PROTON LINAC FOR ADS APPLICATION IN CHINA

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Abstract

In the next two decades, China will be in period of fast development of nuclear power to meet the energy demands of the rapid economy growth and to cut down the CO_2 release. Accelerator Driven System is recognized as the best option for nuclear radioactive waste transmutation. ADS long-term development roadmap has been proposed. Based on the ADS basic study in the last decade, a ADS test facility is going to be built to do experimental research on ADS system. In this paper, we will first review the previous R&D activity on ADS linac research in China, and then introduce the design of the linac in the ADS test facility.

INTRODUCTION

China, as a developing country with a great population and relatively less energy resources, is rapidly developing nuclear energy. The nuclear electricity is foreseen to reach 75 GWe, and meanwhile 30 GWe power will be under development in 2020, according to the recently revised plan of the Chinese government in April 2009. To develop nuclear power in such a large scale, long-lived radioactive nuclear wastes have to be safely disposed to reduce the impact on the environment and to eliminate public fear of nuclear power. Right now only a small amount of spent fuels from nuclear power plants has been accumulated in China. But the situation will become very serious in the future. The accumulated waste is estimated to be more than 10k tons in 2020, and it will be doubled in 2030. How to deal with these wastes has been considered as a very important issue for Chinese nuclear scientists. ADS has been recognized as the best option for the nuclear waste disposal and some basic study programs on ADS have been supported by the Chinese government since 1999 [1]. Since then, some key technology of high-intensity proton linac has been developed. In recent, Chinese Academy of Sciences decided to push forward ADS research much faster. A long-term roadmap of ADS in China was proposed to the Chinese government. As the first step, Chinese Initiative Accelerator Driven System (CIADS) will soon be launched out.

This paper will first present a review of the intense-beam proton linac R&D activities, including the injector, RFQ and medium-β superconducting RF cavity, in the past decade in China. Then it will introduce the roadmap of the ADS development in future, and finally the major design consideration about CIADS will be sketched out in this paper.

R&D ACTIVITIES ON PROTON LINAC

A high current front end consisting of an ECR ion source, LEBT and an RFQ accelerator of 3.5 MeV has been built, as shown in Fig. 1 and Fig. 2 respectively.

Figure 1: High intensity ECR ion source.

ADS demands an extremely high reliability of the driver accelerator and it is identified that the injector is a major source of the beam trip. So, great efforts were made on the reliability and stability of the ion source operation. A high reliability of 99.9% is achieved during an 120 hours continuous operation. The output beam current is around 70 mA in normal operation, and now is pushing to 120 mA in test.

Figure 2: The 3.5MeV RFQ accelerator.

The RFQ is designed for CW operation [2], but as the first step it is operated at 7% duty factor with a beam kicker in the LEBT. This is a four-vane type structure with two coupled resonators and dipole stabilizer rods on the middle coupling plate and the two end-plates, similar to LEDA RFQ [3]. The major design parameters are listed in Table 1. A beam current of 46mA was obtained from the RFQ at 7% duty factor with a beam transmission rate of 93%. The beam energy spectrum is measured in a good agreement with the simulation result from PARMTEQM code, as plotted in Fig. 3. The RF power source is kindly provided by CERN with capability up to CW operation. A digital RF control system based on FPGA was developed at IHEP and added to the RF system. With this new feedback system the operation stability became better in the case of long pulse and heavy beam loading. The RF amplitude and phase stability reached ±1% and ±1^0 respectively.

