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CiADS AND HIAF SUPERCONDUCTING CAVITY DEVELOPMENT STATUS AND THE TRANSITION TO PRODUCTION STAGE*

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Abstract

Two accelerator facilities, China initiative Accelerator Driven Sub-critical System (CiADS) and High Intensity heavy-ion Accelerator Facility (HIAF) are co-funded by the China central and local government are being designed and constructed in Huizhou city, Guangdong Province, China. The Institute of Modern Physics (IMP), Chinese Academy of Science responded to construct and operate both accelerator facilities. CiADS's mission is to demonstrate the principle and technical of employing high power protons to transit fission nuclear plant wastes. HIAF is defined as a nuclear structure research facility. Seven types of Superconducting Radio Frequency (SRF) cavities with a total number of 233, will be constructed in the coming three years for the both linacs. Stable production rate and reliable surface processing will be the main challenges. This paper reports the cavity design, prototype status and massive production plan and status.

INTRODUCTION

The HIAF project will be a scientific user facility, which is aim to expand nuclear structure understanding. The facility contains a superconducting driver linac, a accumulation ring, and a booster Ring [1].

HIAF driver linac has the capability to accelerate uranium ion beams to energies up to 17 MeV/u. Two types of SRF cavities are used for the acceleration. Five Quarter Wave Resonators (QWRs), with an optimal beta of 0.007, are assembled in one cryomodule. There are a total of six QWR cryomodules in the linac. Eleven Half Wave Resonators (HWRs) cryomodules are followed by the QWR cryomodules to accelerate the beam. Each HWR cryomodule contains six cavities with an optimal beta of 0.15. The HWR015 cavity is a mature superconducting cavity in IMP, as the IMP has developed twelve cavities of this type for the demo linac of CaFe. The HIAF linac including the cryogenic system layout is shown in Fig. 1.

CiADS project are located in the same area with HIAF facility. It's a demo facility for showing the technology of transit fission nuclear plant wastes by high power proton beam [2]. The construction started in 2021 by the IMP, at Huizhou city.

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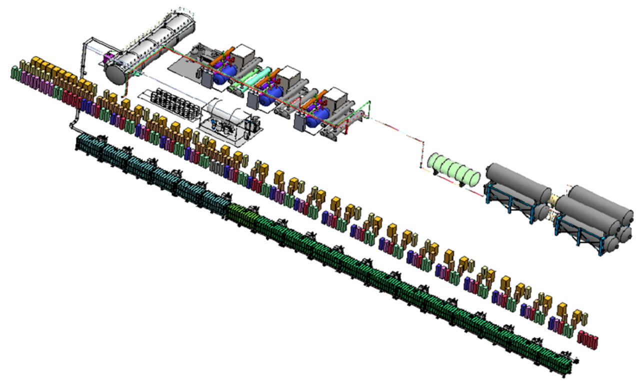

Figure 1: HIAF linac layout, six QWR007 cryomodules and eleven HWR015 cryomodules have capability to accelerate U^{35+} to 17MeV/u.

The CiADS facility contains a driver Linac, a spallation target and a sub-critical reactor. The superconducting linac accelerates the proton beam to higher energies to collide with the spallation target, then produces neutron. The sub-critical reactor employs the produced neutrons to occur nuclear reactions.

CiADS linac utilizes 162.5 MHz with β=0.1 and 0.19 HWR cavities, 325 MHz β=0.42 double Spoke cavity, 650 MHz with β=0.62 and 0.82 elliptical cavity to accelerate the proton beam to 500 MeV. In addition, this linac has the potential to accelerate the proton higher energies up to 1 GeV. The linac's nominal beam current is 5 mA [3]. The layout of CiADS linac is shown as follow Fig. 2.

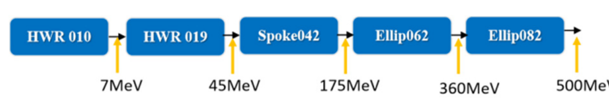

Figure 2: CiADS linac layout, the output energy is 500 MeV.

