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EXTERNAL Q MEASUREMENTS FOR QUARTER WAVE RESONATORS IN RISP*

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Abstract

A heavy-ion accelerator facility is under construction for Rare Isotope Science Project(RISP) in Korea. The super conducting cavity, quarter wave resonator(QWR) which consists of driver and post linear accelerator system, is now in the mass production phase. In order to develop the QWR cavity and cryomodule, the RF couplers are fabricated and tested. In this paper, the study of external Q for QWR coupler will be described.

INTRODUCTION

Several couplers are developed for QWR prototype cavities and cryomodules [1–3]. To conduct the QWR cavity test, which is called the vertical test(VT), the variable coupler is fabricated. For the QWR cryomodule test or horizontal test(HT), the RF power coupler was designed, fabricated and tested. The RF pickup coupler was developed for VT and HT. In order to satisfy the requirements of external Q, the CST-simulation and measurements of external Q are performed.

EXTERNAL Q SIMULATION

The requirements of external Q(Q_{ext}) is summarized in Table 1. From QWR cryomodule tests, the external Q for RF power coupler has been changed to get the LLRF control margin as shown in Table 1.

Table 1: Requirements of the External Q for QWR Couplers

Type of coupler	Target external Q
Variable coupler	$5 \times 10^6 \sim 5 \times 10^{10}$
RF power coupler (prototype)	$1.0 \sim 2.0 \times 10^6$
RF power coupler (mass production)	$3.0 \sim 5.0 \times 10^5$
RF pickup coupler	$> 2.4 \times 10^{10}$

Typically, the external Q is related to the coupling strength with the field of cavity. The coupling strength depends on how much the antenna is penetrated into the cavity. The external Q could be predicted by CST-simulation as the penetration length of antenna tip [4]. In order to compare

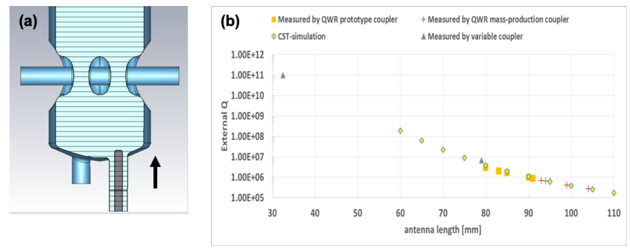

Figure 1: CST-simulation and measured results of external Q. (a): the simulation modeling. (b): the results of simulation and measured.

the results of the simulation with the measurements, the orgin of the antenna length is set at the cavity-coupler flange. The simulation model and the results are shown in Figure 1. For the external Q of variable coupler, the variation of the antenna is about 40 mm. In order to measure the external Q of prototype of RF power coupler, the antenna tips are prepared with 5 mm step. As shown in Figure 1 (b), the measured results are in good agreement with the simulation results. The measurement methods will be discussed in the next section.

MEASUREMENTS OF EXTERNAL Q

Vertical Test

To conduct the VT, the variable coupler and RF pickup coupler are developed. The coupling type of the variable coupler is the capacitive. And the RF pickup coupler type is designed as the inductive. It is important to the measurement of external Q of pickup coupler($Q_{ext,pickup}$) during VT. In order to control the external Q of pickup coupler, the external Q must be calibrated in the room temperature and the cryogenic temperature.

Variable coupler: To provide the adjustment of external of input coupler, variable couplers have been developed. With the collaboration with TRIUMF(prototyping of QWR and HWR) and Cornell Univ.(HWR) [5, 6], two types of variable couplers were fabricated and tested. In Figure 2, the variable couplers are presented. The variable couplers were performed the operation test in cryogenic temperature. the operation test was performed with the liquid nitrogen. The variable couplers were inserted in the liquid nitrogen, and the movement of the coupler was monitored at 77 K. The variable coupler in Figure 2 (a), passed the cold test and the results showed the reproductibility of operation which is enough to use for VT(Figure 2 (c)). The variable coupler in Figure 2 (b) did not operate in the cold test. The shrinkage of

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gear part had malfunction of the coupler in cold temperature. As shown in Figure 2 (c), the operation range of variable coupler is about 40 mm. This operation range can cover the target range of $Q_{ext,varible coupler}$ in Table 1.

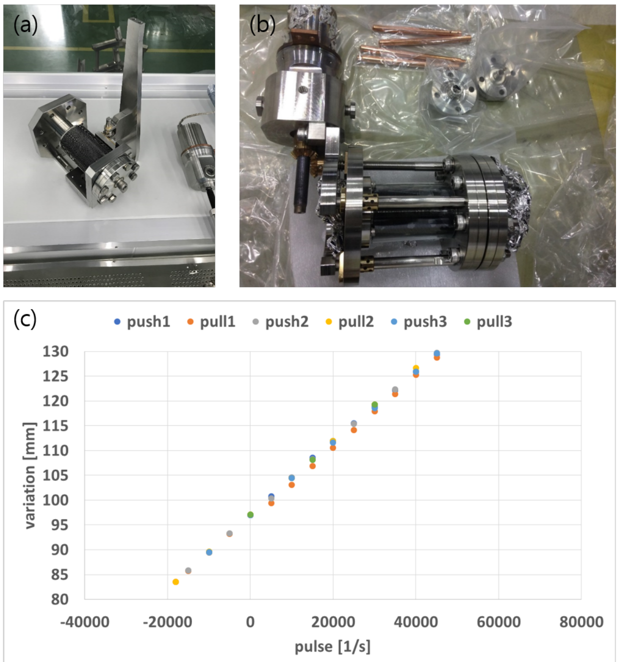

Figure 2: Variable couplers for the vertical test. (a) and (b) show the two different types of variable couplers. Both of the couplers are operated by the cryogenic motor. During the three cycles of the possible bellows stroke (40 mm), the variations were measured in terms of the pulse of controller.

