A NEW PROJECT OF CYCLOTRON BASE RADIOACTIVE ION BEAM FACILITY

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Abstract

For productions of intense proton and radioactive ion beam (RIB) used in fundamental and applied research, e.g., neutron physics, nuclear structure, material and life sciences and medical isotope production, a new project of cyclotron base radioactive ion beam facility is started in CIAE recently. It consists of a 100 MeV cyclotron, a two-stages isotope separator on line system, modification of the existing tandem, a super conducting Linac booster, various experimental terminals and an isotope production station. Recently, we are working on the detailed design of this upgrade project. In this report, a summary of the design aspects and various R&D will be given.

INTRODUCTION

"Upgrade Project of Beijing Tandem Laboratory" is a new project of cyclotron base radioactive ion beam facility which was proposed by the China Institute of Atomic Energy (CIAE) in 1999[1] and was approved by the Chinese government in July 2003.

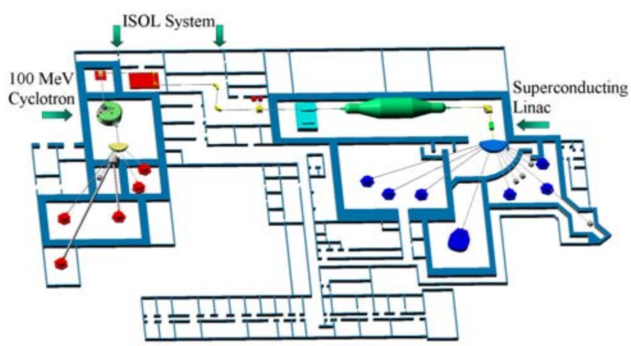

Figure1: The layout of Upgrade Project of Beijing Tandem Laboratory

The layout of upgrade project is shown in Fig. 1. A 100 MeV cyclotron and an isotope separator on line system will be installed in a new building west of the tandem. A super conducting Linac booster will be installed in the existing hall of the tandem. Two proton beams will be provided simultaneously by the cyclotron to south for applications of proton beam directly and to north for RIB generation. More than 40 proton-rich beams and 80 neutron-rich beams with beam intensity higher than 10^6 pps will be provided by this facility.

100 MEV H- CYCLOTRON

General Description

The driving accelerator, a 100 MeV H^- cyclotron, will provide a 75 MeV - 100 MeV, 200 μA - 500 μA proton beam. For a final energy of 100 MeV or below and beam intensity of less than 1 mA, a compact magnet and H^- acceleration with stripping extraction might lead to a smaller and cheaper machine. This driving accelerator is a fix field, four sectors cyclotron. The magnet is 2.6 m in high and 6.4 m in diameter. Tow cavities installed into the valleys of the magnet will accelerate beam 4 times per turn. The machine will own the following features:

- The compact magnet will provide high enough flutter and lower first harmonic though the harmonic coils will be absent.
- The H- acceleration permits us to extract the beam by stripping from the compact machine.
- The external source not only provides higher beam intensity, but also shows us a possibility to provide pulse proton beam by the cyclotron.
- The magnetic field of less than 1.4 T in the hill region will guarantee a low rate of dissociation of H- ions during the whole acceleration.
- Two triangle, half wave cavities are installed into the valleys of the magnet. The RF power from coaxial transmission line is coupled into the cavities capacitively.

Specification

The specification of principal parts are given as following:

- Ion source / Injection

Source		Injection	
Type	Multi-cusp	Energy	~ 30 kV
Current	> 5 mA	Inflector	Spiral

- Magnet

Number of Ssctors	4
Sector Angle	~50°
Field in Hill	1.4 T
Radius of the Pole	1900 mm
Inner Radius of the Yoke	2400 mm
Outer Radius of the Yoke	3100 mm
Gap between the valley	1600 mm
Gap between the Hills	~40 mm

- RF System

Number of Dees	2	Dee Voltage	60 kV
Dee Angle	38 °	Harmonic Mode	4
Frequency		49.5 MHz	

Design Aspects

Beam Dynamics and Magnet

Four simple sectors structure is selected for the main magnet. 52° of sectors with 3° of extended angle at the extraction region are used for 3D field computation firstly.

The isochronous field can be achieved by some adjustment of the shimming bar attached at both sides of the sectors. However, the simulation results show us that the ν_z going down quickly in the high energy region during the magnetic field isochronizing. The spiral sectors will provide a stronger axial focus, but it will bring more complication of the cavities fabrication. For such an AVF machine with not too high energy, we still prefer to use the simple sectors structure. So, a non-uniform hill gap, which is shown in figure 2, is used to improve the axial focusing.

