Ripple Shielding for Accurate Resistivity Measurements in Hybrid Magnets(Part II. Several Instruments and Techniques Developed in HFLSM)

著者	Noto Koshichi, Sasaki Takako, Toyota Naoki, Hasegawa Satoshi
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Ripple Shielding for Accurate Resistivity Measurements in Hybrid Magnets*

Koshichi Noto, Takako Sasaki,
Naoki Toyota and Satoshi Hasegawa**
The Research Institute for Iron, Steel and Other Metals
**National Aerospace Laboratory, Kakuda

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Synopsis

After a preliminary test of ripple shielding by a coil using a prereacted pure Nb_3Sn multifilamentary superconducting wire, a few ripple shielding coils were developed employing a Ti-doped Nb-tube method processed multifilamentary Nb_3Sn superconducting wire with so far highest J_c by the so called W&R method, making it possible to measure the temperature dependence of the resistivity in $Nb_{21}Ti_{79}$ alloy within the accuracy of 10^{-5} at very high magnetic fields above 20 T in the hybrid magnets in the High Field Laboratory for Superconducting Materials at Tohoku University.

I. Introduction

The capacity of the DC high power electric source for the water-cooled magnets installed in the High Field Laboratory for Superconducting Materials, Research Institute for Iron, Steel and Other Metals, Tohoku University is 8 MW(1) (350 V, 23 kA). The stability and ripples of the power source were designed to be $1x10^{-4}$ rms/3 hrs and $1x10^{-4}$ rms, respectively. Due to the flicker noise included in the AC line, which comes from arc-melting furnaces of steel industries in the AC line, DC output of the power source includes low frequency ripples of the order of $2x10^{-4}$ rms from 1 to 10 Hz(2). These ripples result in almost the same level of ripple field in the steady high magnetic field generated by water-cooled magnets which are combined in our hybrid magnet systems, since the self inductance of the water-cooled magnets is so small(3) that it cannot damp down the field ripples at

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the center of the hybrid magnets. Although this level of the field ripples is low enough for usual measurements of various physical properties of materials in the hybrid systems, several measurements which need very calm magnetic field such as precise temperature dependence of the resistivity and/or specific heat in some superconductors at high fields were not succeeded till now.

In this paper, we report design, construction and tested results of a few passive type ripple filters by use of multifilamentary Nb_3Sn superconducting wires for the very accurate resistivity measurements in a NbTi alloy superconductor in our hybrid magnet systems. The results of the resistivity measurements in $Nb_{21}Ti_{79}$ alloy are also presented.

II. Principle of the ripple shielding

Figure 1 shows the principle of the ripple shielding of the developed filter. A superconducting coil with radius a, cross section S, and number of turns N are connected with a resistor R in series forming a closed circuit as can be seen in this figure. The self-inductance L of this coil and the time constant τ of this circuit are given as follows,

$$L = \frac{\mu_0 N^2 S}{2\pi a} , \tag{1}$$

$$\tau = \frac{L}{R} , \tag{2}$$

where μ_0 is the permeability. The minimum shielding frequency f_0 of this coil is, therefore,

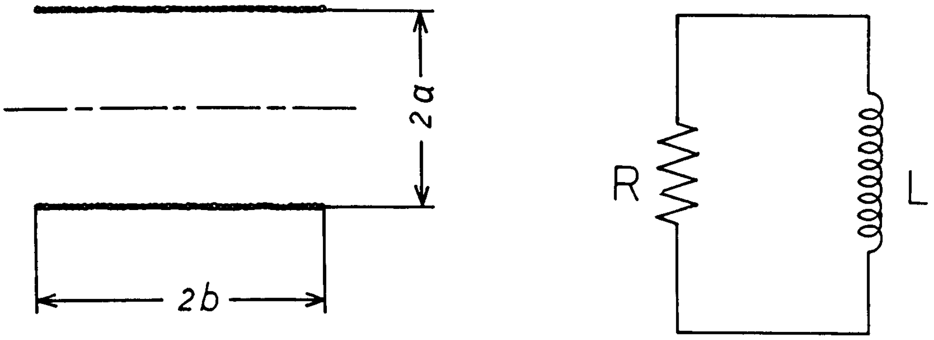

Fig. 1. Principle of the ripple shielding.

Table 1. Important parameters of the ripple shielding coils.

	2a(mm)	2b(mm)	N	R(mΩ)	L(mH)	G(G/A)	f_0(Hz)	comments
A	30	60	194	0.76	0.38	36.25	2.0	0.31Φ, Nb_3Sn
B	34	87	114	0.27	0.14	15.34	1.9	0.64Φ, Nb_3Sn-Ti
B'	34	87	114	—	0.14	15.34	—	0.64Φ, Nb_3Sn-Ti
C	21	87	114	—	—	—	—	0.64Φ, Nb_3Sn-Ti

$$f_0 \cong \frac{1}{\tau} \tag{3}$$

Since the coil constant of this coil is

$$G = \frac{\pi N}{5(a^2+b^2)^{1/2}} , \tag{4}$$

for the given coil length 2b, the maximum shielding ability at the center of the coil becomes as follows,

$$\Delta B = G \cdot I_C(B_0) , \tag{5}$$

where $I_c(B_0)$ is the critical current value under the field B_0 of the hybrid magnet.

