SRF CAVITIES FOR ADS PROJECT IN CHINA*

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Abstract

The project of the Chinese Accelerator Driven transmutation System started in 2011. The driven accelerator of C-ADS is a superconducting linac. The construction of two 10-MeV superconducting injectors and the prototypes of superconducting RF cavities for main linac are developing at the Institute of High Energy Physics (IHEP) and the Institute of Modern Physics (IMP). Seven types of SRF cavities including half wave resonator, spoke, and elliptical are developed in parallel. At present, the Spoke012 has finished the horizontal testing and the Q0 is 2E8 at Epeak = 30 MeV/m; the HWR010 has finished the vertical testing and the Q0 is 4E8 at Epeak = 45 MV/m. The spoke021 and ellip082 are ready for the vertical testing. The HWR015, spoke040, and ellip063 are designed and in fabrication. The design, fabrication, processing, testing, and specifications of the SRF cavities are described in the paper.

INTRODUCTION

Chinese ADS project was proposed by Chinese Academy of Sciences in "Strategic Priority Research Program" in 2011. The project is named as "Accelerator Driven Transmutation System" for green nuclear power. The roadmap of China ADS project is shown in figure 1 [1]. It is a long-term plan with three stages up to 2040. The first stage is including a 250 MeV superconducting accelerator and will be finished in 2023. In the first 5 years, the R&D of the key technologies of accelerator will be done. It will commission two 10-MeV injectors and finish the prototypes of SRF cavities employed in main linac.

Conceptual Design of the Driven Accelerator [2]

The driven accelerator is a superconducting linac in continue-wave mode for China ADS. The RFQ is the only room-temperature acceleration module. The general layout of the linac is shown in figure 2. The accelerator will include two identical injectors with the energy of around 10 MeV for hot spare. Due to the technic risks of the low energy segment, two baselines are pushed forward in parallel in the project. One, the injector I, bases on the frequency of 325 MHz and superconducting spoke cavity, the other one, the injector II, bases on the frequency of 162.5 MHz and superconducting half wave resonator (HWR). The energy of superconducting segment is from 3.2 MeV to 10 MeV for injector I, and from 2.1 MeV to 10 MeV for injector II. The downselection of baseline will be done in 2015. The main linac is designed for matching the two injectors. The final energy of main linac is 1.5 GeV and two types of SRF c avities, the spoke with freqency of 325 MHz and the elliptical with frequecy of 650 MHz, are employed.

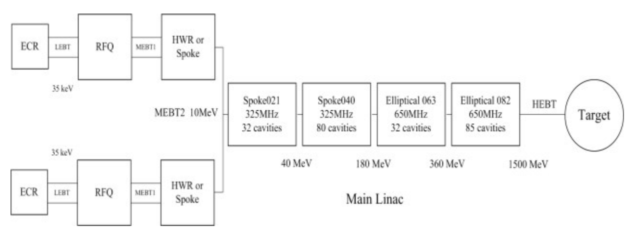

Figure 2: Conceptual design of accelerator for China ADS project.

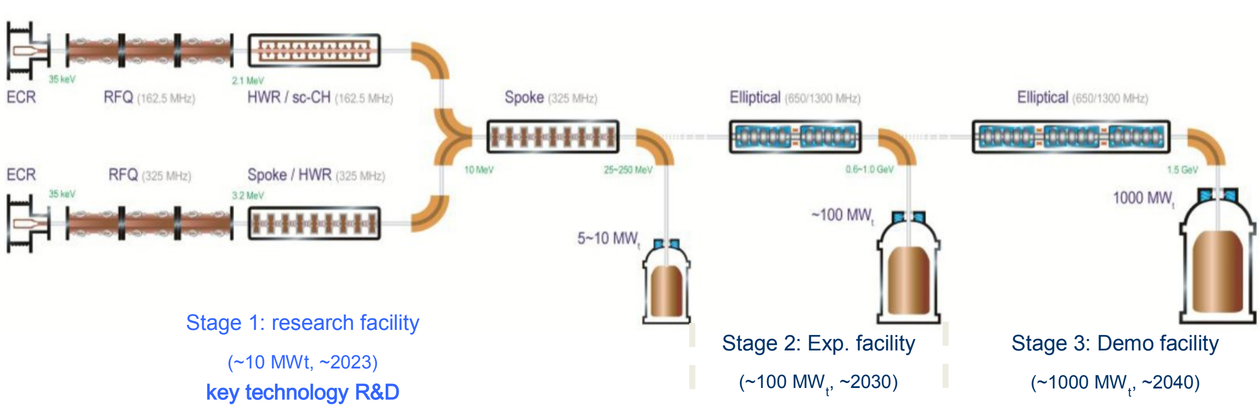

Figure 1: Roadmap of China ADS project.