Table 1: Major Design Parameters of the RFQ

Parameters	**Value**
Input Energy	75 keV
Output Energy	3.5 MeV
Peak Current	50 mA
Structure Type	4-vane
RF Frequency	352.2 MHz
Maximum Surface E	33 MV/m (1.8 Kilp)
Structure Power	420 kW
Beam Power	175 kW
Total Power	595 kW
Total Length	4.75 m

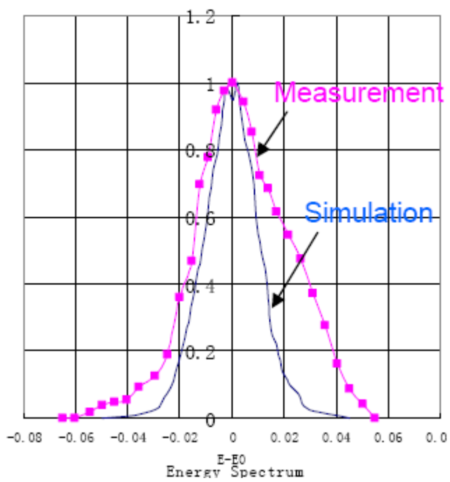

Figure 3: The Beam energy spectrum of the RFQ.

Now we are pushing the RFQ duty factor to 15%. The major modification to the RFQ components is to replace the dipole stabilizers with new ones with cooling water channels in the rods. After the replacement the RFQ was re-aligned and retuned for minimize dipole field component. Most of the tuners were replaced. In the end of September of 2010, high power conditioning will start. And meanwhile a beam line with a periodic focusing channel and some beam diagnostics has started fabrication for beam halo study with the RFQ output beam.

The technology of medium-β superconducting RF cavity has been studied. Three superconducting single ellipsoid cells of 1.3 GHz at β=0.45 were manufactured with assistance from KEK. It is the scaled-down prototype of 700 MHz cell, as shown in Fig. 4. It reaches the surface field E_{sp}=42.4 MV/m.The measured Q_0 versus E_{sp} is plotted in Fig. 5. With the successful experience of 1.3 GHz cell, 700 MHz cell is now under development.

Figure 4: 1.3 GHz single cell at β=0.45.

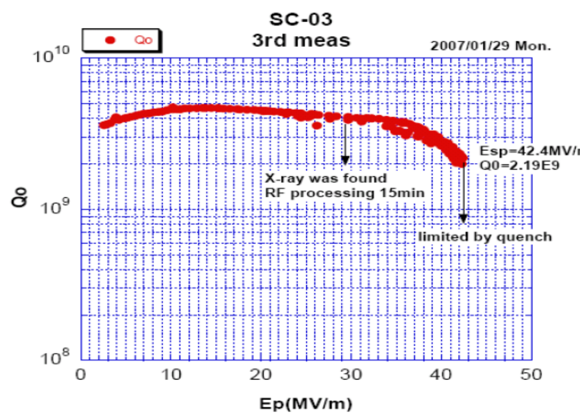

Figure 5: Measured Q_0 of the 1.3 GHz single cell.

For the development of superconducting RF technology at IHEP, an RF superconducting laboratory of 250 m^2 has been set up for the RF cell processing and measurement. A cryostat for 1.3 GHz cavity has been built for vertical measurement at the working temperature of 1.5~4.2 K. The lab is not only used for proton linac R&D, but also serve for the cavity development of ILC and photo cathode gun.

ADS PLAN IN FUTURE

As the completion of the R&D of the key component, ADS further development needs a big project with much more investment. And meanwhile, the nuclear power development in China becomes much faster than over before. In this situation, Chinese Academy of Sciences decided to put much more efforts on ADS next step development. A long-term road map was sketched out, as shown in Fig. 6. According to this plan, we divide the future development into three steps, as follows:

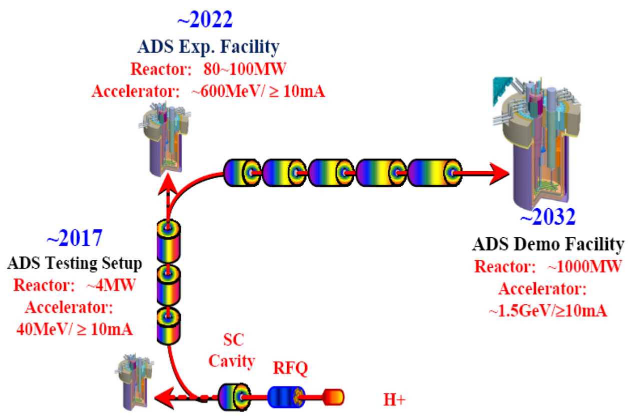

Figure 6: The road map of ADS development in China.

