BEAM COMMISSIONING OF THE i-BNCT LINAC*

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Abstract

The beam commissioning of the linac for the boron neutron capture therapy of Ibaraki prefecture (i-BNCT) has been started. The accelerator of i-BNCT consists of the 3-MeV RFQ and 8-MeV DTL. The 8-MeV beam injected on the target made of Beryllium in order to produce a intense neutron beam. The design of RF structure of the linac is based on the J-PARC linac. After the first observation of neutron production on December 2015, significant modifications to the linac were given in order to increase the operation stability and the beam power. The status of the beam commissioning of the i-BNCT is reported.

INTRODUCTION

The boron neutron capture therapy (BNCT) is one of the candidates for the cancer therapy. The principle of the BNCT is as follows:

- Drug which contains Boron ^{10}B is delivered to the cancer affected part.
- Neutrons are irradiated from the outside to the affected part.
- Neutron (<0.1 eV) reacts with Boron ^{10}B. The reaction $^{10}B(\text{n},\alpha)^{7}Li$ makes α.
- Both of ranges for ^{7}Li and α in a cell are a few µm. Therefore both particles stop in the cell because those loss the whole kinetic energy.
- The cell affected by cancer is destroyed by the lost energy by particles.

At the beginning of the BNCT development, a nuclear reactor was used as the neutron source. Recently the accelerator based BNCT is being developed in the world because it is possible to install the system in the hospital. The BNCT using neutrons produced by a proton linac has been developed by the collaboration in University of Tsukuba, KEK and the Ibaraki prefectural government [1] . This BNCT system is called i-BNCT. The several private companies are also committed to the i-BNCT. The construction of the system was completed and the beam commissioning has been started. The produced neutron was observed on December 2015 [2]. At that time, the peak beam current from the linac was 20 µA. It was a check to find the serious problem in the accelerator system. After the beam demonstration, a lot of significant modifications to the linac were given in order to increase the operation stability and the beam power.

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LINAC PARAMETERS

The layout of the i-BNCT accelerator is shown in Fig. 1. The linac of the i-BNCT is composed of the ion source with a multi-cusp magnetic field, 3-MeV RFQ and 8-MeV DTL [1]. Design parameters of cavities are summarized in Table 1. The design of RF structure of the RFQ and the DTL is the same as one of the J-PARC linac. However the cooling water system of i-BNCT is different from that of J-PARC because the beam duty factor of i-BNCT is eight times larger than that of J-PARC as shown in Table 2 .

Figure 1: Perspective of i-BNCT accelerator system.

Table 1: Design Parameters of Cavities

Items	RFQ	DTL
Length	3.1 m	3.0 m
Frequency	324 MHz	324 MHz
Injection energy	50 kV	3 MeV
Ejection energy	3 MeV	8 MeV
Cell number	-	31
Wall loss	340 kW	320 kW

Ion Source and LEBT

The ECR ion source with a pair of solenoid magnet was used for the beam test carried out at last year. However it was not able to keep the design high-voltage of 50 kV because of defects for the high-voltage insulation. Thus

ISBN 978-3-95450-169-4

Table 2: Design Values for the Beam Pulse

Project	Peak current	Pulse length	Rep. rate
i-BNCT	50 mA	1000 µs	200 Hz
J-PARC	50 mA	500 µs	50 Hz

the ion source has been replaced to the spare one which has a multi-cusp magnetic field by using 10 square bars of a permanent magnet. Although the new ion source can keep the 50 kV stably, it has the problem for the ignition of the plasma because the development of the source in the test bench was not completed. Thus modification is being continued. At the present time, the multi-cusp type ion source is set on the stand with the LEBT made for the previous ion source as shown in Fig. 2. The configuration of the LEBT is not optimized for the present ion source.Thus the new LEBT is being developed.

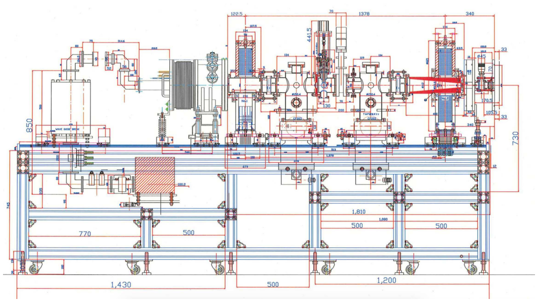

Figure 2: Ion source and LEBT on the stand.

RFQ

As mentioned before, the RF structure of the RFQ for i-BNCT is the same as that for J-PARC. Thus machining and assembling procedure of the RFQ shown in Fig. 3 are also the same as those of the J-PARC RFQ [3].

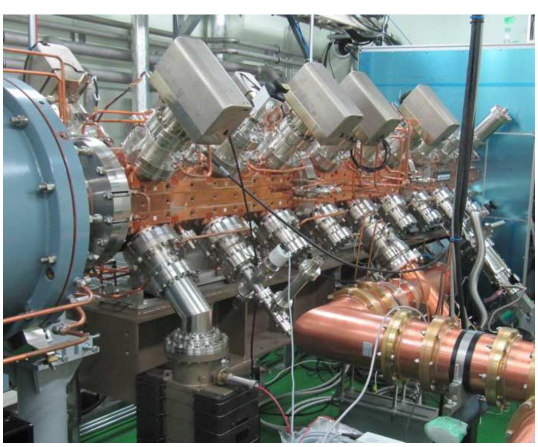

Figure 3: 3-MeV RFQ.

DTL

The focusing quadrupole magnets in the drift tube of i-BNCT are made of the permanent magnet. The DTL shown in Fig. 4 has no post coupler because the length of the cavity is sufficiently short.

Figure 4: 8-MeV DTL.

