Rare Isotope Science Project (RISP), Daejeon, Korea

Abstract

The facility for the vertical test at 2 K with the master frequency 81.25 MHz is being prepared at Rare Isotope Science Project (RISP) and the preliminary tests are being done as the preparation progresses. We briefly describe the vertical test system, the tests being done, and the future plan for the completion of the facility.

INTRODUCTION

At RISP [1], 4 different kinds of the superconducting cavities have been developed. Now the fabrication of the cavities is complete and their vertical test is being prepared. At the moment, as a beginning stage, the minimum facility is prepared with the prospect for further expansion and upgrade of the facility. For now, 4 K cryogenic system is prepared and no surface processing facility is available yet. The simple system check and the leak check at cryogenic temperature is examined and some RF measurement including critical coupling calibration and decay time measurement is made.

The future plan includes the construction for surface processing, the implementation of the magnetic shields, 2 K pumping station, LLRF system for the vertical test, adjustable coupler, radiation shields, and the interlock system.

SYSTEM PREPARATION

The vertical test stand consists of the cryostat, the pit, the test insert, the staging rack, and vacuum pump system.

The cryostat (See Fig. 1(a)) is made of the stainless steel STS304: The vacuum vessel is 3300 mm deep with 800 mm inner diameter. The helium vessel is 3000 mm deep 500 mm with inner diameter with about 250 L helium capacity. The helium vessel is surrounded by the thermal shield. The test insert was designed and fabricated. It consists of the top plate, the support cage, and the thermal baffle to reduce the static heat load through the conduction. The top plate is equipped with the pressure relief system, i.e., 8 cm diameter burst disk combined with a re-closable safety relief valve at a set pressure of 1 bar. The relief system is sized assuming complete helium vaporization due to a leak in insulating vacuum. It must also provide the various feedthroughs for the vacuum port (for the cavity), the temperature sensors, level sensors, N and SMA-type RF cables for the input and pick up couplers, LHe input port, and Gas output port. The vacuum pump system for the cavity evacuation was prepared. The system consists of the turbo molecular pump, the scroll pump, the controller, the compressor, the vacuum gauges (low range and the full range), and the residual gas analyzer (RGA) as shown in Fig. 1(c).

PRELIMINARY MEASUREMENTS

During the first cool down, the preliminary RF measurements were done using the vector network analyzer (VNA) only. Using the VNA, the frequency shift during the evacuation, the cool down (to 4 K), and the helium pressure pres-
surization were measured. (The last were used to estimate the helium pressure fluctuation sensitivity) The decay time and the $Q_e$ were measured during the second cool down.

As a commissioning of the vertical test system, we performed a few preliminary measurements of the cavities. To commission the various vertical test subsystems including the cryogenic system, the RF cables, the pump system, and the sensors, and do leak test at the cryogenic temperature, we cool down the cavity to 77 K using LN$_2$ and subsequently 4 K using LHe. As shown in Fig. 3, the pressurization by 1.5 psi made cool down fast enough so that the parking zone (between 60 and 150 K) was passed within 45 minutes [3], which is much shorter than tolerance limit, 1 hour. In addition, we also measure the resonant frequency using the vector network analyzer (VNA). The measured frequency changed from 162.881 MHz at 301 K to 163.124 MHz at 4.2 K. The change in frequency is

$$\Delta f = 243 \text{ kHz.} \quad (1)$$

This is roughly the same as the expected value from the analytic calculation: From $\delta f / f = -\delta l / l = 0.155$, we have $\delta f = 252 \text{ kHz}$. In general, the various quality factors are related as follows.

$$\frac{1}{Q_L} = \frac{1}{Q_0} + \frac{1}{Q_e} + \frac{1}{Q_t} \quad (2)$$

In the 2-port system, the critical coupling is realized if

$$\frac{1}{Q_0} + \frac{1}{Q_t} = \frac{1}{Q_e}. \quad (3)$$

which implies $Q_e = 2Q_L$. [4] Then in $Q_t \gg Q_0, Q_e$ limit, $Q_0$ is computed to be

$$Q_0 \approx 2Q_L + \frac{4Q_L^2}{Q_t}. \quad (4)$$

A different color corresponds to a different temp. sensors.

Figure 3: Cool down data.

which makes it possible to obtain $Q_0$ from $Q_L$, i.e., $Q_0 \approx 2Q_L$. The $Q_L$ is obtained by the measurement of the decay time $\tau$ via the relation

$$Q_L = \pi f \tau, \quad (5)$$

where $f$ is the resonant frequency of the cavity. Therefore, the measurement of the decay time at critical coupling would give us the $Q_0$ in a good approximation.

4: Hadron Accelerators
A08 - Linear Accelerators
The measurements of the decay times at the critical coupling are done in three steps: with the copper cavity at room temperature, with niobium cavity at 77 K (including the room temperature measurement), and with the niobium cavity at 4 K. To achieve the critical coupling with the fixed coupler in general, we first manufacture the antennae whose lengths are determined according to (3), once the $Q_0$ and $Q_t$ are known.

![Figure 4: The measured $S_{12}$ of the copper cavity at room temperature.](image)

The decay time $\tau_c$ of the copper cavity is measured to be $\tau_c = 21.5 \mu s$, which translates to $Q_L = 1.1 \times 10^4$, which agrees with the measurement by the VNA.

![Figure 5: Decay time measurement of the copper cavity at room temperature.](image)

Secondly, we measured the decay time of the niobium cavity in the critical coupling at 77 K. We first estimate the $Q_0$ of the niobium cavity at 77 K by CST-MWS simulation. The expected $Q_0$ was $Q_0 = 2 \times 10^4$. Using $Q_t$ from room temperature and (3), we expect $Q_e$ to be $Q_e = 1 \times 10^4$ at 77 K. At room temperature where the fixed coupler antenna can be easily exchanged, we fixed the antenna length by repeated measurement of the $Q_L$, and subsequently $Q_e$.

After cool down to 77 K, we measured the decay time $\tau$ and critical coupling by the VNA. The measured decay time was $\tau = 10.04 \mu s$, which leads by (5) to $Q_L = 5.13 \times 10^3$. This is compared with the measurements by the VNA in Table 1.

![Figure 6: The decay time of the Nb cavity at 77 K.](image)

**Table 1: The Measurement by VNA at 77 K**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_L$</td>
<td>-</td>
<td>4816</td>
</tr>
<tr>
<td>VSWR$_e$</td>
<td>-</td>
<td>1.054</td>
</tr>
<tr>
<td>VSWR$_t$</td>
<td>-</td>
<td>60.7</td>
</tr>
<tr>
<td>$\beta_e$</td>
<td>-</td>
<td>0.949</td>
</tr>
<tr>
<td>$\beta_t$</td>
<td>-</td>
<td>0.017</td>
</tr>
<tr>
<td>$Q_0$</td>
<td>MHz</td>
<td>9465</td>
</tr>
</tbody>
</table>

Finally, we plan to measure the decay time of the niobium cavity in the critical coupling at 4 K in near future.

**ACKNOWLEDGMENT**

This work was supported by the Rare Isotope Science Project which is funded by the Ministry of Science, ICT and Future Planning (MSIP) and the National Research Foundation (NRF) of the Republic of Korea under Contract 2013M7A1A1075764.

**REFERENCES**