RRR estimation of Niobium using inflection point on the frequency response of a planar inductive sensor

Pankaj Sagar, Kashif Akber, E. D. A. Lakshmi, Gowri Nanda P. S., Girish P. S., R. Karunanithi

Centre for Cryogenic Technology, Indian Institute of Science, Bangalore, India

pankajs@iisc.ac.in — +91 (961) 136 6896

CEC/ICMC JULY 21-25 2019 CONNECTICUT CONVENTION CENTER HARTFORD

M2Po2C-05 [41]

Abstract

A clear indicator of purity of niobium (Nb) used for fabricating Superconducting Radio Frequency (SRF) cavities is the Residual Resistivity Ratio (RRR) of the bulk Nb. Usual methods of determining the RRR is by Four-probe resistance measurement techniques. This process is destructive in nature and provides an average value of the RRR of the sample that is being used. It has already been shown in other literature's that the RRR of the Nb changes as the RF cavity moves through various fabrication processes. In order to characterize the RF cavity through different stages of fabrication, a local, non-contact method for measuring RRR is required. This paper discusses one such non-destructive, non-contact method for RRR estimation using planar inductive sensor. Whenever a conductor is brought in the presence of an inductive sensor which is excited by an AC signal, the impedance associated with the sensing coil varies. This variation is a function of eddy current penetration depth (δ), the electrical conductivity (σ), the frequency of excitation (f) and the series inductance term (L_s) of the impedance of the sensing coil. The frequency response of the Ls term of the sensor will have an inflection point whenever the eddy current penetration depth becomes equal to the thickness of the sample. By determining the inflection point on the L_s-F graph close to the critical temperature (T_c) and at room temperature (T_r), the RRR can be estimated.

Introduction

- Superconducting RF cavity requires high thermal conductivity
- RRR is the first indicator for the performance of SRF Cavity
- RRR and thermal conductivity (λ) has direct correlation
- RRR gives a direct indication of the purity of the niobium
- Usual method is 4-wire electrical resistance measurement
- 4-wire RRR measurement is destructive and local in nature
- Once RF cavity is fabricated, no way of measuring RRR
- AC methods for RRR measurements are the only solution

Principle of Operation

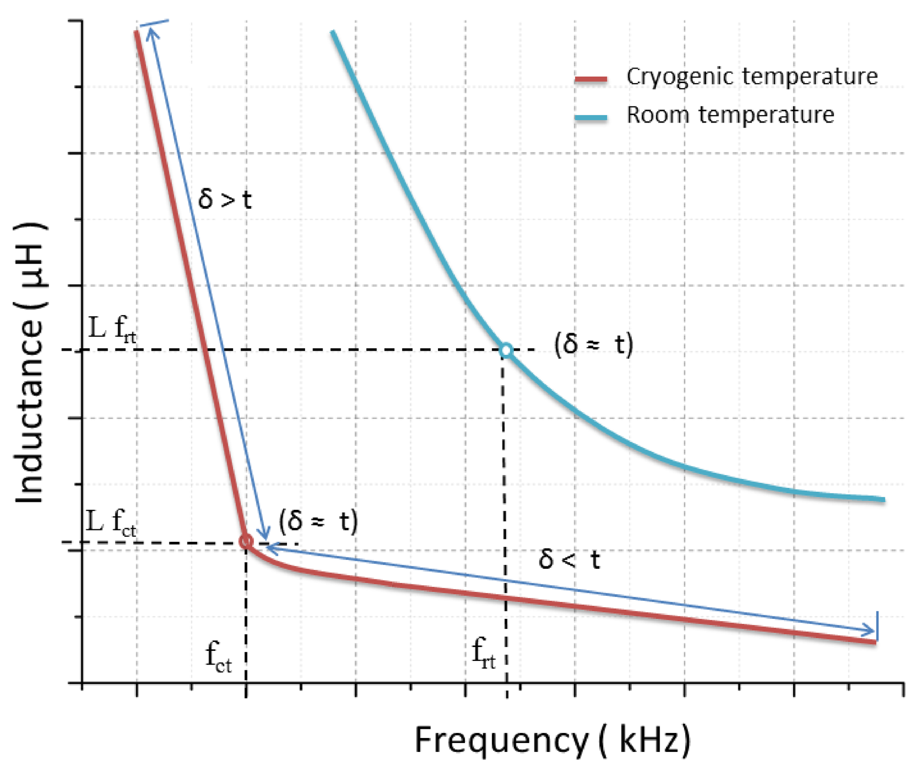

Figure 1: Operating principle for inflection point method of sensing

– The penetration depth for eddy currents is given by,

$$\delta = \frac{1}{\sqrt{(\mu_0 \pi f \sigma)}} \tag{1}$$

– Assuming the thickness of the target remains constant, the series inductance L_s vs frequency plot will have an inflection point when $\delta \simeq$ t,

