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SHORT SAMPLE TEST OF SUPERCONDUCTING WIRE

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Summary

Two different techniques were used for short sample tests of superconducting wires. One method was done with a DC transformer and the other with a high current DC power supply. Three different types of sample holders were used for the latter. Their relative merits and demerits are compared. Many wire designs representing half a dozen companies have been tested, and their results are presented. For the short sample test, quench current and current at various resistivities was determined. Resistivity ratios of ρ_{300}/ρ_{12} were found for copper, and the effect of cold work on these ratios was investigated.

Short Sample Test

Two methods were used for the short sample tests. The first samples were tested using a 50 kG dipole magnet for field, and the samples were powered with a DC current transformer. More recently, samples were tested using a 75 kG solenoid magnet, the sample being excited directly with a high current DC power supply.

DC Transformer Method

The first set of test equipment and the dipole magnet were originally built and used by J. R. Purcell and H. DesPortes of Argonne for Fermilab's 15-foot bubble chamber wire.[1] Its operation principle and circuit diagram are reported in their paper. The magnet, about 2' long and with a 1" bore, was mounted vertically in a Helium dewar.

The test sample, about five feet of wire, was bent double leaving a loop at the end. The sides were glued together and then clamped tightly in a slotted cylindrical aluminum holder. In all cases the samples were bent so the wide faces were adjacent. The sample was long enough so that only the center straight section was in the field.

Effect of Orientation

Most data was taken with the sample oriented with the external field perpendicular to the narrow faces of the sample. The sample was most stable and gave highest quench currents when oriented so the field it generated was opposing the external field. Data was taken in this position at all fields.

At the same external field for each sample, data was taken with the sample field adding to the external field. This orientation gave lowest quench currents.

Corrections were made for the field generated by the current in the two adjacent legs of the sample. They were imposing an additional field on each other in the same direction. For most of the wires tested, the correction was roughly $H = I/5d$, where d is the distance between the centers of the two legs in cm; I, the current in Amps; and H, in Gauss. When these corrections are made, the data from the two orientations lie on the same line. This effect was reported in our report[2] and also in a paper by G. Miranda et al.[3] The measured quench currents for some of our samples are shown in Fig. 1.

DC Current Method

Setup. A block diagram of the equipment for the high current DC method is shown in Fig. 2. The sample current vs. the voltage across the sample is plotted on an x-y recorder. The voltages across the magnet and the sample are monitored and fed into safety circuits. These turn off the respective power supplies if the voltage becomes too high

The solenoid magnet used for this method is composed of two parts; the outside 5-inch i.d. solenoid[4] and an inserted 3-inch i.d. solenoid.[5] The combined magnet is 10" high, 10" in diameter and has a 3" bore. The two magnets are run in series and give fields up to 72 kG. Magnet stability is good and it can be excited to 65 kG in two or three minutes. The field was measured in the air at low current along the axis of the magnet, and near the edge of the bore. In the center 2", the total combined axial and radial field variation is 3%.

The sample is centered in the solenoid both horizontally and vertically. The sample wire itself is epoxied to the holder and clamped down with screws. Usually, the outside surface of the wire is exposed to liquid He. Voltage taps are attached below the power leads. For samples with quench currents from 800 to 5000 Amps, a Transrex power supply is used; and for samples with quench currents from 50 to 1000 Amps, a single 6463 Hewlet-Packard power supply is utilized.

Procedure. At selected fields, the current in the sample is increased until it quenches. The sample current and the voltage across the sample are constantly monitored and plotted on an x-y recorder. Voltage changes of less than 1μV can be detected through an amplification of 100 in a DVM.

For each wire, representative I-V curves at each field value are plotted on the same graph. Resistivity lines in the appropriate range, usually between 10^{-11} and 10^{-13} Ωcm, are calculated and plotted on the same graph as the I-V curves. The intersection points give the resistivities at selected fields and currents. Then B-I curves corresponding to several resistivities, as shown in Fig. 3 are drawn.

