DESIGN OF RF PICK-UP FOR THE CYCLOTRON

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Abstract

The radio-frequency (RF) pick-up for RFT-30 cyclotron which was located in the Korea Atomic Energy Research Institute (KAERI) was designed by Sungkyunkwan University in Korea. This paper covers proper position of RF pick-up and things to consider when designing. Our RF pick-up antenna is designed for RFT-30, but approach to design process can be used any RF pick-up antenna design. This paper provide some tendency graph according to position of RF pick-up.

INTRODUCTION

Recently cyclotron is used many research field such as nuclear reactions, nuclear physics, radioisotope applications, life science and so on. Various field needs variable performance of beam. Reliable output beam is necessary to get good results [1].

Cyclotron is a kind of particle accelerator. RF cavity is a component of cyclotron, which accept electromagnetic field from RF source and serves accelerating field to particles.

There are some problems when RF power input to RF cavity, such as inputting power variation or mismatched impedance. Sometimes device should be stopped operating because of these problems. It is possible to solve these problem that using RF pick-up. Because RF pick-up accept electromagnetic signal in real time. The signal of RF pick-up is applied to cyclotron control system, it is possible to safe driving. Our RF pick-up design is going to use RFT-30 and RF pick-up used in RF system, so Table.1 is contained. Simulation results were performed by CST microwave studio [2].

Table 1: Specification of RFT - 30 Cyclotron RF System [3]

Parameter	Value
RF frequency	64.05 MHz
Number of Dees	2
Dee angular width	39 deg
RF amplifier power	50 kW
Number of Harmonics	4

SIMULATION PROCEDURE

RF pick-up is measuring resonance signals in RF cavity, such as resonance frequency. In this work, we can find RF cavity quality factor, impedance matching status and so on by using these signals.

RF pick-up is same principle to RF power coupler. However role of two things are different. Purpose of RF coupler is transportation of RF power from RF generator to RF cavity, whereas purpose of RF pick-up antenna is measuring electric field in excited RF cavity by RF power. RF pick-up is connected with a measuring instrument directly. So, in design of RF pick-up, we must consider status of measuring instrument such as maximum acceptance power.

It would be significant to take the appropriate location of the RF pick-up and not to affect the performance of the RF cavity when designing the RF pick-up. The appropriate position represents to get RF power supplement that should not exceed the measurement limitation of the network analyser.

Prior to starting the design, coupling type must be determined.

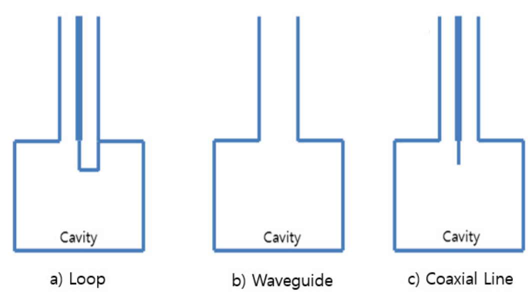

Figure 1: Different types of RF power coupler.

There are 3 types of RF power coupler are shown in Fig. 1. If magnetic field passing through the loop, induced current is generated. This current becomes pick-up signal at loop type coupler. Waveguide type is directly connected to RF cavity and waveguide performs a RF pick-up, coaxial line type usually is used in electric field.

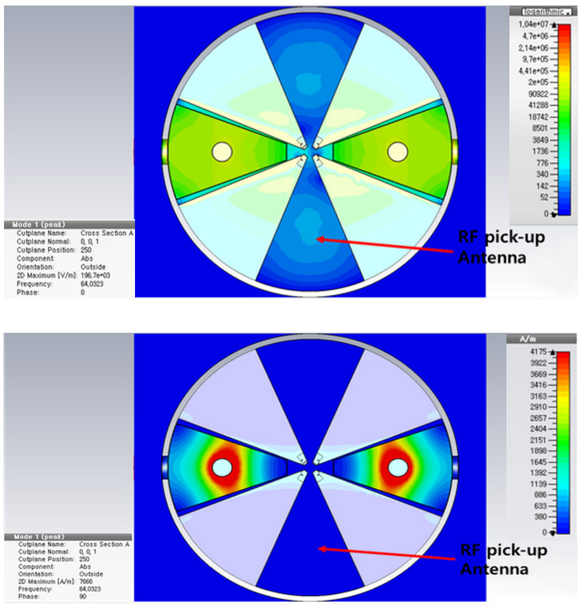

Figure 2: The electric field (upper) and magnetic field (lower) at RF pick-up position.

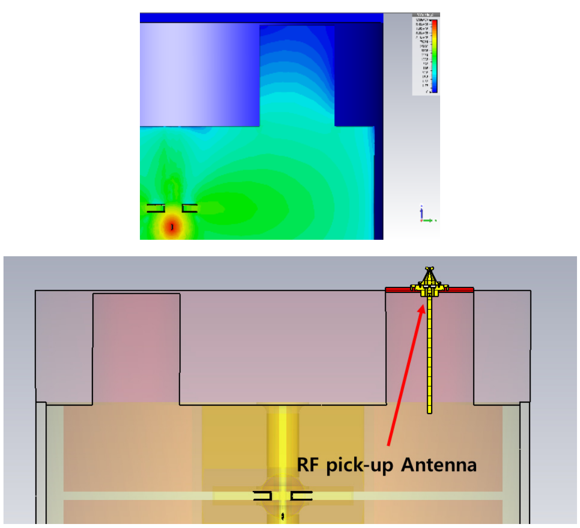

Figure 3: Electric field in cavity (upper) and position of RF pick-up (lower).