There are a total of 233 SRF cavities will be fabricated in the coming three years for both projects CiADS and HIAF. The cryomodule configurations and parameters are summarized in Table 1. Cryomodule length is limited to less than 6m, due to the linac tunnel entrance design. The low beta cavity have superconducting solenoid for beam control, which is located inside cryomodule. The elliptical cavity have no solenoid inside cryomodule.

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Table 1: CiADS and HIAF Cryomodules and Configuration

Project	Cavity Type	Frequency [MHz]	Cryomodule Quantity	Cavity Quantity
CiADS	HWR010	162.5	1	9
	HWR019	162.5	4	24
	SPOKE042	325.0	10	40
	Elliptical062	650.0	10	40
	Elliptical082	650.0	6	24
HIAF	QWR007	81.25	6	30
	HWR015	162.5	11	66

SRF CAVITIES PARAMETERS

CiADS and HIAF cavity design parameters are summarized in Table 2. The basic cavity optimization principles, lower Ep/Eacc and Bp/Eacc ratios, enlarge the G factor and R/Q to minimize the cryogenic loss, are used for all cavities[1]. The two linacs are required to operate at pulse and Continues-Wave (CW) modes. To avoid the field emission effect, the cavity gradient E_{acc} is limited by the peak electric field ($E_p \leq 33$ MV/m), which is based on the experience of surface processing.

In both coaxial resonators (QWR and HWR), taper structures are used to maintain the peak magnetic field less than 70 mT. The specifications of cavities parameters are summarized in Table 2 at 2 Kelvin operation for both linacs.

Table 2: CiADS and HIAF Cavities Parameters at 2 Kelvin

Project		CiADS					HIAF	
Cavity parameter	Unit	HWR010	HWR019	Spoke042	Elliptical062	Elliptical082	QWR007	HWR015
Beta		0.10	0.19	0.42	0.62	0.82	0.07	0.15
Frequency	[MHz]	162.5	162.5	325.0	650.0	650.0	81.25	162.5
Beam aperture	[mm]	40.0	40.0	50.0	100.0	100.0	40.0	40.0
L_{eff}	[mm]	185.0	351.0	580.0	824.0	895.0	258.0	276.0
Epk/E_{acc}		5.71	4.24	3.79	2.80	2.10	4.69	4.89
B_{pk}/E_{acc}	[mT/MV/m]	12.52	6.21	7.05	4.86	3.98	5.84	6.11
TTF		0.83	0.887	0.80	0.72	0.74	0.87	0.87
Veff	[MV]	1.17	2.73	5.06	9.72	14.07	1.54	1.58
G	[Ohm]	28.0	66.43	109.0	187.0	229.0	30.0	51.0
R/Q	[Ohm]	158.3	337.2	431.3	334.0	501.0	482.0	292.0
R_{bcs}[2K]	[nOhm]	0.17	0.17	0.68	2.73	2.73	0.04	0.17
Specific Q_0		1.5×10^9	3.7×10^9	3.6×10^9	1.1×10^{10}	1.3×10^{10}	1.7×10^9	2.8×10^9

CAVITY FABRICATION

Before the CiADS and HIAF projects, the IMP has developed more than 40 low beta SRF cavities for research purposes and CaFe LINAC application. The state of art technology is used in production and surface treatment. The SRF cavities are fabricated using high purity grade niobium materials (RRR > 300). The thickness of niobium sheets are between 3 to 3.5 mm, the last Electron Beam Welding (EBW) locations are trimmed to 2mm for an adequate inside welding joints. The vendor at Ningxia supplied 8.5T niobium material for CiADS project. A new supplier at Xi'an product 7.5T niobium for HIAF project.

Cavity's helium vessel is made of titanium, then the TIG weldings are used to weld cavity NbTi flanges with titanium vessel. Three main vendors are participating in the cavities production.

Due to the compact structure of the linacs, all the low beta cavities have four additional rinsing ports for full surface covering during High Pressure Rinsing (HPR). The cavity's mechanical design for CiADS and HIAF projects are shown in Fig. 3.