Discussion of Data on Short Sample Test

Comparison Between the Two Methods

Using a high current DC power supply, we are able to observe the transition in considerably greater detail. A very slow ramp (∿ 4 min.) can be used and a very small amount of current-sharing can be detected.

With the DC current transformer, the secondary, soldered to a sample wire, is a closed loop with a moderate resistance, mostly due to solder joints. Thus, the system has a finite time constant and the current in the primary must be increased in 30 sec or less.

Different Types of Sample Holders

When testing with the solenoid and high current DC power supply, three different sample holders are used, as shown in Fig. 4. Two of these are cylinders made of G-10 material for bifilar winding. One had a diameter of 1-5/8" (Berkeley type) and the other a 2-1/2" diameter (Fermilab type). With both bifilar windings, the narrow face of the wire is perpendicular to the applied magnetic field. The third holder has a 1-1/8" radius and is hairpin-shaped. This design has the wide face of the sample perpendicular to the field.

Supercon stranded wires gave the same data on all three sample holders. Solid wire wound on a smaller radius showed a couple of percent smaller critical currents. Data for solid wire on the hairpin holder was lower than that on the cylindrical holders. This can vary from a few percent to more than 15%. A sample of solid MCA 50 x 150 showed a difference of 10% at 50 kG for the two configurations. This effect is due to the field orientation, relative to the deformed shape of filaments.

The hairpin sample is easier to prepare, can be held more securely, and does not require as much wire. This is also its main disadvantage in some cases, due to a low signal to noise ratio. With longer samples, it is much easier to obtain information of what went on before quench. As about six times the voltage is developed in the cylindrical sample before quench; resistivity at quench, as well as current at lower resistivities, can be more easily measured.

Critical Current and Cross Sectional Area

Critical currents were measured for two series of wire with the same structure. One series had five wires and the other had four wires with identical treatment until the final drawing. The final sizes were .015, .020, .025, and .030 inch, and one .037 inch in diameter.

At constant resistivity, 5×10^{-13} Ωcm, a plot of area versus current gives two straight lines, as shown in Fig. 5. It shows the critical current is proportional to the cross sectional area for a series of wire with the same structure and heat treatment. The diameter of the superconducting filaments ranges from 12 μ to 4.8 μ for these wires.

MISCELLANEOUS EFFECTS

Thermal Insulation Effect. In the tests on bifilar and hairpin samples, the sample is epoxied to the holder, but care is taken to ensure that one surface has direct contact with Helium. In a recent check to determine the importance of this, a Supercon 7 strand sample was first tested with the standard gluing scheme, then the sample was completely covered with a thick layer (0.1" thick) of epoxy and retested. The critical current had been lowered, but by less than 1%, which may be within an experimental error.

Keystoning Effect. Two sets of tests have been run on wires from the same billet with one sample not keystoned and the other keystoned. In the first set, a 75 x 150 solid MCA wire, there was improvement in critical current of about 10% for the keystoned sample. Although the critical currents were much higher for the keystoned sample, it is unclear whether this was due to keystoning or changes in sample preparation. The second set, a 50 x 150 eleven strand cable, had both samples prepared the same and the results varied by less than 2%. It appears keystoning has no appreciable effect on a stranded cable.

Different Wires

Testing has been concentrated on solid MCA wires and Supercon cable wires, both 50 x 150 mils and 75 x 150 mils.[6] Recently, an eleven strand cable was made at Fermilab with wire supplied by IGC. Important data for these wires, as well as for other wire samples are given in Table I. Figure 6 and 7 show the quench curves and critical current curves for some of these wires.

Resistance Test

Resistance tests have been run on superconducting wire samples. Resistance was measured at room temperature, extrapolatingto 300°K. It was measured also at many points around the transition temperature, as the sample was gradually cooled in vapor from liquid He.

