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An Instrument for Spatial Conductivity Measurements of High T_c Superconducting (HTSC) Materials

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HTSC thin films have been suggested for use in a number of aerospace applications such as an IR bolometer and as electromagnetic shielding. As part of its flight assurance role, the Materials Branch of the Goddard Space Flight Center has initiated development of an instrument capable of measuring variations in conductivity for flat samples using an eddy current testing device and an X-Y positioning table. This instrument has been used to examine bulk HTSC samples. System changes that would enable characterization of thin film materials are discussed.

Introduction

Blendell et al (1) have noted the correlation between room temperature conductivity of $YBa_2Cu_3O_{7-x}$ specimens and transition temperature (T_c). Viens (2) reported success using a simple eddy current scope to distinguish between superconductive and nonsuperconductive $YBa_2Cu_3O_{7-x}$ specimens of identical geometries and that the strength of eddy current readings was directly correlated with room temperature conductivity.

This series of findings led to the suspicion that initial screening of bulk samples using various compositions and processes could then be done quickly at room temperature. It was hoped that combination of precise motion control and a data acquisition system would provide information about the spatial variation in conductivity in flat samples at room temperature.

Instrument Description

The eddy current testing system is shown schematically in Figure 1. A conventional eddyscope is used to generate eddy currents in the HTSC samples. This instrument generates an alternating current in a coil placed over a flat specimen, thereby creating a changing magnetic field. This changing magnetic field in turn creates an electric field and a current flows in response. This current creates a magnetic field which bucks that of the probe. An impedance bridge internal to the eddyscope attempts to balance the impedance of a reference coil and the coupled probe and sample. The eddyscope displays the measured response in two dimensions corresponding to the real and imaginary components of the effect of the specimen impedance.

Probe widths used in this test varied from 50 to 125 mils; driving frequencies ranged from 100kHz to 6MHz. The skin depth (δ) of an electromagnetic field is given by:

$$\delta = \frac{1}{\sqrt{\pi \mu \sigma f}} \quad (1)$$

where μ is the magnetic permeability, σ the conductivity, and f the frequency of the field (3). Assuming a conductivity of 200 S/cm (1), skin depths could vary from ~1 cm at 100kHz to ~1.5mm at 6MHz. Precise determination of skin depth is difficult since probe width also is a contributing factor. Ultimately, 6MHz proved a suitable frequency for bulk materials (but thin films will require different hardware capable of much higher frequencies).

A scan is accomplished as follows. A flat specimen is positioned on a PC-controlled, XY table. The table's two stepping motors are controlled by separate indexing boards which occupy single slots on the PC

