RECENT STATUS OF THE NIRS CYCLOTRON FACILITY

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Abstract

Several modifications and improvements in the NIRS-930 cyclotron have been performed in past fiscal year later on 2005 to early of 2007. One of the most important in them was to replace the RF-system including Dee-electrodes, resonator, power-amplifier, and its control system. In the present the new RF-system can be provided the maximum frequency up to 21.4MHz, that covers an acceleration of proton energy of 90 MeV, and the system is successfully used. At the same time another beam extraction channel was installed in the cyclotron to extraction of a high beam current by mean of charge exchange. Almost 100% of extraction efficiency for 40MeV of H^+ beam had been obtained at an extraction channel. Meanwhile another new beam line has been constructed for the vertically irradiation to solid-targets.

INTRODUCTION

The cyclotron facility [1] of National Institute of Radiological Science (NIRS) constitutes of AVF930 cyclotron (NIRS-930) having K_m=110MeV and K_f=90MeV constructed by Thomson-CSF (now CGR-MeV) in 1974, and a small cyclotron (HM-18) by Sumitomo-Heavy-Industry, and nine experimental beam lines. Figure 1 shows the recent states of the cyclotron vault.

The NIRS-930 has been used for development of new short-lived radio-pharmaceuticals for PET in conjunction with a heavy ion therapy in HIMAC [2] (Heavy Ion Medical Accelerator in Chiba), research of biophysics, development of the equipments for space application and so on. In the cyclotron operation the beam has been provided by a compact ECR-IS (Kei-Source) [3] via an external injection system since Jun of 2006.

The small HM-18 has been operating routinely to product short-lived radio-pharmaceuticals for PET in conjunction with a heavy ion therapy in HIMAC. Operation of those two cyclotrons has been scheduled in the daytime from Monday afternoon to Friday except the regular maintenance time during two weeks of March and August annually.

Some kind of modifications and improvements in the NIRS-930 cyclotron had been performed in later on 2005 to early of 2007 as described under.

The first of them is to replace two sets of RF-system included Dee-electrodes, resonator, power-amplifier, and its control unit, due to their superannuated.

In the second a charge exchange device has been newly install in the cyclotron, and constructed a new extraction beam port to obtained higher beam current by mean of negative beam acceleration. And the third, a vertically irradiation system has been designed and installed in the existing beam line in order to develop newly radiopharmaceuticals for PET diagnostic in the research field of molecule imaging.

A brief review of the improvements together with typical applications of latest experiments at in the NIRS-930 is presented.

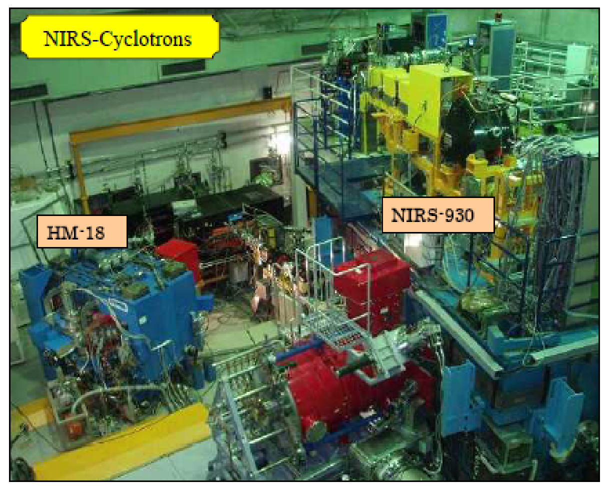

Figure 1: Photo of two cyclotrons(NIRS-930 and HM-18) in NIRS-cyclotron vault.

IMPROVEMENT & DEVELOPMENT

Update of RF-system

Two sets of the RF-system consisting Dee-electrodes, Resonators, Power-amplifiers, and their Control-unit had been renewed to a new one. One of the major differences between an old system and the new one was changed from the moving-panel to the moving-short for the type of resonator, which is consisting of cylindrical form as can be seen in Fig.1. The Dee-electrodes were also renewed, but they are maintained in the same shape as the old-one in order to adopting the existed dummy-Dee electrodes.

The resonant frequency of the RF-system has been covered with the range of 11.47 to 21.14MHz within the movable span of 1050mm for the moving-short. A fine-tuning of the resonant frequency is performed by capacitor type of compensator in the maximum range of 400kHz by self-adjusting equipment attached to one side of the each Dee-electrodes.

One of the major improvement point was realized that Q-value of the resonator having the range of around 4000 to 7000 at the frequency range between 21.2 to 11MHz, respectively. That means more than 1.6 times of highly Q-value was obtained at the maximum resonant frequency compare with the old (moving-panel) type resonator as shown in Figure 2.

