Homogeneity Investigations on Superconducting Wires and Cables

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Abstract

Two procedures are described which enable a control of the homogeneity of the copper plating and the magnetization of the superconducting cross section along great lengths of superconducting wires and cables.

With the first method irregularities of the copper plating as e.g. different thickness, holes or separation from the core can be conceived quantitatively.

With the second method one can investigate the homogeneity of superconductors according to their magnetic characteristics.

We discusses the conclusions which can be drawn from magnetization on the I_c-H_c-characteristics.

1. Homogeneity of Copperplating in Superconducting Wire.

It is well known, that copperplated superconductors or superconducting cables stranded together with copper wires or other normal conductors are successfully used for constructing superconducting magnets. With such stabilized superconductors degradation effects can be avoided or considerably reduced especially in large coils. However it is of importance, that the low resistive material, which surrounds the superconductor, be homogeneous all over the length of the wire and nowhere damaged.

In a coil made of Nb 25% Zr 10 mill wire we found two spots, where the copper plating was fully destroyed. These spots had caused remarkable degradation. After cutting off the defective wire length, the coil could be powered to much higher current values than before. The damaged wire parts are shown in figure 11.

These two spots were situated in the outer region of the winding volume. One can assume, that the copperplating was initially damaged only to a certain extent, and it was eventually fully destroyed by repeated quenches.

The arrangement shown in figure 12 allows the measurement of the homogeneity of plated superconducting wire of arbitrary lengths. It allows to detect such defects as holes, cracks or changes in thickness.

The plated superconducting wire is made to run through a gap of a small magnet excited by a high frequency current, between 50 and several hundred kHz. The magnetic field is perfectly shielded from the core of the wire as long as the surrounding copper is completely faultless.

In correspondence to the spots, where the copper plating is damaged the field will not be perfectly shielded. This results in a change of the primary circuit inductance of the high frequency magnet. The difference of the resistivity of copper and the superconducting alloy is so great, that shielding effect of the superconducting core can be neglected.

To make the measuring arrangement highly sensitive even for small changes of inductance the primary circuit is excited in resonance.

A normal inductance measuring device ("LARU") is used as power supply and indicator. The measuring voltage is transferred to an X-Y recorder.

By means of this method several thousand meters of 0,25 mm NbZr and NbTi wire were tested. A quantity of manufacturing defects could be discovered.

In figure 13 some typical diagrams are shown.

On the upper line at first a diagram of a short wire test is plotted. The diagram begins on the left side, where no conductor passes through the gap. Then follows a zone, where the bare superconductor was put into the gap. One can see that the relatively high resistive superconductor does not influence the geometry of the field. Then follows a wire length with a heavily damaged copper plating and at last the perfectly normal wire with homogeneous copper plating.

The lower curves are details of long wire tests. 1 cm in the X-direction corresponds to a 50 cm wire length. The wire is made to run through the gap with a continuous velocity of about 10 cm/s.

Some lengths are seen to be damaged by the presence of a dense series of defects located 5 to 1o cm apart. On other wires only some single defects can be discovered.

In the same fashion a quantity of a NbTi wire delivered in 1966 was tested.

Some defects were discovered and are shown on microscopic pictures on the right side of figure 14. Cracks, holes and narrow spots can be clearly seen.

On the next picture (figure 15) another type of inhomogeneity is shown. The copper is separated from the core of the superconductor. In comparison the cross section of a normal plated conductor is shown on the second photograph.

Evidently defects of these kinds can influence the behavior of the superconductor wound into a coil. A single spot on the wire can remarkably lower the critical current of the whole coil.

Since wire manufacturers cannot guarantee better homogeneity the behavior of the wire can hardly be quantitatively predicted.

During the last two years superconducting cables in combination with a great amount of normal conductive material have been used especially for the construction of large magnet coils. Thereby it is of importance that the single strands be electrically well connected. Generally indium is used as a means of impregnation.

The just described arrangement allows also the measurement of the homogeneity of this impregnation.

On the following figure 16 the diagram of a 7 strand NbZr cable is shown. The diagram on the first line corresponds to a cable where the seven strands are insulated from each other. Then follows a length, where the single strands are not insulated and the last part of the diagram corresponds to a perfectly impregnated cable.

The dependance on the frequency is shown in the diagram below.

2. Magnetization Measurements

The electrical properties of a superconducting wire are usually described by its I_c-H_c-characteristic. It is very difficult to measure this characteristic along a certain length of a wire.

Now, between the I_c-H_c-characteristic and the magnetization curve of a superconductor exists a certain relation, according to Bean's model (1) and other workers investigations (Kim and al (2) and Le Blanc (3).

The magnetization at a certain magnetic field can be measured on a continuously running wire of arbitrary length. On figure 17 a measuring arrangement is represented, by means of which the magnetization of a single 0,254 mm wire can be studied.

The wire is made to run from outside into a cryostat, where it is cooled down to liquid He temperature. The wire passes then through a magnetic field, produced by a superconducting coil. The flux, which penetrates the wire volume can be measured by a small coil probe, the normal flux of which is compensated by a similar shaped coil nearby. The resulting signal is amplified, then integrated, and at last plotted on a X-Y recorder. The schematic set-up is shown in figure 18.

The next diagram (figure 19) represents the magnetization curve of a single NbZr wire with a diameter of 0,254 mm (10 mill).

The values of the increasing branch on the right side of the magnetization curve have been transferred to the I_c-H_c-characteristic. This characteristic received by using the written equations is compared with the usually measured I_c-H_c-characteristic of a short sample.

The magnetization curve consists of two parts, which are represented by equation I and II. They coincide at the point, where

$$\frac{Ba - Bi}{Ba} = \frac{1}{4}$$

$$I: \quad i_I = \frac{B_a}{\mu_0 \cdot 2r_1\left(1 - \frac{B_a - B_i}{B_a}\right)}\left(1 + \sqrt{\frac{3}{4}\,\frac{B_a - B_i}{B_a} - \frac{1}{3}}\right)$$

$$II: \quad i_{II} = \frac{3\,(B_a - B_i)}{r_1 \cdot \mu_0} \qquad \text{with } B_i = \frac{2}{r_1^2}\int_0^{r_1} B(r)\,dr$$

It is approximately assumed that the current density is constant across the penetrated part of the conductor cross section. This approximation is sufficient for very small conductor diameters.

There is a good agreement between the shapes of the two characteristics.

Similar diagrams for a NbTi-wire also of 0,254 mm diameter are shown on the next picture (figure 21).

