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PROGRESS OF THE 2x4-CELL SUPERCONDUCTING ACCELERATOR FOR THE CAEP THz-FEL FACILITY*

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Abstract

The high average power THz radiation facility is now under construction in China Academy of Engineering Physics. The superconducting accelerator is one of the most important components for this facility, including two 4-Cell TESLA superconducting radio frequency cavities. The designed effective field gradients for both cavities are 10-12 MV/m. This paper will present the progress of the 2x4-cell superconducting accelerator, mainly including its construction and cryogenic test in Chengdu. At 2 K state, the cryomodule works smoothly and stably. The effective field gradients of both cavities have achieved 10 MV/m. Further beam loading experiments are now in progress.

INTRODUCTION

At present, China Academy of Engineering Physics (CAEP) is developing a THz radiation facility (THz-FEL) with Peking university and Tsinghua university. This is the first high average power THz user facility based on superconducting radio frequency (SRF) technology in China [1]. The THz-FEL facility consists of a high-brilliance electron gun, a superconducting accelerator, a high-performance undulator and so on, as shown in Fig. 1. The designed frequency of the THz radiation is 1-3 THz with the average output power beyond 10 W. Correspondingly, the electron energy after acceleration is 6-8 MeV and the effective field gradient should be 10-12 MV/m.

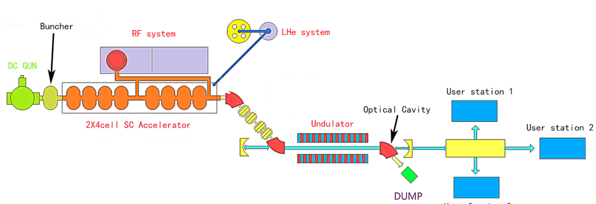

Figure 1: General layout of the CAEP FEL-THz facility.

The superconducting accelerator is one of the most important components for this facility, which contains the following subsystems: a cryostat, double 4-cell TESLA SRF cavities, double tuners, double main couplers and some auxiliary systems, including the microwave system, the cryogenic system and the low level RF control system, as shown in

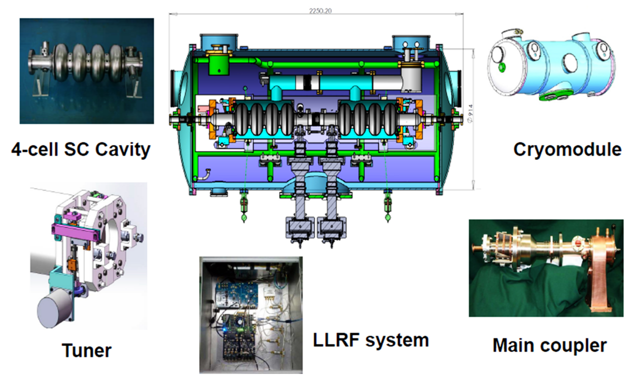

Figure 2: The cross-section and components of the superconducting accelerator [2].

Fig. 2. The design and fabrication of these subsystems have been finished [2]. This paper presents the construction and cryogenic test of the 2x4-cell superconducting accelerator.

CONSTRUCTION

The operation of the superconducting accelerator asks for extremely strict conditions: free of contamination, high vacuum, cryogenic temperature and low magnetic field. So, the assembly process is especially important for the superconducting accelerator to achieve good performances. The first step is the conditioning of the main couplers, which is operated in Chengdu. The microwave power from an induced output tube (IOT) has run up to about 25 kW in both pulse mode and CW mode.

