QUALITY FACTOR MEASUREMENT METHOD USING MULTI DECAY TIME CONSTANTS ON CAVITY*

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Abstract

Quality factor measurement method using multi decay time constants on superconducting cavity is suggested. In most cases of vertical test, one decay time constant is measured around critical coupling and coupling constants are measured using forward and reflected rf power to get intrinsic quality factor. We use multi decay time constants method to measure the quality factor, which uses three decay time constants. Two more switches before and after the cavity are added to the measurement system. Decay time constants are measured by switching off the rf power switch in front of rf source, the forward power switch in front of input power coupler, and then the pickup power switch behind the pickup coupler, respectively, at the same power of steady state.

INTRODUCTION

Nb superconducting cavity can be operated below the critical temperature of superfluid, 2.172 K. Superfluid helium shows negligible viscosity and extremely high thermal conductivity. Properties of superfluid helium fog generated from the liquid helium surface were studied [1-3]. RAON superconducting radio frequency (SRF) test facility was designed [4] and constructed. The RAON SRF test facility consists of cavity test, cryomodule test cryogenic system, and cleanroom. The cleanroom is used for cavity processes and assembles. Residual resistivity ratio test of niobium was performed and the conditions of electron-beam welding were studied [5]. A half-wave resonator cryomodule was test in low temperature [6]. RF system and useful information such as gradient quality factor, RF-heat loads and loaded Q's were shown to test superconducting cavity [7]. Measurement of quality factor is important to test superconducting cavity.

In this research, we show how to measure quality factors from multi decay time constants measurement.

MULTI DECAY TIME CONSTANTS

The width of the resonance for a cavity in frequency spectrum is measured by either a network analyzer or a spectrum analyzer. The quality factor of the cavity can be expressed as $\omega / \Delta\omega$ where $\Delta\omega$ is half the resonance width. In normal conducting cavities, $\Delta\omega$ can be measured since it is order of kHz. It is very hard to measure the quality factor of a typical niobium superconducting cavity with a network analyzer since the value of the quality factor is very big and $\Delta\omega$ is too small.

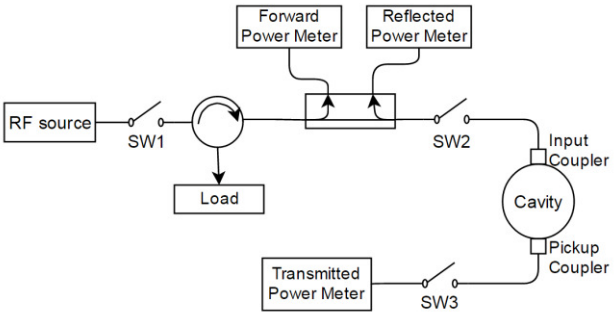

Figure 1: Schematic diagram of a cavity for quality factor measurement using multi decay time constants.

Figure 1 shows the schematic diagram of a cavity for quality factor measurement using multi decay time constants. RF source, circulator, bidirectional coupler, cavity, input coupler, pickup coupler, transmitted power meter, and three switches are shown in Fig. 1. Three switches are useful to measure the decay time constants.

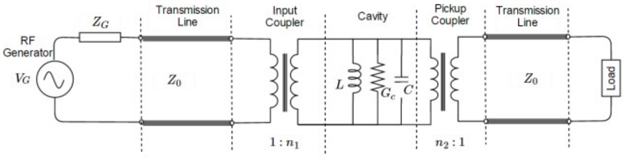

Figure 2: Equivalent circuit for a cavity with two couplers such as input coupler and pickup coupler. The input coupler is being driven by an rf generator and the pickup coupler helps to measure transmitted power.

The schematic diagram of the quality factor measurement of Fig. 1 corresponds to the equivalent circuit of Fig. 2 which does not include switches. Figure 2 shows the equivalent circuit for a cavity with two couplers. The input coupler is being driven by an rf generator and transmitted power is measured with the pickup coupler. After the rf generator is turned off, the total dissipated power is the sum of the power dissipated in the cavity and the power which leaks out the couplers [8].

$$P_{tot} = P_c + P_e + P_t, \quad (1)$$

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where P_e represents the power leaking back out the input coupler and P_t represents the power coming out the pickup coupler. Assuming there is no field emission from the surface of the cavity, the stored energy of the cavity decays as

$$\frac{dU}{dt} = -\frac{\omega U}{Q_L}, \tag{2}$$

where Q_L is the loaded quality factor and ω is the resonance frequency. From Eq. (2), the stored energy of the cavity decays as

$$U = U_o \exp\left(\frac{-\omega t}{Q_L}\right), \tag{3}$$

where U_o is the stored energy at $t = 0$. The electromagnetic energy in the cavity decays exponentially with a time constant, $\tau_L = \frac{Q_L}{\omega}$. From Eq. (1), quality factors can be expressed as

$$\frac{1}{Q_L} = \frac{1}{Q_o} + \frac{1}{Q_e} + \frac{1}{Q_t}, \tag{4}$$

where $Q_o = \frac{\omega U}{P_c}$ is the intrinsic quality factor, $Q_e = \frac{\omega U}{P_e}$ is the external quality factor, and $Q_t = \frac{\omega U}{P_t}$ is the transmitted quality factor. Coupling parameters is defined as $\beta_e = \frac{Q_o}{Q_e}$ and $\beta_t = \frac{Q_o}{Q_t}$. From Eq. (4), the intrinsic quality factor is expressed with the coupling parameters and loaded quality factor.