In order to prove the validity of magnetization measurements as a means of ascertaining the homogeneity of I_c-H_c characteristic in superconducting wire, the reproducibility of magnetization measurements was investigated.

The magnetization of a spot in a superconducting wire was measured several times, and the results are reported on the next figure (22). Only single branches of the curve are compared.

Details of magnetization curves in different spots are compared in figure 23. It can be observed that the position and the shape of the flux-jumps - expecially on the left branch of the curve, in correspondence to the region with opposite magnetic field - are not well reproducible, that is the 3-6 KGauss region does not lend itself to homogeneity investigations, due to the difficulty of discriminating flux jumps from real defects in the wire.

This critic region is also put in evidence in the next figure 24, which shows diagrams obtained for NbZr wire running at different values of magnetic field through the apparatus for continuous measurements previously described.

Our observations are therefore concentrated on the region beyond 6 KGauss, which appears to lend itself to homogeneity measurements. The observation of a sufficient quantity of wire proves the validity of such measurements.

1) C.P. Bean, Phys. Rev. Letters 8 (1962) 250

2) Y.B. Kim, C.F. Hempstead, A.R. Strnad
Phys. Rev. 1929 (1963) 528

3) M.A.R. Le Blanc
Phys. Letters 6 (1963) 140

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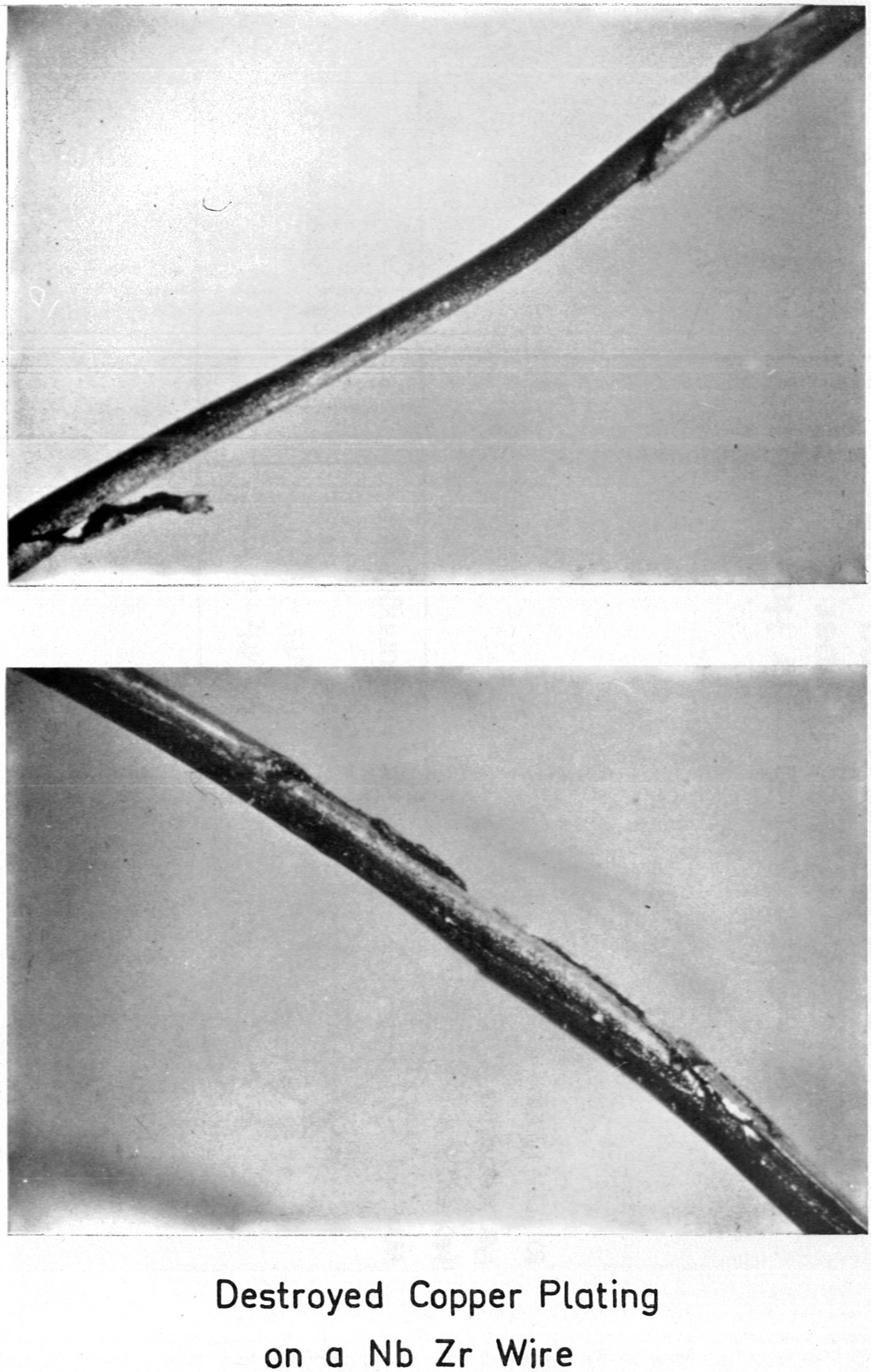
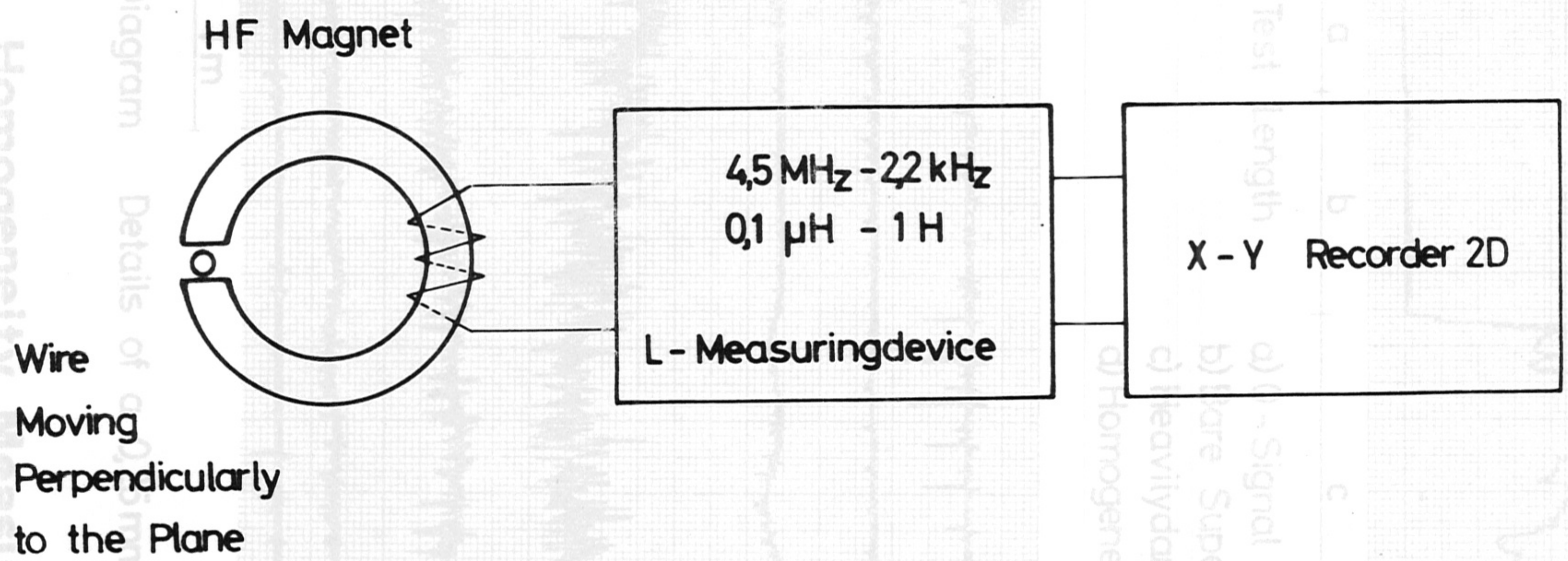
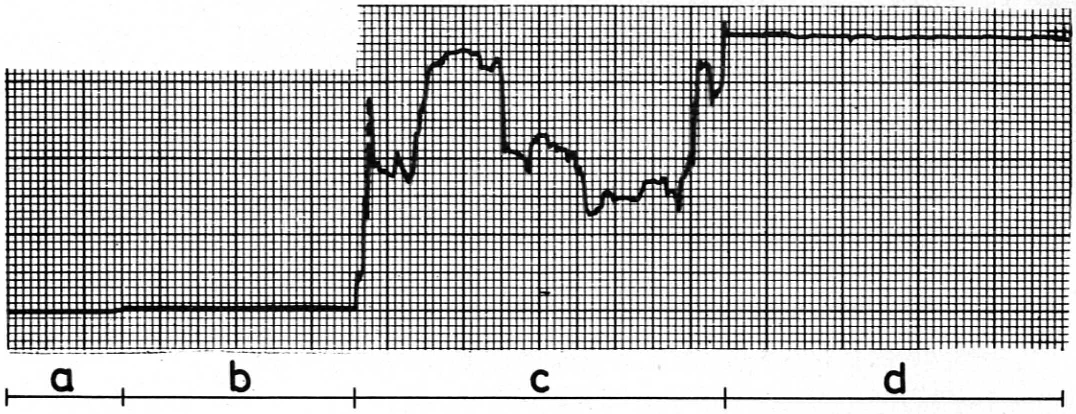