Resistances at 300°K and right before the transition temperature were compared to get the resistivity ratio. Voltage was recorded with no current through the sample and with a well regulated current of 10.00 Amp. Several samples were tested using 10, 4, and 1 Amp with less than 1% difference in the ratio. Solid wires and unsoldered cables had higher resistance ratios than soldered cables. A typical resistance curve is shown in Fig. 8.

Tests were run to see if cold work due to bending affected the resistivity ratio. Long samples of MCA solid wire and of Supercon cable were wrapped on rods of progressively smaller diameters of 8", 2", 1", and 1/2". At each diameter resistance was measured in a water bath, and extrapolated to 300°K, and in liquid nitrogen, 77.4°K.

The cable showed no change in resistance in nitrogen for bending on any diameter. The solid wire showed very little resistance change from an 8" diameter to a 2" diameter. In nitrogen, the solid wire registered a resistance change of 1.1% for samples 50 mils thick and 1.6% for samples 75 mils thick when data for 8" and 1/2" diameter wire compared.

Extrapolating this to the transition temperature, the resistance of solid wires wound on a 1/2" cylinder, would increase by about 20% for the 75 mil sample and 15% for the 50 mil sample. Resistivity ratios for adjacent samples of solid wire wound on the original 1-5/8" diameter cylinder and on the newer 2-1/2" cylinder were measured, and were 94 for the small cylinder and 96 for the larger one.

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References

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1. J. R. Purcell and H. DesPortes, Rev. Sci. Instrum. 44, 295.
2. R. Yamada, P. Price, and J. Pachnik. TM-523, Fermilab Internal Report (1974).
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4. Designed and built by W. S. Gilbert at LBL, Univ. of Calif.
5. Designed by B. P. Strauss at Fermilab.
6. P. Price and R. Yamada. TM-538, Fermilab Internal Report (1974).

TABLE I Data of Different Samples

Name of Company	Type of Wire	Size Mils	ρ300 /ρ12	Filament Size (μ)	Filament Number	cu/S.C.	At 50kG Iq (Amps)	at 50kG and at $\rho=10^{-12}\Omega$cm Ic (Amps)	Jc (KA/cm^2)	Ieff (KA/cm^2)	Iq/Ic
MCA	Solid	49x148	94	29	2300	2.2/1	1770	1730	117	37	1.02
Supercon	11 strand	46x145	45	20 14	6x520 5x1050	1/1	2300	1910	110	44	1.20
Fermilab	11 strand	52x146	97	29	11x162	2.2/1	2150	2000	189	41	1.08
MCA	Solid	74x148	85	35	2300	2.2/1	2630	2620$^+$	119	37	1.00
Supercon	7 strand	72x144	68	29 21	4x520 3x1050	1/1	3580	3320	135	50	1.08
Furukawa	Braid	75x160	94	27	3840	1.1/1	3560*	3150*	143	41	1.13
MCA	Cable	91x91	71	17	36x180	1.8/1	3010	2630	179	50	1.14
Berkeley	9 strand	58x170	125	11	9x2035	1.3/1	2300*	2200*	126	35	1.05
BNL	Braid	31x790	19	7	186x361	1.75/1	4160	3730	140	24	1.12
French L	Braid	107x188	181	20	36x1045	1.4/1	5210	4440	124	34	1.17