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Table 1: General Specifications of SRF Cavities for China ADS Project

	Spoke012	HWR010	HWR015	Spoke021	Spoke040	Ellip063	Ellip082	Unit
Freq.	325	162.5	162.5	325	325	650	650	MHz
βg	0.12	0.09	0.14	0.21	0.40	0.63	0.82	-
Aperture	35	40	40	50	50	100	100	mm
Uacc Max	0.82	0.78	1.82	1.64	2.86	10.26	15.63	MV
Epeak	32.5	25	32	24/31	25/32	29/38	28/36	MV/m
Bpeak	46	50	40	50/65	50/65	50/65	50/65	mT
Temp.	4.5	4.5	4.5	4.5	2	2	2	K
Ploss	10	10	15.5	16.8	6.5	21	39	W

General Requirements on SRF Cavities

Taking requirements of reliability of ADS into account, the moderate specifications, in Table 1, at operation for SRF cavities are employed in physics design. The criteria of Bpeak and Epeak are set to 50 mT and 32 MV/m separately at the segment of injectors. 65 mT and 32 MV/m are criteria for the spoke cavities at the segments of main linac. 65 mT and 40 MV/m are criteria for the elliptical cavities. A cavity failure at main linac during operation will be compensated by the cavities nearby by increasing power. So, 30% ability of the cavities is reserved for failure compansation. The Bpeak for a normal operation cavity is 50 mT.

SRF CAVITY FOR INJECTOR I [3]

The basic frequency of injector I is 325 MHz. The layout is shown in figure 3. The spoke012 is employed for the superconducting segment of injector I. The 12 cavities in one cryomodule accelerate proton beam from 3.2 MeV to 10 MeV.

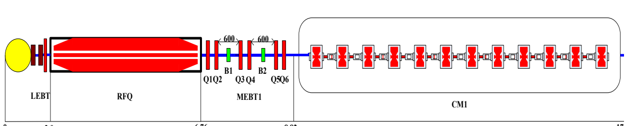

Figure 3: Layout of injector I.

Design and Specifications of Spoke012

Collaborated with Peking University and Harbin Institute of Technology, IHEP has designed, fabricated the spoke012 prototype cavity successfully. Two cavities (figure 4) have been fabricated in Nov. 2012.

Figure 4: Prototypes of spoke021.

Table 2: Specifications of Spoke012 for Injector I

	Spoke012	Unit
Freq.	325	MHz
Epeak/Eacc	4.5	-
Bpeak/Eacc	6.4	mT/(MV/m)
βopt	0.14	-
R/Q	142	Ω
G	0.12	Ω
Leff (=βλ)	110	mm

Vertical Testing

The surface processing of the prototype of Spoke012-2 was finished in December 2012, including ultrasonic cleaning, BCP and HPR. More details can be found in reference [3]. The vertical testing of the first cavity was finished on Dec. 23rd, 2012. Q0 vs Eacc is shown in figure 5. The residual surface resistance (Rs) is 50 nΩ. Here, Eacc is defined as the total accelerating voltage divided byβλ (110 mm). The X-ray appeared at 5 MV/m, and the maximum surface field was limited to 36 MV/m. The Q0 is 3.4E8 at Eacc = 7 MV/m. Testing ended due to strong mutipacting.

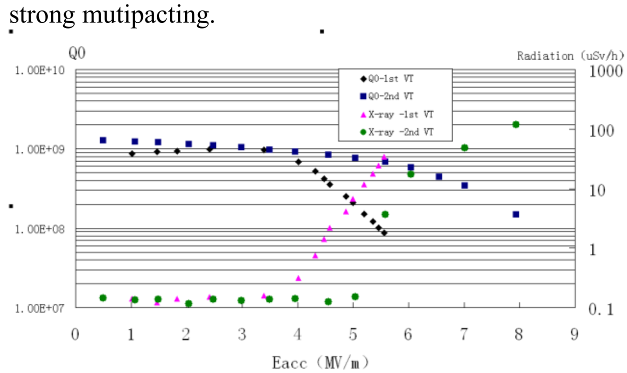

Figure 5: Results of vertical testing of spoke012-2.

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Horizontal Testing

The horizontal testing of the first cavity was done on Sept. 11th, 2013. The Q0 vs Eacc is shown in figure 6. During the test, a heavy Multipacting effect played a critical role in the limitation of increasing the accelerating gradient. The performance improved much after sufficient RF aging, while the radiation reduced obviously. As shown in Figure 6, the maximum accelerating gradient for CW mode reached 6.5 MV/m, with Q_0 is 2.2×10^8.

