RRR EFFECT ON THE FLUX TRAPPING OF NIOBIUM SC CAVITIES

Kenji Saito#, KEK, 1-1 Oho Tsukuba-shi, Ibaraki-ken, Japan

Abstract

We sometimes observe flux trapping phenomena in cold test of niobium superconduction RF cavities. Especially, it is a serious problem with Nb/Cu clad cavities. In this paper, RRR effect on this problem is considered from the theoretical point of view and investigated experimentally.

ADDITIONAL SURFACE RESISTANCE DUE TO FLUX TRAPPING

Cooling down a superconducting (sc) RF cavity in a DC external magnetic field, flux trapping happens below the transition temperature (Tc) as shown in Fig.1 [1]. If the superconducting material is ideal, external magnetic fields less than Hc1 (the lower critical magnetic field) must be excelled perfectly due to the Meissner effect however, current niobium material used for sc RF cavities usually have imperfections like impurities, lattice defects, other inhomogeneities, and so on. In such a case, external magnetic fluxes are trapped on such pin-centres and produces normal conducting cores. For the frequency range > 100MHz, only the normal cores are responsible for additional surface resistance in RF cavities even in a case Hext < Hc1. The surface resistance due to the flux trapping is calculated as following [2]:

\[ R_s(H_{ext}) = R_n \frac{H_{ext}}{H_{c2}(T)} \]  

where, Hc2 is the higher critical magnetic field, H_{ext} an applied magnetic field, and Rn a surface resistance of the material in the normal conducting state, which is calculated as:

\[ R_n = \frac{\mu_0}{2\sigma} \]  

where \( \mu \) is the magnetic permeability of the material, \( \omega \) angular frequency of the microwave and \( \sigma \) electric conductivity of the normal conducting state. As the flux trapping happens at Tc, \( \sigma \) is the value at Tc. Using the \( \sigma \), at room temperature (300K), Eq.(1) is rewritten by RRR and \( \sigma(300K) \) [3]:

\[ R_s(H_{ext}) = \frac{\mu_0}{RRR \sigma(300K)} \frac{H_{ext}}{H_{c2}} = R_n(300K) \frac{H_{ext}}{RRR \cdot H_{c2}} \]  

here, the RRR is defined as:

\[ RRR = \frac{\sigma(T \cong T_c)}{\sigma(300K)} \]  

RRR strongly depends on the amount of impurities in the niobium material, while the electric conductivity at the room temperature is insensitive to the impurities because electron scattering dominates. Hc2 also depends on the RRR and temperature, however the temperature is fixed that of the cold measurement. Generally saying, Hc2 becomes higher with decreased RRR value. Thus the constant term in Eq.(1) depends on only RRR at the fixed temperature. Here, a question happens how Hc2 depends on RRR.

RRR DEPENDENCE OF Hc2

We measured the RRR dependence of Hc2 with niobium material. The result is presented in Fig.2. It was done for niobium materials with RRR=54, 246 and 398 from Tokyo Denkai. Usually KEK makes high gradient measurement of sc cavities at 1.5K. We fix the

![Figure 1: Flux trapping at imperfection in a superconducting material (copied from the ref.[1]).](image1)

![Figure 2: RRR dependence of Hc2 on niobium.](image2)

# #: ksaito@post.kek.jp
temperature at 1.5K to see the RRR dependence on $H_{c2}$. Fig.3 shows the RRR dependence of $H_{c2}$ at 1.5K. It is well fitted as a function of RRR:

$$H_{c2}(1.5K) = H_{c2}(RRR)$$

$$= 7089.7 - 1072.3 \log(\text{RRR})$$  (5).

RRR DEPENDENCE OF FLUX TRAPPING

Putting Eq.(5) into Eq.(3), one has the following formula:

$$R_s(H_{ext}) = \frac{R_o(300K)}{\sqrt{\text{RRR} \cdot [7089.7 - 1072.3 \log(\text{RRR})]}} \cdot H_{ext}$$  (6)

$$= R_o(\text{RRR}) \cdot H_{ext}$$

here $R_o$ depends on only RRR value. For niobium, $R_o(300K)$ is 2.53E-2 $\Omega$ at 1300MHz. Using the number, $R_o(\text{RRR})$ is calculated in Fig.3. $R_o$ is fitted as the function of RRR by a much simple experimental formula:

$$R_o(\text{RRR}) = 3.15 \cdot \text{RRR}^{0.394}$$  (7).

For 1300MHz sc niobium cavity, thus the additional surface resistance due to flux trapping is calculated as:

$$R_s(H_{ext}) [n\Omega] = 3.15 \cdot \text{RRR}^{-0.394} \cdot H_{ext}[\text{mGauss}]$$  (8).

COMPARISON WITH EXPERIMENTAL RESULTS

We measured the surface resistance due to the external magnetic field for 1300 MHz niobium cavities with RRR=100 and 400 [4, 5]. In those measurements external magnetic fields were applied in parallel with cavity beam axis. The results were:

$R_o(\text{mG}) = 10.8 + 0.56 \cdot H_{ext}[\text{mGauss}]$ for RRR=100,

$R_o(\text{mG}) = 3.3 + 0.43 \cdot H_{ext}[\text{mGauss}]$ for RRR=400.

Similar measurements have been done at CEBAF [3] or Saclay [6] for 1500MHz niobium cavities. CEBAF result was $R_o=0.25\Omega$/m with RRR $\geq$ 500 and Saclay 0.35$m\Omega$/m with RRR=180. When these results are scaled for 1300MHz by $\omega^{1/2}$ dependence of $R_o$, the results are 0.23$n\Omega$/m and 0.33$n\Omega$/m. These results are also plotted in Fig.4. Experimental formula (9) can reasonably fit all the data.

**REFERENCES**