Irradiation Room and the Target

There is no space for the target in the accelerator room of i-BNCT. Furthermore the floor level of the target room is 1.85 m higher than that of the accelerator room. Therefore the i-BNCT has a long beam line, which has 4 bending magnets, from DTL to the target. Figure 5 shows the beam line and the target in the irradiation room. At the present time, the target is surrounded by the radiation shield and modulator.

The target is made of Beryllium. The target has a complicated structure to minimize the blistering effect which is the most serious problem of the target [4].

Figure 5: 8-MeV beam line and the target.

BEAM COMMISSIONING

First object of the beam commissioning is to accelerate the 8-MeV beam of which the average beam is 1mA and transport to the target. The beam loss must be less than 10^{-4} of the total beam. For instance, the average current of 1mA is gotten with the peak beam current of 10 mA, the beam pulse width of 1 ms and the pulse repetition rate of 100 Hz. It is required to get the official inspection as an accelerator facility. Medical experiment with animals requires 2 mA average current at least. Thus it is the next object. Final goal of the beam current is already shown in Table 2. It corresponds to the average beam current of 10 mA.

The subjects to be done for RF system before the beam commissioning are summarized below:

- Unification of the operation system for LLRF control, cooling water control and DTL movable tuner control,
- Optimization of the feed-forward (FF) and feed-back (FB) system for the klystron by LLRF tuning.

ISBN 978-3-95450-169-4

In particular, it is important to tune the LLRF system for FF/FB because the original LLRF system of i-BNCT had no FB circuit. Original design of LLRF for the klystron control is as follows:

- Klystron is operated at the saturation point.
- Beam loading is compensated by changing HV level of the klystron cathode.

However it is so difficult to apply the fine tuning to keep the tank level constant with beam because one klystron drives both of the RFQ and the DTL. Thus the klystron operation point is changed to the region where the klystron has the linear response and the FF/FB system developed at J-PARC linac has been introduced to i-BNCT. First tuning result of the klystron is shown in Fig. 6 which shows the effect of the FB.

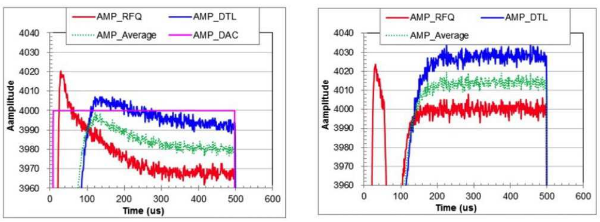

Figure 6: RFQ tank level: left: without FB, right: with FB.

Transverse beam profile in the LEBT is shown in the left side of Fig. 7. The right side of the Fig. 7 is the typical beam pulse pattern measured by the CT at the end of LEBT. The profile shows that the beam from the ion source has a cylindrical hollow shape.

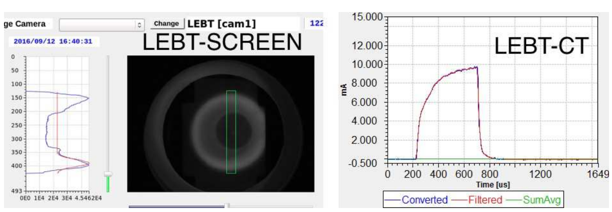

Figure 7: Beam profile and pulse pattern at LEBT.

Quadrupole magnets after the DTL are being tuned by using a Q-scan method. Figure 8 show the typical beam profile measure by the screen monitor at the 4th (and the last) bending magnet during the Q-scan measurement.

REMAINING SUBJECTS

Reaminnig subjects to be done before the practical operation are as follows:

- Fast machine protection system (MPS)

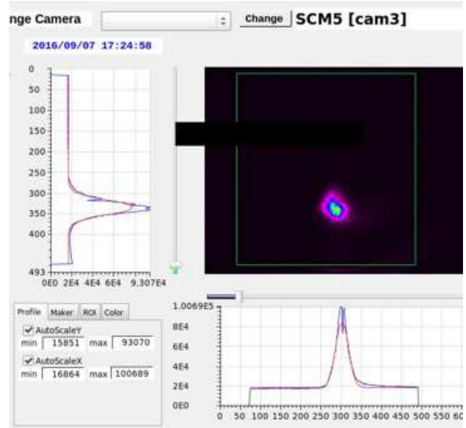

Figure 8: Beam profile at the last bending magnet.

- Exchange of LEBT
- Observation system for the target surface

Preparation of each subjects is on going.

CONCLUSION

We have started the real beam commissioning of the i-BNCT linac system after the demonstration of the neutron production. Although the ion source still has a lot of troubles, the beam tuning is on-going. First goal is to achieve the acceleration of the beam of 1mA average current for the official inspection as an accelerator facility.

ACKNOWLEDGEMENT

The authors are deeply grateful to Prof. Y. Kamiya (KEK), Prof. S. Yamaguchi (KEK) and Prof. A. Matsumura (Univ. of Tsukuba) for their support.

REFERENCES

[1] M. Yoshioka *et al.*, "Construction of an Accelerator-based BNCT Facility at the Ibaraki Neutron Medical Research Center", in *Proc. of LINAC'14*, Geneva, Switzerland, (2014) pp. 230–232.

[2] H. Sakurai, "Accelerator based BNCT in Tsukuba University", *Proc. of BNCT Sympo.*, Tokyo, Japan, Sep. 2016, pp. 61–65.

[3] T. Morishita *et al.*, "Vacuum Brazing of the New RFQ for the J-PARC Linac", in *Proc. of LINAC'10*, Tsukuba, Japan, (2010) pp. 521–523.

[4] T. Kurihara *et al.*, "Neutron target research and development for BNCT: direct observation of proton induced blistering using light-polarization and reflectivity changes", *Journal of Radioanalytical and Nuclear Chemistry* (2015) 305, pp. 935–942.