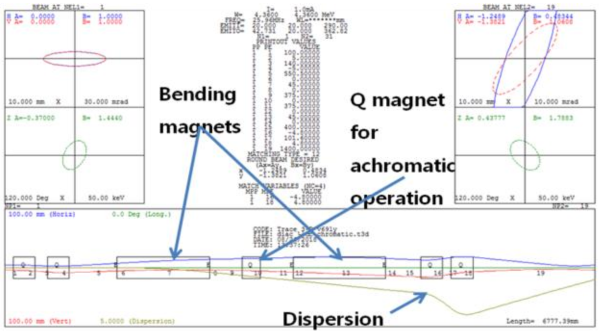

Fig. 2. Beam optics of chromatic operation.

2.2 Optics of Achromatic Operation

To minimize beam divergence due energy spread of the beam at the target, a condition must be found that the dispersion is zero at the target location. Fig. 3 shows the result of adjusting the strength of the quadrupole magnet between the two bending magnets. Assuming that the effective length of the quadrupole magnet is 205 mm, it has been found that the strength of 5.968 T/m is required. In addition, it can be seen that the beam is well focused at the target location.

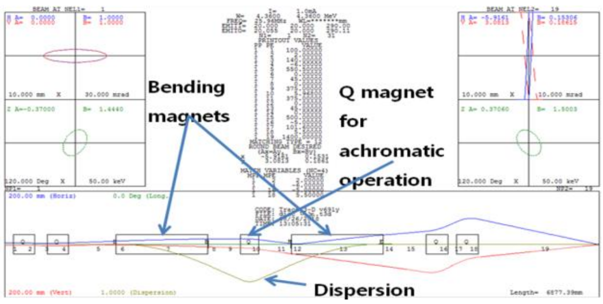

Fig. 3. Beam optics of achromatic operation.

2.3 Quadrupole Magnet for Achromatic Operation

The quadrupole magnet currently installed in the Nano-beamline is transferred from KEK along with DIAC. Fig. 4 shows the installation. Unfortunately, this magnet was made very long ago in Japan and its specifications are unknown. Therefore, it is necessary to know the specifications of this magnet through experiments. Especially, in order to achieve achromatic operation of beams with charge-to-mass ratio less than 1/9, the strength at 13.5 T/m or more must be obtained. Therefore, the magnet experiment at the maximum current is very important and this experiment will be ready.

Fig. 4. Quadrupole magnet between two bending magnets.

3. Conclusions

The specifications of the quadrupole magnet for the achromatic operation of the Nano-beamline for DIAC have been investigated. Experimental confirmation is needed to see if the current quadrupole magnet satisfies the specifications. Based on these experiments, the whole system for the achromatic operation will be designed and prepared for user service.

REFERENCES

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