Destroyed Copper Plating
on a Nb Zr Wire



Schematic Set-up for Homogeneity Measurements of Copper Coating of Superconducting Wires



Test Length

a) 0 - Signal
b) Bare Superconductor
c) Heavilydamaged Copper - Plating
d) Homogeneous Copper - Plating

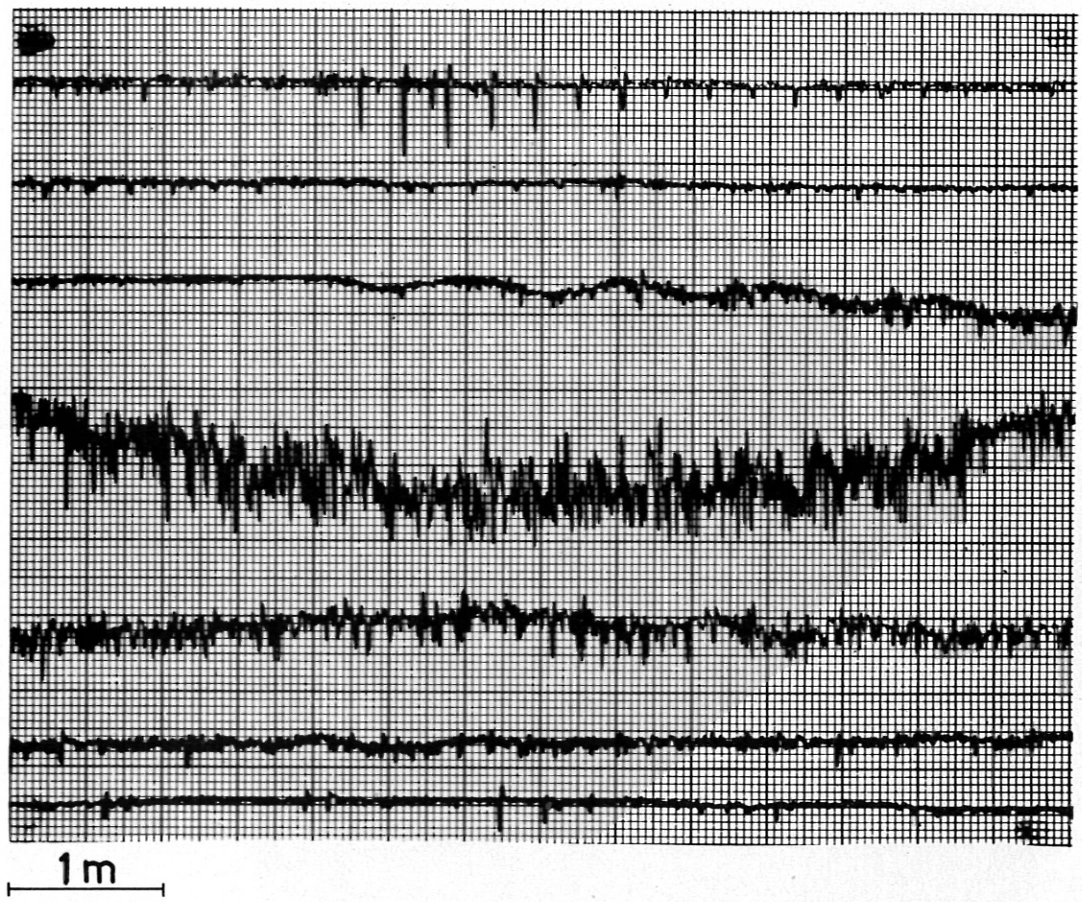
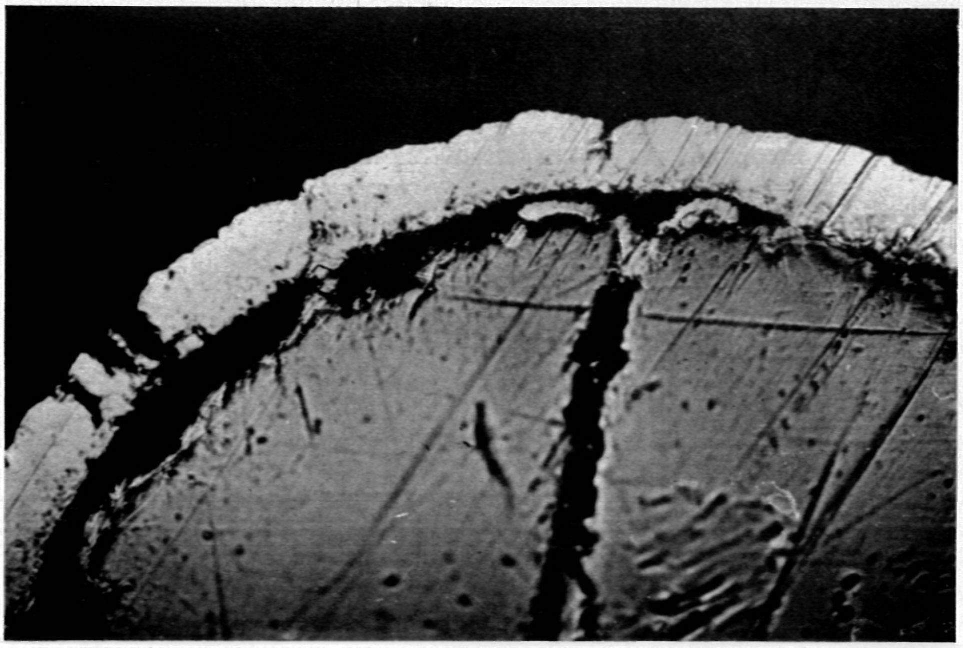
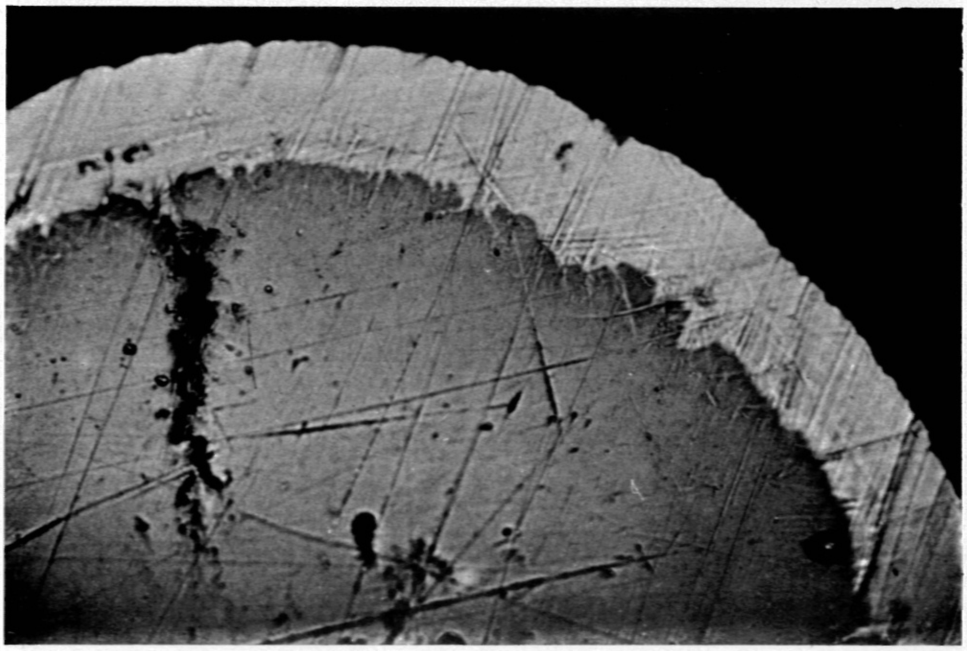