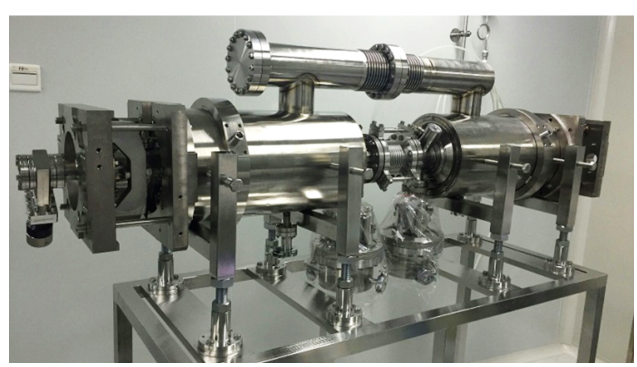

Figure 3: The axis part of the SC accelerator after assembly.

Since there is no 100-class clean room in our laboratory temporarily, we did the axis part assembling at Peking University after the conditioning of the main couplers. The cold

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ends of the main couplers connected with the SRF cavities ware also taken to Peking University with nitrogen protection. Before the clean assembly, the buffered chemistry polish (BCP) and high pressure rinsing (HPR) for the 4-cell cavities had been done. The assembly of the axis part was finished in a 100-class clean room, as shown in Fig. 3, with a laser airborne particle counter monitoring the cleanliness of the components, screws and surroundings.

Then, the axis part was transited to our lab in Chengdu by road after the vacuum leak hunting and filling protective gas, clean nitrogen. The next step is the final assembly at the local experimental hall. The major steps includes components cleaning with ultra pure water, installation of heat anchors, tuners and temperature sensors, package of diathermic membrane and magnetic shield, installation of suspension structures and detective wires and so on. Finally, the warm ends of the main couplers were installed in a removable clean room. The yellow part in Figure 4 is the superconducting cryomodule after assembly, which has been connected with the cryogenic system and the microwave system.

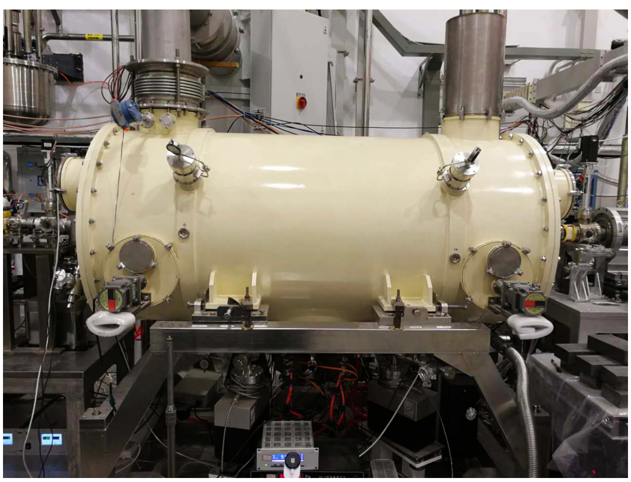

Figure 4: The superconducting cryomodule after assembly.

CRYOGENIC TEST

After the assembly of the superconducting accelerator, a cryogenic test platform has been built. As shown in Fig. 5, the superconducting accelerator is equipped with an RF control system. The pickup signal is detected by a weakly coupled antenna from the cavity and delivered to the low level RF (LLRF) control system. The amplitude and phase of the cavity field are modulated in the LLRF control system and a low power output signal is generated to drive the IOT. The forward high power microwave is transited through the waveguide, directional coupler and main coupler and fed into the cavity. To protect the safety of the cavities and couplers, the vacuum, temperature and arc signals are monitored by a protective interlock. If there is anything abnormal, the protective switch will cut off the driving signal immediately. Additionally, the forward, reflected and pickup signals are measured by power meter and oscilloscope simultaneously in the control room.

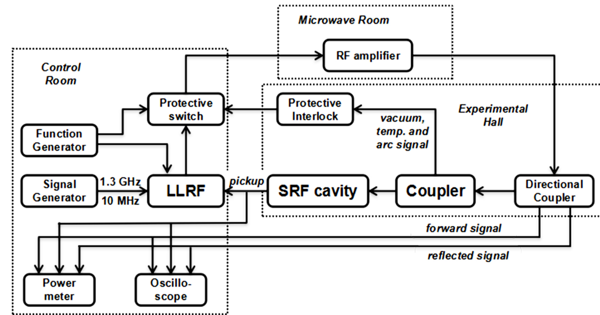

Figure 5: The diagrammatic sketch of the cryogenic test platform.