*extrapolated
$^+5 \times 10^{-13}\Omega$m

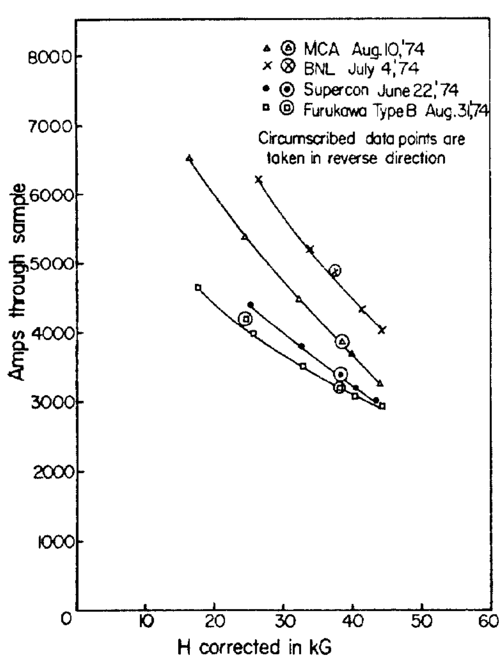

Fig.1 Quench Current vs Corrected Field

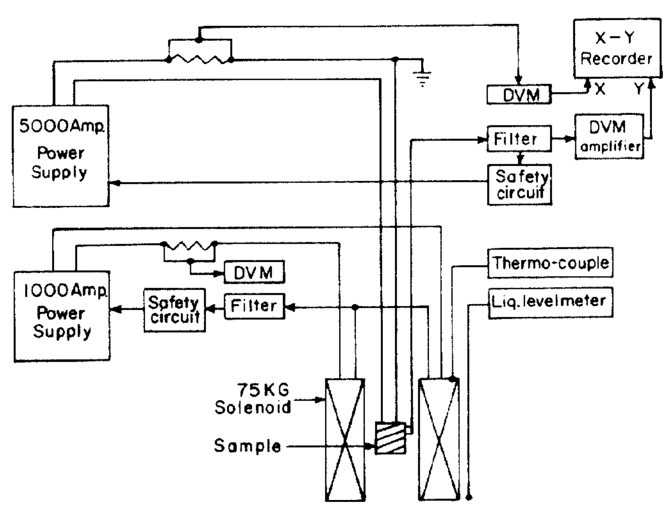

Fig. 2 Block diagram of DC current method.

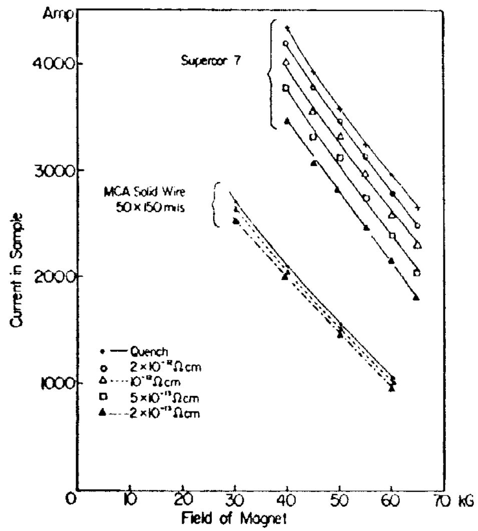

Fig.3 Critical Currents vs. Magnetic Field

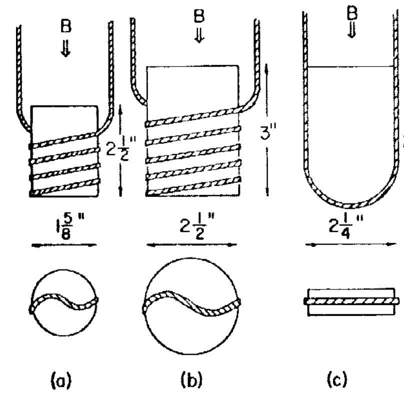

Fig.4 Different Types of Sample Holders
a) Berkeley type bifilar
b) Fermilab type bifilar
c) Fermilab type hairpin