Almost one and a half year operation of the cyclotron after changing the RF-system; the maximum proton energy of 90 MeV has been successfully extracted from the cyclotron at the maximum resonant frequency of 21.4MHz, that the energy is the focusing-limit for proton acceleration in the NIRS-930. Reason that the high Q value was obtained in the higher frequency region as can be seen in the Fig. 2 in contrast with the old one.

The new RF-system is not only providing more higher proton energy but also a simple tuning for the cyclotron operation in the daily operation.

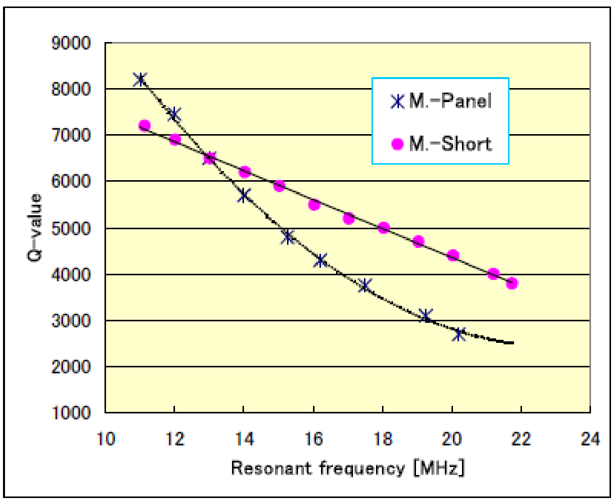

Figure 2: Comparison of the Q-values between the old RF-system(*; Moving-panel) and new one (•; Moving-short) with the function of the resonant frequencies.

Charge-Exchanging Extraction

Charge-exchanging equipment for negative-ion acceleration such as H^- and D^- had been newly installed in the NIRS-930 cyclotron in order to extract higher beam-current from the cyclotron.

In the designing study, some cases of orbit simulation for the charge-changed H^+-ions were performed numerically. Typical results of the calculation are shown in Figure 3 for the H^+ ions having its energy of around 40MeV with the various charge-exchanging radius together with the small span of azimuthally positions. As can be seen in the figure the charge-exchanging position has to be set at 78 ~ 88 cm in the cyclotron radius, and it can be shifted in the azimuthally angle within around 3 degrees. This region is covered with the extraction beam energy of between 35 ~ 45MeV and 55 ~ 72MeV for H^+, respect to the setting parameter of 50 and 80MeV at the extraction radius of 93cm at the case of normal proton beam accelerations, respectively.

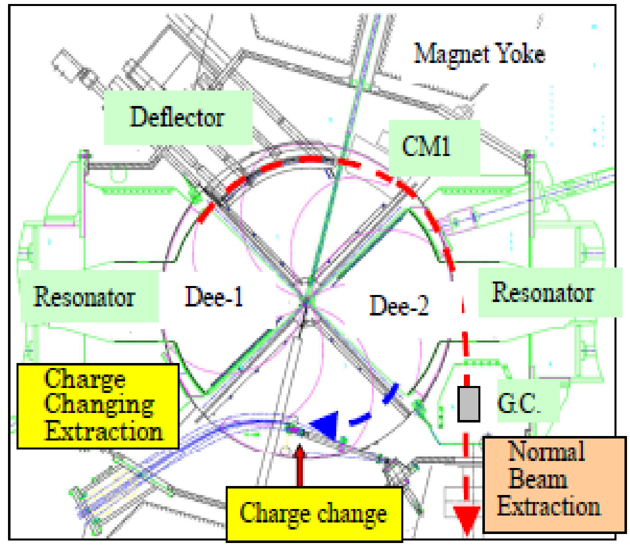

Figure 3: Schematic drawing of the charge changing extraction in contrast with the normal beam extraction.

In the preliminary test, measurement of transmission efficiencies for the H^- beam during the acceleration for each cases of 50MeV and 80MeV were performed for radius from 20 cm to 90 cm in the cyclotron. Resulting, non-beam loss and about 95% of the efficiencies were obtained for the both of the energies, respectively at the vacuum pressure of around 1×10^{-4}Pa in the cyclotron.

A charge changing equipment is consisting of four carbon foils that are two of 100 $\mu g/cm^2$ and others are 500 $\mu g/cm^2$ of thickness and they are able to changed by a rotating mechanism when one of it was broken. Here, a multiple scattering effect was calculated in the case of 500 $\mu g/cm^2$. That showed the average angle of around 0.3 mrad at $1/e$ for the 40MeV of H^+ beam.