Diagram Details of a 0,25 mm Nb Zr Wire

Homogeneity Measurements of Copper Plating in Superconducting Wires

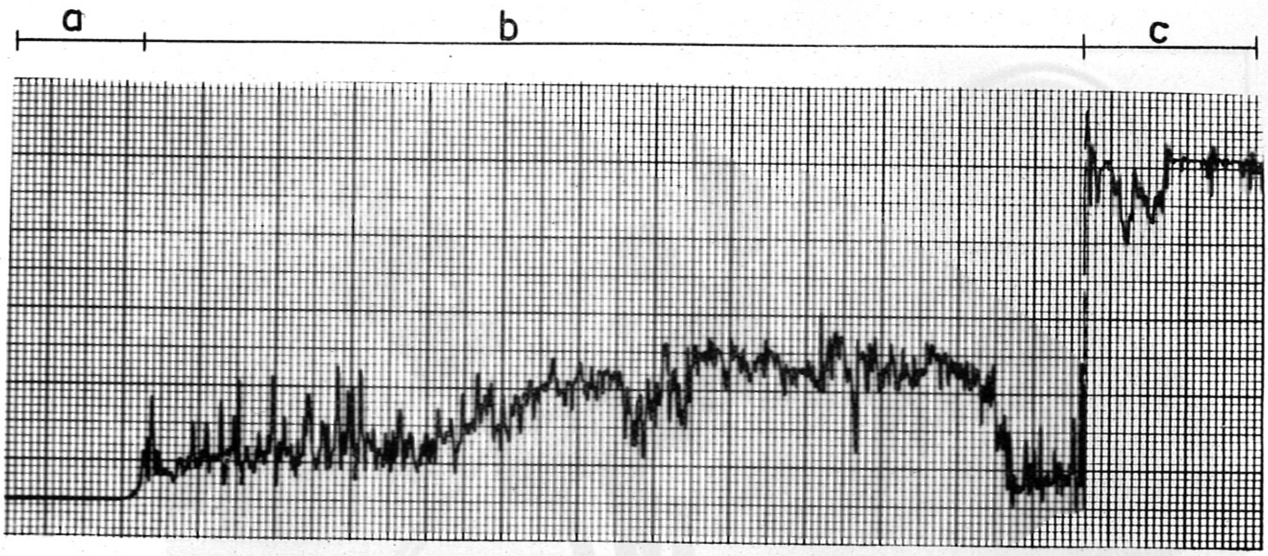




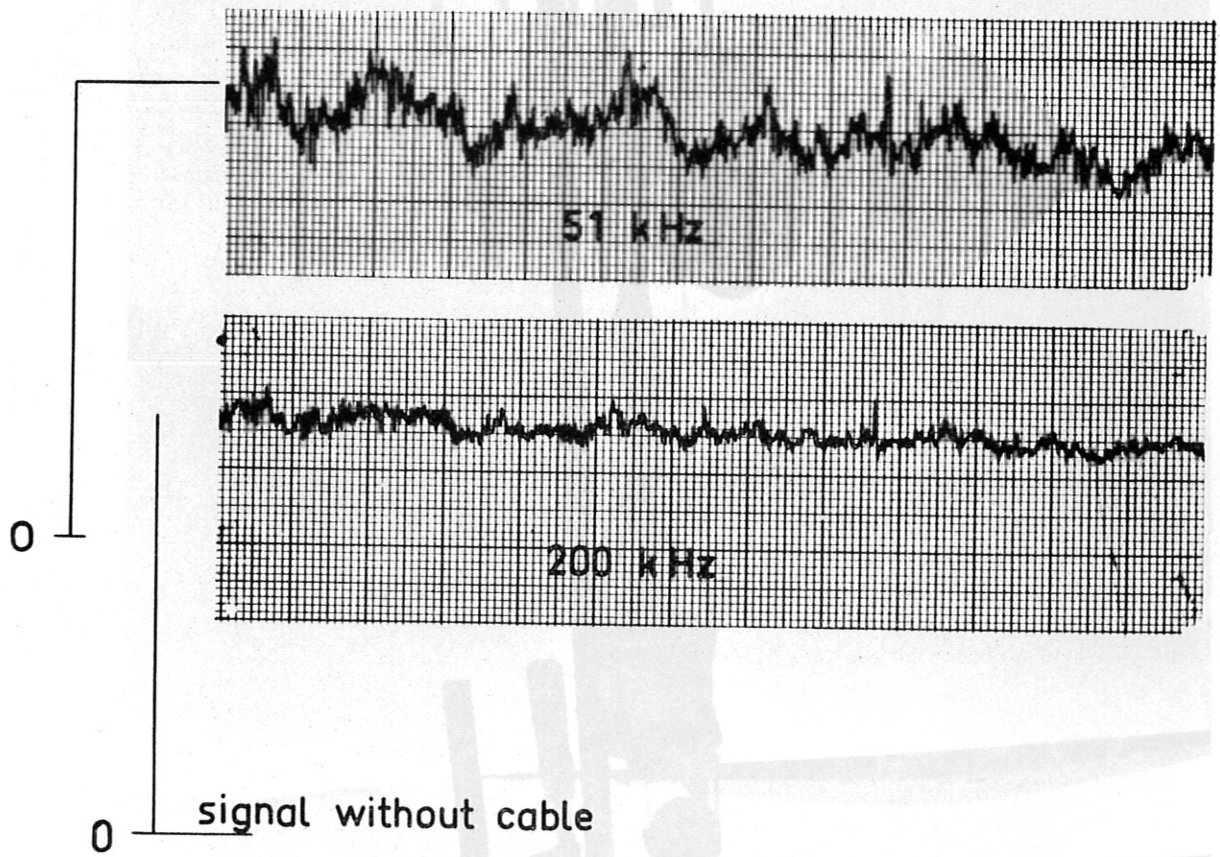
Copperplated Nb (25%) Zr Wire

0,254 mm Diameter

Damaged and Faultless Copperplating



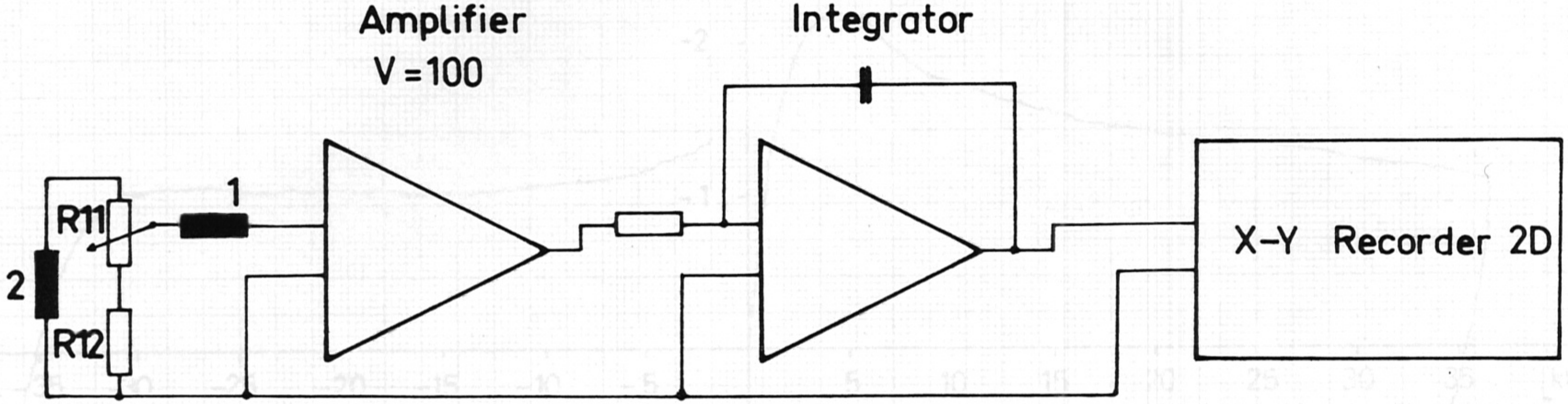
7 strand Nb Zr cable, copper plated
a) single strands, insulated
b) single strands, not insulated
c) Indium impregnated



