Characterization on DECY-13 Cyclotron Components

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Abstract

The development of Decy-13 Cyclotron at the Center for Accelerator Science and Technology, National Nuclear Energy Agency of Indonesia is nearly to be finalized in construction. This cyclotron is very important to produce radioisotopes used in Positron Emission Tomography Imaging Technique which is growing in Indonesia. In the next few years the cyclotron will be commissioned in getting energy proton beam. However, the characterization of the cyclotron components has not been reviewed. The characterization has been done by investigation and testing of the cyclotron components. The investigation of the central region design was done by simulating the beam path, testing of the ion source was done by measuring ion beam current, testing on magnet was done by mapping magnetic field and testing of roof system was done by measuring power of the rf generator. The results of the beam simulation showed that the initial path of the beam on the right track. Testing result of the ion source showed that the ion beam was more of adequate value. The magnetic field of the magnet was in the near of synchronous pattern. The performance of the rf generator still has to be increased in resulting power. These results provide an information that the most of cyclotron components that have been constructed, except the rf generator, have right characteristics that are accordance with the requirements.

Keywords: Cyclotron, Component Construction, Testing, Characterization, Commissioning

Introduction

Commissioning stage of the cyclotron is commissioning on the ion beam test [1,2]. Other literature also mentions that the test phase in the cyclotron subsystem for example the test phase in the RF subsystem mentioned as commissioning on the subsystem [3,4]. The DECY-13 Cyclotron is planned to accelerate H^- ions and then the ions be converted to be protons to be bombarded to O-18 to produce F-18. F-18 will be synthesized with glucose to produce FDG that used in PET imaging. The cyclotron will be commissioned by the end of 2019, which accelerates proton until 13 MeV energy and a current of 50 μA. Prior to the commissioning, a characterization on cyclotron components or subsystems has been done. The characterization consist of investigation on the central region design, testing on the function of the magnet, testing the ion source in the central region and testing of function of the rf generator.

In the central region of the cyclotron there are an ion source head, a puller, a central part of dee, a dummy dee and a beam guide [5]. The central region will most decisive the characteristics of the produced ion beam in the cyclotron [6], so it is necessary to investigate design of the central region. This investigation is to look at the configuration and geometry functions of the components in the central region that can extract the ion beam from the ion source head and produce the first few rounds of the ion beam perfectly.

The main function of the magnetic field is to make the cyclic ion movement in the process of acceleration. The magnetic field in the central region is set in the value of 1.275 T. The problem encountered in the construction of a cyclotron magnet is sometimes magnetic field patterns that do not meet the criteria for isochronous and focusing requirements as already designed. The large difference between the real magnetic field and the isochronous magnetic field causes a phase difference between particles phase and rf phase of the acceleration. If the cumulative phase difference (or phase shift, or phase excursion) for all radius is so large it causes the accelerating energy becomes less efficient. The value of the feasible phase difference based on the reference for the 13 MeV cyclotron is 15^0 [7].

The magnetic field is also useful for forming strong ionizations in the Penning type ion source in this cyclotron. Ionization in this type of ion source is possible in the magnetic field of a few kilogauss [8,9].

Testing of the ion source in the cyclotron center region is performed after testing in a special test device outside the cyclotron is performed. Testing is done in two stages. The first stage is to test the optimum ability of ion source in generating ion beam. At this stage a magnetic function is required but does not require the operation of the rf-dee subsystem. The puller voltage is supplied with a multiple DC voltage of several kV and the ion beam is measured with a beam probe at a fixed position at the end of the puller canal. A similar testing that had been by Yang et al, and it was getting a beam current of in about 250 μA [8], and by Obrados et al that was getting 170 μA [10].

The second stage is to test the ability to generate ion beam currents after several turns of the ion beam. At this stage it is necessary to operate rf-dee component, however, the rf-dee has not been installed, so the second test has not carried out yet.

The stages of the ion beam test must be carried out with ion beam current as small as a possible value, to maintain the cyclotron condition and limit the radiation exposure [11].

