THE ACTIVITIES OF HPPA TECHNOLOGY RELATED TO ADS IN CHINA

Guan Xialing, Jiang weisheng, Cui Baocun, Peng Chaohua,Ding Dazhao
CIAE, Beijing, 102413, China
Fu Shinian,Yu Qingchang, Luo Zihua, Xu Wenwu, Ouyang Huafu, Xu Taoguang,
Zhao shengchu, Zhang Zonghua, Li Jian, Fang Shouxian IHEP, Beijing, 100039, China
Fang Jiaxun,Guo Zhiyu PKU, IHIP, Beijing 100078 China

Abstract

High Power Proton Accelerator (HPPA) is being studied all over world for numerous applications, which includes the waste transmutation, spallation neutron source and material irradiation facilities. In China, a multi-purpose verification system as a first phase of our ADS program consists of a low energy accelerator (150MeV/3mA proton linac) and a swimming pool light water sub-critical reactor. In this paper the activities of HPPA technology related to ADS in China, which includes the intense proton ECR source, the RFQ accelerator and some other technology of HPPA, are described.

1 Introduction

High Power Proton Accelerator (HPPA) is being studied all over world for numerous applications, which includes the waste transmutation, spallation neutron source and material irradiation facilities. The R/D activities of the technology of HPPA are of key importance for development of the Accelerator Driven Sub-critical System (ADS), which is an entirely new approach for 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], which consists of a low energy accelerator (150MeV/3mA proton linac) and a swimming pool light water sub-critical reactor.

CIAE (China Institute of Atomic Energy), IHEP (Institute of High Energy Physics) and PKU-IHIP (Institute of Heavy Ion Physics in Peking University) are jointly carrying on the R/D of the proposed accelerator since 1999.

Since then, some R/D, such as ECR high current ion source, RFQ design and technology study, super-conducting cavity study, conceptual design of 150MeV/3mA proton linac, preliminary design of 1GeV 20mA linac and intense-beam Physics, were started.

In the last year we have very close cooperation with LNL (Laboratori Nazionali di Legnaro), INFN, Italy and KAERI (Korea Atomic Energy Research Institute). It is really a great help to our HPPA work.

2 The main results on ADS reactor physics concept study

According the five years' program (phase 1) mentioned in ref.[3], some basic researches on the physical and the technical problems related to ADS system were carried out in last year at CIAE. Some preliminary results of the study on the performance of different blanket show the advantages of ADS in comparing with that of critical one.

The system optimization has been focused on three versions:

1. Sodium cooled fast breeder reactor driven by an accelerator with the Pb/Bi target;
2. Fast breeder reactor cooled by lead and driven by an accelerator with the Pb target;
3. Fast- Thermal Coupled System with the Pb target.

A set of 2D transport and Neutronics Codes System and Thermo-Hydraulic simulation system are used for these investigations.

In the aspect of the study on spallation target physics, the experimental studies of compatibility between tungsten and water, tungsten and sodium are in progressing. The experimental studies of the radiation damage of the tungsten material and the stainless steel simulated by heavy ions are also under progress. For the neutron source term, the neutron yield and spectrum from lead and tungsten target (φ200x600) were calculated by SHIELD code CEM CODE and LAHET.

In the aspect of study on neutron data, according the requirement of ADS, the theoretical calculations and evaluations of the complete sets of neutron reaction data for n +^{129}I, ^{125}Sb and ^{209}Bi have been finished. The researches on n + ^{232}Th and ^{244}Cm reaction data are in progress. The first phase work of cross-section library of neutron has been accomplished for M-C calculation in MCNP format.

In the aspect of study on reactor physics, the possibility of transmutation nuclear waste in the ADS with dense lattice cell heavy/light water reactor is under investigation. A light water zero-power sub-critical assembly driven by steady external neutron source (Cf^{252}) has been set up. The experiment was started in July of this year. The neutron flux distribution and k_{eff} will be measured at this facility.

