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The Activities of HPPA Technology Related to ADS in China

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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 (150 MeV/3 mA proton linac) and a swimming pool light water sub-critical reactor. 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.

Key words: High power proton accelerator, ADS, ECR source, RFQ

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 (150 MeV/3 mA 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 150 MeV/3 mA proton linac, preliminary design of 1 GeV 20 mA 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.

1 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 (ϕ 200 mm×600 mm) 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 (^{252}Cf) 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.

2 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].

Fig. 1 The ECR proton source at CIAE

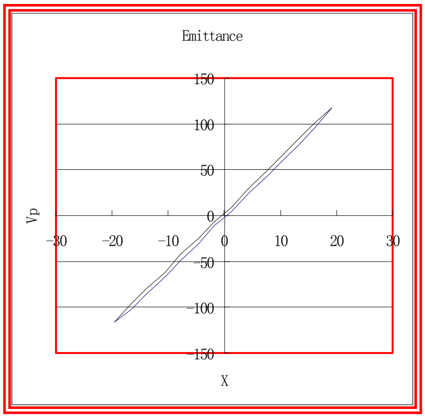

Fig. 2 The measurement result of beam emittance
(W=30 keV, I=65 mA, $\varepsilon_{(\mathrm{norm.\ rms})}$=0.2 π mm • mrad)

2.45 GHz microwave power is adopted. 1 kW 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 100 mm long and 100 mm in diameter. An accelerating and decelerating three-electrode extraction structure is adopted. A beam with normalized r.m.s. emittance of 0.2 πmm • mrad is anticipated. The discharging chamber is designed to withstand up to 75 kV potential voltage. The measurement result of beam emittance for this ion source with 65 mA and 30 keV is shown in Fig. 2.

The performances of the ECR source are listed in the Table 1. 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 ϕ 100 mm to the compact type of ϕ 30～ϕ 50 mm, the proton fraction have been changed from 80%～85% to 90%～95% and the intensity from 100 mA/ϕ 7.3 mm to 70 mA/ϕ 5 mm[5].

Table 1 The performances of the ECR source

	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 /mm • mrad	0.2	0.11	0.2	0.2[1)]

Note: 1) 65 mA; 30 keV.

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 h at 65 mA/35 keV.

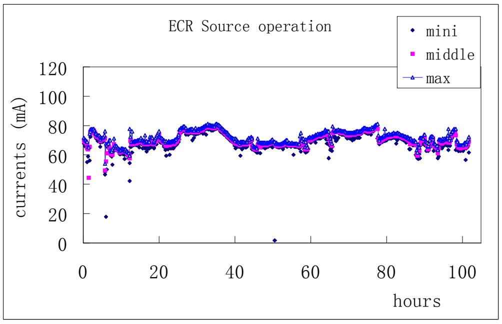

Fig. 3 100 h operation at 65 mA/35 kV

3 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 50 mA peak current of proton beam with input energy of 80 kV. 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 into 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 is shown in Table 2.

Table 2 The parameters of our RFQ

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

Beam dynamics 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, the main parameters of the RFQ calculated by the PARMTEQM is shown[7].

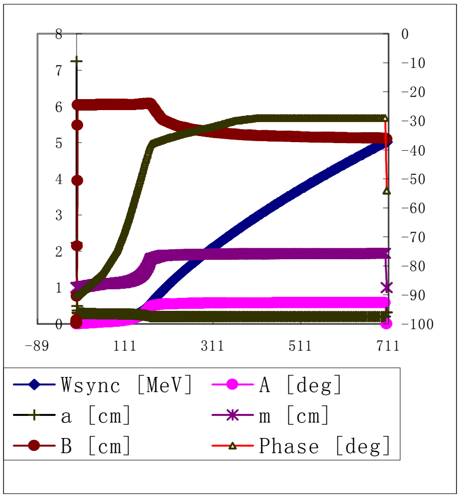

Fig. 4 Main parameters of the RFQ

The envelope of a beam with 50 mA passing through the channel has been got by using the code of Lidos.rfq at IHEP. The transmission for a 50 mA beam current and 50, 000 macro-particles is 97.6% (Lidos. rfq 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 structural analysis was studied with the ANSYS code at CIAE. Different cooling-pipe distributions of design results are shown in Fig. 5 (a and b).