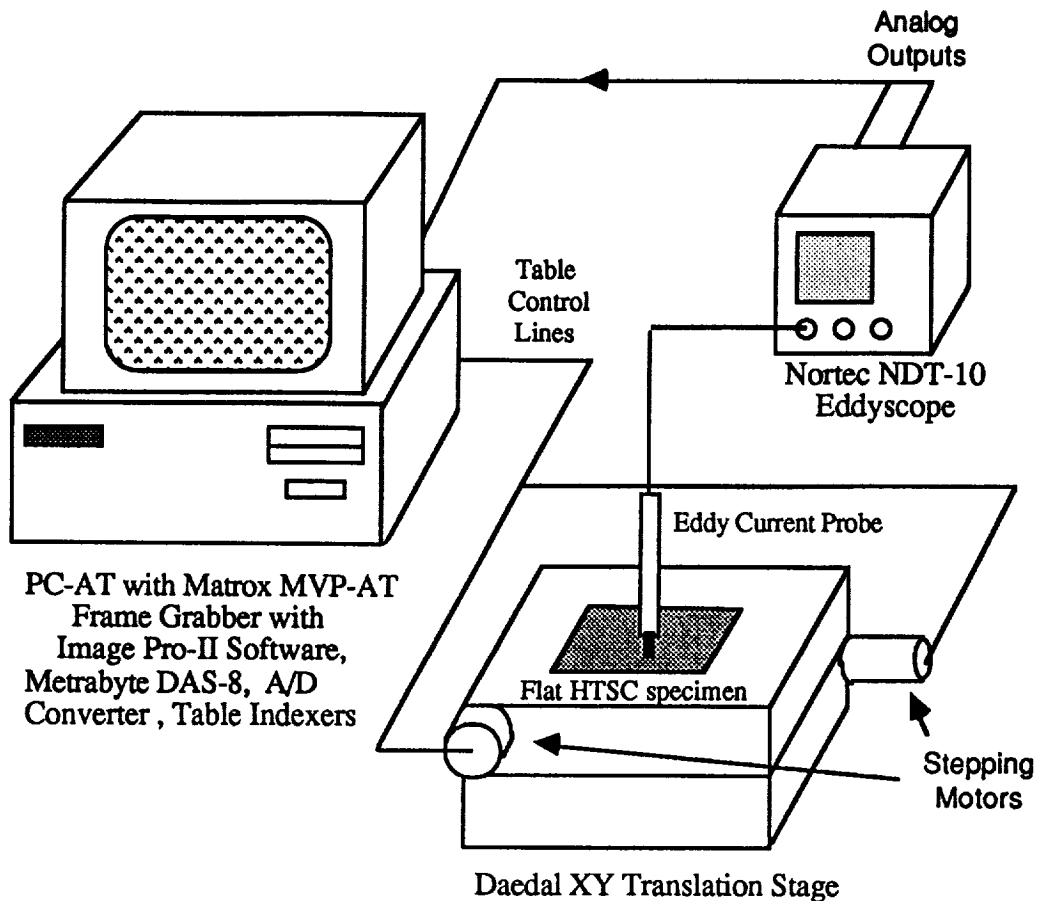


Figure 1 The Eddy Current Scanner

expansion bus. Command of the table is accomplished in software via subroutine calls from a BASIC program.

The scanning control software executes a "raster" scan (unidirectional scans with a non-sampling retrace) of a rectangular area with the range of travel determined at the beginning of run. Digitization of the two eddyscope data channels is done with a 12-bit A/D converter board which resides in the PC. Control of digitization is managed from within the same BASIC program which controls table motion. Scanning dimensions and the distances between columns and rows in the resulting image can be selected prior to scanning. The software automatically computes the required sampling rate for the A/D board and synchronizes data taking so that the resulting image is registered correctly.

Following the run, display of the conductivity map is done with a PC-AT based imaging system using a microcomputer imaging software package. This hardware is capable of displaying 512 x 480 x 8-bit images, but typical image sizes ranged from 100 to 200 pixels on a side. Using information about the dynamic range of the data channels compiled during run-time, a post-run program compresses (or expands) the 12-bit data to fit the 8-bit display range. The two channels from the eddyscope (x and y) can be

displayed separately but only single channel images are presented in this paper since the x and y channel images differ only slightly.*

Results

Some preliminary scans with metal samples were done to assure proper scan line registration. Once image registration was confirmed, scans were done of bulk $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ material produced in-house. These were disc-shaped specimens 12.7 mm in diameter and 2 mm thick. An "ideal" scanner would have an infinitesimally small probe and a driving frequency such that δ is approximately material thickness. It is expected that an "ideal" scan would produce a circular region with diameter equal to the specimen diameter, would have high contrast compared to its surroundings, and would possess a boundary at the edge of the circle that is quite abrupt. Figure 2a shows the eddy current image of a scan from the disc done with a 0.125" wide probe at 100kHz. This "real" image is dominated by edge effects; the result of the relatively wide probe and low driving frequency (hence large δ) which combine to smear out any detail.

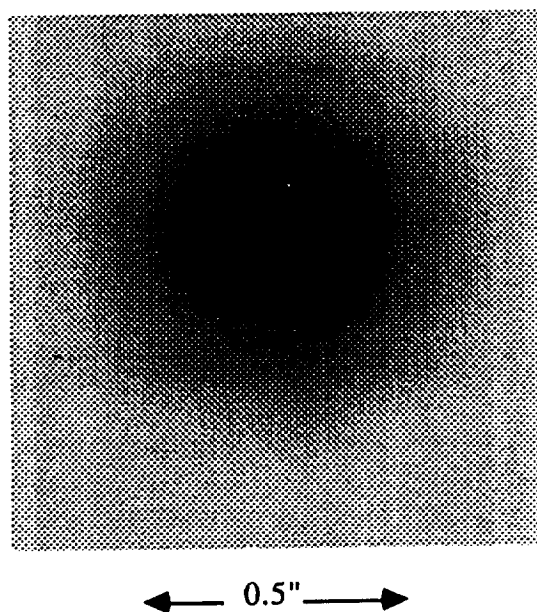
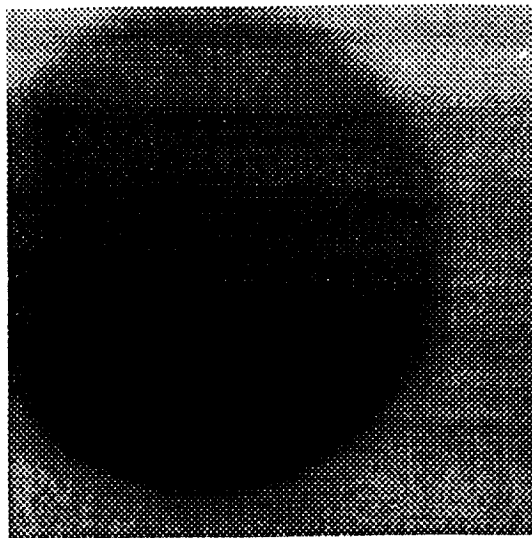


