Initial optimization of fine tuner’s position on the cyclotron DECY-13’s rf dee system

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Abstract. Initial optimization of fine tuner’s position has been carried out on the cyclotron DECY-13’s RF dee system. The initial optimization was carried out to obtain the resonance frequency 77.76 MHz between RF generator and RF dee system in accordance with the specification of cyclotron DECY-13. The optimization was performed by measuring cyclotron DECY-13’s frequency using the Network Analyzer tool while shifting the fine tuner’s position. The shifting of fine tuner’s position started from the farthest to the closest gap between fine tuner and dee component with an increment of 5 mm continued with an increment of 1 mm from the nearest measured frequency. We obtain cyclotron DECY-13’s frequency for position 0 mm, 5 mm, 10 mm, 15 mm, 20 mm, 25 mm respectively 77.925 MHz, 77.875 MHz, 77.775 MHz, 77.625 MHz, 77.325 MHz, 76.075 MHz and the nearest frequency is 77.75 MHz, obtained in the position of 11 mm from the farthest gap. These results could be used as a reference point in the future experiment mainly in cyclotron’s hot test and fine tuner’s control system.

1. Introduction

The cyclotron is an ion accelerating tool, positive or negative periodically using alternating voltage on two hollow electrodes. The magnetic field is used to produce Lorentz force which is a centripetal force so that the ion track could be in the form of a circular path thus could be accelerated each time the ion pass through the gap of the hollow electrode. Ion beam from ion source in between two-pole magnet is pulled at a certain energy, after accelerated then the energy will increase. Thus the greater the circle path, the greater the ion beam energy. Ion beam will be extracted at certain energy and radius to have collided with solid, gas or liquid target that will produce radioisotope that used for sterilization, therapy as well as material properties modification [1][2]. Magnet and RF dee system design is 4 sector with dee located on a valley and operated on 77.76 MHz. With 12.745 kG of the magnetic field, it will be obtained 13 MeV of proton energy on a 408 mm extraction radius [3]. At this time, Center for Accelerator Science and Technology - BATAN are conducting research and development on 13 MeV cyclotron to produce radioisotope which called Design Experimental of Cyclotron in Yogyakarta - 13 MeV (DECY-13).

One of the main systems in a cyclotron is the RF dee system which functions as an accelerating component for hydrogen ions. The design of the RF dee system’s components of 13 MeV cyclotron has been done in the year of 2011 [4]. RF dee system’s components consist of the center of dee, central region, dee plate, dee stem, cavity, coupler, liner and fine tuner [5]. After the design process, the next step is to manufacture the components in the workshop. In this manufacturing process, due to hardware
limitations and tolerance, there will be a difference between the design and the manufacturing result. This difference can cause differences in frequency between the design and the manufacturing result [6]. The component designated to overcome these issues is a fine tuner, this component act as a frequency adjuster capacitively and could be adjusted via rotation-to-linear feedthrough located outside the vacuum chamber. To obtain the correct frequency according to the specification of DECY-13 (77.76 MHz), the initial optimization of fine tuner’s position need to be done.

RF dee system is designed to be operated with 20 kW of power transmitted from RF generator [7][8]. When the RF dee system receives power from the RF generator, heat will be generated in the RF dee system thus the components will be slightly expanding. The expanding of the RF dee system’s component will change the cyclotron frequency [9]. So another optimization of fine tuner’s position needed to be done. Another optimization needed to be done is when the control system of the fine tuner will be applied. This initial optimization will provide a reference point for the next experiment and further optimization.

2. Methods
The initial optimization of fine tuner’s position on the rf dee system was carried out by measuring the frequency of the cyclotron using a network analyzer tool while shifting the fine tuner’s position. The tools and components used are:

1. RF dee system which installed in the magnet and vacuum system of cyclotron consists of the cavity, dee stem, dee plate, center of dee, central region, liner, coupler and fine tuner. The fine tuner is equipped with rotation-to-linear feedthrough.
2. N9913A FieldFox Handheld Microwave Analyzer (network analyzer) [10].
3. Network analyzer’s calibration kit.
4. Coaxial cable with BNC connector.
5. Connector BNC - 5/8”.

![Figure 1. Rf dee system installed in the cyclotron](image)

The first step of the initial optimization of the fine tuner’s position on the rf dee system was to calibrate the network analyzer using a calibration kit. The next step was to connect the coaxial cable (attached with BNC - 5/8” connector) into port 1 of the network analyzer. The calibration continued in response mode of the network analyzer. After the calibration is finished, the next step was to connect the other end of coaxial cable (attached with BNC - 5/8” connector) onto the coupler’s rf dee system. The frequency of the cyclotron is measured using a network analyzer. The measurement is started from the farthest to the closest gap between fine tuner and dee component with a 5 mm increment. The measurement is continued with a 1 mm increment from the nearest measured frequency of 77.76 MHz.
Figure 2. Fine tuner and rotation-to-linear feedthrough installed in a cyclotron with the closest gap between fine tuner and dee component setup

3. Results and Discussions
The measuring result is as follow:

Table 1. Cyclotron’s frequency measured by network analyzer for 5mm increment.

| Fine tuner’s position (mm) | Frequency (MHz) |
|---------------------------|----------------|
| 0                         | 77.925         |
| 5                         | 77.875         |
| 10                        | 77.775         |
| 15                        | 77.625         |
| 20                        | 77.325         |
| 25                        | 76.075         |

Figure 3. Display of frequency measurement using network analyzer for fine tuner’s position of 10 mm valued 77.775 MHz and 38.2 Ω + j33.1 Ω.
The experiment was continued with measurement for a 1 mm increment. From those six measurement data, the nearest frequency from 77.76 MHz is 77.775 MHz which is 10 mm in fine tuner’s position. From that point, the position of fine tuner was shifted with a 1 mm increment. The measurement results are as follow:

**Table 2.** Cyclotron’s frequency measured by network analyzer for 1 mm increment from 10 mm fine tuner’s position.

| Fine tuner’s position (mm) | Frequency (MHz) |
|---------------------------|-----------------|
| 10                        | 77.775          |
| 11                        | 77.75           |
| 12                        | 77.725          |
| 13                        | 77.7            |
| 14                        | 77.675          |
| 15                        | 76.625          |

**Figure 4.** Display of frequency measurement using network analyzer for fine tuner’s position of 11 mm valued 77.75 MHz and 32.6 Ω + J29.0 Ω.

From table 2 it can be seen that the nearest frequency from 77.76 MHz is 77.75 MHz obtained from fine tuner’s position of 11 mm. The exact values of 77.76 MHz could not be obtained due to the limitation of the network analyzer’s resolution.
The correlation between frequency against fine tuner’s position is presented in figure 5. In the first 15 mm increment of fine tuner’s position, the frequency is decreased linearly. While in the next 10 mm increment, the frequency is decreased exponentially.

4. Conclusion
From the experiment of frequency measurement using a network analyzer on cyclotron with fine tuner’s position variation, it could be drawn several conclusions as follows. The most optimum position of the fine tuner is at 11 mm (feedthrough’s indicator) valued 77.75 MHz. This frequency is the nearest frequency from 77.76 MHz that cloud is obtained, this difference is mainly caused by the limitation in the network analyzer’s resolution. As for the impedance results valued 32.6 Ω + J29.0 Ω, is not yet reached the characteristic impedance value of 50 Ω. The characteristic impedance could be reached by modifying the coupler’s loop geometry. This initial optimization could be used as a reference point for future experiments mainly in cyclotron’s hot test and fine tuner’s control system.

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