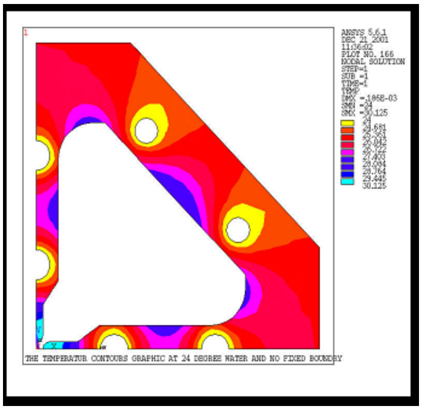

Fig. 5(a) Thermal and structure analysis for five cooling pipes

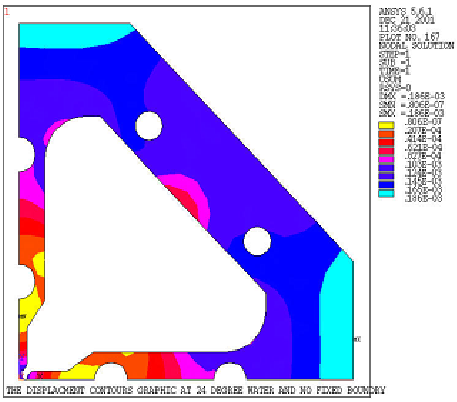

Fig. 5(b) Thermal and structure analysis for four cooling pipes

The fabrication of the RFQ copper model will be performed in a company of Shanghai, China. At first, some tests for development of 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 with 12 mm in diameter through the 1.2 m RFQ cavity; the precision machining of the vane electrodes on the numerically controlled mill.

In the 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 drawing for one sections by the end of first quarter of next year;
- To build one section (～1.2 m) 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 lend us a key part of RF power supply, a set of Klystron with 352.2 MHz/1.3 MW 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.

4 CONCEPTUAL DESIGN OF DTL AND CCL PART

After RFQ section, a 352 MHz DTL accelerates the beam from 5 MeV to 86.7 MeV, which consists of six tanks. The DTL is a conventional Alvarez type with stabilization by post couplers. The DTL main parameters is an initial and 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 7 m 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 energies are 10.7 MeV, 26.4 MeV, 42.0 MeV, 57.8 MeV, 73.1 MeV and 86.8 MeV. The inner diameter of the tank is near 50 cm. The diameters of the drift-tube are 10 cm and 12 cm for first two tanks and others respectively.

But the bore diameters are the same (2.5 cm). The 86.7 MeV beam from the DTL is injected into a 704 MHz coupled cavity linac (CCL) and accelerated up to 157.2 MeV, which is the final energy of the verification facility. Table 3 lists the CCL main parameters.

Table 3 Main parameters of the CCL

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^{-1}	2.4～2.7	2.9	2.9	2.9	2.9	2.9
Sychro. phase/deg	−30	−30	−30	−30	−30	−30
Quadruple gradient/T • m^{-1}	～32	～27	～26	～24	～22	～20
Quadruple 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

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 β=0.45, f=700 MHz. As a training, we have completed the optimizing design for a single cell with 1.3 GHz and β=0.45. Machinning and measurement will be finished by the end of next year. The parameters of this cavity are listed in Table 4[13].

Table 4 Parameters of the cavity

Frequency	f=1295.516 MHz
Synchronous	β=0.45
Cavity length	L=309.86 mm

Table 4 (Continued)

Cavity radius	D=216 mm
Accel. Gap	g=49.86 mm
Bore of cavity	d=76 mm
Quality factor	Q=4.208e+9
E_p/E_a	5.13
H_p/E_a	134.41

5 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.

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与 ADS 相关的高功率质子加速器技术在我国的进展

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摘　要：叙述了一个由中国原子能科学研究院、中科院高能物理所和北京大学重离子物理所共同承担，于2000年9月启动的，以丁大钊院士为首席科学家的国家重点基础研究发展规划项目(973项目)—“加速器驱动洁净核能系统(ADS)的物理及技术基础研究”研究项目中与HPPA相关的主要研究内容，包括：强流离子源研制、低能束传输段研究、中能强流RFQ加速器研究及强流加速器总体设计等部分进展情况。