# DEVELOPMENT OF INTENSE BEAM PROTON LINAC IN CHINA

S.N.Fu[1], X.L.Guan[2], H.F.Ouyang[1], S.C.Zhao[1], B.Q.Cui[2], Z.Y.Guo[3], J.X.Fang[3], S.X.Fang[1]

[1]IHEP, Institute of High Energy Physics, P.O.Box 918, Beijing 100039, China

[2]CIAE, China Institute of Atomic Energy, Beijing 102413, China

[3]IHIP, Institute of Heavy Ion Physics, Peking University, Beijing 100871, China

*Abstract*

Study on intense beam proton linac was started about four years ago in a national program for the basic research on ADS in China. This ADS program is meant for the future development of the clean nuclear power generation. Another important application of HPPA for Chinese Spallation Neutron Source was also proposed recently in China, and it is now financially supported by Chinese Academy of Sciences. In this paper, the research progress on intense beam proton linac in these two application fields will be outlined including the test result of a high-current ECR proton source, construction status of a 3.5MeV RFQ accelerator, medium- $\beta$ superconducting cavity test and the design of a DTL linac.

## INTRODUCTION

Shortage of electricity supply is becoming a bottleneck for the rapid economy growth in China. However, fossil energy resources in the newly-increased power supply must be reduced for the environment protection (at present, coal contributes about 70% electricity). Nuclear power must play a more important role, especially, in the eastern part of China. So, there is a rapid development of nuclear power plant in China: 25 new nuclear power stations are going to be built within next 15 years. It means the electricity from nuclear power will increase from 3.8% to 9% of the total electricity supply in China.

Accelerator Driven Subcritical system (ADS) is recognized as one of the best options of fission nuclear power source. A basic research program of ADS[1] was lunched in 2000 under the support of the Ministry of Science and Technology, China. In this program, we have studied some key technologies of an intense beam proton linac, including construction of an ECR proton source and a pulsed beam RFQ accelerator. Chinese Academy of Sciences also gave a support to the linac research in the field of medium- $\beta$ superconducting cavity. Institute of High Energy Physics, China Institute of Atomic Energy and Institute of Heavy Ion Physics of Peking University jointly conduct the researches.Chinese Spallation Neutron Source (CSNS) is a multidiscipline platform, as a complementary to synchrotron radiation (SR) facility. China will soon have 3 SR facilities in the mainland, but no spallation neutron source at all. There is a common sense among Chinese scientists that China should build a spallation neutron source as soon as possible, and it

should rank in the world-class but within the limitation of financial capability of China, as a developing country. A preliminary research program for CSNS with a small budget was lunched in 2002 under the support of CAS. Institute of Physics and Institute of High Energy Physics undertook this task. A physics design and R&D prototyping program has been proposed and is now waiting for the ratification of our government. In comparison with ADS, CSNS is a near-term program with relatively mature technology.

In this paper, we will present our research progress in intense beam proton linac, including the test result of a high-current ECR proton source, construction status of a 3.5MeV RFQ accelerator, medium- $\beta$ superconducting cavity test and the design of a DTL linac.

## THE ECR PROTON SOURCE[2]

An ECR proton source and LEBT have been built at CIAE as the injector of the RFQ. Fig.1 shows the source and its major performance parameters. Our great efforts were made on the reliability and stability of the source operation. We have overcome the problems associated with the breakdown of the RF input ceramic window resulted from the electron back strike. The electrodes have been optimized for minimum spark rate. At present a high reliability of 99.9% is achieved during an 120 hours continuous operation.
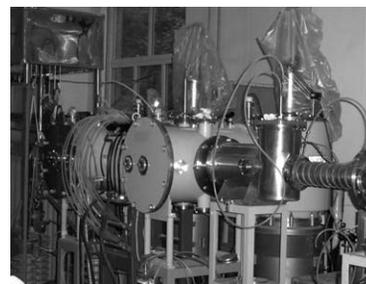


| E(KeV) | 75 |
| --- | --- |
| I(mA) | 70 |
| $f_{RF}$(GHz) | 2.45 |
| $P_{RF}$(kw) | 1 |
| $E_{n,rms}$ ($\pi$ mm-mrad) | 0.13 |
| H$^+$ Ratio | 80% |
| Raliability | 99% |

Figure 1: The ECR source and its major parameters.

## DEVELOPMENT OF THE RFQ[3-4]

The major parameters of the RFQ are listed in Table 1. It is separated into two segments and each segment consists of two technological modules. On each module there are 16 tuners distributed on the 4 quadrants for frequency and field tuning. Dipole stabilizer rods on both

the end plates and the coupling plate are applied. There are 20 cooling channels on the cavity body in each module. Four vane-wall pieces are brazed to form a cavity for both RF and vacuum seals.