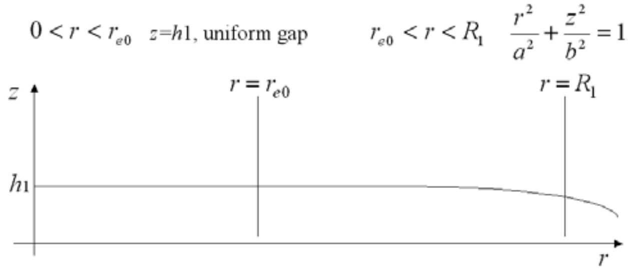

Figure 2: The non-uniform hill gap of simple sector magnet.

When the hill gap is changed from 5 cm at the central region to about 4 cm at the extraction region and extended angle of the sector magnet is removed, the field distribution by adjusting the shimming bar attached at both sides of the sectors reaches a good isochronism. The integral of phase shift is limited within ±30°. In this case, the tune diagram based on the field calculation is illustrated in figure 3. It can be found that the ν_z is high enough and the $\nu_r = 2\nu_z$ resonance should be avoided. The tracking of accelerated orbit shows that the vertical envelop at the extraction region can be kept small when the off centre is limited in 5 mm.

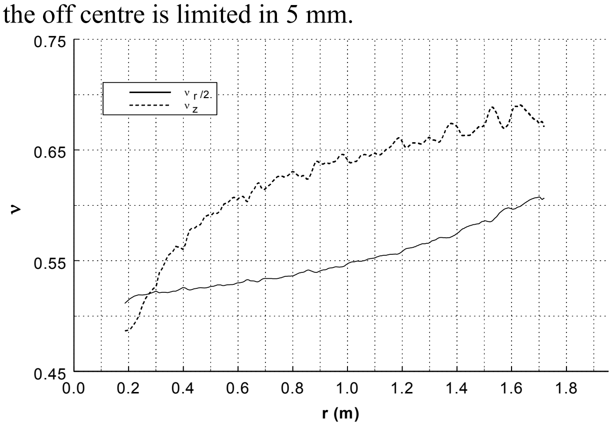

Figure 3: The tune diagram.

RF Cavity and Injection Line

The design of RF Cavity and injection line are described in more detail elsewhere [1,2].

R&D for 100 MeV H- Cyclotron

Test Stand for Ion Source and Injection Line

In the compact, H- machine, the bright external source and high efficiency injection system become one of the bottleneck problems for intense beam generation. The arrangement of injection line is modified to match the optics better for very low energy, high intensity beam injection[2]. Due to the limit of acceptance by the cyclotron central region, a new H^- cusp source was developed at CIAE. The design of this new source is based on TRIUMF's experience[3]. More than 10 mA of H^- beam with a measured emittance of 0.65 π mm mrad are got at a voltage of 28 kV from an extraction hole of 11mm in diameter.

Central Region Model

A central region model of 100 MeV H- cyclotron was designed and is under fabrication recently. It will use the beam injected from the test stand of ion source and injection line and accelerate beam up to about 10 MeV. A simulation of installation done on PC is given in figure 4.

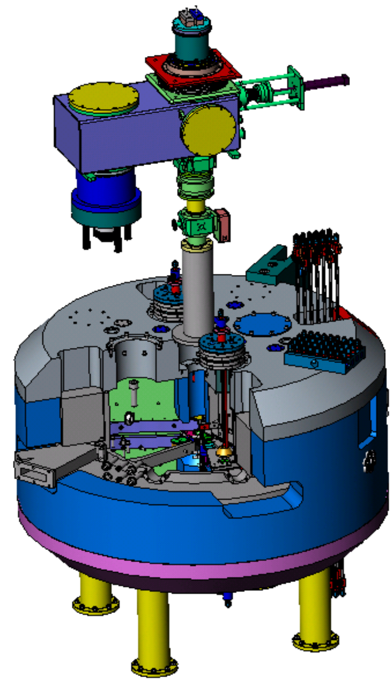

Figure 4: The central region model.

ISOTOPES SEPARATOR ON LINE

Design Aspects

The ISOL system is composed of the target/ion source system, match lenses, 90° magnetic analyzers, charge exchange canal and isobar separator. All of the components, except the isobar separator, are located on a high-voltage platform with potential up to 300 kV. The platform connects the primary proton beam line and the isobar separator system beam line by two accelerator tubes. The technical specifications of the first stage magnetic analyzers are as follows: mass resolution 1000; radius of ion central obit 0.6 m; deflection angle 90°. In order to achieve a high performance isobar separation, two 100°, ρ=2.5m opposite bending magnets at ground potential have been designed. The mass resolution is about 20000. The configuration of ISOL system is given in Fig 5.