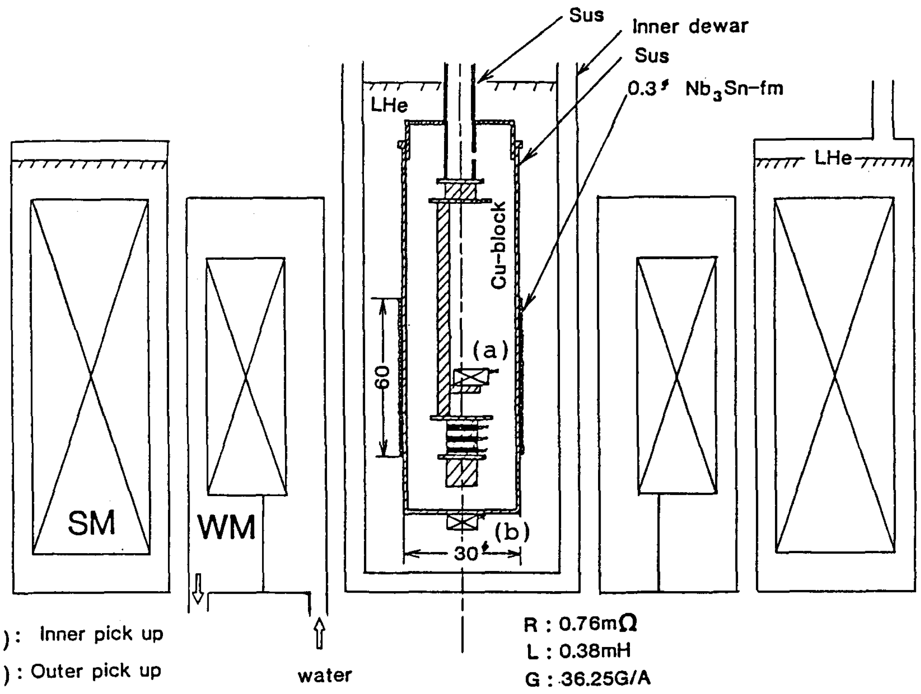

Fig. 2. Schematic illustration of the preliminary ripple shielding test.

III. Design and construction

Table 1 is a list of the constructed shielding coils. The coil A is a prototype for the preliminary test, which was wound with a prereacted Nb_3Sn wire(~0.3 ϕ) of Japanese reference samples(4) on a vacuum case of a temperature variable cryostat. This coil was, therefore, prepared by the "React and Wind (R&W)" method. The wire has no insulation and soldered directly on the stainless steel case of the cryostat. The coil B was wound on a bobbin made of high purity copper with unreacted wire of Ti-doped Nb-tube method processed Nb_3Sn conductor(5) with a very high critical current up to high magnetic fields. The coil was then heat-treated for the Nb_3Sn layer growth and, finally, soldered on the copper bobbin. The copper bobbin might serve as a ripple filter at high fields above about 21 T, where critical current of the Nb_3Sn wire becomes very small. The coil B' with stainless steel bobbin and the coil C with smaller diameter for the smaller bore hybrid system, HM-3, were also prepared. These three coils were, therefore, made by the "Wind and React" (W&R) method. The resistance of the solder served as the resistor R in Fig. 1.