It took about 10 days for the cool down process from room temperature to 2 K. To prevent sudden deformation of the inner mechanic structure, the precooling of liquid nitrogen processed slowly, which took about a week to cool down to 80 K. Figure 6 presents the temperature distribution of the cryomodule at 2 K state. During the whole cool down process, the vacuum variations of the cryostat, the cavities and the couplers have been kept a close watch on, as shown in Fig. 7. It follows that the cooling procedure is beneficial for the increase of vacuum.

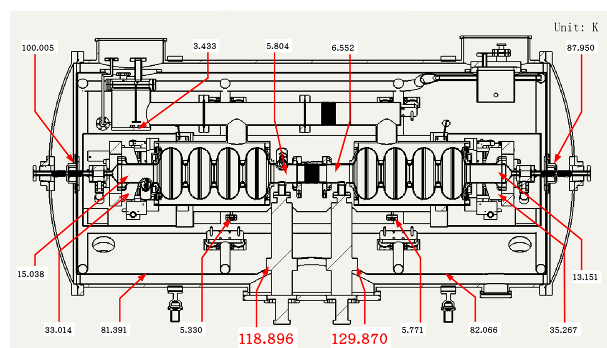

Figure 6: The temperature distribution of the cryomodule at 2 K state.

In order to measure the field gradient at 2 K state conveniently, the calibration of the relationship between the effective field gradient E_{acc} and the amplitude of the pickup signal V_{pickup} should be done at 4 K state. The LLRF system works in self exited loop (SEL) mode building up RF field in the cavity. By adjusting LLRF system parameters, both cavities succeed in achieving superconducting state and building up stable field. The forward, reflected and pickup signals are monitored on the oscilloscope, as shown in Fig. 8. The external quality factor of the main coupler (Q_e) is calculated according to the decay time of the pickup signal. By changing the depth of the inner conductor inserted into the cavity, Q_e of both couplers are adjusted to the designed optimal value $1.6{\times}10^6$. Then, we gradually increase the forward

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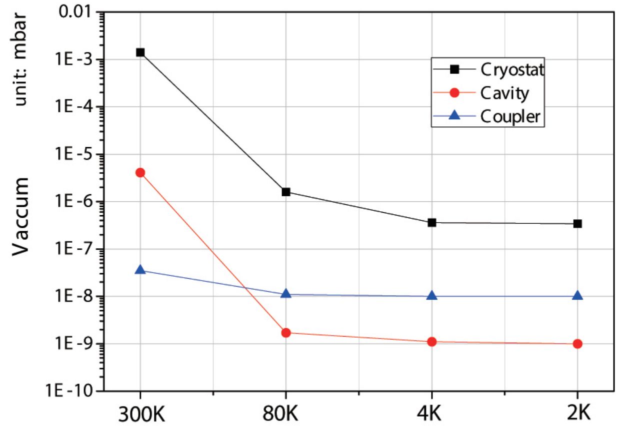

Figure 7: The vacuum variation of the cryomodule during the cooling down process.

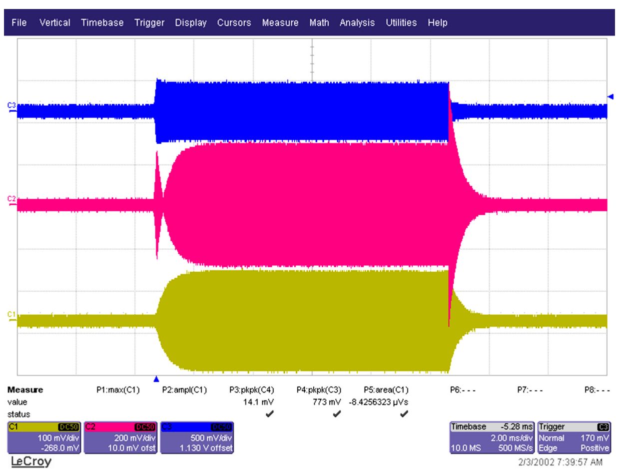

Figure 8: The waveforms of forward (blue), reflected (red), and pickup (yellow) signals at 4 K state.