Figure 2a Eddy Current Image of HTSC Disc
Probe width = 0.125"
Frequency = 100 kHz

Figure 2b shows a scan of the same disc using a 0.050" probe at 6MHz. The edges of the disc are clearly visible in this image, as is an intensity gradient running from top to bottom. This gradient represents liftoff of the probe from the surface of the specimen due to a tilted bottom surface. The slightly brighter rectangular area at the top of Figure 3 is not specimen-related; it is the result of manipulation of eddyscope gain during the run.

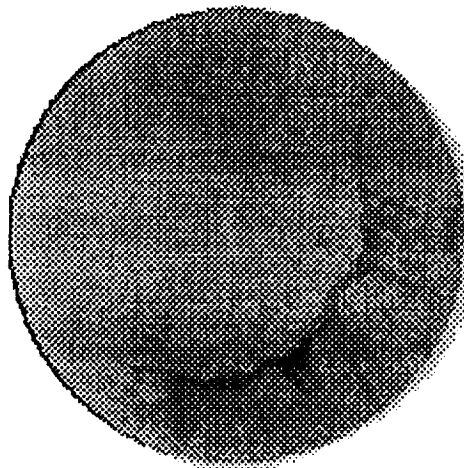
* This is due to the arbitrary rotation one can apply to an eddyscope's display (and hence, its analog outputs). Often the eddyscope operator positions this rotation so that the liftoff phenomenon, generally an undesirable experimental artifact that can obscure information, affects only one channel of data. The channel not "corrupted" by liftoff is then monitored. While interpreting the images that follow please note that a change in image intensity reflects only *some change* in conductivity. Increased brightness does *not necessarily* correspond then to increased conductivity but rather to a conductivity gradient between that region and some other portion of the scan area.



← 0.5" →

Figure 2b Eddy Current Image of HTSC Disc
Probe width = 0.050"
Frequency = 6 MHz

Another HTSC disc specimen examined (with similar dimensions) had a crack clearly visible on its surface (see the photograph in Figure 3). Figure 4 shows the eddy current image when scanned with a 0.050" probe at 6 MHz. The crack can be seen in the lower right-hand corner running from 3 to 5 o'clock. There is also a slight irregularity in the disc edge to the right of the crack; this corresponds to a small notch in the specimen.



← 0.5" →

Figure 3 Photograph of HTSC Disc with Crack
Probe width = 0.050"
Frequency = 6 MHz

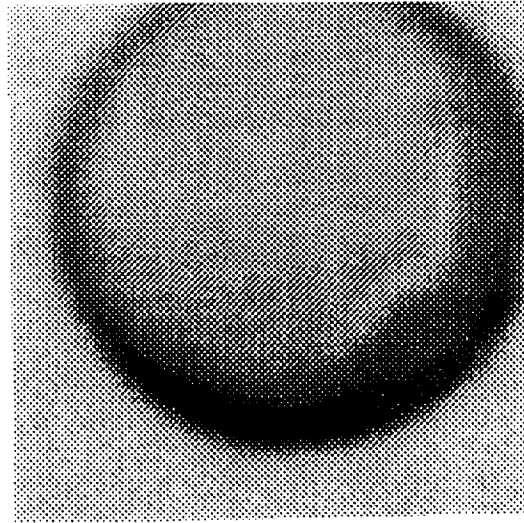


Figure 4 Eddy Current Image of HTSC Disc with Crack
Probe width = 0.050"
Frequency = 6 MHz

Conclusions

A scanning eddy current instrument has been developed and used to inspect bulk HTSC materials. The system produces an image of the spatial variation in eddyscope signal, which corresponds to a mapping of room temperature conductivity. This presently can be done for flat bulk specimens with thicknesses \geq several millimeters.

Consideration is being given to extension of this technique to use with thin films. If probes suitable for use at 100 MHz can be secured, this would yield a $\delta \approx 350 \mu\text{m}$ (.014"). This may be further reduced by thin probes. A digital impedance meter with a high-stability impedance bridge would be needed to replace the eddyscope, which cannot operate at higher frequencies. The impedance values this instrument would provide might provide sufficient data for extraction of absolute room temperature conductivity, which would provide information about spatial variation in superconductive performance.

Acknowledgements

The author would like to acknowledge the invaluable assistance provided by Charles Powers, Gloria Oh, and Michael Viens in the development of this instrument. Dr. Henning Leidecker also provided technical suggestions. This work was also supported in part by the Director's Discretionary Fund and the Office of Flight Assurance of Goddard Space Flight Center.

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