Development of prototype superconducting linac for low-beta ions

N. Sakamoto,*1 O. Kamigaito,*1 K. Ozeki,*1 K. Suda,*1 Y. Watanabe,*1 and K. Yamada*1

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 \( \beta \) 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 performed3 and a \( Q_0 \) of 2.3 \( \times \) 10^9 was achieved at an \( E_{acc} \) of 4.5 MV/m (Fig. 2).

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 \( Q_0 \) of 1 \( \times \) 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.

This research work was funded by the ImPACT Program of the Japan Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

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.

References
3) N. Sakamoto et al., SRF2017, WEYA01; K. Yamada et al., PASJ 14th Annual Meeting, TUOL02.