IV. Tests and results

A preliminary test was done by using the shielding coil A in the

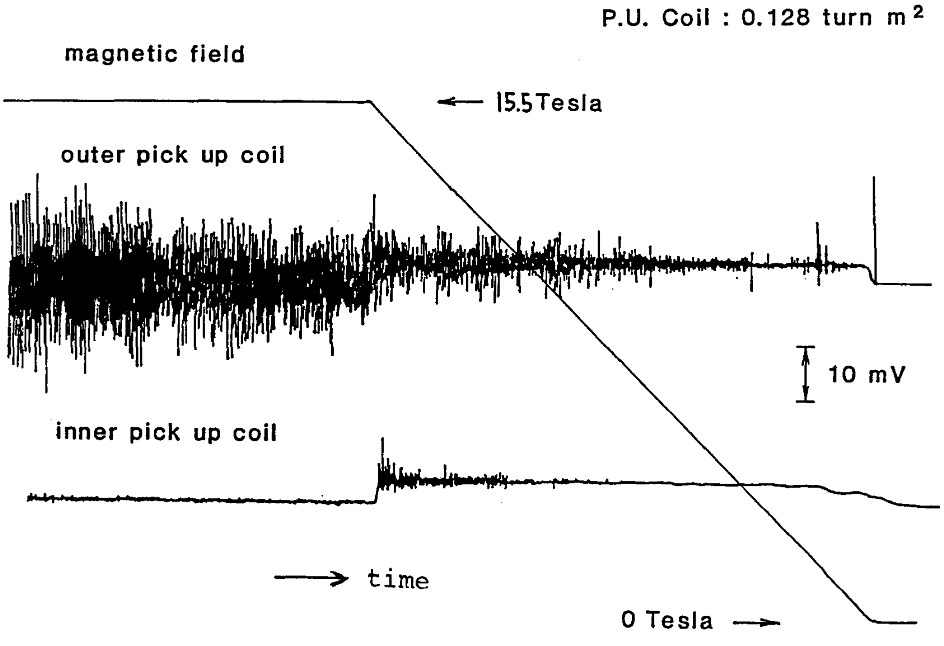

Fig. 3. Results of the preliminary ripple shielding test.

configuration schematically shown in Fig. 2. Outer combination of the superconducting (SM-2) and water-cooled (WM-2) magnet is the 52 mm bore hybrid magnet (HM-2)(6). Two pick-up coils, (a) and (b), with almost the same winding cross section of 0.128 turn•m^2 were set at the center and the outer part of the shielding coil as shown in the figure.

Since the shielding coil A had been wound with pure Nb_3Sn wire by R&W method with about 1 % bending strain, it was expected that there must be a considerable performance degradation in the employed superconducting wire. The test was, therefore, performed by operating only inner water-cooled magnet, WM-2, up to 16 T. Figure 3 shows the results of the preliminary test. Though the shielding ability is a little lower during the sweep of magnetic field between 15.5 and about 13 T, the effect of shielding is outstanding during the flat top (at 15.5 T) and the sweep down below about 13 T as can be seen in Fig. 3. Less ability during the sweep between 15.5 and 13 T is thought to come from either AC losses and/or degradation in the pinning ability (J_c) under the varying external field.

Following the preliminary test, in which we have confirmed the remarkable effect of the ripple shielding, the shielding coils B, B' and C were designed and fabricated for the accurate measurements of resistivity employing an advanced-high performance multifilamentary Nb_3Sn wire processed by Ti-doped Nb-tube method by W&R method.

The shielding coil B was used for the accurate measurements of the resistivity in $Nb_{21}Ti_{79}$ alloy in HM-2 under the configuration schematically shown in Fig. 4. Figure 5 is the picture of the developed shielding coils.

Figure 6 is a comparison in the temperature fluctuation between experiments without and with the shielding coil at about 2.3 K and

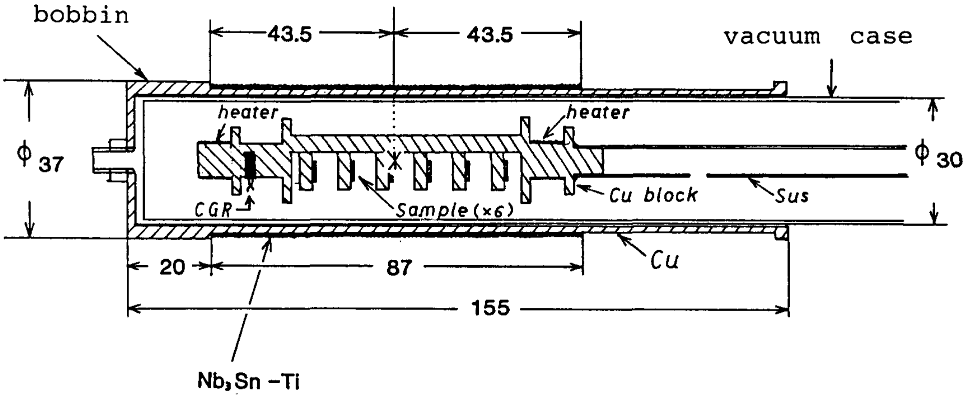

Fig. 4. Schematic illustration of the accurate resistivity measurements by use of the ripple shielding coil B.

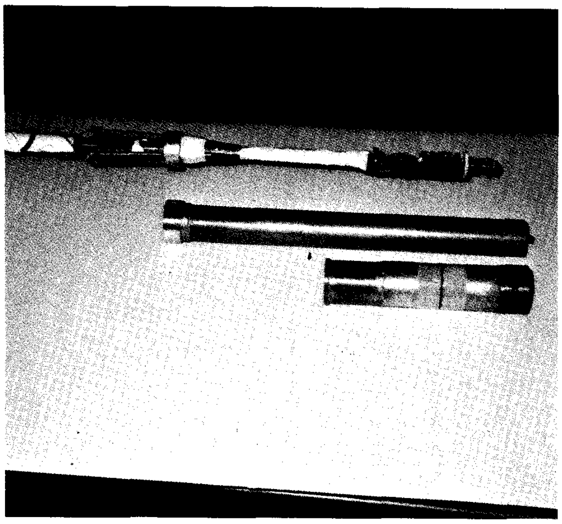

Fig. 5. Picture of the ripple shielding coils.