Measurements in room temperature: Following is the relation of the several external Q.

$$\frac{1}{Q_L} = \frac{1}{Q_0} + \frac{1}{Q_{in}} + \frac{1}{Q_t} \quad (1)$$

where, Q_L is the loaded Q, Q_0 is the intrinsic quality factor of the cavity, Q_{in} is the external Q of the RF input coupler and Q_t is the external Q of the RF pickup coupler. At the room temperature, Q_0 of QWR cavity is 2500 ~ 4500. As shown in Table 1, the external Q of input and pickup coupler are much larget than the Q_0. Therefore, the Q_0 is measured by the Q_L with VNA at the room temperature. The coupling constants are measured by S-parameter by following relations [7].

$$VSWR = \frac{1 + S_{11}}{1 - S_{11}} \quad (2)$$

$$\beta_{in} = \frac{1}{VSWR}. \quad (3)$$

$$\beta_t = \frac{|S_{21}|^2}{1 - (\frac{S_{11}}{S'_{11}})^2 - |S_{21}|^2} \quad (4)$$

Here, S'_{11} is the S_{11} value away from the resonace frequency. The external Q of input and pickup are obtained by $Q_{in} = Q_0/\beta_{in} = Q_L/\beta_{in}$, $Q_t = Q_0/\beta_t = Q_L/\beta_t$.

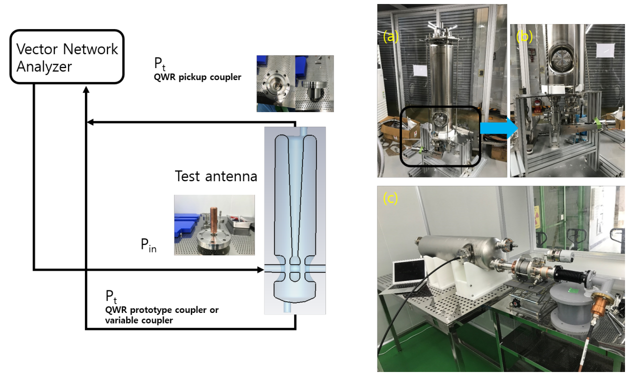

Figure 3: Test setup for the room teperature measurement in the vertical test. The left picture shows the schematic flow of the test. The assembled of the cavity and couplers are presented in the right pictures. The upper of the right picture shows the QWR cavity with the variable coupler, the lower of the right picture shows the setup for measuring the external Q of prototype RF power coupler.

The schematic setup for the room temperature measurements is presented in Figure 3. In order to deliver RF signal without noise, the test antenna is used as in Figure 3. The test antenna is assembled at the beam port, and the other couplers are attached to the lower or upper HPR port of cavity. Through the test antenna, the RF signal is incident to cavity. The transmitted RF is measured by the variable coupler or prototype of RF power coupler or RF pickup coupler. The port 1 of VNA is assigned to test antenna, and the port 2 is corresponding to variable coupler or RF power coupler or RF pickup coupler. During the measurement, one pair of RF input and pickup coupler is assembled with the cavity, the test antenna-variable coupler or the test antena-pickup coupler. The measured external Q of variable coupler and prototype of power coupler are presented in Figure 1.

Measurements after cool down: After the cool down of the cavity, the Q_0 is 10^8 ~ 10^9. The Q_t is obtained by measuring the decay time method [8].

Table 2: Results of External Q During VT

Type of coupler	$Q_{ext,RT}$	$Q_{ext,4.2K}$
Variable coupler		
Minimum value	7.2×10^6	4.0×10^7
Maximum value	~ 1.3×10^{10}	~ 2.3×10^{11}
QWR-1 pickup	4.25×10^{10}	5.58×10^{10}
QWR-3 pickup	2.82×10^{10}	6.6×10^{10}
QWR-5 pickup	-	1.31×10^{11}

The results of $Q_{ext,pickup}$ by the two methods are summized in Table 2. For the QWR-5 pickup coupler, the room temperature measurement was skipped. Due to the HPR of cavities, the pickup couplers were took apart from cavities

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after the VT. In the cryomodule test, the external Q of the input and pickup coupler were measured again, and the results will be presented in the next section.

Cryomodule Test

After the VT, the variable coupler is replaced by the RF power coupler in the cleanroom. During the cleanroom assembly, the external Q of power coupler(or $Q_{ext,in}$) and the external Q of pickup coupler(or $Q_{ext,t}$) are checked.