– From equation (1),

$$\delta_{290K}(\simeq t) = \frac{1}{\sqrt{(\pi \mu \sigma_{RT} f_{RT})}} \tag{2}$$

$$\delta_{10K}(\simeq t) = \frac{1}{\sqrt{(\pi \mu \sigma_{CT} f_{CT})}} \tag{3}$$

here, CT is cryogenic temperature and RT is room temperature

– From equation (2) and (3) we have,

$$RRR = \frac{f_{RT}}{f_{CT}} = \frac{\sigma_{CT}}{\sigma_{RT}} \tag{4}$$

Multilayer planar coil design

Inductor Parameters	
Parameters	Value
D_{in}	1.9 mm
D_{out}	14 mm
Conductor Thickness (W)	0.127 mm
Conductor Spacing (S)	0.254 mm
Fill Factor	0.6232

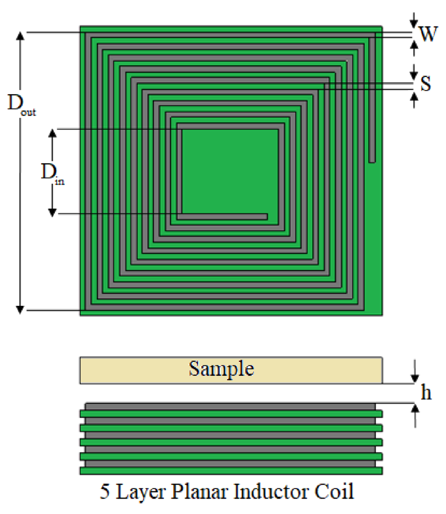

Figure 2: Physical dimensions of the planar multi-layer inductor sensor

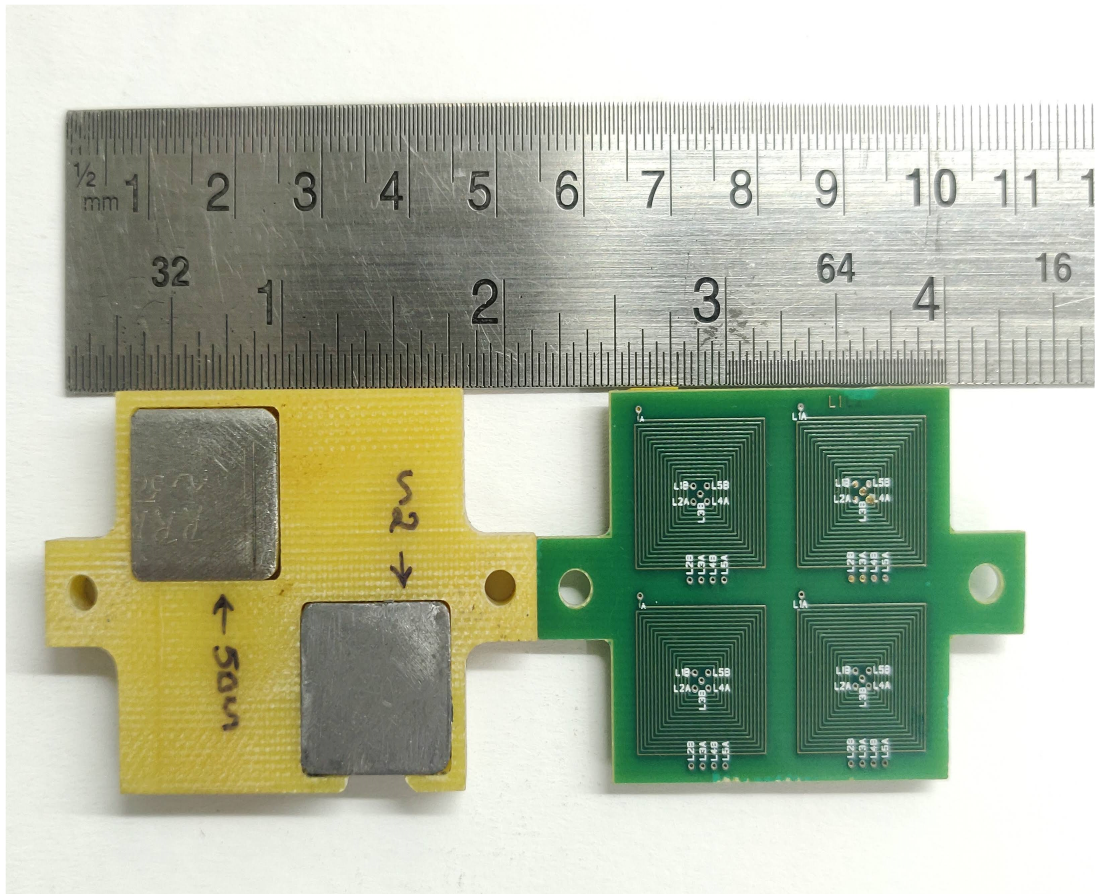