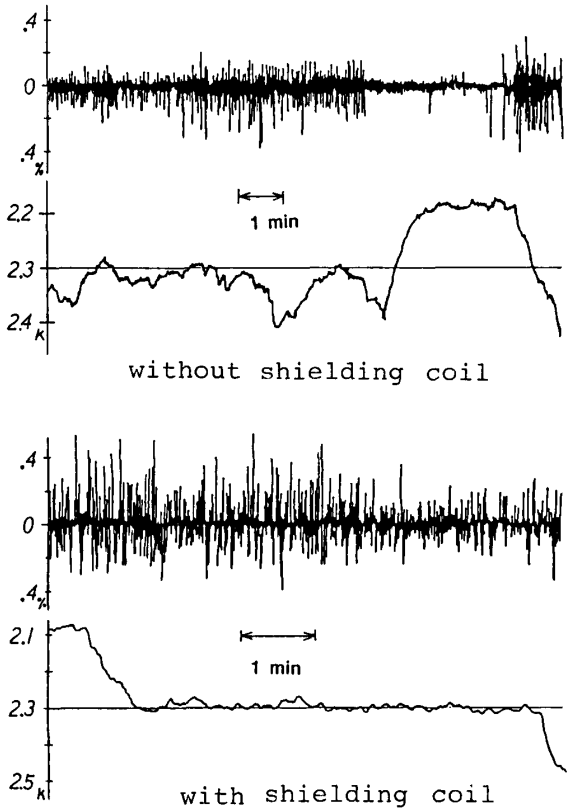

Fig. 6. Comparison of temperature fluctuation between experiments with and without shielding coil.

20.6 T. In each figure, upper curves show the field ripples and lower ones the temperature fluctuation of the copper block in the cryostat measured by a carbon-glass resistor (CGR) thermometer also shown in Fig. 4. The effect of ripple shielding was outstanding and we could control the temperature of the copper block within 20 mK(7). The results of very accurate resistivity measurements are given in Fig. 7 by use of the cryostat with the ripple shielding coil B. The resistivity ρ_n in $Nb_{21}Ti_{79}$ alloy has been measured by the accuracy within 10^{-5}. The -log T dependence of ρ_n is thought to come from two level states of atom positions in disordered NbTi alloy(8).

V. Summary and the future

In summary, a development of a ripple shielding coil employing a Ti-doped Nb-tube method processed multifilamentary Nb_3Sn superconducting wire with so far world highest J_c characteristics has made it

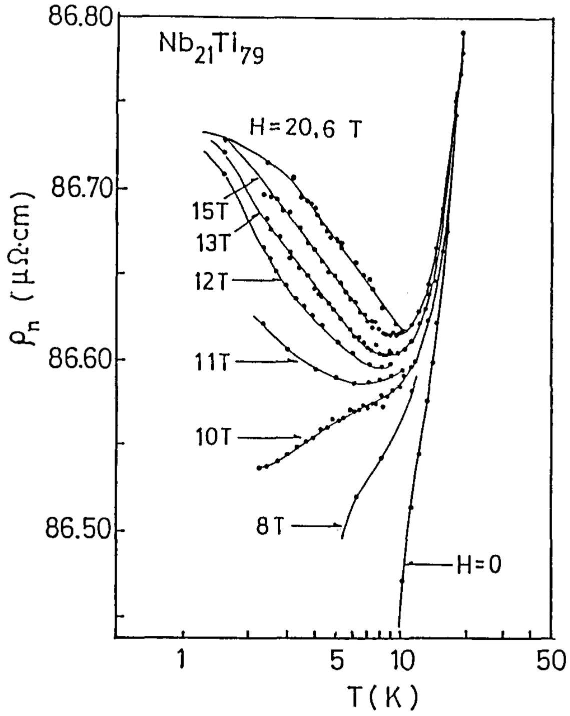

Fig. 7. An example of accurate resistivity measurements in $Nb_{21}Ti_{79}$.

possible to measure the temperature dependence of ρ_n in $Nb_{21}Ti_{79}$ alloy with the accuracy of 10^{-5} in the hybrid magnet, HM-2, above 20 T.

We are now trying to measure the specific heat of several high field superconductors under high magnetic field in the hybrid magnets by use of the ripple shielding coils. Such ripple shielding coils will also make it possible to combine a dilution refrigerator with one of our hybrid magnet systems in near future.

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