CHINESE STATUS OF HPPA DEVELOPMENT

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Abstract

A 3.5-MeV RFQ accelerator for a Chinese accelerator-driven subcritical reactor system (ADS) has been under construction in China over the past two years. It is is a 75-keV/3.5-MeV, 352.2-Hz, 50-mA four-vane type RFQ. In this paper the characteristics of the machine are described, including its physical parameters, RF characteristics, thermal and structural analyses, cold model measurements, RF power system and its fabrication test of technology model. The microwave ion source and the LEBT also are described.

Introduction

The R&D activities of HPPA technology are of key importance for the development of the accelerator-driven subcritical system (ADS), which is an entirely new approach toward the exploitation of next-generation nuclear energy [1].

According to present technical and budget status in China, a multi-purpose verification system is under consideration [2,3], which consists of a low-energy accelerator (150-MeV/3-mA proton linac) and a swimming pool light water subcritical reactor.

The China Institute of Atomic Energy (CIAE), the Institute of High Energy Physics (IHEP) and the Institute of Heavy Ion Physics at Peking University (PKU-IHIP) have been collaborating on the R&D necessary for the proposed accelerator since 2000.

Since then, various aspects of their R&D work, such as ECR high-current ion source, RFQ design and technology study, superconducting cavity study, the conceptual design of a 150-MeV/3-mA proton linac, and the preliminary design of a 1-GeV, 20-mA linac and intense-beam physics, have been proceeded with.

Two ECR proton sources have been built. As a first step toward a CW beam, a high duty factor RFQ is now being built at IHEP. Some R&D activities have been performed to pave the way for the final fabrication of the RFQ accelerator. The formal RFQ cavity is now under construction. Over the past few years, close co-operation with LNL, INFN, KAERI, KEK and CERN have been of extremely helpful regarding our HPPA work.

ECR ion source

An electron cyclotron resonance (ECR) ion source [4] is selected for the source of our verification facility system. A microwave power of 2.45 GHz is adopted. The 1-kW microwave power is coupled to the plasma chamber by a rectangular-to-ridged wave guide through a microwave window. The plasma chamber is a 100-mm long cylinder with a diameter of 100 mm. An accelerating and decelerating three-electrode extraction structure is adopted. The beam is anticipated to have a normalised rms emittance of 0.129 pmm mrad. The discharging chamber is designed to withstand a potential voltage of up to 75 kV.

A multi-slit and single-thread emittance measuring unit has been installed and measurements have been carried out.

The measurement result of beam emittance for this ion source with 60 mA and 60 keV is shown in Figure 1, as is the configuration of the ECR ion source.

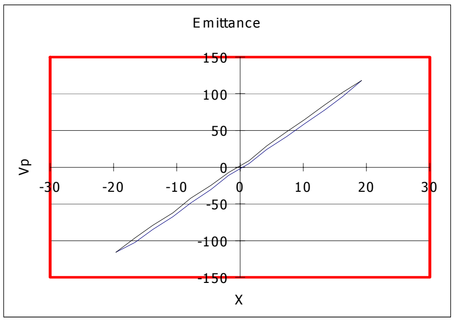
Various efforts have been made to optimise the reliability [5]. A reliability test operating for more than 120 hours at 65 mA/75 keV is shown in Figure 2. Over the entire operation period, there are only three trips, and the mean time of recovery is 3 minutes; the longest uninterrupted period reached is up to 110 hours. The reliability of this kind of source can attain 99.9%.

High-current RFQ

A first step toward a CW beam, a high duty-factor RFQ, is now being built at IHEP, financially supported by a national programme of the MOST. Some R&D activities have been performed to pave the way for the final fabrication of the RFQ accelerator. The formal RFQ cavity is now being constructed.

Figure 1

The measurement result of beam emittance
(W = 60 keV, I = 60 mA, $\varepsilon_{(norm.\ rms)}$ = 0.129 πmm-mrad)



The configuration of the ECR ion source

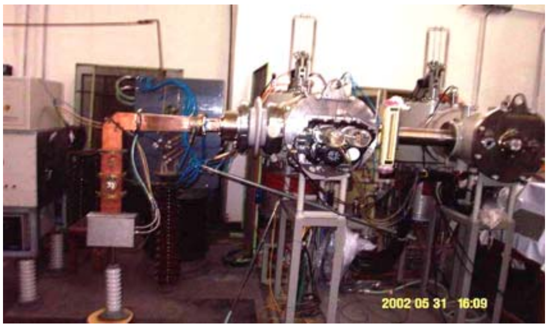
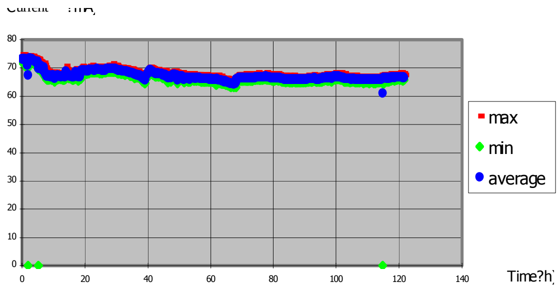