The rf system consists of two main components i.e. a rf generator and a rf-dee component. The rf generator supplies rf power through a transmission line and then feed to the rf-dee component by using an inductive coupler. At the present, the rf generator has been constructed meanwhile the rf-dee be still under construction. So that, only the test of the rf generator will be characterized. The frequency must satisfy a relation of $f = N\frac{qB}{2\pi m}$, where f frequency of rf-dee, N harmonic number of rf-dee operating, q and m are charge and mass of H^- respectively. In the DECY-13 Cyclotron, the rf-dee will be operated with N=4.

The object of characterization is limited to the specific components of the cyclotron those are the cyclotron central region, the ion source subsystem, the magnetic subsystem and the rf subsystem. The data were obtained from some testing that have been done by the DECY-13 Cyclotron group at several times ago which is mentioned in the references list. The characterization aims to assess the readiness of the final commissioning of the cyclotron.

Materials and MethodsDECY-13 cyclotron systemhe cyclotron architecture of DECY-13 is shown in Fig. 1, here are shown only four main sub-subsystems, namely central region, ion source, magnet and rf-dee.

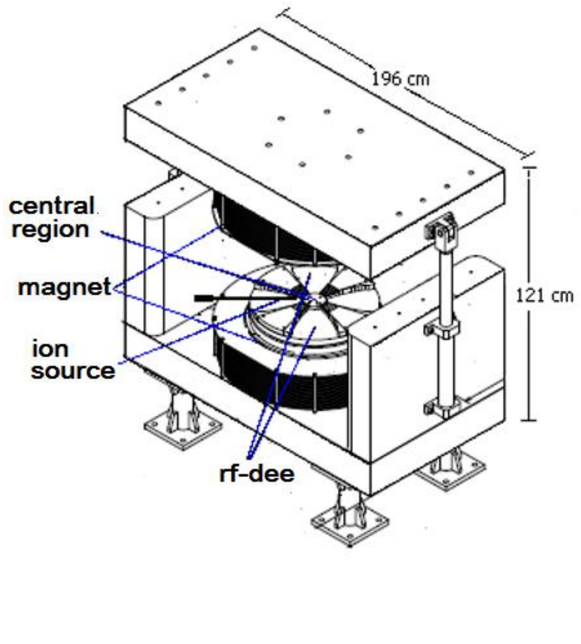

Fig. 1. The cyclotron architecture of DECY-13 Cyclotron

The design specification is a Penning type ion source capable of producing 100 μA beam currents in the central region, magnetic field strength of 1.275 T at central region, peak voltage dee of 40 kV with 78 MHz frequency, proton energy at a maximum radius of 13 MeV, and beam current protons in the outer radius directed to the target of 50 μA

Investigation of central region setting

This investigation is to look at the configuration and geometry functions of the components in the central region that can extract the ion beam from the ion source head and produce the first few rounds of the beam perfectly. This investigation is performed by simulating the dynamics or the initial path of the ion beam after exiting the ion source head. To do the simulation used a beam tracking program (beam tracking).

In the central region there are components of a puller attaching in a center part of dee, a magnet bump and ion source head. The geometry and position of components are fixed (unchangeable) except the position of the ion source head. It will be simulated the extraction and the path of the beam on the central region to find the best position of the ion source head relative to the puller. The simulations are performed using a beam tracking program written in Scilab 5.4.1 which has been developed by the simulation group in our institute. To run this simulation program, the magnetic field and electric field in the central region are numerically calculated using an Opera 3D software Tosca module.

Configuration and geometry of the components in the central region will be judged appropriately if the simulation result of the beam trajectory passes the extraction without hit the components and also there is no collision between turns of trajectory. The scheme of the central region is shown as Fig. 2 [12].

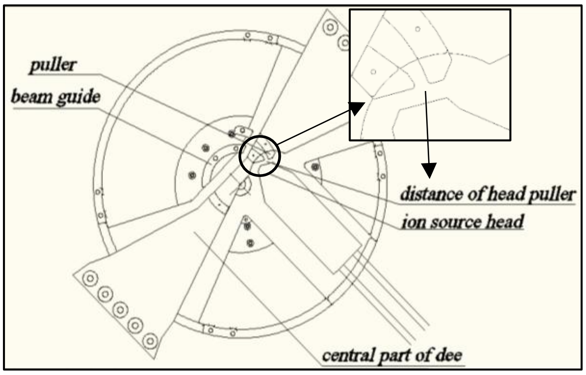

Fig. 2. The scheme of the central region of Dcy-13 cyclotron [12].

