Particle Accelerators, 1970, Vol. 1, pp. 205–207

RESISTANCE IN SMALL, TWISTED, MULTICORE SUPERCONDUCTING WIRES†

FERD VOELKER

Lawrence Radiation Laboratory, University of California Berkeley, California, USA

We have been testing twisted, multicore, superconducting wires with a nominal 0.008 in. diameter, and we find that there is no clear-cut value for critical current. Instead, the resistance of a given wire increases continuously as the current-density or field is increased, until a range is reached where the wire becomes unstable and resistivity increases with time. If the current or field is not reduced quickly the wire will go normal.

Four samples of wire are reported on. One was a single core whose characteristics were compared with the multicore wires. One sample was mechanically defective and had approximately 25 per cent broken strands in a one-inch length.

The losses in pulsed superconducting magnets are proportional to the diameter of the superconducting filaments and to the quantity of superconductor in the magnet. Refrigeration to take care of the losses is expensive, and to be economically feasible, pulsed magnets must make full use of the available current density. We have been measuring critical current vs field for small diameter, twisted, multicore superconducting wires as samples have become available to us.

We recently have been testing wires with a nominal 0.008 in. diameter, and we find that there is no clear-cut value for the critical current. Instead the resistivity of a given wire increases continuously as the current density or field is increased until a range is reached where the wire becomes unstable and the resistivity increases with time. If the current or field is not reduced quickly, the wire will then go normal.

This report describes the properties of the following four wires:

(1) Supercon,[1] 0.0083 in. dia., 1.1Cu/SC, ~400 cores, 54 in. sample.
(2) Cryomagnetics,[2] 0.0086 in. dia., 2 Cu/SC, 355 cores, 54 in. sample.
(3) Cryomagnetics, 0.0091 in. dia., 1.25 Cu/SC, 211 cores, 54 in. sample.
(4) Thomson-Houston,[3] 0.003 in. dia., 1.25 Cu/SC, 1 core, 12 in. sample.

Number (2) was known to be a mechanically defective wire. The copper was carefully etched away with dilute nitric acid, and the filaments were studied with a low power microscope. The defective material had between 15 and 50 broken strands in a one-inch sample, and the surface of the filaments was rough and looked corroded. The other multicore wires had only 2 or 3 broken strands in a one-inch sample, and the surface of the filaments was smooth and bright. Material (4) was tested so that we would have a comparison between the characteristics of a single core wire with a filament size nearly the same as the filament size in the multicore wires. Some larger diameter wires have been tested and exhibit the same kind of phenomena, but the larger wires are harder to measure, and have not been studied as extensively.

The apparatus is shown in Fig. 1. The magnet is a 4 in. diameter $2\frac{1}{2}$ in. long solenoid wound of 0.065 in. twisted Cryomagnetics wire. The magnet will develop 45 kG at 738 A and can be pulsed at about 35 kG/sec with our power supply. The usual sample consists of 1 in. of bifilar winding on a $\frac{3}{4}$ in. diameter rod which can be inserted into the center of the solenoid. Large wires such as the 0.045 in. × 0.091 in. sample shown in the photograph, are wound on a $1\frac{1}{2}$ in. diameter form. In all cases, the middle of the sample is returned on itself over a relatively large radius of curvature to avoid stress in the material. Voltage taps are made as close as possible to the end of the winding and are brought to the top of the Dewar with twisted-pair.

The voltage across the sample is measured with a chopper-amplifier which gives a maximum sensitivity of 1 μV per division on our multichannel recorder. Current in the magnet and in the sample is monitored by series shunts, and a field signal is obtained from a bismuth probe which is mounted

† Work done under the auspices of the U.S. Atomic Energy Commission.