Figure 2. Reliability test – operation for more than 120 hours at 65 mA/75 keV



120 hours reliability test run

The RFQ structure is a four-vane type designed to accelerate a 50-mA peak current proton beam with an input energy of 75 kV. The structure was divided into four sections: the radial matching section (RMS), the shaper (SH), the gentle bunch (GB) and the accelerating section. The RFQ is 5.5 times longer than the RF wavelength. The longer the RFQ, the less stable it is against perturbations. In order to overcome this problem, the resonant coupling concept is applied, as is the case at LANL. The RFQ is longitudinally divided into two pieces separated by a coupling cell where electrodes belonging to two different RFQ pieces are facing one other. The parameters of the RFQ beam dynamics are determined. The cell design and beam dynamics simulation are provided by PARI and PARMTEQM, which decide the cell parameters used for machining the vane modulation as shown in Figure 3 [6]. The exact location of the segment gap is determined by LIDOS.RFQ [7] for zero-field crossing the gap ($\cos(k\delta z + \varphi_s) = 0$), as shown in Figure 4.

The RF cavity is designed with the 3-D EM code for under-cut, coupling cell and vacuum port. Thermal deformation of the cavity is simulated with the ANSYS code and the water cooling channels have been designed as shown in Figure 5 [8].

R&D of the technological model

The fabrication of the RFQ copper model will be performed by a company situated in Shanghai, China. Some tests for development the mechanical technology must be undertaken [9]. The purpose of the mechanical technology mode is to test the brazing technology for assembling the four vanes together with required mechanical tolerance, for the characteristics of melting filler, for the structure surface and

Figure 3. The results of PARMTEQM to give the main parameters and envelopment

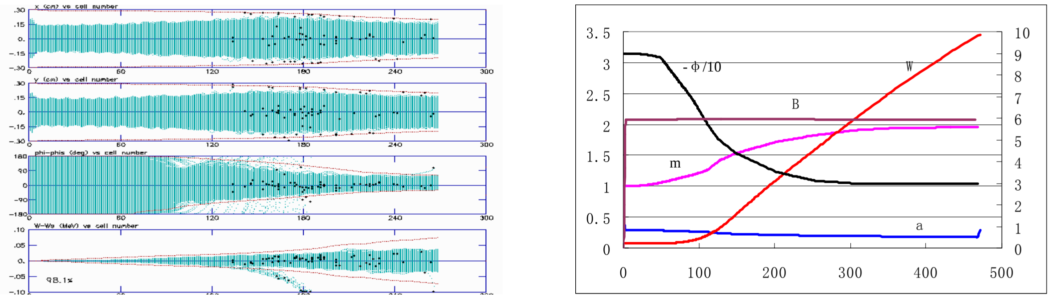


Figure 4. The results of LIDOS.RFQ to determine the exact location of segment gap

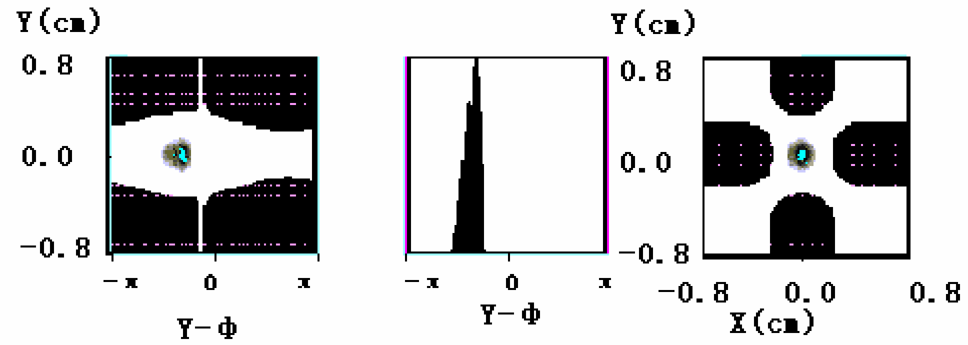
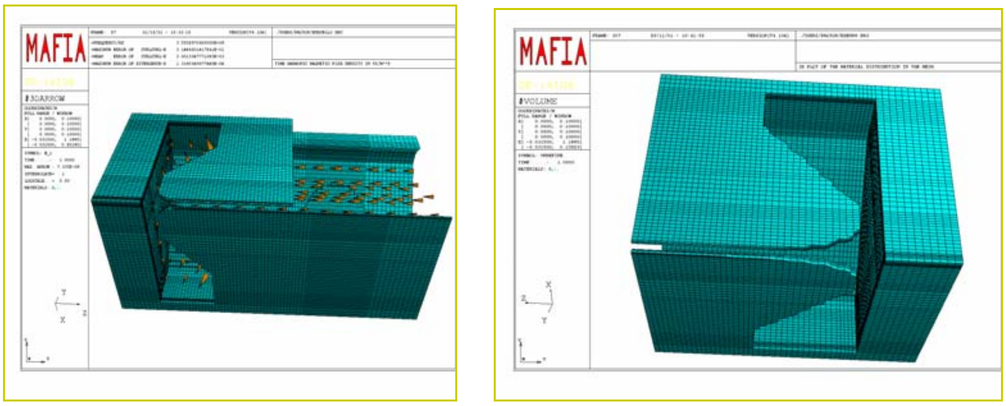