Figure 3: a) Sensor having 4 coils, 2 are used as reference and 2 are used to measure the modified impedance b) Target mounting mechanism made of hylam

Experimental Procedure

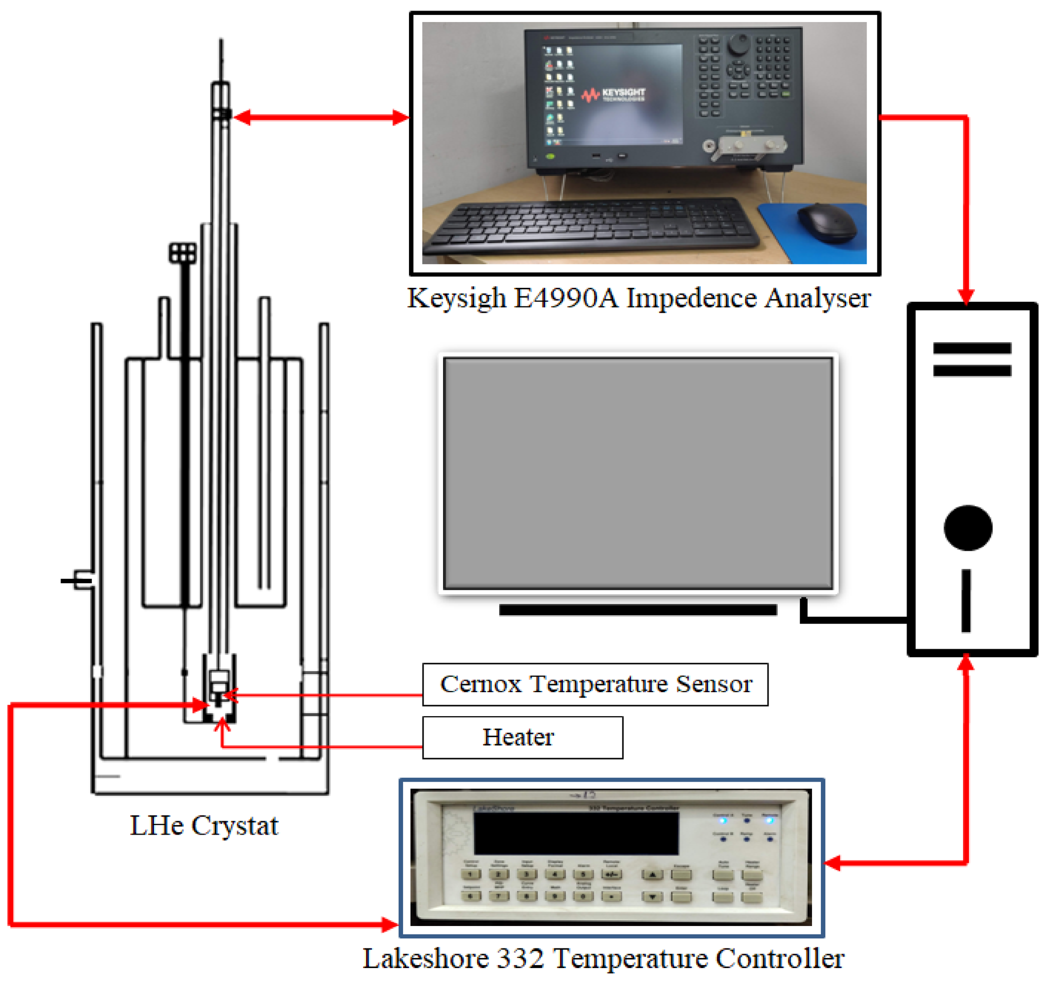

Figure 4: Schematic of measurement setup

- Four samples of different RRR values 1) 3.21 2) 58.2 3) 259 and 4) 367 was used in the experiment
- RRR for each sample was determined by 4-wire resistance measurement
- Each sample was mounted in a Hylam sample holder and kept at 1mm separation from the sensing coils by using SS washers.
- Temperature was reduced and measurements (L_s and R_s) where acquired at specific temperatures (290K and 10K).
- Temperature control was done through heater and temperature sensor (Cernox)combination.
- The schematic of the experimental setup is shown in figure 4.