Because RFT-30 cyclotron was already development, so the position of RF pick-up is limited. We can use only two regions of valley. Figure 2 shows electric field and magnetic field in valley region. The electric field exists in this region whereas magnetic field rarely exists. This is the reason we are using coaxial type probe.

Figure 3 is Electric field in cavity and position of RF pick-up. The closer to the beam acceleration plane, the closer to the beam acceleration plane, the stronger intensity of electric field is generated. And the closer to the electromagnet yoke, the weaker electric field is generated. This means that it is possible to get high intensity signals at RF pick-up, which is closer to the beam acceleration plane.

For proper positioning of RF pick-up, simulation is progressed according to penetration depth. The result of simulation is checked by S-parameter S21.

$$S21[\text{Magnitude, dB}] = 10 \times \log_{10}\frac{P2}{P1} \qquad (1)$$

P2 means power coming into port 2. In other words, it means pick-up signals intensity at RF pick-up antenna. P1 means power coming into RF cavity from RF coupler. Therefore S21 means ratio of delivered power in RF cavity to pick-up power at RF pick-up. We can calculate real electric power at RF pick-up by using S21 data.

Figure 4 shows relation between antenna penetration depth and S21 magnitude (dB). Range of RF pick-up penetration depth is determined from 200 mm to 400 mm because there are rarely magnitude signals below 200 mm and it is possible to cause structurally unstable above 400 mm. In this graph, the more deeply penetration depth of the antenna is able to get more magnitude at RF pick-up.

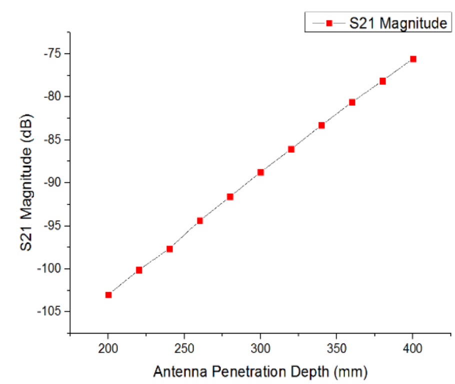

Figure 4: RF pick-up penetration depth versus S21 magnitude (dB).

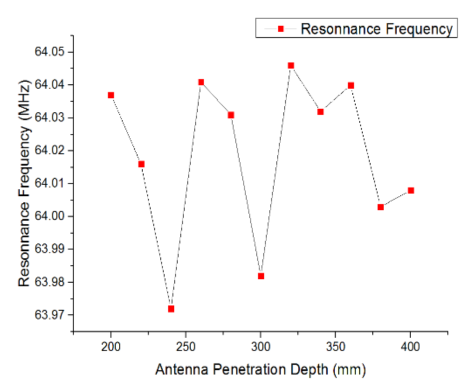

Figure 5: RF pick-up penetration depth and resonance frequency (MHz).

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As mentioned earlier, RF pick-up should minimize effect on RF cavity systems. So, simulation was done for resonance frequency, and impedance matching according to RF pick-up penetration depth. Figure 5 shows Relation between Antenna penetration depth and resonance frequency (MHz)

There are some changes in frequency (±0.03 MHz). Resonance frequency of RFT-30 is 64.05 MHz, 0.03 MHz is just 0.05%, so this value is negligible.

Figure 6 shows impedance matching state. This means that it is often called coupling state. Through smith chart, it is possible to know RF coupling state. Smith chart is usually expressed circle. If the circle passing through exactly smith chart center (50Ω), this state is called critical-coupled state. When the circle is drawn larger than critical-coupled state, this state called over-coupled state. And the circle is drawn smaller than critical-coupled stated, this stated called under-coupled state. When RF cavity is critical-coupled state, RF cavity is accept all power from RF power coupler. In other words, there is no power reflection.

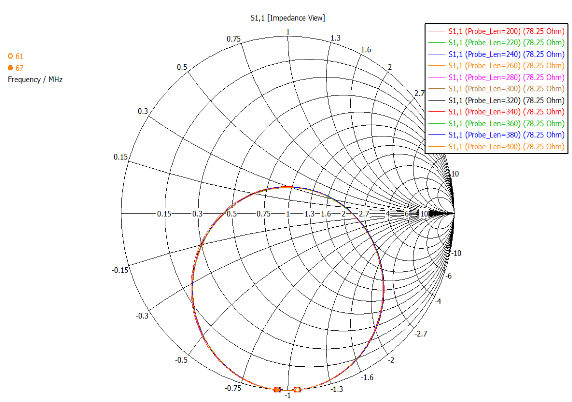

Figure 6: Smith chart according to RF pick-up penetration depth.

Also particle accelerators are designed critical-coupled state during operation. When particle beam enter into RF cavity, this beam act as impedance section (beam loading). In General, RF cavity for particle accelerators is designed over-coupled state, and when beam enter into RF cavity, over-coupled state moved critical-coupled state [4].

CONCLUSION AND DISCUSSION

Although the RF pick-up penetrate deeply, RF cavity has little effect as shown Fig. 6. However antenna length becomes longer, it can cause structurally unstable. Signals from RF pick-up is used measuring instrument and control systems. If high power enter into measuring instrument and control systems, it can cause equipment failure. So, we must know exactly pick-up power. When length of the antenna is 400 mm, S21 magnitude is -75 dB. It means that if inputting power is 50 kW, pick-up power is 1.58 mW. This power is proper to control systems and is not dangerous to the measuring instruments and control systems.

This RF pick-up is very useful to withdraw reliable beam at RFT-30 cyclotron. In addition, approaching method to the RF pick-up design and production will be useful in the design of all the cyclotrons RF pick-up.

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