Testing on the magnet

The magnetic field pattern testing was done by mapping the magnetic field at points between magnetic poles uses a facility of magnetic field mapping device. By using a computer code of Genspeo, data from the mapping then was applied to calculate azimuthal average magnetic field as a function of radius (B_r), azimuthal average magnetic field, radial betatron frequency (υ_r) and vertical betatron frequency (υ_z) at along the radius acceleration of particle. The B_r was checked for compatibility with isochronous radial patterns. If it had not been compatible then the shimming process would be carried out by machining on the edge of the hill of the magnetic pole symmetrically and accurately. In the Fig. 3 is shown of the device for mapping the magnetic field in the cyclotron.

A graph of relation between υ_r and υ_z (for same radius) was made and the probability of resonance was checked. The criterion for determining the occurrence of resonance is if the graph does not cross the equation of lines [13]:

$4\nu_r = 4$, $3\nu_r = 4$, $2\nu_r = 4$, $\nu_r - 2\nu_z = 0$, $2\nu_r + 2\nu_z = 4$.

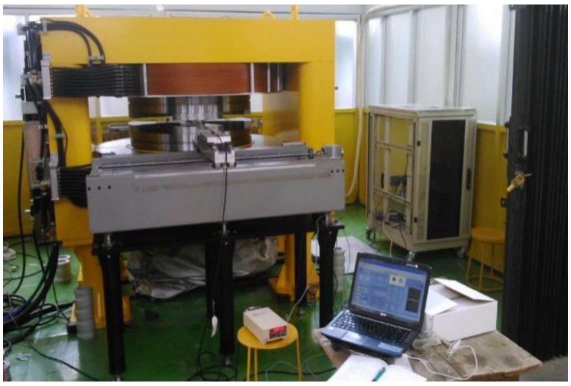

Fig. 3. The device for mapping magnetic field in the cyclotron

Testing of ion source in the central region

The ion source produces H^- ions to be accelerated in the cyclotron, which the ions come from the ionization process of hydrogen gas. This testing is the first stage of testing to test the ability of ion source to produce ion beams using DC voltage of puller. In this experiment operation parameters are kept on nominal parameters of the ion source operation, the parameters are the vacuum in the cyclotron chamber, the cathode voltage of the ion source, the magnet and the flow of hydrogen gas supply. The ion beam current output is measured using a beam probe and is observed as a function of time to see its stability.

To perform this test, the vacuum condition has to be about 1-2 × 10-6 Torr so that when the flow of hydrogen gas 5 sccm incoming to form H- ions this vacuum is about 7-8 × 10^{-6} Torr. The magnetic field be operated in the common value of between 0.4 and 0.88 T [7,14]. The voltage of puller was set in 2 kV and the ion source cathode was operated at the 1300 V, 50 mA. The photograph of the performed test of the ion source is shown in Fig. 4.

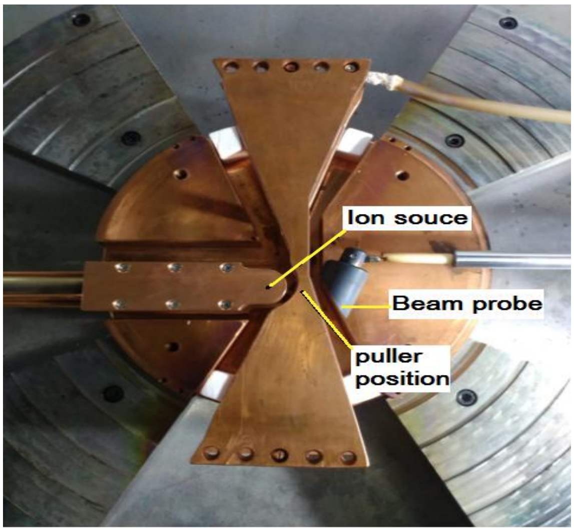

Fig. 4. Photograph of ion source testing in the central region of the cyclotron.