Experimental Results

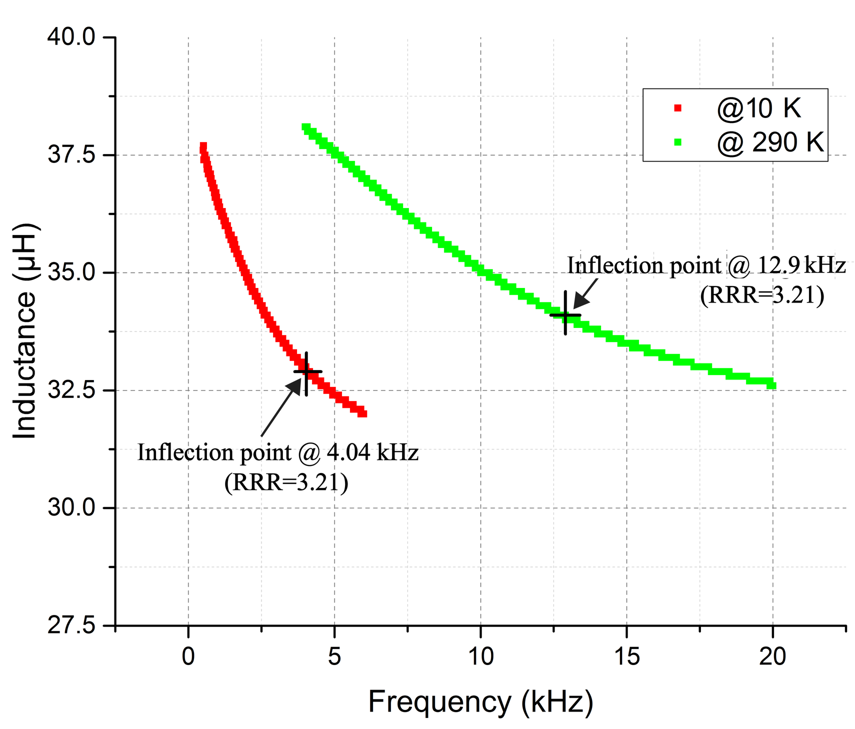

Figure 5: Inductance plot (L_s) of RRR = 3.21 sample with inflection point at 12.9 kHz at 290 K and 4.04 kHz at 10 K

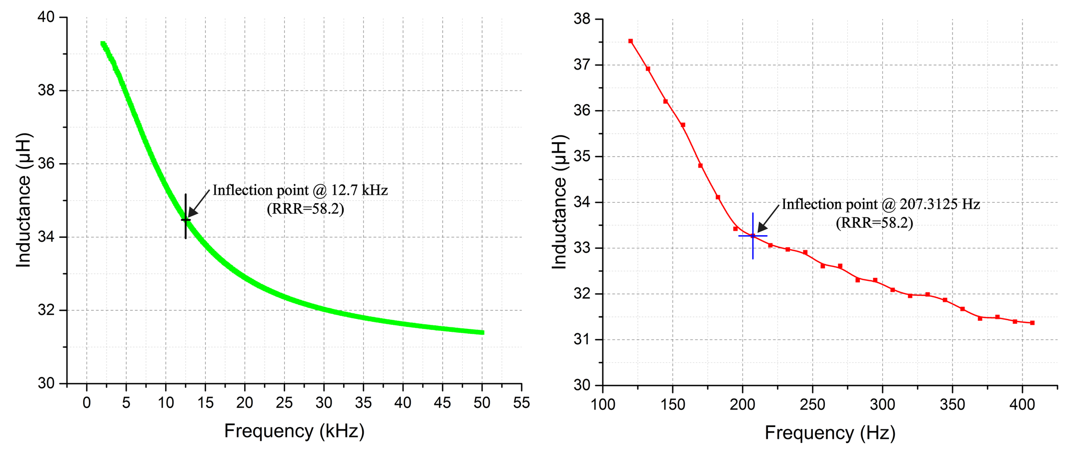

Figure 6: Inductance plot (L_s) for RRR = 58.2 sample with inflection point at 12.7 kHz at 290 K and 201.31 Hz at 10 K

