Development of prototype superconducting linac for low-beta ions

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Since 2015, the accelerator group of Nishina Center has joined the ImPACT program, led by Dr. Fujita, to develop a system for processing the so-called long-lived fission products (LLFPs) via nuclear reactions and transmutations induced by ion beams provided by a particle accelerator.[1] As a part of this program, a prototype superconducting (SC) linac has been developed. The main purpose of this prototype is to realize a high acceleration field gradient E_{acc} with a high performance SC-cavity (high-Q_0) and a spatially efficient cryomodule. The cryomodule is the main component of SC-linac, which comprises 4 K SC-cavities. Finally, we tried to evaluate its stability and reliability using the prototype cryomodule.

The prototype cryomodule (Fig. 1) consists of one SC-cavity, one dummy, cavity and a vacuum vessel equipped with a thermal shield. The length of the cryomodule was designed as 1.34 m. The SC-cavity, whose beam ports are connected with bellow pipes and are equipped with a power coupler, is supported by four hollow pillars made of GFRP. To minimize heat conduction from the room temperature part to the 4 K cold part, a thermal shield is installed between the room temperature part and the 4 K cold part. The thermal shield provides thermal anchors to the beam pipes, the power couplers, and the cavity supports.

The developed SC-cavity was based on the structure of a quarter-wave resonator (QWR) (See Fig. 1) with optimum β as low as 0.08 and a resonant frequency of 75.5 MHz, which can be changed up to 5 kHz with a mechanical tuner. The planned operating E_{acc} is 4.5 MV/m with a Q_0 of 8.9 $\times 10^8$, which is estimated by using the 3D simulation package Micro Wave Studio (MWS).[2] Note that Q_0 is defined as the ratio of its stored energy to the wall loss of the cavity. The SC-QWR cavity was fabricated using pure niobium sheets. Q_0 was measured by an RF(radio frequency) test, cooling the bulk SC-cavity to 4 K with liquid helium. Extensive study of surface treatment was performed[3] and a Q_0 of 2.3$\times 10^9$ was achieved at an E_{acc} of 4.5 MV/m (Fig. 2).

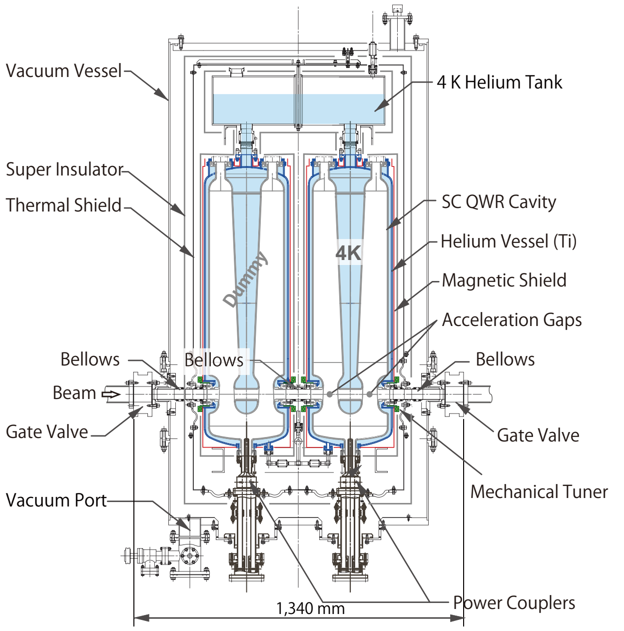

Fig. 1. Schematic of the prototype cryomodule.

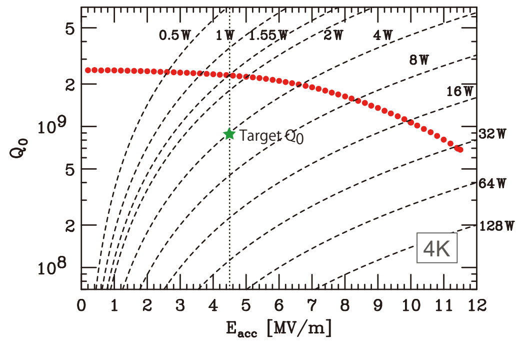

Fig. 2. Measured Q_0 plotted as a function of E_{acc}. The dashed lines indicate contours of the wall loss.

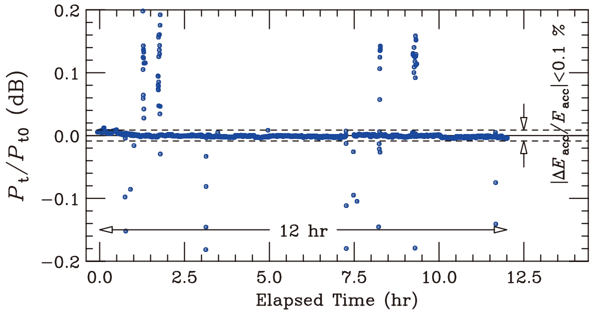

Fig. 3. Power level of the pickup signal (P_t) from the SC-cavity during the long-term operation test.

After integration of the SC-cavity to the prototype cryomodule, a long-term operation test was successfully performed. A solid state amplifier with a maximum output power of 4.5 kW and a digital feedback module have been developed, which excite the SC-cavity with an external Q of 1×10^6. In the feedback loop, the amplitude of E_{acc} was limited by an RF limiter and its phase was locked to the reference signal provided by the external signal generator. The amplitude and phase errors were 0.1% and 1 degree, respectively. In Fig. 3, the deviation of the power level of the pickup signal (P_t/P_{t0}) was plotted as a function of the elapsed time during the 12 hr operation test at an E_{acc} of 4.75 MV/m. The reliability with a criteria of $|\Delta E_{acc}/E_{acc}| \leq 0.1\%$, was evaluated as 95%. This can be improved by tuning the tuner control.

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References

1) http://www.jst.go.jp/impact/en/program/08.html .
2) http://www.cst.com .
3) N. Sakamoto *et al.*, SRF2017, WEYA01; K. Yamada *et al.*, PASJ 14th Annual Meeting, TUOL02.

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