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COMMISSIONING OF THE 2×4-CELL SUPERCONDUCTING ACCELERATOR FOR THE CAEP THz-FEL FACILITY *

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Abstract

The CAEP THz-FEL facility is the first high average power THz radiation user facility in China. The superconducting accelerator including double 4-cell superconducting radio frequency (SRF) cavities is one of the most important components for this facility. The construction and horizontal test of the superconducting accelerator have been finished. At 2K state, the effective gradients of both cavities have reached our designed goal, 10 MV/m. This paper mainly presents the commissioning results of the superconducting accelerator. In the commissioning experiments, the kinetic energy of 5mA electron beams can be accelerated to 8 MeV successfully, with the energy spread less than 0.2%, much better than our design goal. Further beam loading experiments are in progress.

INTRODUCTION

At present, China Academy of Engineering Physics (CAEP) is developing a THz radiation facility (THz-FEL), which is the first high average power THz user facility in China based on SRF drived oscillator type free electron laser [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 superconducting accelerator is expected to provide 6-8 MeV quasi-CW electron beams with the average current of 1-5 mA.

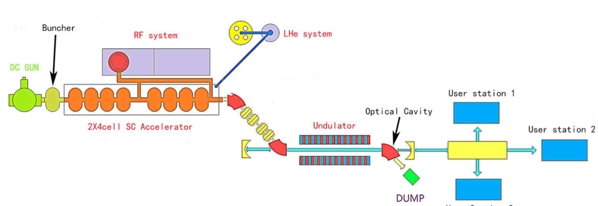

Figure 1: General layout of the CAEP FEL-THz facility.

The superconducting accelerator is one of the most important components for this facility, which contains 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 Fig. 2. The design and fabrication of these subsystems have been finished [3]. All these components have reached their designed goals and the linac module has also finished its assembling and horizontal test at Chengdu. At 2 K state, the whole superconducting accelerator works well and stably. The effective field gradients of both cavities have achieved 10 MV/m [4]. This paper mainly presents the commissioning results of the 2x4-cell superconducting accelerator, including some beam loading experiments and the measurement of energy and energy spread of the electron beams.

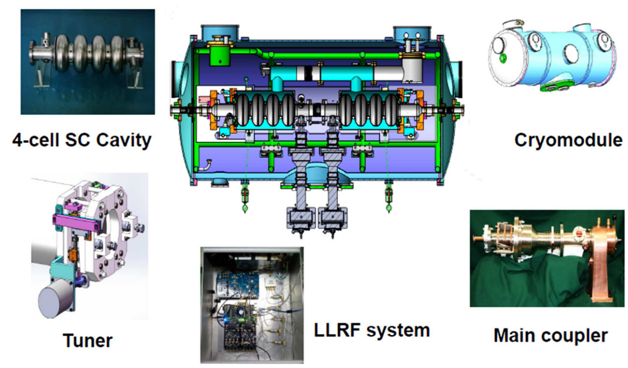

Figure 2: The cross-section and components of the superconducting accelerator [2].

Table 1: Designed Parameters of the 2×4-cell Superconducting Accelerator.

Parameters	*Designed value*
Frequency	1.300 GHz
Q_0	$\geq 5\times10^9$
Q_e	8×10^5-5×10^6
E_{acc}	8-10 MV/m
I_b	1-5 mA
Repetition rate	54.17 MHz
Energy gained	6-8 MeV
Energy spread	0.75%
2 K heat loss	$\leq$ 20 W
Magnetic field @ central axis	$\leq$20 mGs

BEAM LOADING EXPERIMENTS

The superconducting linac module has been connected with the beam line after the horizontal test. Figure 3 shows

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the sketch map of the straight beam line and Figure 4 is a picture of the CAEP THz-FEL facility after installation. The first and most important component is the photocathode DC injector. The high voltage acting on the surface of the photocathode is up to 320 kV. Before the superconducting accelerator, there is a buncher cavity to provide longitudinal manipulation of electron beams. The bunch length of electron beams at the entrance of the superconducting cavity should be compressed to 6-8 ps.

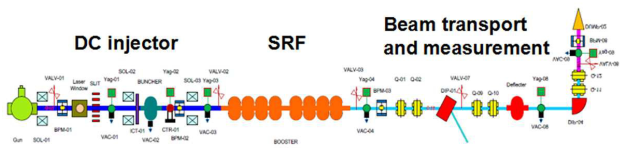

Figure 3: Sketch map of the straight beam line.

Figure 4: Picture of the CAEP THz-FEL facility.

Some beam loading experiments have been done with the straight beam line. The beam loading effect has been observed successfully in pulse mode, as shown in Fig. 5. The repetition rate and macro pulse length of the microwave are 10 Hz and 10 ms. The macro pulse length of the electron beams is 200 us and the measured beam current is 5 mA. The electron beams taking away microwave power when travelling through the cavity, which leads to the decrease of the storage energy as well as the field gradient of the cavity. To maintain the stablity of the field gradient, the low level RF (LLRF) system will increase the forward power. Meanwhile, when beam loading exists, the loaded quality factor Q_L decreses, which causes the decrease of transmission resistance and reflected power.