power and measure the effective field E_{acc} and the amplitude of the pickup signal V_{pickup}.

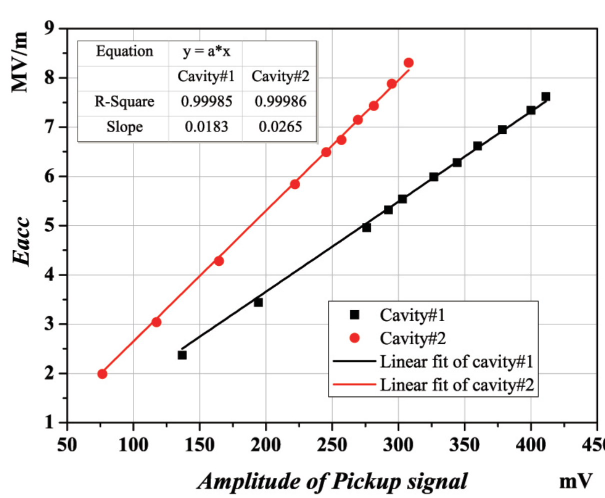

Figure 9: The relationship between the effective field gradient E_{acc} and the amplitude of the pickup signal V_{pickup}.

Figure 9 demonstrates good linear relationships between E_{acc} and V_{pickup}. The maximum field gradients of both cavities at 4 K have reached 7.6 MV/m and 8.3 MV/m respectively. Subsequently, the cryomodule succeeds in realizing 2 K state. The corresponding helium pressure is 25 mbar. The superconducting accelerator works smoothly and stably at 2 K. The effective field gradients of both cavities have reached 10 MV/m, which have satisfied our designed goal. The LLRF system works in amplitude-phase (AP) mode, and the amplitude and phase stability of LLRF is 0.06% and 0.03° in Fig 10, much better than the designed goal (0.3%, 0.3°).

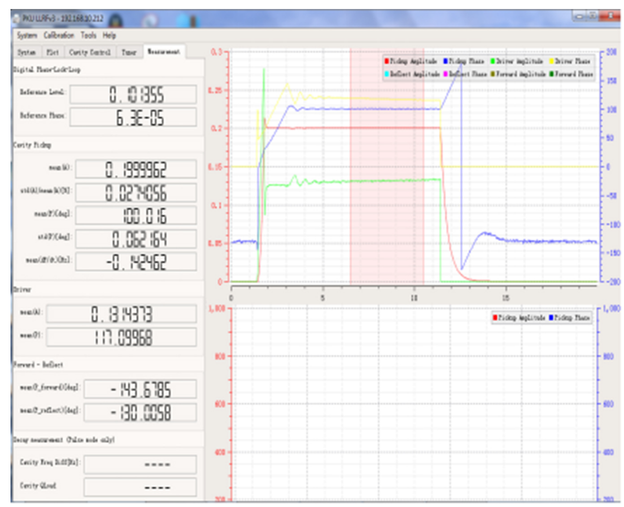

Figure 10: The interface of the LLRF control system.

CONCLUSION

The 2x4-cell superconducting accelerator for THz-FEL facility has finished its construction and cryogenic test. The construction of the cryomodule are treated seriously and carefully. The cooling down process is carried out smoothly. At 2 K state, the whole superconducting cyomodule works well and stably. The effective field gradients of both cavities have achieved our target, 10 MV/m. Further beam loading experiments are now in progress.

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