7 Strand 0,25mm Nb Zr - Cable
Homogeneity of Copper Coating
and Impregnation

Device for Magnetization

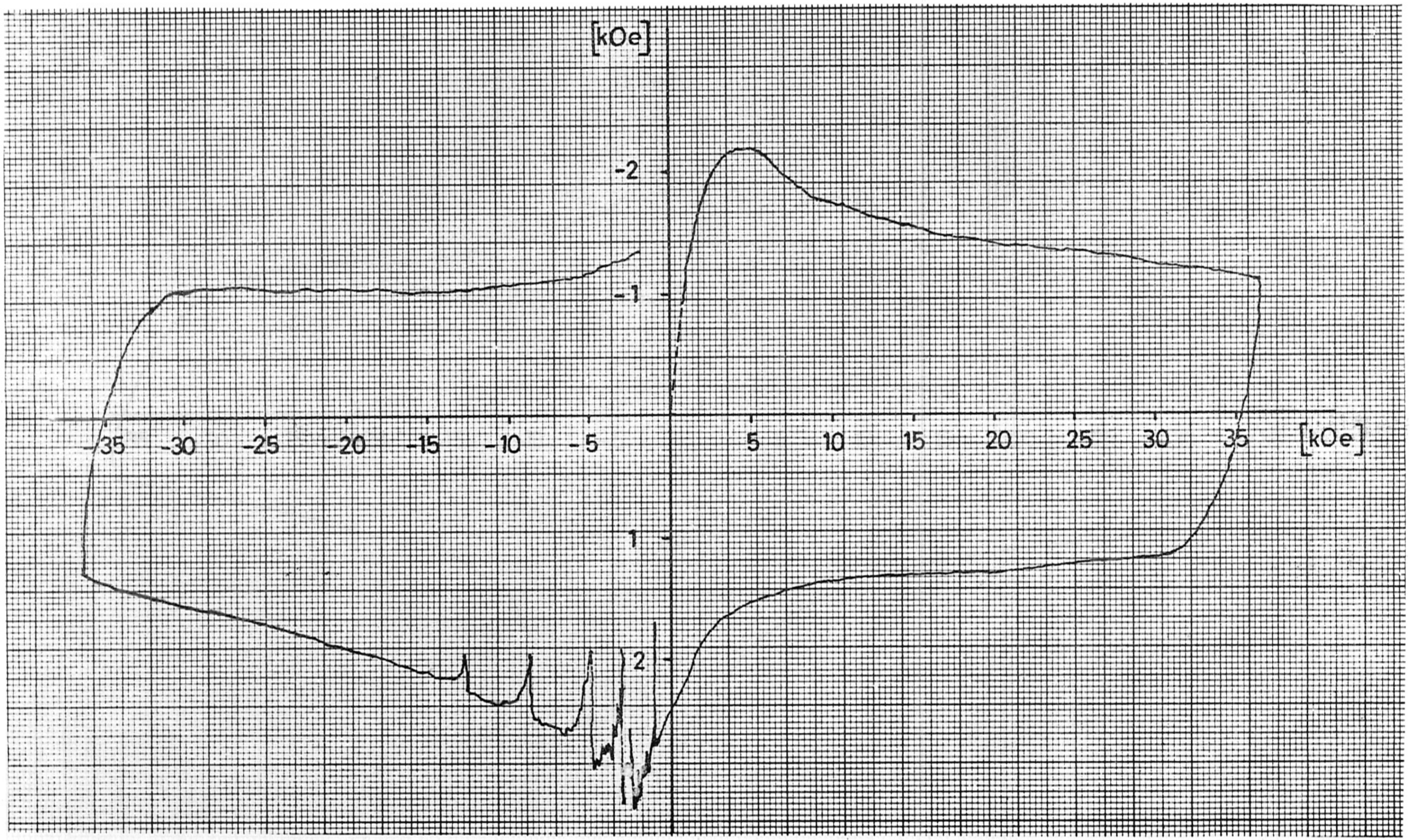
Measurements



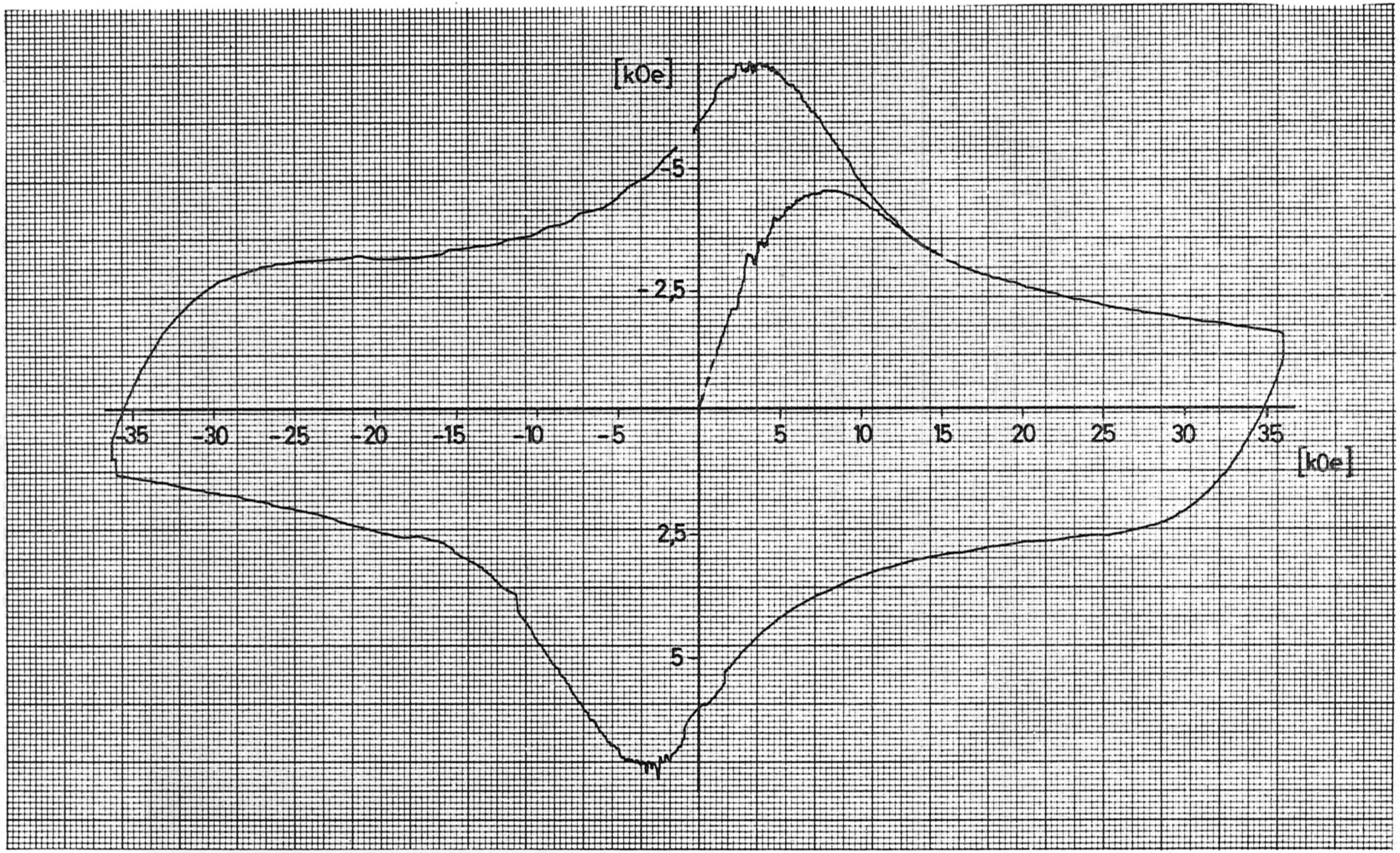
1 Coil measuring [wire passing through]