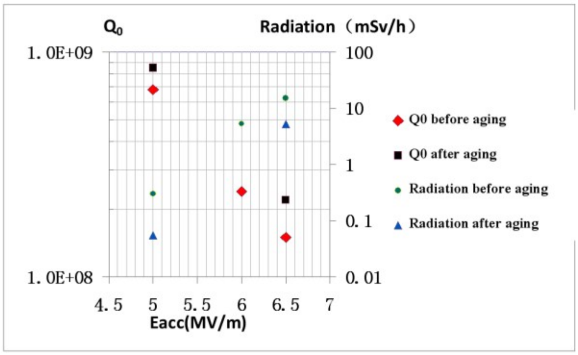


Figure 6: Results of horizontal testing of spoke012-2.

High Power Coupler for Spoke012 Cavity [4]

The couplers for Spoke-012 cavities were developed and conditioned in IHEP. Main parameters were showed in table 3. Figure 7 gives the cross-section view of the coupler. This coupler has passed through high power test with an RF power of 10 kW in continuous travelling wave mode as well as standing wave mode.

Table 3: Specifications of the Coupler for Spoke012

Freqency	325 MHz
Type	Coaxial, antenna e-coupling
Window	Single, warm, coaxial disk
Coupling	fixed
Qext	7.1E5
Input power	16 kW
Impedence	50 Ω

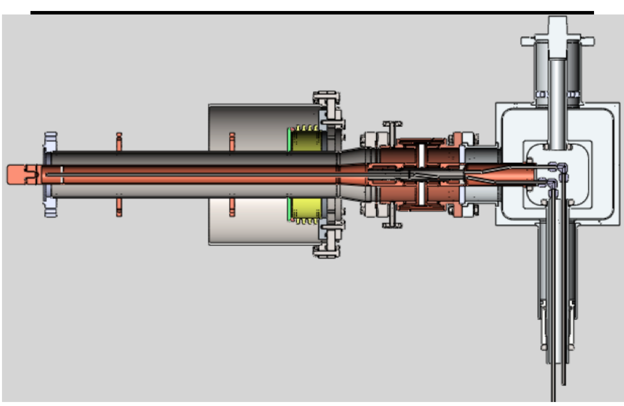


Figure 7: Cross-section view of coupler.

SRF CAVITY FOR INJECTOR II [5][6]

Thinking of the thermal problem of the RFQ, 162.5 MHz is used as the basic frequency. It is the half of the main linac. The layout of the injector II is shown in figure 8. Two types of HWRs are employed for the superconducting segment of the injector II. The first one is squeezed cavity, shown in figure 10 (a), and the βopt is 0.10. The six squeezed cavities in a cryomodule accelerate proton beam from 2.1 MeV to 5 MeV. The second one is taper cavity, shown in figure 10 (b) and the βopt is 0.15. The six taper cavities in a cryomodule accelerate proton beam from 5 MeV to 10 MeV.

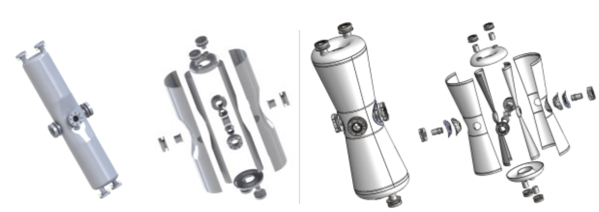
Figure 8: Layout of injector II.

Design and Specifications of HWRs

The HWR010 is a cylinder type cavity, and it is squeezed for a lower beta at the waist. The Bpeak/Eacc is quite high and limits the performance of the cavity. The HWR015 is a taper type cavity as the design of ANL. A low Bpeak/Eacc is the main consideration during RF optimization. The specifications of the two cavities are listed in table 4. The HWR010 was designed by IMP and fabricated at the Harbin Institute of Technology. The first batch of two HWR010s is finished in Oct. 2012. And the second batch of three was finished in March 2013. Except the first cavity, which was made a hole by electron beam, the others were tested vertically. The HWR015 is designed and ready for a review.

Table 4: Specifications of HWRs for Injector II

	HWR010	**HWR015**	**Unit**
Freq.	162.5	162.5	MHz
Epeak/Eacc	5.9	4.9	-
Bpeak/Eacc	12.1	6.1	mT/(MV/m)
βopt	0.101	0.151	-
R/Q	148	292	Ω
G	28.5	51.7	Ω
df/dp	18	2.1	Hz/mbar



(a) (b)

Figure 9: Structures of HWR010 (a) and HWR015 (b).

Vertical Testing of HWR010

The first tested cavity is #2. It was tested at SINAP on Dec. 1st 2012 and re-tested at IMP on Jan. 27th 2013 independently. Only light BCP and HPR have been done between the two testing. Considering the altitude deference, 1.5 km between Lanzhou and Shanghai, the two testing results are almost same.