Table 1: RFQ major parameters

| Input Energy | 75keV |
|---|---|
| Output Energy | 3.5MeV |
| Peak Current | 50mA |
| Structure Type | 4 vane |
| Duty Factor | 6% |
| RF Frequency | 352.2MHz |
| Maximum $E_s$ | 33MV/m |
| Total Power | 630kW |
| Total Length | 4.75 m |

### Short RFQ Model

As the high accuracy fabrication of the RFQ cavity is a rather tough issue for us, we started with some technological models before the manufacture of the formal cavity. A short OFEC copper RFQ section of 0.42m long was fabricated with fine machining, as shown in Fig.2. There are two major purposes to make this model: one is to test the high-accuracy machining and another is to verify the brazing deformation. The machining tolerance reaches $\pm 20 \mu$ m on the vane tip and cavity wall measured with a CMM.



Figure 2: A Short RFQ technological model after final braze.

We measured the resonant modes and field distribution without any tuning in each brazing step. The measurement results indicate that there is a little frequency down-shift after the first brazing, which forms the cavity, but a little up-shift after the second brazing, which brazes all flanges and pipes, as listed in Tab.2. Field analysis indicates a dipole components of 3% exist in 1-3 quadrant after the final brazing.

Table 2: Operating frequency shift between brazing steps and comparison with the simulation.

| Brazing Step | $f_Q$(MHz) | $\delta f_Q$(MHz) |
|---|---|---|
| Before 1st brazing | 351.232 | |
| After 1st brazing | 350.955 | -0.277 |
| After 2nd brazing | 351.119 | +0.164 |
| Simulation by code | 351.345 | -0.226 |

### Full-Size RFQ Model

Another technological model is a full-length brazing test cavity. This cavity contains all of the flange ports in order to verify the furnace temperature's evenness in both radial and vertical directions. The stainless steel flange was first brazed with copper neck for the tuner port, or with the vacuum grid copper body. All of these flanges were then brazed onto the cavity after the four vane pieces had been brazed together. In Fig. 3 the up-left are the flanges of tuner port, the down-left is the vacuum grid body with the cooling-water channel covers, and the right is the 1.2 meter long brazing test model after the final brazing. Vacuum leak check demonstrates all of the brazing is vacuum tight. The leakage rate is $1.9 \times 10^{-9}$ Torr l/s. The success of this model validates the design of the filler slot distribution, the machining accuracy of the brazing surface, the proper and balanced press force in the assembly of the four vanes, as well as the adequate control of the brazing temperature.
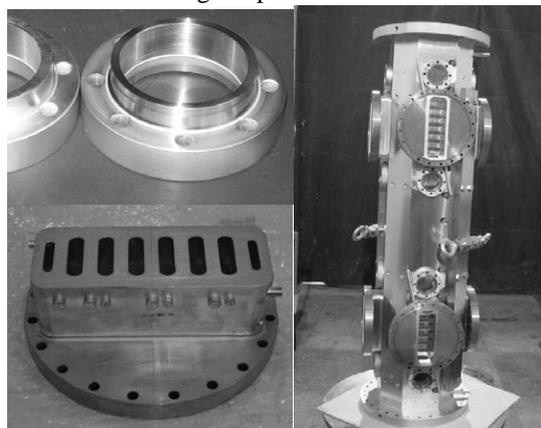


Figure 3: The 1.2m long full size model for brazing test with tuner and vacuum flanges.

After the success of the model cavities, the formal RFQ cavity is now under final-fine machining. It is expected all the modules will be manufactured in early next year.

### RF Power Source

The RF power source for the RFQ, which was transferred from CERN, has been installed at IHEP. It was a CW RF power source of 352.2MHz/1.2MW, decommissioned from LEPII. The TH2098 klystron, modulator, HV power supply, Y-junction circulator, RF control system, dummy loads and water-cooling system have been connected. The modulator from CERN worked in ramping mode for LEPII. To adapt to our RFQ's square pulse mode at various duty factors, some necessary modifications of the modulator have been made.

The klystron is now in the process of high power conditioning. The 403kW output power in pulse mode has been delivered to the dummy loads. More details about the work on the source is presented in this conference[4].