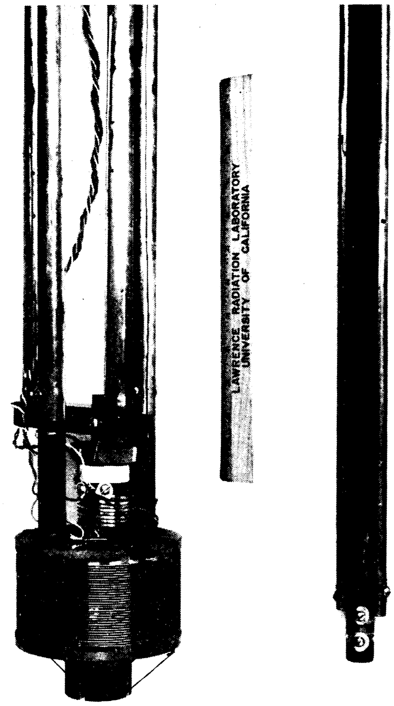

FIG. 1. Short sample apparatus.

on the sample holder. All these signals are recorded continuously. The resistivity of a given material can be obtained from the cross-sectional area of the superconductor, the length of the sample, the voltage across the sample, and the current. We have an integrator which will allow us to measure voltage as low as 0.01 μV across the sample, but because of thermal emf's we cannot use this method without bringing special continuous leads out of the Dewar to the input of the integrator. This technique should enable us to measure resistivity down to 2×10^{-16} Ω-cm on the small wires.

A family of resistivity curves is shown for two similar wires. The wire in Fig. 2 was known to have as many as 25 per cent broken filaments, while that in Fig. 3 had very few broken filaments. The ratio $\log \rho / \log J$ varies slowly over a wide range of field and current for a given material, but is quite different for the two wires.

Partial families of resistivity for three 'good' wires are shown in Fig. 4. The resistivity of the single core wire (4) varies approximately as the 100th power of the current density. This is what one expects from a superconducting wire, and since the current density only varies by 2.5 per cent for resistivity change of 10^4 times, it is feasible to

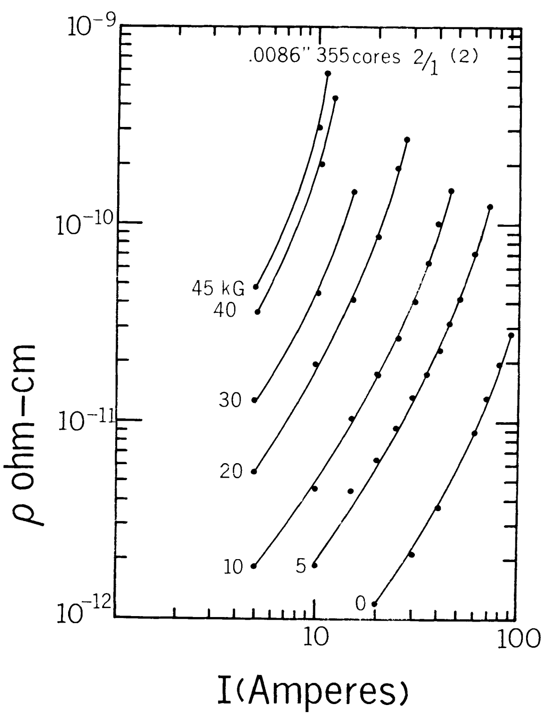

FIG. 2. Resistivity for a bad multicore wire.

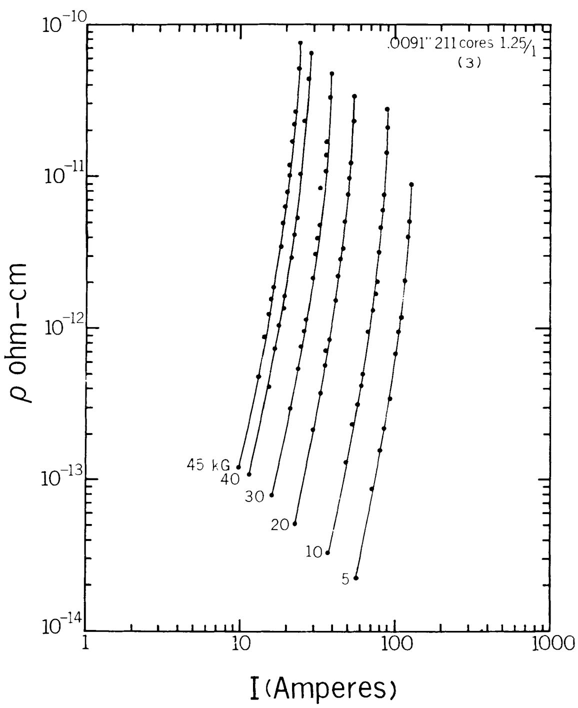

FIG. 3. Resistivity for a good multicore wire.