$$Q_o = (1 + \beta_e + \beta_t) Q_L . \tag{5}$$

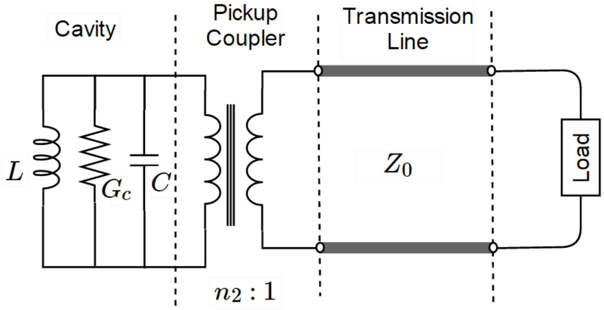

Figure 3: Simplified equivalent circuit which corresponds to SW2 off, and SW3 on in Fig. 1.

Decay time constants can be measured by switching off the rf power switch in front of rf source, the forward power switch in front of input power coupler, and then the pickup power switch behind the pickup coupler, respectively, at the same power of steady state, which is shown in Fig. 1.

Figure 3 shows the simplified equivalent circuit which corresponds to SW2 off, and SW3 on in Fig. 1. The dissipated power through the input coupler is assumed to be negligible after SW2 is turned off. Intrinsic quality factor for Fig. 3 can be expressed as

$$Q_o = (1 + \beta_t) Q_{L1}, \tag{6}$$

where $Q_{L1} = \omega \tau_1$.

Figure 4 shows the simplified equivalent circuit which represents SW1 off, SW2 on, and SW3 off in Fig. 1. The dissipated power through the pickup coupler is assumed to be negligible after both of the SW1 and SW3 are turned off at the same time. Intrinsic quality factor for Fig. 4 becomes

$$Q_o = (1 + \beta_e) Q_{L2}, \tag{7}$$

where $Q_{L2} = \omega \tau_2$.

Figure 5 shows the simplified equivalent circuit which corresponds to SW1 off, SW2 on, and SW3 on in Fig. 1. Intrinsic quality factor for Fig. 5 can be expressed as

$$Q_o = (1 + \beta_e + \beta_t) Q_{L3}, \tag{8}$$

where $Q_{L3} = \omega \tau_3$.

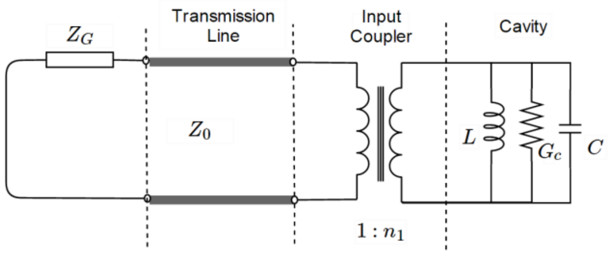

Figure 4: Simplified equivalent circuit which represents SW1 off, SW2 on, and SW3 off in Fig. 1.

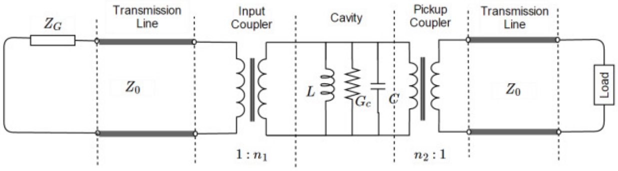

Figure 5: Simplified equivalent circuit which corresponds to SW1 off, SW2 on, and SW3 on in Fig. 1.

From Eqs. (6, 7, 8), the decay time constants becomes

$$\frac{1}{\tau_o} = \frac{1}{\tau_1} + \frac{1}{\tau_2} - \frac{1}{\tau_3}, \tag{9}$$

where $\tau_o = Q_o/\omega$, $\tau_1 = Q_{L1}/\omega$, $\tau_2 = Q_{L2}/\omega$, and $\tau_3 = Q_{L3}/\omega$. The quality factors for Q_{L1}, Q_{L2}, and Q_{L3} are determined by measuring the decay time constants of τ_1, τ_2, and τ_3, respectively. The intrinsic quality factor of Q_o, the external quality factor of Q_e, and the transmitted quality factor of Q_t are determined from Eqs. (6,7,8). From Eqs. (6, 7, 8), the coupling constants such as β_e and β_t can also be determined.

SUMMARY

We have shown the quality factor measurement method using multi decay time constants on superconducting cavity. Three decay time constants can be measured using three switches for the quality factor measurement of the cavity. Intrinsic quality factor, external quality factor, transmitted quality factor, and loaded quality factor can be determined by measuring the decay time constants. The coupling parameters are also determined by measuring the decay time constants.

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