*Study on the Dipole Stabilizer Rods*

IHIP has built a full-size module jointly with IHEP before the manufacture of the accelerator cavity[6]. There are vane undercuts of about 46mm long at each end of the module. Four dipole stabilization rods with variable insertion length are mounted on one end plate of the cavity. When we inserted rods into 1 and 3 quadrants only, the 1-3 dipole mode has no response to the rods. Instead, 2-4 dipole mode shifts, as shown in Fig. 4. This result agrees with 3D simulation, which reveals that the additional capacitance existing between the rods and the vanes decreases the frequency of the 2-4 dipole mode. The 1-3 rods insertion with a proper length can also reduce the 2-4 dipole field component in an asymmetrical cavity, but it can not decrease the tilt of the dipole field. And it does not correspond to the smallest dipole component if the two dipole-mode frequencies become the closest due to the rods insertion.
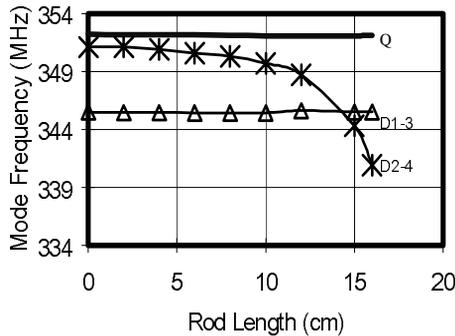


Figure 4: Two rods are inserted into 1 and 3 quadrants, resulting in the frequency shift of 2-4 dipole mode, but no effect on 1-3 dipole and quadrupole mode.

## SUPERCONDUCTING CAVITY

The technology of medium-$\beta$ superconducting RF cavity has been studied for the medium energy section of 1GeV proton linac for ADS. A superconducting single ellipsoid cell of 1.3GHz at $\beta$ =0.45 was manufactured jointly with KEK. The measured $Q_0$ versus $E_{sp}$ is plotted in Fig. 5.
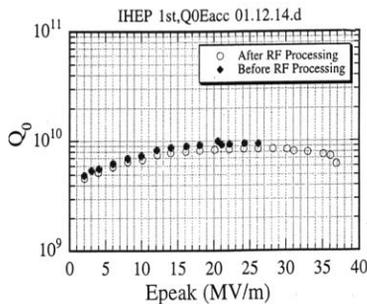


Figure 5: Measured $Q_0$ of the cell of 1.3GHz at $\beta$ =0.45 with designed $E_{sp}/E_{acc}$=5.13.

Recently IHEP has set up an RF superconducting laboratory for the RF cell processing and measurement. A cryostat for 1.3GHz cavity has been built for vertical measurement at the working temperature of 1.5~4.2K.

## LINAC DESIGN FOR CSNS

100kW CSNS uses a 70MeV H⁻ linac as an injector of a rapid-cycling synchrotron of 1.6GeV at a repetition rate of 25Hz. It consists of a H⁻ ion source, an RFQ and a conventional DTL. The RFQ described in section 3 can not be directly utilized for ADS linac because it is a pulsed machine, but it can be used in the CSNS. The following DTL linac is designed at the same RF frequency as the RFQ. The upgrade program of CSNS will raise its power to 200kW and the DTL energy will be 130MeV. The DTL consists of 8 tanks with the first half for 70MeV. Beam dynamic design was conducted with PARMILA code. The beam profile is shown in Fig.6 with a FODO lattice for transversal focusing.
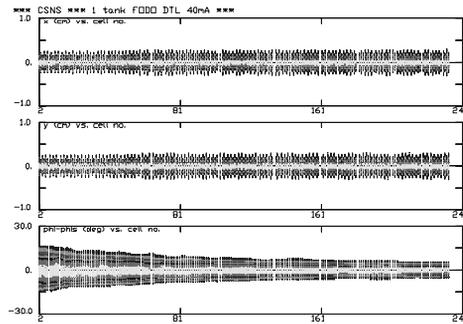


Figure 6: The beam profile in the 130MeV DTL.

## ACKNOWLEDGEMENTS

## REFERENCES

[1] S.X.Fang, Current Status of ADS R&D in China, http://www.kaeri.re.kr/npet/WS-9/KOMAC/main.htm
[2] Baoqun Cui et al, Rev. of Sci. Instru., Vol.75(5), 2004, p.1457.
[3] Shinian Fu, et al., Proc. of LINAC'02, p.154.
[4] Xialing Guan, et al., Proc. of 4th Inter. Workshop on the Utilization and Reliability of High Power Proton Accelerators, KAERI, Daejeon, May 16-19,2004.
[5] Zhang Zonghua, et. al., on this conference THP-47.
[6] J.X.Fang, et al., Proc. of LINAC'02, p.335.