PRECISION COAXIAL MANGANIN SHUNTS*

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Summary

High precision, four-terminal resistors (shunts) of coaxial design have been developed at Argonne National Laboratory (ANL) for measuring and controlling constant or pulsed magnet currents. Air or water-cooled shunts for currents between 50 A and 10 kA have been built. Their frequency response ranges from dc to tens of kilohertz, and their resistance is reproducible within ±0.001%. The resistance-stress coefficient of shunt-manganin was determined for compressive stresses applied transverse to the direction of current flow.

Introduction

Stringent demands are made on the stability and the reproducibility of current settings for magnet power supplies of beam bending magnets. In addition to constant current regulation, there are many applications that call for the magnet current to be pulsed in accordance with a programmed reference waveform. The stability of a current setting is influenced by the stability of the current sensing device. For precision current measurements in the frequency range from dc to tens of kilohertz, the commonly used devices are low inductance shunts.

Liquid Cooled Shunts

Manganin Cylinder Cooled on the Inside Surface

A comprehensive report on the design of high current shunts, including impedance formulas, was published in 1966.[1] The manganin cylinders of these shunts have a heat flow as high as 10 W cm^{-2} and they are water cooled on the inside surface. Errors in shunt readings due to stray fields, to end effects, to changes in resistance due to stresses caused by temperature changes, pressure of the coolant, magnetic fields, and mounting arrangements were analyzed in reference 1. These early designs have slotted current terminal plates to force a uniform current distribution through the coaxial cylinders, and the manganin cylinder is protected against damage by a fiberglass jacket.

Manganin Cylinder Cooled on the Outside

A simplified design with the manganin being cooled on the outside surface is shown in Fig. 1. The manganin is supported from a base plate via the lower extension cylinder. The outer copper cylinder protects the manganin and has a circular current terminal. A second circular current terminal is rigidly supported from the first via insulation bushings. The all-important freedom of vertical expansion for the manganin is assured by a copper braid assembly that connects the second current terminal to the manganin via an upper extension cylinder. An O-ring seals the space between the coaxial cylinders. End effects are reduced by arranging cables, to connect the shunt to the external buswork, symmetrically around the axis of the shunt as shown in Figs. 1 and 2.

Resistance Change Due to Compressive Stresses Appearing Transverse to the Direction of Current Flow

The dependence of resistance upon stress is:

$$R_\sigma = R_0 (1 + \alpha\sigma) \qquad (1)$$

where

R_σ = resistance under stress,
R_0 = resistance under zero stress,
α = $(1/R)(dR/d\sigma)$ = resistance-stress coefficient,
σ = stress.

Circumferential pressure is exerted on the manganin cylinder of Fig. 1 by the coolant causing compression in a direction transverse to the current flow. The resistance-stress coefficient for transverse compressive stresses could not be found in the literature and was, therefore, measured.[2] The change of resistance versus transverse compressive stress is shown in Fig. 3. From this figure the resistance-stress coefficient for compression, transverse to the direction of current flow, was determined as $\alpha_c^\perp = 1.73 \times 10^{-6}$ cm^{2}kg^{-1}, the compressive stress that causes a 0.001% change in resistance is $\Delta\sigma_c^\perp = \Delta R/R_0\alpha_c^\perp = 10^{-5}/(1.73 \times 10^{-6}) = 5.78$ kg cm^{-2}.

The resistance-stress coefficients of manganin[1,2] in cm^{2}kg^{-1} x 10^{-6} are:

For tension in the direction of current flow; $\alpha_t^\parallel = 0.59$
For tension transverse to the direction of current flow; $\alpha_t^\perp = -0.78$
For compression in the direction of current flow; $\alpha_c^\parallel = 2.31$
For compression transverse to the direction of current flow $\alpha_c^\perp = 1.73$

Manganin Cylinder Cooled on Both Sides

Shunts are often used in conjunction with water-cooled power supplies. Usually these water circuits operate at static pressures too high for one-sided cooling. To relieve the manganin from static pressure both sides must be exposed to the coolant. Figure 4 illustrates a design with both sides of the manganin equally cooled. In the design of Fig. 5 a few

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holes have been provided in the extension cylinder and in the disk soldered to the top of the manganin to relieve static pressure. Here the cooling is done essentially on the outside of the manganin.

Air Cooled Shunts

Simple convection cooling can dissipate approximately 0.04 W cm^{-2} at a temperature rise of about $15^{o}C$ above a $20^{o}C$ ambient. Forced air cooling will increase the dissipation by up to an order of mangitude. An inexpensive design is illustrated by Fig. 6. If commercial tubing of suitable diameter is not available for the outer cylinder, it can simply be rolled from a copper sheet.

References

1. W. F. Praeg, "Stress Sensitivity of Manganin Resistor in High-Current Precision Coaxial Shunt," IEEE Transactions on Instrumentation and Measurement, IM-15, 4, pp. 234-242, (December, 1966).

2. W. F. Praeg, "Notes on the Design of Precision Coaxial Shunts," Argonne National Laboratory (internal report), WFP-6, (February, 1971).