2 Coil compensation

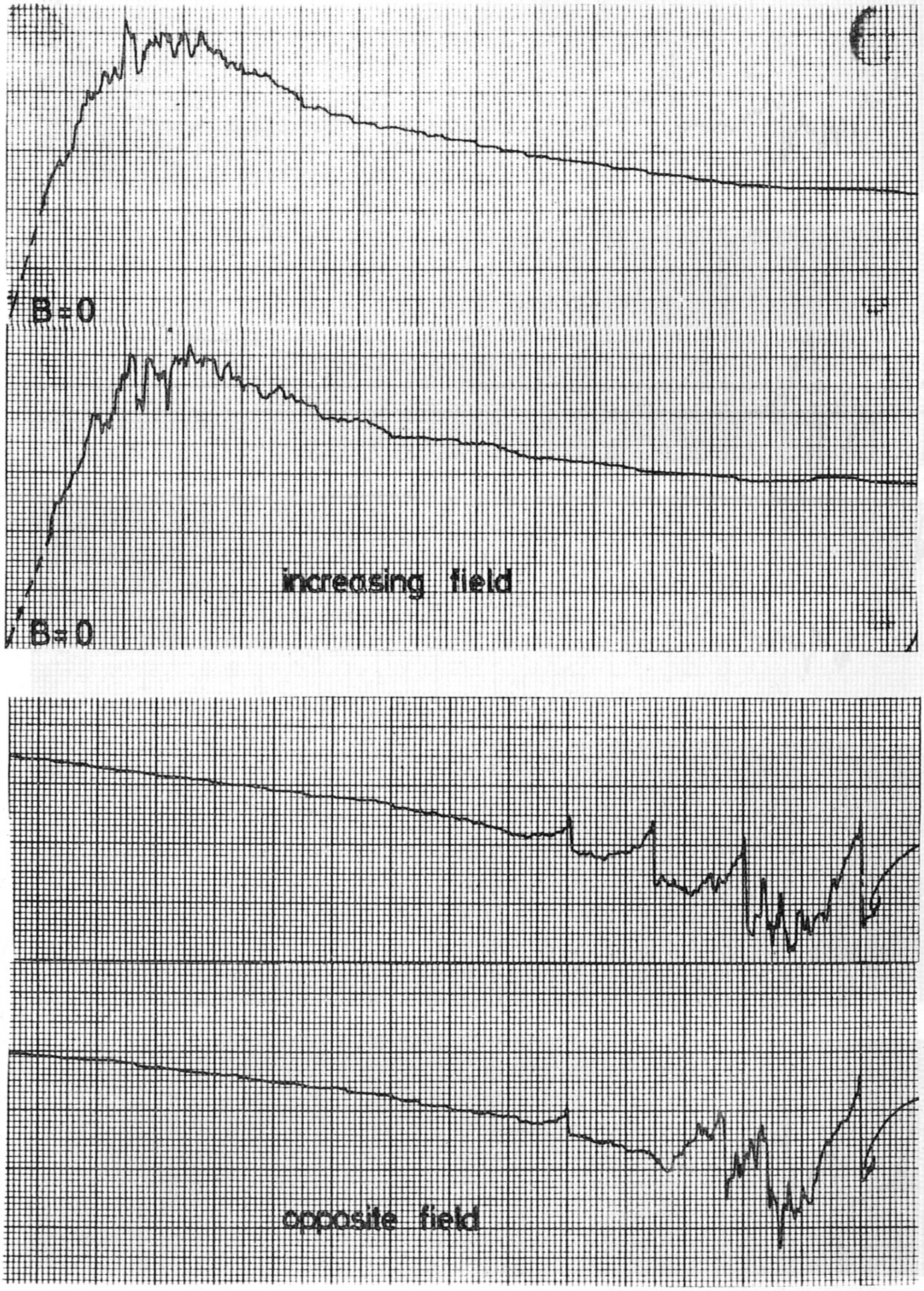
Circuit for Magnetization Measurements



Nb Zr Wire 0,254 mm Magnetization Curve

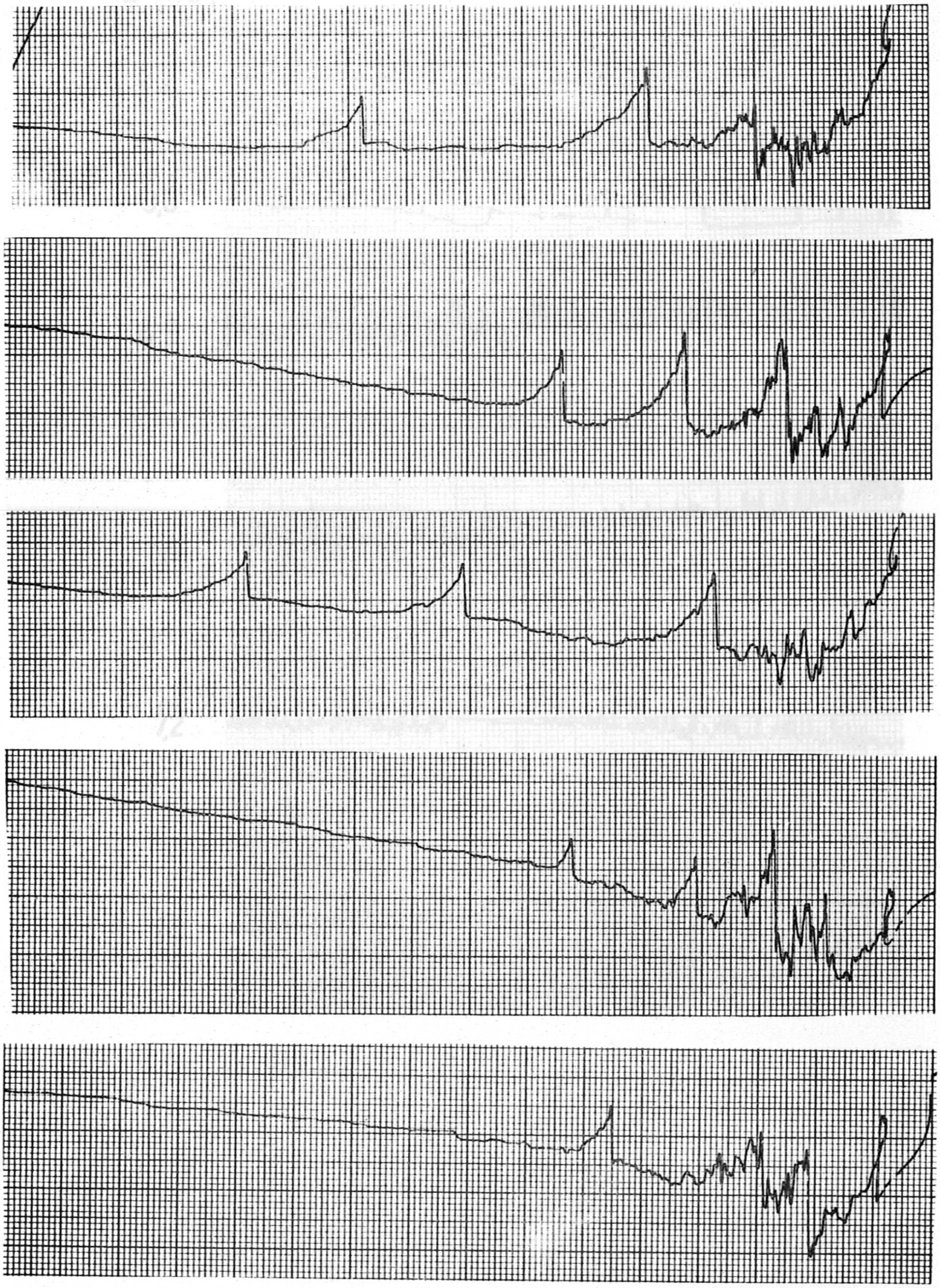


Nb Ti Wire 0,254mm Diameter Magnetization Curve