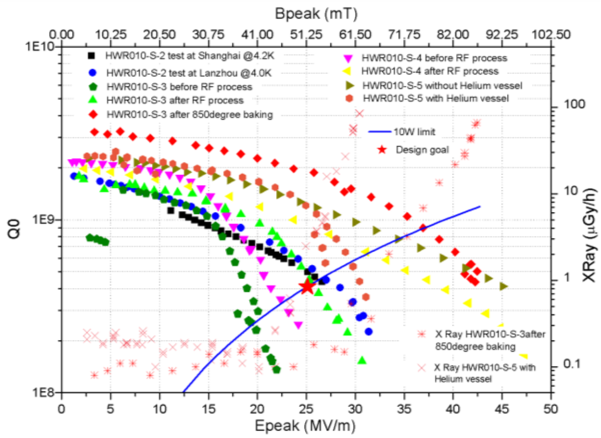


Figure 10: Vertical testing results of HWR010-02~05.

The HWR010-02 ~ 05 were tested at Lanzhou. All results are shown in figure 10. The helium temperature is 4.0 K at 630 mbar, local atmosphere pressure. All testing ended due to quench. The highest Epeak is around 45 MV/m while Bpeak is larger than 90 mT and Q0 is higher than 2E8. The highest line in the figure 9 is #3 cavity. The Q0 at very low field is around 3E9. The performance of the four cavities varied in a large range due to slightly change of surface treatment.

High Power Coupler for HWR010 [4]

Couplers for Half Wave Resonators were designed to transfer 20 kW at the frequency of 162.5 MHz. The outer conductor was designed to be cooled by helium gas through the spiral grooves around the outer surface while the inner conductor was cooled by water as figure 11 shown below. The coupler has passed an RF power of 20 kW in continuous travelling wave mode limited by the RF source available.

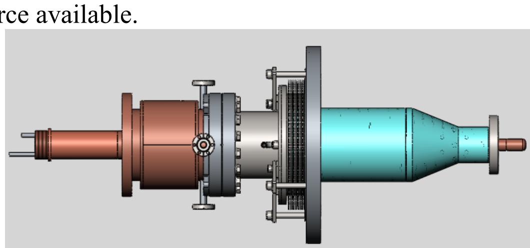


Figure11: General layout of coupler for HWR.

SRF CAVITIES FOR MAIN LINAC

Design and Specifications of Spoke021

Refer to the existed structure of spoke cavities which have been developed at other lab, such as LANL, Fermilab etc., spoke021 has been designed. Compare with the SSR021 of Fermi's, the spoke021 for China ADS is more compact, no enhanced wings around beam tube, the tuner will be enforced on side stiffen ring, not to beam tube flange, to keep cavity on tune.

According to the optimized structure, a set of electromagnetic parameters calculated by CST, are shown in Table 5.

Table 5：Main Parameters of the Spoke021

	Spoke021	**Unit**
Freq.	3.8	MHz
Epeak/Eacc	3.8	-
Bpeak/Eacc	8.1	mT/ (MV/m)
R/Q	191	Ω
G	71	Ω
β opt	0.246	-
df/dL	632	kHz/mm

Design and Specifications of Ellip082

The ellip082 is used to accelerate proton beam from 367 MeV to 1500 MeV. For a 10 mA, continue wave beam, the principles listed below should be followed in the cavity design:

- Proper cell numbers, to balance the efficiency and accelerating length.
- Epeak/Eacc and Bpeak/Eacc should be low.
- No hard multipacting barrier caused by shape.
- Proper beam aperture to damp high order modes.

The specifications of ellip082 are shown in table 6.

The multipacting simulation has been done with E_{acc} ranges from 1 MV/m to 20 MV/m with an interval of 1MV/m using a ten degrees slice of the cavity. The simulation results show that there is no hard multipacting barrier in the cavity.

Table 6: Specifications of Ellip082

	Ellip082	**unit**
Freq.	650	MHz
No. of cells	5	-
Cavity length	1281.7	mm
R/Q	514.6	Ω
G	235.5	Ω
Epeak/Eacc	2.12	-
Bpeak/Eacc	4.05	mT/(MV/m)
Field flatness	>98	%

The Lorentz factor is calculated by ANSYS. The cavity wall thickness of 3.7 mm is selected to keep a stable structure, which also saves the stiffness rings. The Lorentz factor is -1.04 Hz/(MV/m)^2 without stiffening ring.

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CONCLUSION

The SRF cavities, HWR, Spoke, and elliptical, are all employed by the superconducting linac of ADS project in China. The cavities and high power couplers of HWR010 and Spoke012 for two injectors have been qualified and will be in mass production.

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