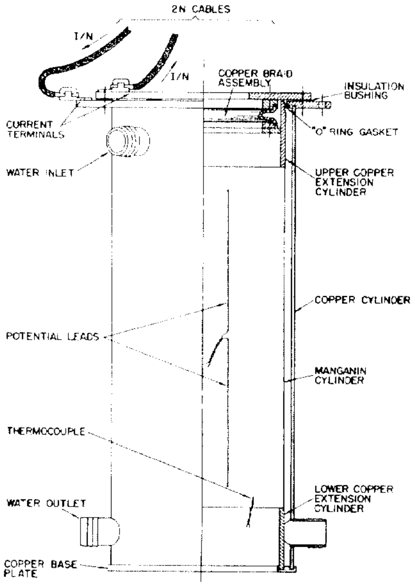

Fig. 1. Assembly view of water-cooled shunt

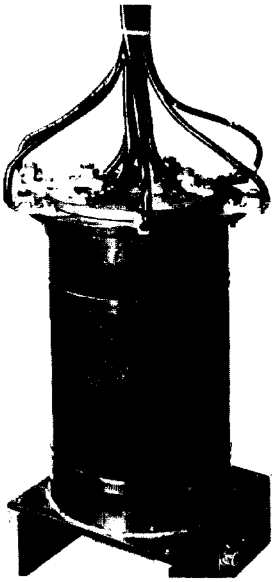

Fig. 2. Shunt and external connections

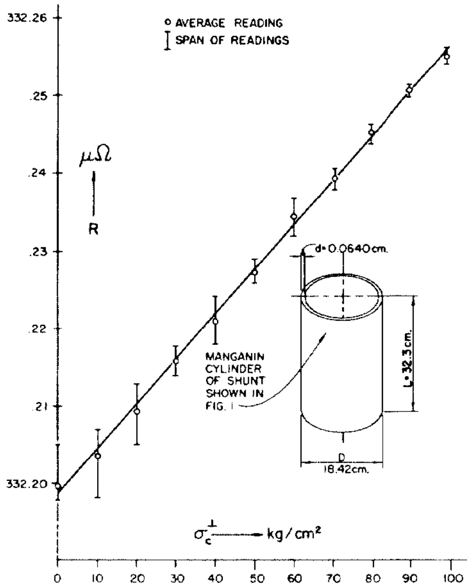

Fig. 3. Change of resistance of manganin vs. transverse compressive stress

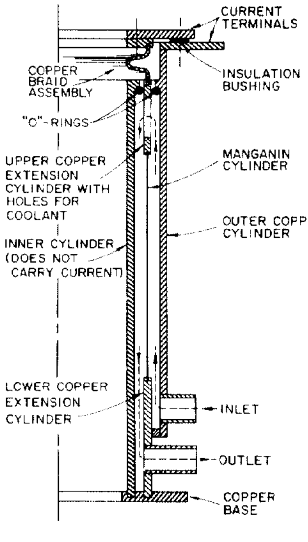

Fig. 4. Shunt with manganin cooled on both sides

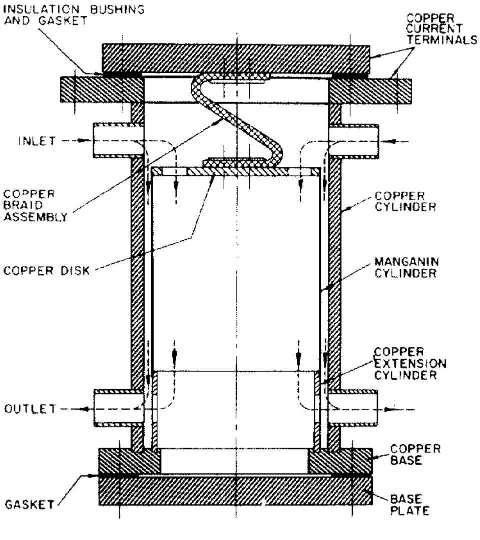

Fig. 5. Shunt essentially cooled on outside but without static pressure on manganin

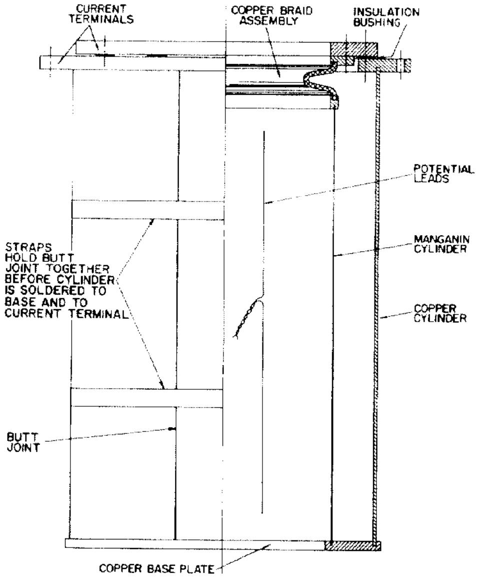

Fig. 6. Assembly view of air-cooled shunt