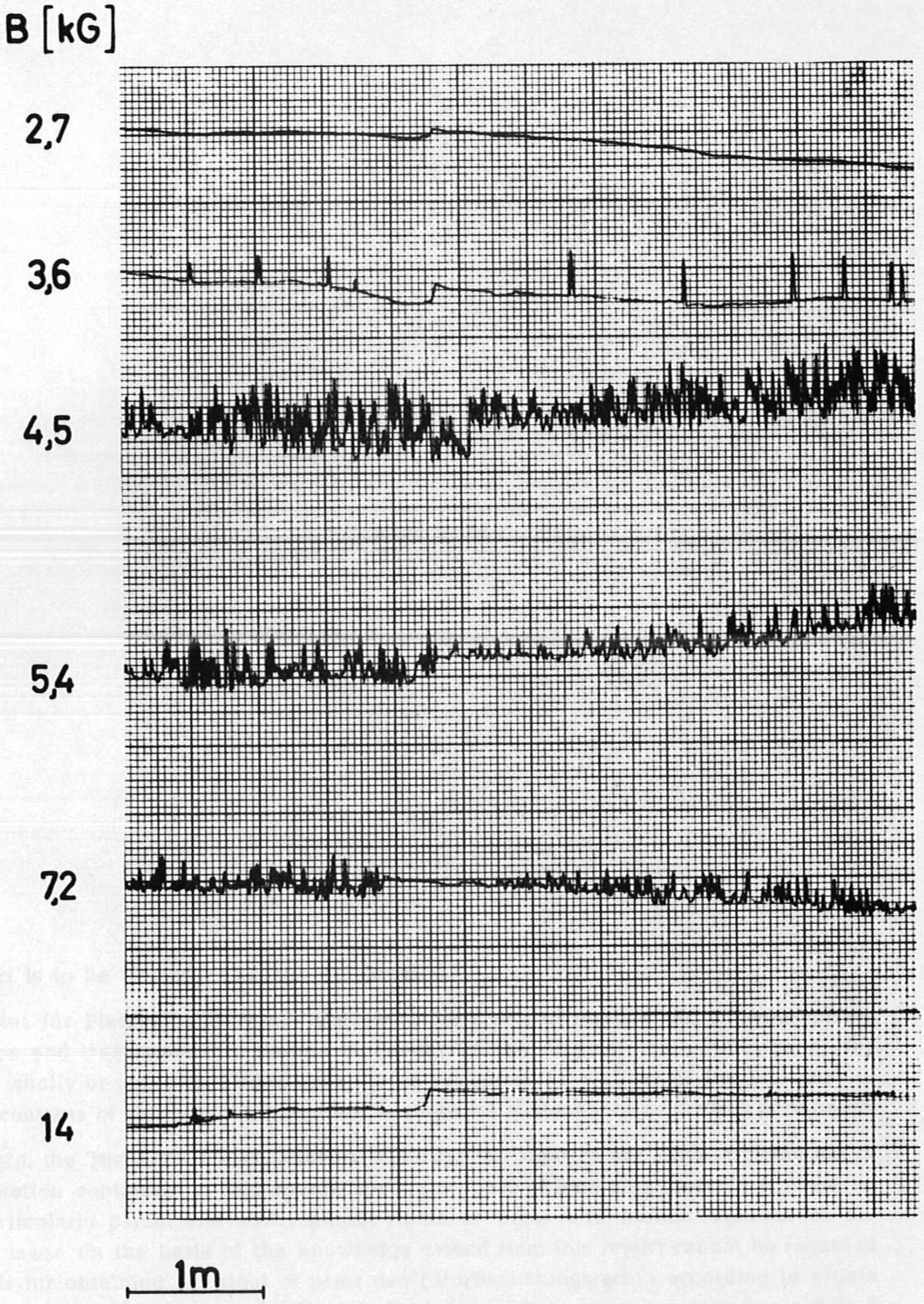


Details of Magnetization Curves

Single Spot



Details of Magnetization Curves
in Opposite Field
Different Spots



Nb Zr Wire 0,254mm

Homogeneity of the Magnetization