Fig 1: The ECR proton source in CIAE

3 Intense Proton Ion Source

An electron cyclotron resonance (ECR) ion source is selected for the source of our verification facility system. The structure of ECR source is similar to the one at Chalk River Laboratory in 1993 [4].

2.45 GHz microwave power is adopted. 1kW microwave power is coupled to the plasma chamber by a rectangular-to-ridged wave-guide through a microwave window, which is shown in fig 1.

The plasma chamber is a cylinder 100mm long and 100mm in diameter. An accelerating and decelerating three-electrode extraction structure is adopted. A beam with normalized rms emittance of 0.2 πmm mrad is anticipated. The discharging chamber is designed to withstand up to 75kV potential voltage. The measurement result of beam emittance for this ion source with 65mA and 30kev is shown in fig.2.

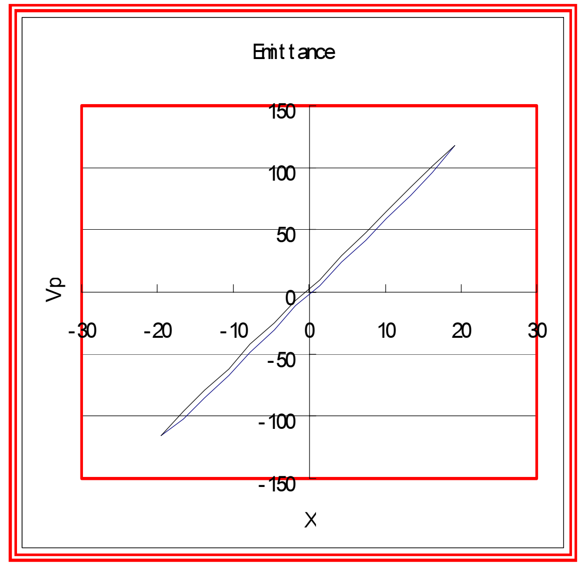

Fig.2: The measurement result of beam emittance (W=30keV I=65mA $\varepsilon_{(norm.\ rms)}$=0.2πmmmrad)

The performances of the ECR source are listed in the table I. For comparison, the performances of the ECR in some other laboratories are also listed.

In order to optimize the parameters of the ion source, some tests have been performed, for example, various tests of magnetic configurations to increase the discharge efficiency; various tests of microwave window configurations to increase the life time. We modified the diameter of the discharge chamber from the normal type of φ100mm to the compact type of φ30 --50mm, the proton fraction have been changed from 80--85% to 90--95% and the intensity from 100mA/φ7.3mm to 70mA/φ5mm[5].

Table 1

	Chalk river	CEA	LANL	CIAE
Energy (kev)	50	95	50	35
Current (mA)	90	126	122	100
Intensity (mA/cm^2)	458	243	336	350
Proton fraction	90%	88%	90%	90%
Gas (sccm)		2	3.3	2
ε mmmrad	0.2	0.11	0.2	0.2*

* 65mA; 30keV

In CIAE, various efforts have been made to optimize the reliability. As shown in Fig 3., this kind of source has been running reliably for near 100 hours at 65mA/35kev.

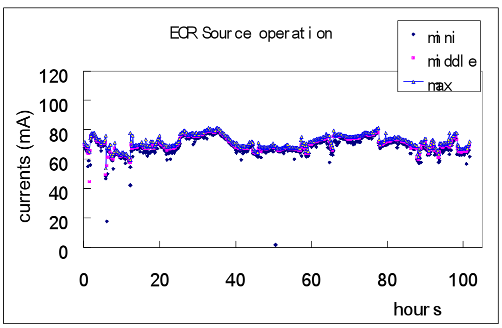

Fig. 3: 100 hours operation at 65mA/35kV

4 RFQ Accelerator study

The high current RFQ working group in IHEP CAS started their researches at the end of last year. The structure of RFQ is a four-vane type and designed to accelerate 50mA peak current of proton beam with input energy of 80kV. The structure was divided in four sections, the radial matching section (RMS), the shaper (SH), the gentle bunch (GB) and the accelerating section. The RFQ is 8.3 times longer than the RF wavelength. The longer the RFQ, the less stable is against perturbations. In order to overcome this problem, the resonant coupling concept is applied as that of LANL. The RFQ is longitudinally divided in three pieces separated by a coupling cell where electrodes belonging to two different RFQ pieces are facing one each other. The parameters of our RFQ was shown in table 2.