Testing on rf system

The mention of rf system here is the rf generator and without rf–dee which is has yet not been installed. There are three main components in the rf generator: low power rf frequency generator using DDS, driver amplifier

DA) and final amplifier (FA). The output of FA is connected through a coaxial transmission line to a 50 ohm resistor dummy load. Testing will see how much power can be produced by varying the input power in the final amplifier. The frequency output must be a relation of $f=N\ qB/2\pi m$ as mentioned in the introduction section above. Testing was carried out by measure the output of frequency and the rf power output in the FA. The measurement of power by connecting the FA to a 50 ohm dummy load resistor.

Results and Discussion

Investigation of central region setting

Fig. 5 shows an ion beam initial path after several rounds that is a best result of beam path without hitting central region components when extracted from ion source and for several rounds afterward. Through several simulations by varying the positions of ion source head, then the best position was achieved in 2 cm radius and 4 mm distance from the puller [12].

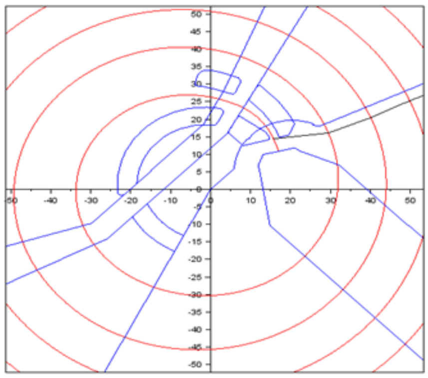

Fig. 5. The ion beam initial path (result of simulation)

The trajectory is not seen hitting the components and there is no collision between turns.

By those results it can be concluded that the central region geometry has been in the right setting.

Testing on the function of the magnet

The results of mapping indicate that the magnetic field strength in the central region (B_0) is 1.275 T [15], which is corresponding to a rf frequency of 77.667 MHZ. The B_r meets with the isochronous requirement in the next bigger radius, as it is showed in the Fig. 6. The cumulative phase difference of the particles relative to the rf phase is 15^0. This result is not unlike the phase difference in the 13 MeV cyclotron at Korea Cancer Center Hospital (KCCH) which is the main reference of the DECY-13 cyclotron design [7]. At the MH-18 cyclotron facility in NIRS Japan there is a phase difference about 18^0 before optimization and only a few degrees after optimization [16]. Thus, for the initial stage, the phase difference of 15^0 obtained in the DECY-13 magnet is temporarily considered adequate, although further optimization of the magnetic field becomes a consideration for obtaining the smallest possible phase difference.

The relation between calculated radial betatron frequency (υ_r) and vertical betatron frequency (υ_z) provided that its graph did not cross the line equation that can cause the dangerous resonances.

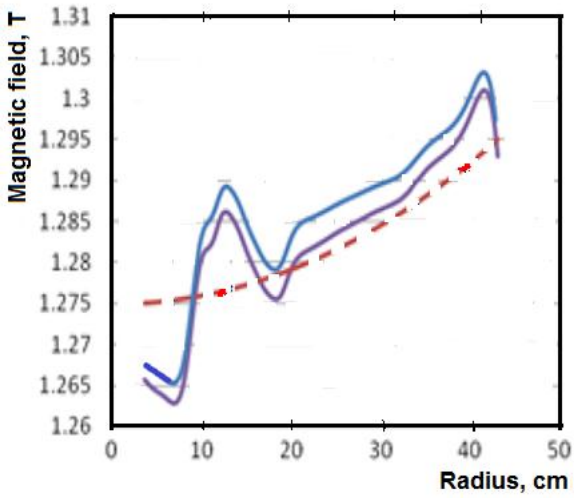

Fig. 6. The measured magnetic field (using two hall probes, solid lines) and isochronous magnetic field (dashed line).