In the present almost 100% of transmission efficiency for 40MeV of H^+ beam current have been obtained on a Faraday-cup, which was installed about 2.5m down stream from the charge exchanging position in a new extraction channel.

The new extraction beam channel has to be separated to the normally used beam extraction system, because it was not possible to share with the existing channel.

Vertical Irradiation System

A vertical beam line was newly designed and constructed for irradiation of solid-target such as ^{124}Se and ^{76}Te for production of short-lived R.I.s. The beam transport system was connected to one of the existing horizontal beam line in the NIRS-930, and bend down by 90 degrees vertically. The vertical beam line is composed of two quadrupole magnets, steering magnet, Faraday cup, and beam collimator having its aperture of 10mm. The target station is positioned at 3.3m downstream from the center of the horizontal beam line. Figure 4 show a part of the vertical beam line after installation.

In the designing study of the beam optics, the beam size at the target position was set as about Φ10mm, where two dispersion functions for both of transverse planes were fitted them into less than 0.5m by adjusting the setting parameter of the quadrupole magnets.

The new beam course will be used for the production of new radiation proves in a molecular imaging research which is a one of the future plans in NIRS.

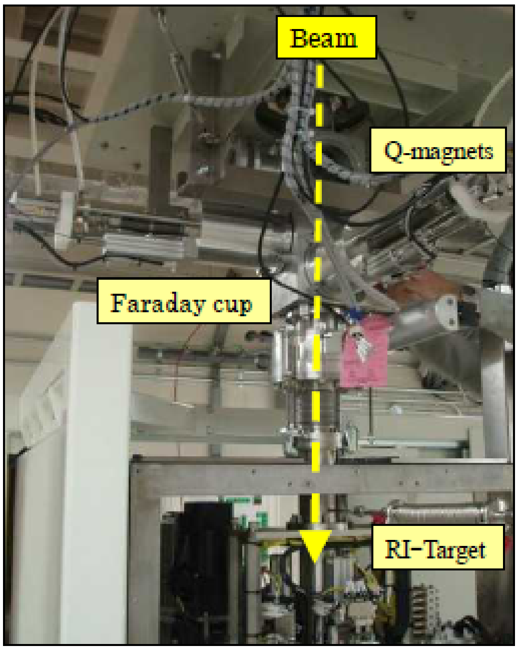

Figure 4: Photo of the vertical irradiation beam line, which was installed down stair in NIRS cyclotron facility.

APPLICATION

Short-lived R.I. production

Collaborative studies for the usefulness of $^{62}Zn/^{62}Cu$ generator produced [^{62}Cu]ATSM for tumor hypoxia imaging was stared among NIRS, National Institute of Cancer Research, Fukui University and Yokohama City University from last year. $^{62}Zn/^{62}Cu$ generator, a source of ^{62}Cu for [^{62}Cu]ATSM labelling, has been produced in NIRS using AVF cyclotron and delivered to other PET facilities. Production of ^{62}Zn has been achieved by the irradiation of 30 MeV proton beams on natural Cu target via the $^{nat}Cu(p,xn)^{62}Zn$. Irradiation was carried out at 20 μA beam current for 10 h (9:00-19:00) to obtain sufficient amount of ^{62}Zn for delivery. After irradiation production of $^{62}Zn/^{62}Cu$ generator, including purification of ^{62}Zn, filling in generator column and quality control, was started (19:00 - 24:00). Usually 4 generators were prepared (approx. 2.96 GBq/one generator) at EOS (24:00) and shipped to other facilities to reach next morning (8:30).

Bio-Physics study

In 2006, we started the measurements of the doubly differential cross sections (DDCSs) of electron emission from water vapor with 6.0 MeV/u C^{6+} ion impact. Using a cooling cover made from μ-metal, the DDCSs were successfully measured even for low-energy (1-10eV) electrons. For 1-5eV electrons, unexpectedly large DDCSs were observed at the forward and backward angles, which cannot be predicted form the soft collision theory. The singly differential cross section (SDCS) for 6.0MeV/u C^{6+}, which is obtained by integrating the DDCSs with respect to the ejected angles, showed about 9 times greater value than that for He^{2+} with the same impact energy.

In 2007, in order to analyze a fast heavy-ion track in liquid water, the previously measured DDCSs for He^{2+} ion impact on water vapor were incorporated in the KURBUC Monte-Carlo track structure code system. Radial dose distributions for 6.0MeV/u He^{2+} ion were also evaluated.

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