Figure 5. The results of MAFIA to design the RF characteristics of the RFQ



the vacuum leak, to test drill the coolant hole through the 1.2-meter RFQ cavity (12 mm in diameter), and to test the precision machining for the vane electrodes on the numerical controlled mill. At first, a short OFEC copper RFQ section 0.42 m in length was fabricated with fine machining, as shown in Figure 6. The machining tolerance reaches –20 ㎜ on the vane tip and cavity wall measured on a CMM.

Three-step braze: 1) The water cooling channel was covered by brazing plugs before the semi-fine machining. 2) The four vane wall pieces were brazed to form the cavity, and then the end-flange step was machined. 3) All the flanges, i.e. end flanges, vacuum port flanges and tuner flanges, as well as all cooling-water pipes were brazed. A bead-pull measurement was performed for the field distribution analysis of the short model with aluminium undercut ends.

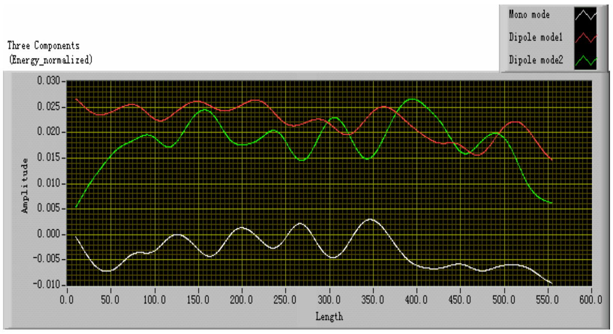
Figure 6. A 0.42-m short OFEC copper section test mode

Two Lab-VIEW codes were applied during the measurements. One was used to control the measurement process and data acquisition via a GPIB-ENET/100 box. The measurement results indicate that there is a little frequency downshift after the second brazing, but a little up-shift after the third brazing. Dipole field distribution along the cavity after final brazing shows about 3% component as shown in Figure 7.

Table 1. The frequency shift after brazing

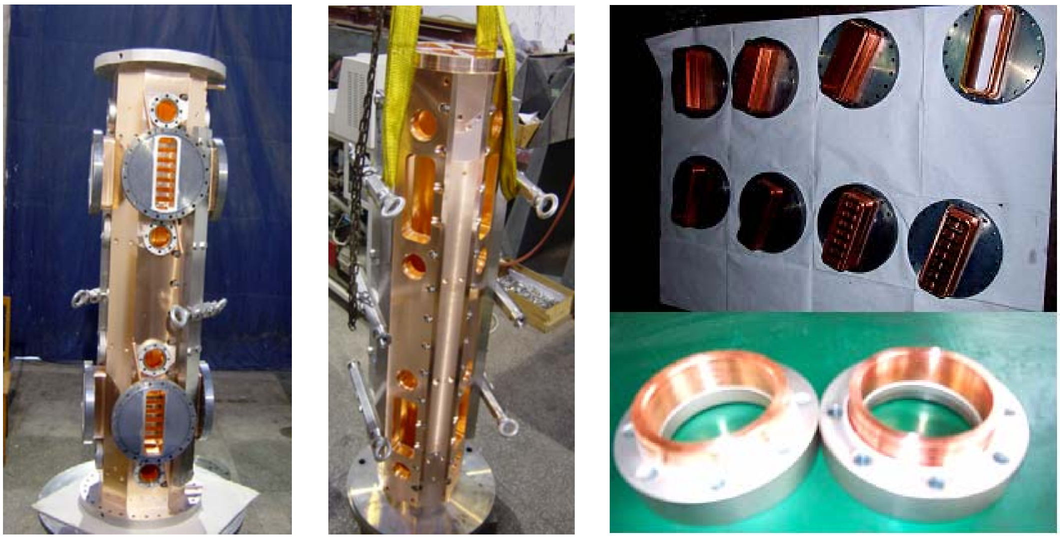
Brazing step	f_Q(MHz)	df_Q
Before 2nd brazing	351.232	
After 2nd brazing	350.955	-0.277
After 3rd brazing	351.119	+0.171
3-D simulation	351.345	-0.226