(1) From 2011 to 2017 we are going to construct an ADS test facility, called CIADS, which is the abbreviation of Chinese Initiative Accelerator Driven System. It is the first coupled system of an high intensity proton accelerator with subcritical reactor through a neutron target. The thermal power of the reactor is designed at 4 MW_{th}. It is driven by a 40 MeV proton linac consisting an ECR proton source, a RFQ, room temperature CH cavities and a section of superconducting spoke cavity.

(2) From 2017 to 2022, the same linac in the first step will be prolonged with more superconducting spoke cavities and medium-β superconducting ellipsoid cavities to increase the proton beam energy to about 600 MeV. It is coupled with a new subcritical assembly of 80-100 MW thermal power through a spallation neutron target of liquid metal. This is a medium scale ADS facility and we called it as ADS Experimental Facility.

(3) From 2022 to 2032, a whole scale ADS demonstration facility will be built with thermal power of 1000 MW_{th}. More superconducting ellipsoid cavities will be added to the linac to raise beam energy up to 1.5 GeV. At this step, industry will join the project and the technology will be transferred to industry from research institution.

The linac design is under consideration, which is now focused on the low energy section for the CIADS construction. Instate of 352 MHz and 704 MHz RF frequency in the previous ADS linac design, the new design uses 325 MHz and 650 MHz RF frequency. The major consideration on the RF frequency choice is connected with ILC 1.3 GHz superconducting technology, as Project-X at Fermilab.

LINAC DESIGN FOR CIADS

Figure 7 plots the 40 MeV linac consisting of an ECR proton source, a 3 MeV RFQ, 6.4 MeV CH structure at room temperature and 40 MeV superconducting spoke cavities. The linac major design parameters are listed in Table 2.

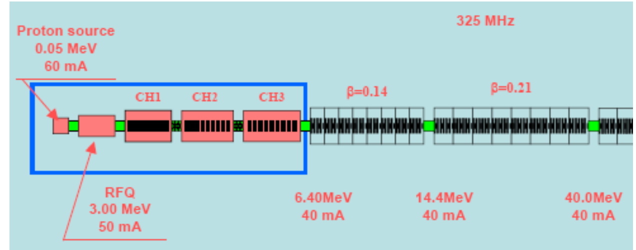

Figure 7: Sketch of the 325 MHz linac for CIADS.

Table 2: Linac Major Design Parameters

Parameters	Value
RFQ	
Injection energy	50 keV
Output energy	3.0 MeV
Pulsed beam current	50 mA
Beam duty factor	100%
Inter-vane voltage	80 kV
Beam transmission	98.6%
Maximum surface field	31.91 MV/m (1.79Kilp.)
Input norm. rms emittance	0.2π mm.mrad
Vane length	403.4 cm
Cavity Power	432 kW
Total Power	582 kW
CH Structure	
Output energy	6.4 MeV
Cavity number	3
Total Length	2.5 m
Kilpatrick factor	1.6
Power density	< 80 kW/m
Spoke Cavity 1	
Geometry β	0.14
Output energy	14 MeV
Max single gap voltage	0.28 MV
Cavity number	16
Spoke Cavity 2	
Geometry β	0.21
Output energy	40 MeV
Max single gap voltage	0.44 kV
Cavity number	34

CONCLUSIONS

Some R&D on high-intensity proton linac has been conducted for ADS basic research in China. Now a new plan has been proposed for ADS long-tern development. A CW proton linac will be built step by step.

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