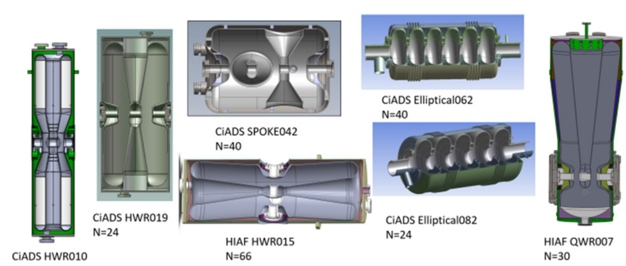

Figure 3: CiADS and HIAF cavities with helium jackets.

Since 2019, pre-production of cavities has been started. All seven types of cavities are fabricated in the vendor. The naked HWR010 cavities have been completed. Figure 4 shows some of the fabricated HWR010 cavities.

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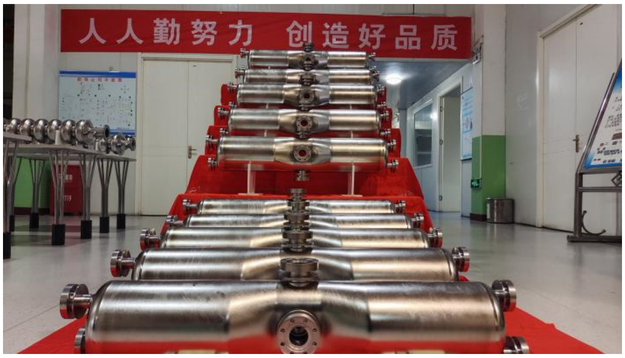

Figure 4: CiADS HWR010 cavity production.

PRE-PRODUCTION CAVITIES TESTING

To ensure the stability of quality control during SRF cavity fabrication, the cavity pre-production for each vendor has been tested at 4.2 K. The Fig. 5 shows a test result of HWR010 cavity, which is supplied by Ningxia company. The E_p reached 49 MV/m, which corresponds to B_p=107 mT. These are the limits for reliable niobium cavities operating at 4.2 K.

The cavity was polished 200 microns by BCP followed by a 600 ^{0}C heat treatment for 10 hours degassing in a high vacuum furnace. Then the cavity was light polished 20 microns by BCP. HPR was used to remove the residual contamination. The cavity was assembled in a clean room and a 120 ^{0}C baking for 48 hours was used for this cavity.

After this validation test, the massive production were carried on.

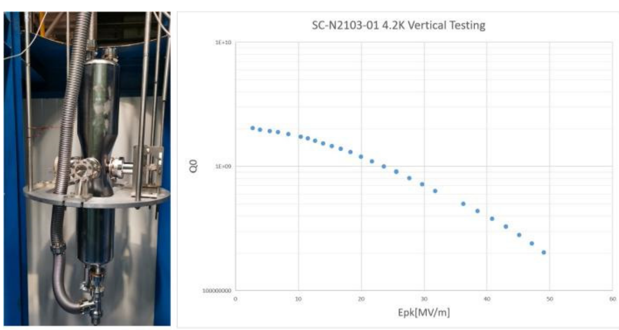

Figure 5: The Q_0 vs E_p curve of HWR010 naked cavity during vertical testing (right), the cavity in the testing fixture (left).

SCHEDULE

The HIAF project will start beam commissioning in 2025. All the cryomodules are expected to be completed and installed in the tunnel before the mid of 2024. The SRF cavity's production and processing will be completed in the beginning of 2024. So the total 96 cavities will be produced in the coming two and half years.

The linac section of CiADS shares the same schedule with HAIF linac, so the cavity production will be completed and testing by 2024.

CONCLUSION

The design stage of the SRF cavities for both projects CiADS and HIAF has been completed. The pre-production for all types of SRF cavities has been started since 2019. Now the massive production for both linacs have been launched. It's expected that the total of 233 SRF cavities will be completed in the next three years.

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