Figure 7. Dipole mode



In order to grasp the machining and welding technology, and to examine the creditability of the simulation code, one full-size (1.2-m) section of RFQ cold model was fabricated. There are 16 tuners and four vacuum ports on the cavity, the same number as the real RFQ. However, the electrode is not modulated. A full-length brazing cavity was made for drilling long and small holes for cooling water and brazing a full-volume cavity with all flanges. The vane wall shape was machined after drilling the cooling water channels, and then the holes for vacuum and tuner ports were made. The channels were covered with plugs by brazing. The four pieces were brazed to form the cavity, and the vacuum leakage rate was $1.5 \cdot 10^{-9}$ torr l/s. All ports and the end flanges were then brazed, and leakage was found. After repairing the braze, the leakage rate reached $1.9 \cdot 10^{-9}$ torr l/s. Following the R&D experiences in these technological models, fabrication of the formal cavities has started. The semi-fine machining has been finished. Figure 8 shows a photo of a 1.2-meter full-size section.

Figure 8. Full-size (1.2-m) section of RFQ cold model, fabricated and brazed



With the tuners, tuning and measuring of RFQ are carried out. With all tuners flush with the inside surface of the cavity, frequencies of the operating mode and the dipole modes are measured [10]. Figure 9 shows a photo of the dipole rods and the measurement result.

Figure 9. The measured dipole-rod effect on quadrupole and dipole modes

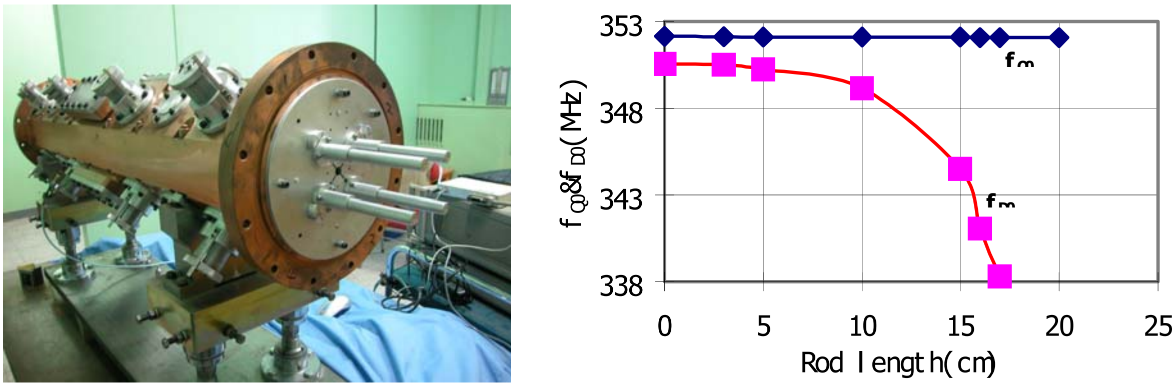


Table 2. The measured and simulated frequency for the quadruple and dipole modes in the case without/with rods

	Rod length	
	0 (cm)	**15 (cm)**
Meas. freq. of TE_{210} (MHz)	350.85	351.15
Simul. freq. of TE_{210} (MHz)	351.15	351.15
Meas. freq. of D_{13} (MHz)	344.82	338.68
Simul. freq. of D_{13} (MHz)	347.81	341.93
Meas. freq. of D_{24} (MHz)	348.50	342.49
Simul. freq. of D_{24} (MHz)	347.81	341.93

The RF power source

CERN kindly provided IHEP with some RF power source equipment for our RFQ .The equipment has been installed at IHEP as shown in Figure 10. It is a CW RF power source of 352.2 MHz/1.2 MW, decommissioned from LEPII. We reconnected the cables of the control rack, which were cut during transportation from CERN.

Figure 10. The RF power source for the RFQ been installed at IHEP

During the preliminary research phase, the 352.2-MHz RF system will be operated in pulse mode. Because the given RF system was previously used for CW operation at CERN, some modifications and improvements are necessary in order to apply them to our pulse mode operation. We have made some indispensable assemblies, and also did some tests and commissioning of every subsystem. At present, we have completed the 100-kV power supply test and long pulse floating desk hard tube modulator test. Furthermore, the initial high-power conditioning of the klystron is being carried out, and output power can reach up to 334 kW in CW mode and 402 kW in pulse mode [11].

Acknowledgements

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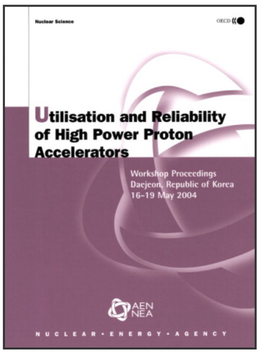

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