Measurements in room temperature: With the RF power coupler, the coupling constants could be obtained by the equation 3. The schematic setup for cryomodule test is shown in Figure 4.

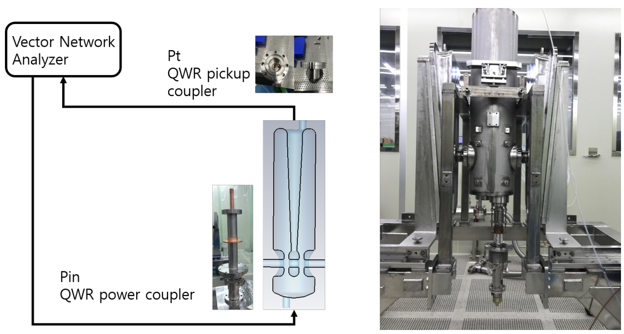

Figure 4: Test setup for the room teperature measurement in the cryomodule test. The left picture shows the schematic measurement flow. The RF power coupler is replaced in the cleanroom as shown in right picture.

Measurements after cool down: In the cryomodule test, the β_{in} is over-coupled. It means the calibration of $Q_{ext,in}$ could be obtained by measuring the loaded Q by VNA. Also, the formula for $Q_{ext,t}$ should be changed with the VT.

The measured external Q of power coupler and pickup coupler are shown in Figure 5. The decrease of $Q_{ext,in}$ is observed from tests. According to the Figure 1, the reason of changing external Q was caused by the changing of the penetration length of antenna after cool down due to the thermal shrinkage of the cavity and the outer conductor of the coupler. According to the simulation result shown in the Figure 1, the displacement of the antenna tip is estimated about 4.4 mm. Comparing the Figure 5 with the Table 2, the tendancy of the external Q for pickup coupler is opposite. From the VT, the external Q of pickup coupler was increased after the cool down, and the external Q of pickup was decreased after the cool down of the cryomodule. For the vertical test, the cavity is inserted in the cryostat with the liquid helium. This condition of cooling could be made the larger thermal shrinkage of the cavity then the shrinkage of the outer conductor of the couplers. As shown Table 2, the external Q of the variable and pickup couplers were increased after the cool down. On the other hand, the liquid helium exists in the transfer line and the helium jacket of the cavity in the HT. And, the cavity is mounted in the different mechanical condition with the vertical test, for instance the strong back is only used for suspending of the cavity in

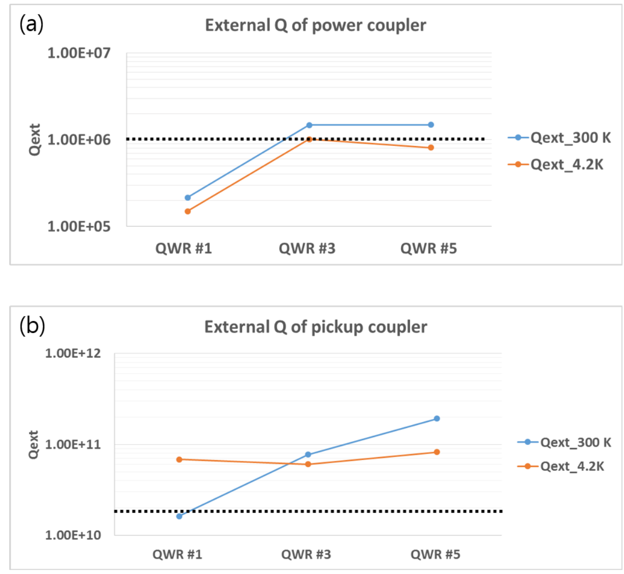

Figure 5: The results of the external Q of power coupler and pickup coupler in the cryomodule test. (a): the measured external Q of input coupler at the room temperature and 4.2 K are presented. After cool down of the cryomodule, the external Q value are decreased. (b): the measured external Q of RF pickup coupler at the warm and cold temperature. At 4.2 K, the external Q values are satisfied with the requirement of $Q_{ext,pickup}$.

the cryomodule. These different boundary conditions could cause the opposite change of the thermal shrinkage in the HT. From the Figure 5, the thermal shrinkage of the cavity is larger than the thermal shrinkage of the outer conductor of the couplers in terms of the decreased external Q, except for the external Q of QWR 1 CM in 4.2 K. The measued external Q at the room temperature for QWR 1 CM was conducted without the cable calibration, it means the value of S-parameters was incorrect.

CONCLUSION

The RF couplers, variable coupler, RF power coupler, RF pickup coupler were developed for QWR cavity and cryomodule in RISP. The external Q of the RF couplers are studied by the CST-simulation and the measurements. For the vertical test, the external Q of the variable coupler and RF pickup coupler are measured in the room temperature and the cryogenic temperature. For the cryomodule test, the external Q of the RF power coupler are also measured in warm and cold temperature. Based on the measured external Q, the mass production of QWR power coupler and RF pickup coupler are fabricated. With the above studies, the RF couplers for HWR, SSR1 and SSR2 will be prepared in terms of the external Q in RISP.

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