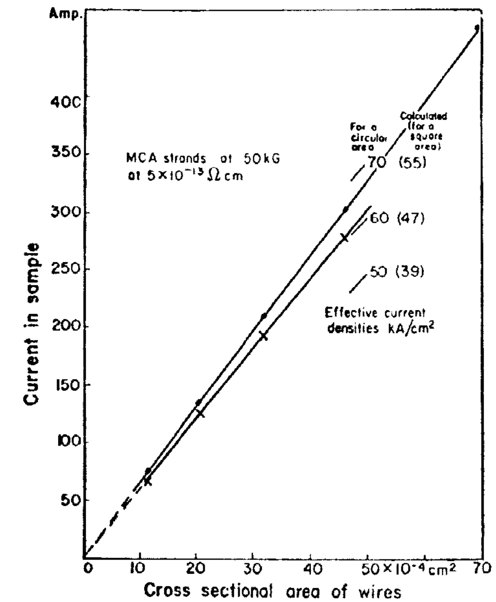

Fig.5 Relation between critical current at $5\times10^{-13}\Omega cm$ and cross sectional area

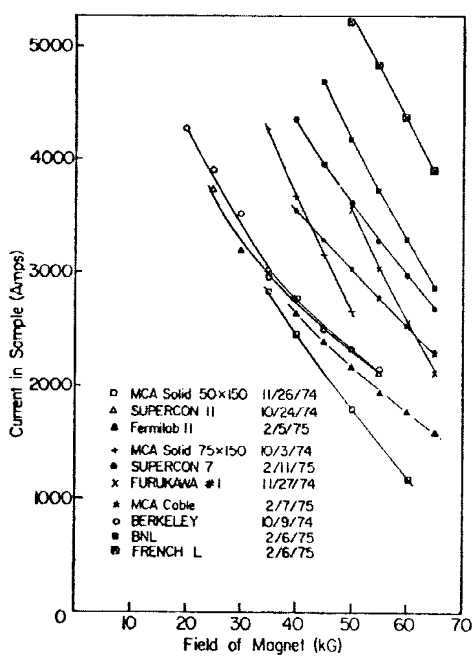

Fig.6 Quench Current of Different Samples

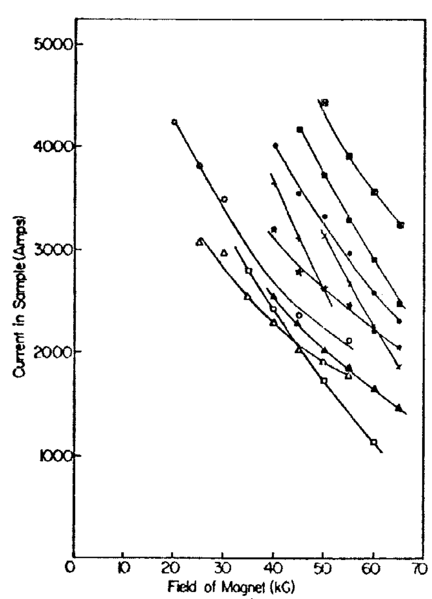

Fig.7 Critical Current at $10^{-12}\Omega cm$ of Different Samples

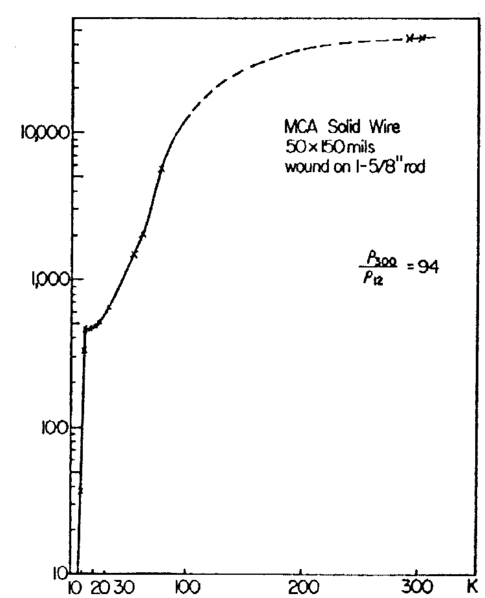

Fig.8 Typical Resistance Curve of a Sample