Table 2

Structure	4 vanes
Particle	Proton
Input Energy	80keV
Output Energy	5.0MeV
Peak Current	50mA
Duty Factor	6%
Frequency	352MHz
Total length	7.13 m
Resonant coupling section	3

A beam dynamics study of a 7.13 m long 352 MHz RFQ has been studied using the code of PARMTEQM, VANES and. LIDOS.RFQ[6] In fig. 4, it is shown that the main parameters of the RFQ calculated by the PARMTEQM[7].

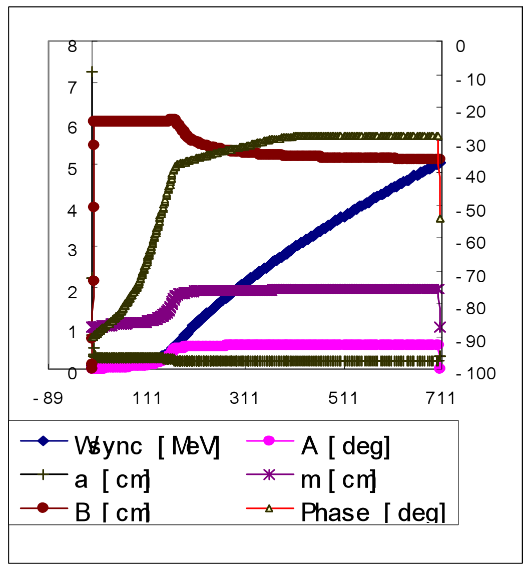

Fig. 4: main parameters of the RFQ

The envelop of a beam with 50mA past through the channel has been got by using the code of Lidos.rfq in IHEP. The transmission for a 50mA beam current and 50,000 macro-particles is 97.6% (Lidos.frq result). It is under progress using computer simulation codes for calculating radio-frequency electromagnetic fields in either 2-D coordinates (SUPERFISH) for the main region of the RFQ and 3-D coordinates (MAFIA) for the end regions and coupling regions[8].

The thermal and structure analysis was studied with the ANSYS code in CIAE. Different cooling distributions of design results were shown in Fig. 5(a and b).

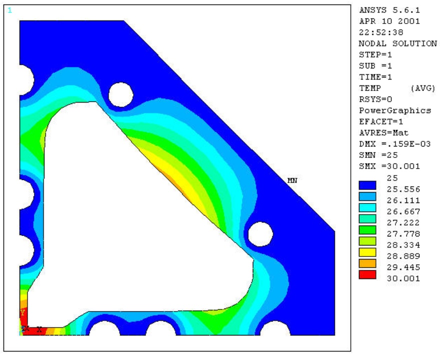

Fig. 5(a): Thermal and structure analysis for five cooling pipes

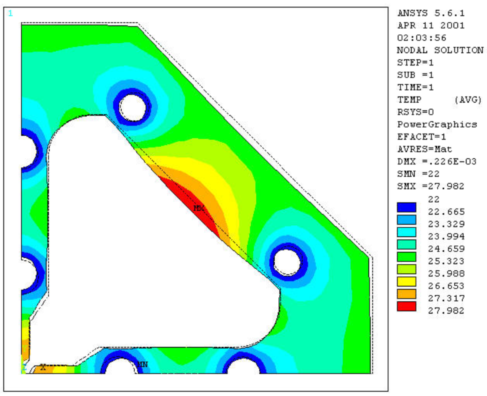

Fig. 5(b): Thermal and structure analysis for four cooling pipes

The fabrication of the RFQ copper model will be performed in a company of Shanghai, China. At first, some tests for development the mechanical technology have to be done, for example, the brazing technology for assembling four vanes together with required mechanical tolerance, the characteristics of melting filler, the structure surface and the vacuum leak; the drilling of the coolant hole through the 1.2meter RFQ cavity with 12mm in diameter; the precision machining of the vane electrodes on the numerical controlled mill.