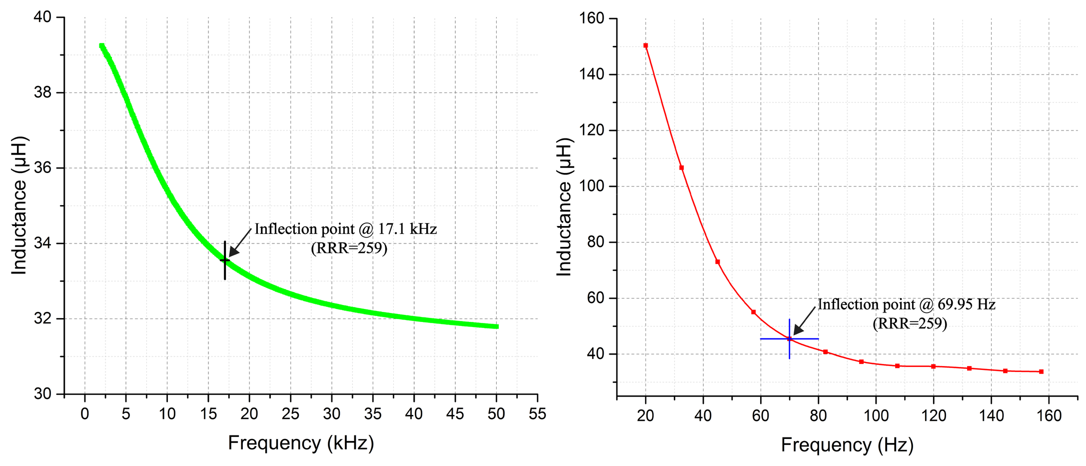

Figure 7: Inductance plot (L_s) for RRR = 259 sample with inflection point at 17.1 kHz at 290 K and 69.95 Hz at 10 K

Table 1: Summary of Experimental Results

Measured RRR	Thickness (mm)	Temperature (K)	Inflection point frequency	Calculated RRR	Percentage error
3.21	1.92	10	12.9 kHz	3.19	0.623 %
		290	4.04 kHz		
58.2	1.42	10	207.31 Hz	61.26	5.32 %
		290	12.7 kHz		
259	1.51	10	69.95 kHz	244.46	5.61 %
		290	17.1 kHz		

Conclusions

- A technique for measuring RRR and conductivity of Nb using planar multilayer inductor was tested for a samples of unknown RRR
- The method was confirmed with existing RRR measurement technique (4-probe electrical resistance measurement)
- Inflection point method was found to be less data intensive than dual slope methods for RRR measurement.
- Percentage errors for different RRR values were determined and found to be around 5%.
- Higher errors can be eliminated by considering the co-efficient of thermal expansion of the material into consideration.

Acknowledgment

This work was carried out using the funds provided by Science and Engineering Research Board (SERB) under Department of Science and Technology (DST), India. This author would also like to acknowledge Dr. T. S. Datta from IUAC, Delhi for providing the reference Nb samples that was used to calibrate the sensor.

References

[1] Wasserbäh W 1978 *Philosophical Magazine A* **38** 401–431

[2] Singer W, Ermakov A and Singer X 2010 *TTC report* **2**

[3] Sagar P, Gour A S and Karunanithi R 2017 *Sensors and Actuators A: Physical* **264** 151–156

[4] Ma X and Peyton A J 2006 *IEEE Transactions on instrumentation and measurement* **55** 570–576

[5] Padamsee H 2009 *RF superconductivity: science, technology, and applications* (John Wiley & Sons)

[6] Pankaj Sagar R K 2019 *Measurements* **146** 758–769

[7] Sagar P, Karunanithi R, Hassan H K, Akber K, Girish P S, Lakshmi S C and A E D 2019 *IOP Conf. Series: Materials Science and Engineering* vol 502 (012154)

[8] Aizaz A, Bauer P, Grimm T L, Wright N T and Antoine C Z 2007 *IEEE transactions on applied superconductivity* **17** 1310–1313

[9] Bousson S 1999 *9th SRF Workshop, Santa Fe, USA*

[10] Russo R 2007 *Measurement Science and Technology* **18** 2299