ENERGY AND ENERGY SPREAD MEASUREMENT

The basic principle of measuring energy and energy spread is based on the deflection of electron beams in the perpendicular dipole magnetic field due to Lorentz force, as shown in Fig. 6. The radius curvature of our analysis magnet is 300 mm. The beam spot can be adjusted to the center of the YaG screen by changing the current of the analysis magnet. So the kinetic energy of the electron beams can be calculated from the following formula:

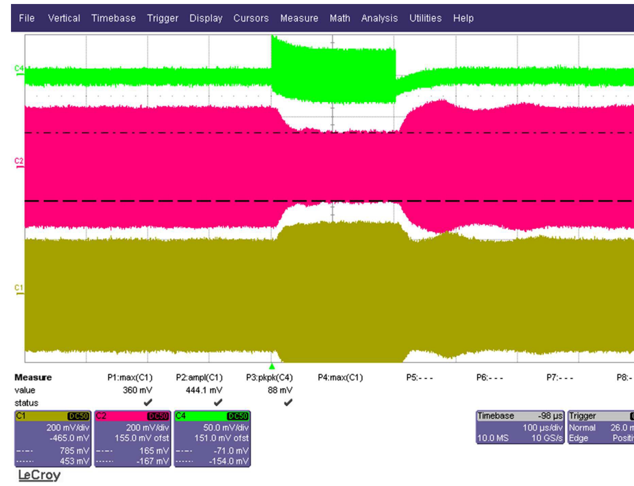

Figure 5: Beam current signal (green), reflected signal (red) and forward signal (yellow) in pulse mode.

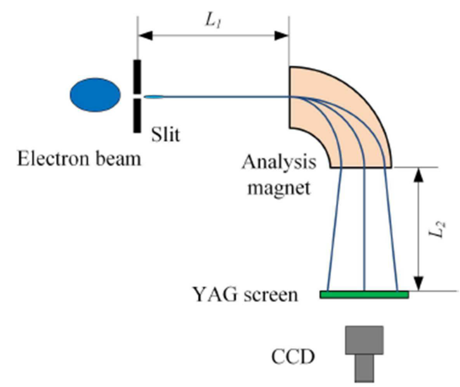

Figure 6: The energy and energy spread measuring principle.

$$E_k[\mathrm{MeV}]=2.1224\ I[\mathrm{A}]-0.2977$$

Where E_k is the kinetic energy of electron beams and I is the current of the analysis magnet. Table 2 lists some measurement results with different electron energies. $E_{acc,cav\#1}$ and $E_{acc,cav\#2}$ are field gradients of the upstream cavity and the downstream cavity correspondingly. To maintain the longitudinal compression of electron beams, the initial accelerating phases of both cavities are set to be about $-10°$ comparing to the optimal accelerating phase. So the measured energy gained is a bit smaller than the maximum energy gained in theory. The kinetic energy of electron beams can be accelerated to 8 MeV successfully.

Figure 7(a) shows the colored beam spot after analysis magnet, when the beam current is 5 mA and the macro pulse length is 400 ns. The measured current of the analysis magnet is 4.02 A. So, the measured central kinetic energy of the electron beams is 8.22 MeV. Figure 7(b) gives the energy

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Table 2: Measurement Results with Different Electron E ergies

$\mathbf{E}_{acc,cav\#1}$ (MV/m)	$\mathbf{E}_{acc,cav\#2}$ (MV/m)	**I** (A)	$\mathbf{E}_k$ (MeV)	**Measured energy gained** (MeV)	**Maximum energy gained** (MeV)
6.2	0	1.64	3.17	2.85	3.01
8.4	0	2.13	4.22	3.90	4.06
4.2	6.6	2.79	5.30	4.98	5.22
7.5	6.7	3.40	6.92	6.60	6.88
8.25	8.7	3.96	8.11	7.79	8.2

distribution curve of the electron beams, and the measured rms energy spread is 0.19%, which is much better than our designed goal.

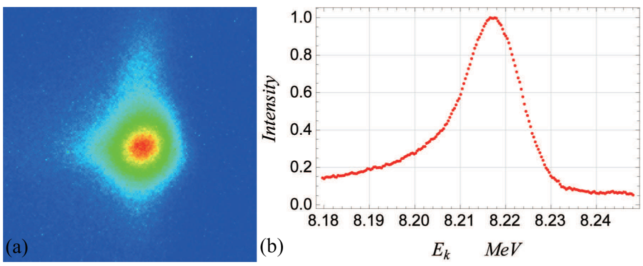

Figure 7: (a) Colored beam spot on YaG screen after analysis magnet, (b) the energy distribution curve of the electron beams.

CONCLUSION

The 2×4-cell superconducting accelerator for the THz-FEL facility has finished its construction, performance test and commissioning. In the commissioning experiments, the beam loading effect has been observed successfully and the measured kinetic energy of 5 mA electron beams is beyond 8 MeV, with its rms energy spread less than 0.2%, much better than our designed goal. So far, the debugging of this facility has made significant progress with the support of the superconducting accelerator.

ACKNOWLEDGEMENT

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REFERENCES

[1] X. Zhou *et al.*, "Design of a high average power terahertz-FEL faiclity", in *Journal of Terahertz Science and Electronic Information Technology*, 2013, 11(1): p.1-6.

[2] X. Luo *et al.*, "Design of the 2x4-cell superconducting cryomodule for the free-electron laser", Presented at the 18th International Conference on RF Superconductivity, Lanzhou, China, July 17-21, 2017, paper MOPB010, unpublished.

[3] X. Luo *et al.*, "Design and fabrication of the 2×4-cell superconducting linac module for the free-electron laser", *Nuclear Instruments and Methods in Physics Research Section A*, 2017, 871: pp.30-34.

[4] K. Zhou *et al.*, "Progress of the 2x4-cell superconducting accelerator for the CAEP THz-FEL facility", Presented at the 18th International Conference on RF Superconductivity, Lanzhou, China, July 17-21, 2017, paper MOPB037, unpublished.