R&D for the ISOL System

A modified version of the ISOLDE type electron beam plasma ion source will be chosen as the main source for our ISOL system, which has been redesigned and used for HRIBF facility at Oak Ridge National Laboratory[4]. A prototype radioactive target/ion source has been developed at CIAE. It was installed at the downstream of the Tandem to generate the keV RIB, such as the ^{62}Zn. The off-line efficiency of the target/ion source for Ar is better than 10%. The on-line test has been carried out recently. To generate required ^{62}Zn, 10 pieces of 0.05mm copper foils are used as target [$^{63}Cu(p,2n)^{62}Zn$]. With 1 uA proton beam at 25 MeV energy from HI-13 tandem as primary beam, a ^{62}Zn radioactive ion beam of great than 10^6 pps at 25 keV has been obtained on line.

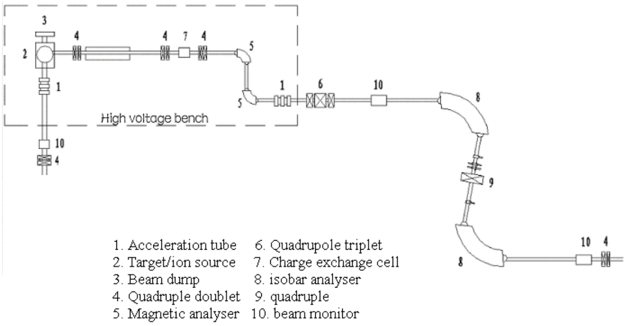

Figure 5: The Layout of Isotopes Separator on Line.

SUPPER CONDUCTING LINAC BOOSTER AND EXISTING TANDEM

Design Aspects

The sketch of the booster linac is shown in Fig 6. A new post stripper accepts the high energy beam coming from the tandem, in order to increase the ions charge state. The 90° bending magnet can select desired charge state into the linac. The design goal of our linac booster is to have an energy gain of 2 MeV/q, table 1 shows the main parameters for some particles accelerated by the superconducting linac. In table 1, the ion species from Al to Cs with different probability charge state q at post-accelerator, it has listed their energy gains and the energy gains per charge for various particles. The mode of the resonator for linac sections is the cylindrical coaxial quarter wave resonator (QWR). The super-conducting booster is composed of four QWR cavities, which are located into one cryostat, which has a diameter of 1.1meter. We choose the cavities of the optimum β=0.07 for frequency of 108 MHz.

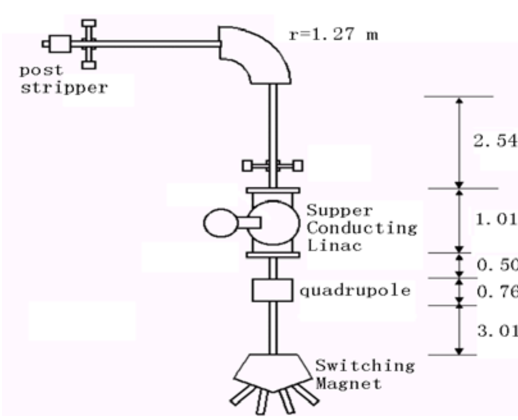

Figure 6: The sketch of the booster linac

Table 1: The energy gains for various particles

P	Z	A AMU	q	W_{in} MeV	β	W_{out} MeV	ΔW MeV	$\Delta W/q$ MeV/q
Al	17	35	16	108	0.081	147.78	39.78	2.48
Ni	28	58	22	120	0.066	177.35	57.35	2.61
Ag	47	108	29	144	0.053	216.72	72.72	2.51
Sn	50	118	29	156	0.050	230.91	74.91	2.50
I	53	127	30	156	0.051	229.07	73.07	2.44
Cs	55	133	31	156.	0.050	230.20	74.20	2.39

R&D for the Supper Conducting LINAC

The Existing Tandem Accelerator

The modification of the 2×13 Tandem accelerator consists of:

Its accelerating tubes used on the machine for fifteen years was replaced by the extended tubes and the terminal voltage was increased to 15MV.

The two gap single drift bunching system at the working frequency of 4MHz on the low energy extension of the HI-13 tandem accelerator is going to be replaced with double drift bunchers to increase the bunching efficiency to about 60% and to match the super-conducting booster at the working frequency of 108MHz.

And the electrostatic potential at the injector platform is going to be increased from 150 kV to 300 kV.

The QWR Cavity

The R & D of the mechanical and electrochemical preparation of the substrate of the cavity, the technology of the Niobium-sputtered copper Quarter wave resonators have been testing in Peking University. The figure 7 is a picture of the test stand for on line test of a single QWR cavity.

Figure 7: The single cavity test on line

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[4] G.D.Alton et al., Nucl. Instr and Meth A328(1993)325