In next two years, our time schedule for RFQ fabrication is:

- to complete the test of technology sample (300 mm long) by the end of 2001;
- to finish the mechanical design draw for one sections by the end of first quarter of next year;
- to building one section (～1.2meter) of a prototype with OFEC at the end of 2002.
- At the middle of next year, we will have a semi-manufactured section for the cold test.

During the study progress of RFQ, CERN is very kind to loan us a key part of RF power supply, a set of Klystron with 352.2 MHz/1.3MW CW power. The TRASCO team of LNL, INFN, Italy[9,10] and the KOMAC team of KAERI, Korea[11] also give us a lot of help.

5 Conceptual design of DTL and CCL part

After RFQ section, a 352MHz DTL accelerates the beam from 5MeV to 86.7MeV, which consists of six tanks. The DTL is a conventional Alvarez type with stabilization by post couplers. The DTL main parameters is an initial non-optimized design [12]. The DTL linac will be divided into six tanks, which has 30,42,30,26,23 and 21 cells respectively. The length of tank is near 7meters for each one. The post couplers are the one third of cell numbers minus one for the first tank; half of cell numbers minus one for second and third tanks; the numbers of cell minus one for other tanks. Their output

Table 3

Parameters	CCL1	CCL2	CCL3	CCL4	CCL5	CCL6
Output energy（MeV）	96. 1	107. 2	118. 9	131. 1	143. 9	157. 2
Tank length（m）	6. 84	7. 16	7. 50	7. 82	8. 12	8. 44
Cavity number	6	6	6	6	6	6
Cell number/cavity	8	8	8	8	8	8
Bore diameter（cm）	3	3	3	3	3	3
Accel. gradient E_0T（MV/m）	2. 4-2. 7	2. 9	2. 9	2. 9	2. 9	2. 9
Sychro. phase（deg）	-30	-30	-30	-30	-30	-30
Quadrupole gradient（T/m）	~32	~27	~26	~24	~22	~20
Quadrpole length（cm）	8	8	8	8	8	8
Cavity power（MW）	0. 9	1. 09	1. 14	1. 15	1. 16	1. 17
Beam power（MW）	0. 47	0. 55	0. 58	0. 61	0. 64	0. 67

energies are 10.7MeV, 26.4MeV, 42.0MeV, 57.8MeV, 73.1MeV, and 86.8MeV. The inner diameter of the tank is near 50cm. The diameters of the drift-tube are 10cm and 12cm for first two tanks and others respectively. But the bore diameters are the same (2.5cm). The 86.7Mev beam from the DTL is injected into a 704 MHz coupled cavity linac (CCL) and accelerated up to 157.2MeV, which is the final energy of the verification facility. Table 4 lists the CCL main parameters.

In recent years, a superconducting cavity laboratory will be established for research and development of the superconducting cavities supported by CAS from last year (2000). The main task is to develop a prototype of single-cell ellipsoid cavity with ß=0.45, f=700MHz. As a training, we have completed the optimizing design for a single cell with 1.3GHz and ß=0.45. Machine and measurement will be finished by the end of next year. The parameters of this cavity are listed in table 5[13].

Table 4: parameters of the cavity

Frequency	f=1295.516 MHz
Synchronous	β=0.45
Cavity length	L=309.86mm
Cavity radius	D=216mm
Accel. Gap	g=49.86mm
Bore of cavity	d=76mm
Quality factor	Q=4.208e+9
E_p/E_a	5.13
H_p/E_a	134.41

6 Conclusion

The development of HPPA technology undertaken in China nowadays is in its early stage. The works for HPPA related to ADS are conceptual study, critical technology and the key component development. Nevertheless, all of work described in this paper, such as the intense ion source test, the study of RFQ accelerator and some conceptual research of the linac, present a good start point in China.

7 Acknowledgments

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