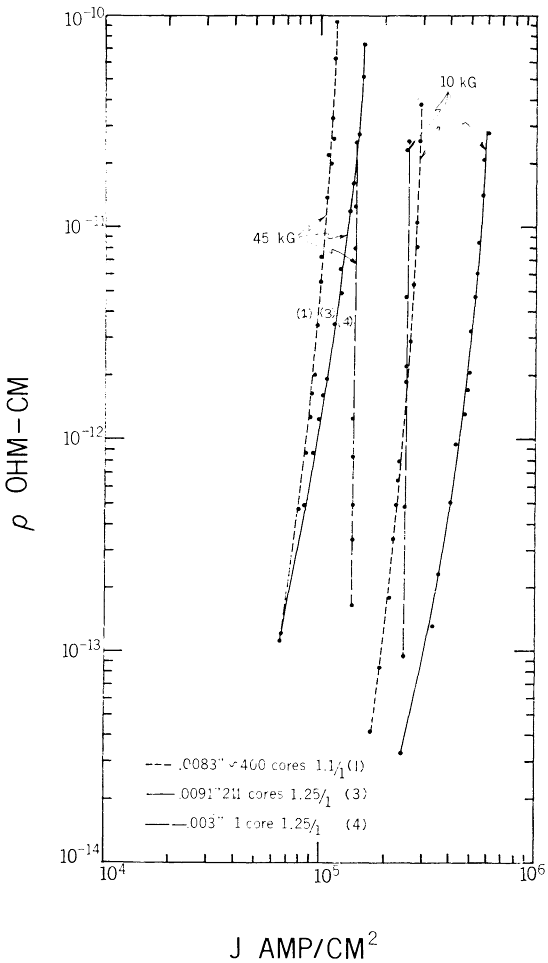

FIG. 4. Resistivity for three wire samples.

define a critical current density for this wire. With the multicore wires there is no definite value of current density that can be considered critical except perhaps the value where the wire becomes unstable. This value is probably related to ventilation of the wire, and so would be different in a magnet than in a short sample. Also it may be noted that in high fields some of the wires are still stable at $\rho = 10^{-10}$ Ω-cm, and perhaps higher. This is only two order of magnitudes better than copper at liquid helium temperature, and might result in undesirable resistive heat generation in the high field regions of a magnet.

If the resistivity of the 'good' multicore wire were caused by current flowing in the copper between occasional broken strands, then as current density is increased more current might be forced to flow in the copper. Any continuous filaments would carry all the current at low current densities; gradually filaments with the fewest breaks would begin to carry current as the total wire current is increased. Eventually, all the filaments would be carrying current. This may explain in a qualitative way the dependence of resistivity on current density. The resistivity may also be related to twist, metallurgical treatment or copper-to-superconductor bond, or some other property. We do not yet have enough data to know whether there is something more subtle going on than just current flowing in copper. It is well known that superconductors carry less current in high magnetic fields, so there is no mystery about the field dependence of resistivity.

Regardless of why small, twisted, multicore wire behaves in this way, we must still design magnets from the bulk characteristics of presently available wire, and we need some other criterion than critical current. Perhaps we should define a 'design-maximum' current density determined at an arbitrary resistivity (such as $\rho = 10^{-12}$ Ω-cm). For the 'good' multicore wires the 'design-maximum' current-density is only 60 per cent of the current-density at which the wire goes normal. It will be interesting to see whether in the future, improved manufacturing techniques will eliminate these differences between single core and multicore wires. We plan to continue to test a variety of sizes and materials from different manufacturers to help us better our understanding of this phenomenon.

Much of the tedious work of taking these data was done by Robert C. Acker.

REFERENCES

1. Norton Company, Supercon Division, 9 Erie Drive, Natick, Mass. 01760.
2. Cryomagnetics Corp., Research and Development, 4955 Bannock St., Denver, Colorado 80216.
3. Kawecki Berylco Industries, Inc., P.O. Box 60, Boyertown, Penn. 19512. American agents for Compagnie Francaise Thomson Houston, 51 Boulevard de la Republique, P.O. Box 17, 78 Chatou France.

Received 13 April 1970