Testing of Ion Source in the Central Region

The result of testing consists of the ion beam current as a function of time is shown in the Fig. 7. This experiment was carried out at the following parameters:

1. Pressure in cyclotron chamber 9×10^{-6}Torr,

2. Gas flow: 5 sccm

3. Magnetic field: 8.6 kG

4. Cathode voltage 1250 V

5. Cathode current: 50 mA

6. Puller voltage: 2 kV.

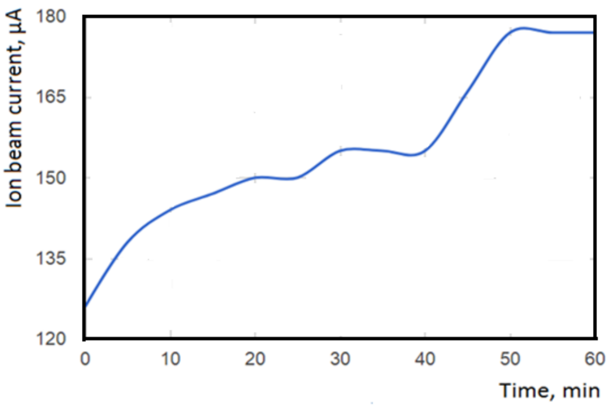

Fig. 7. The ion beam current versus time.

The achieved beam current maximum is in a round of 170 µA and be relatively stable after 50 minutes. This result is not significant differences with other experiments.

Testing on the rf system

Refer to the result of the magnet testing above, the correspond of the rf-frequency must be 77.667 MHz. The testing of frequency by setting a required frequency then observed the frequency using a GW Intelligent Counter GFC-8131. When the frequency value was set in 77.667 MHz, the showing on the counter was 77.667063 and it means just only differ 63 Hz compared to the setting value [17].

The Fig. 8 shows the output of rf power in the final amplifier (FA) as a function of supplied power from the driver amplifier (DA). The reflected power is very small compared to the forward power. It means that the parameters in the rf generator have been tuned correctly. But the maximum power is not more than 5 kW. Meanwhile, a calculation that has been done shows that the rf-dee component requires a power of 8 kW. The some examinations will be done, include checking the performance of the DDS, the driver amplifier and the final amplifier individually. The joints in the transmission line also will be checked.

The preliminary testing (cold test) on the experimental rf-dee component by using a network analyzer for getting a resonance has been done. Adjustment of coupler position, modification of rf-pickup dimension and setting of center part component of the dee have been done during the testing. The optimum of adjustment and setting resulted of a resonance frequency of 77.66 MHz which is accordance with the design. The functional test (hot test) in supplying rf power to the rf-dee will be done after the completion of the rf-dee component be installed in the cyclotron system

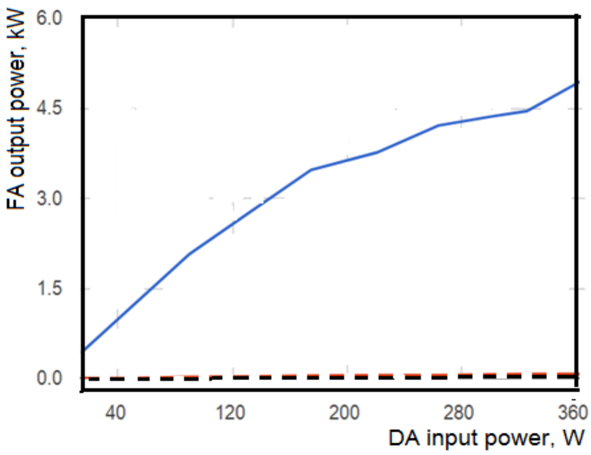

Fig. 8. The forward power (solid line) and reflected power (dashed line) of rf generator.

Conclussion

The review on the readiness of the Decy-13 cyclotron have been carried out by a study on the results of testing in the components. The components of the central region, ion source and the magnet have been in the right performance, meanwhile performance of the rf generator still must be improved by checking and improving the characteristic of the constituent components. For getting the whole rf system is still the completion of the rf-dee construction and installation.

Data Availability

Raw data were generated at the Center for Accelerator Science and Technology, National NuclearEnergy Agency in Indonesia. Derived data supporting the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors whose names are listed below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this manuscript.

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