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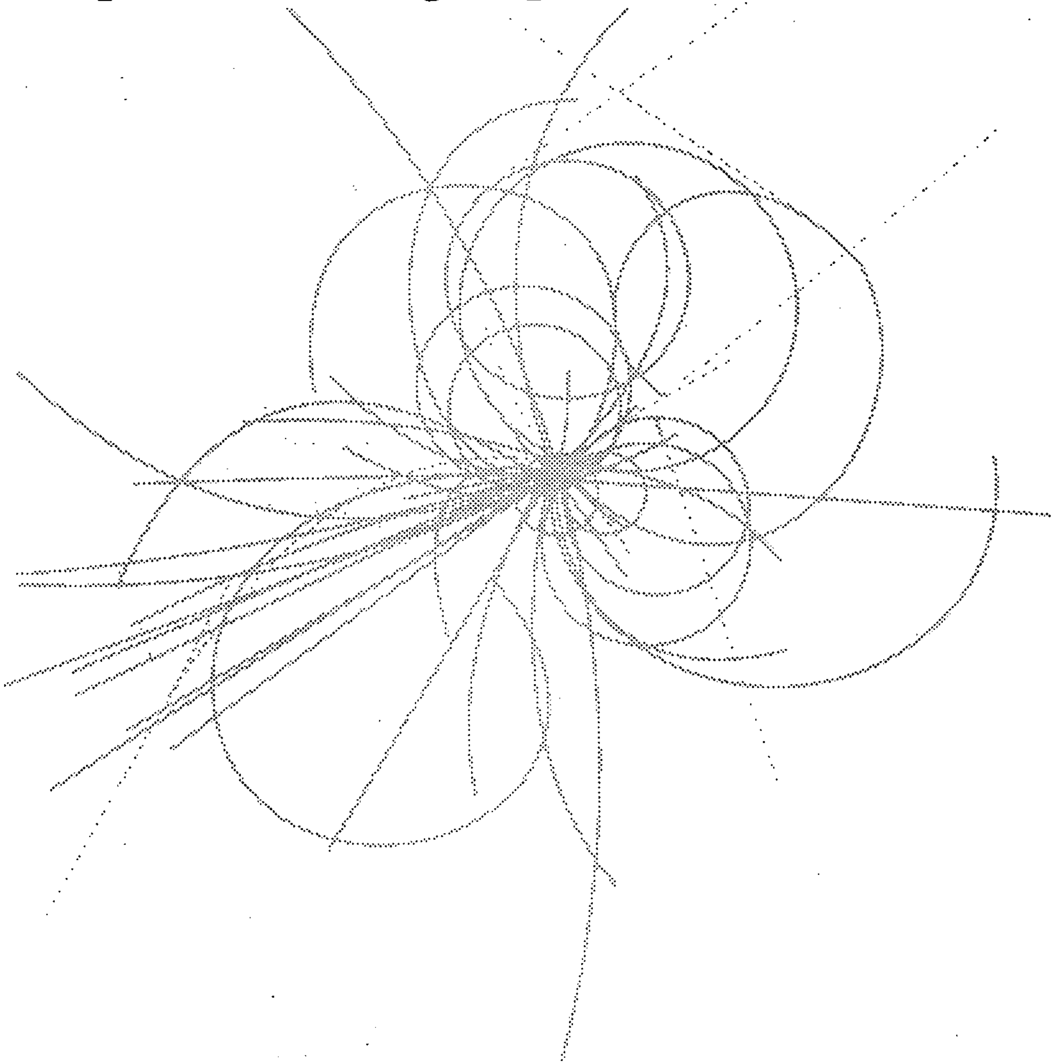

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Eddy Current Inspection of Superconducting Cable During Manufacturing*

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EDDY CURRENT INSPECTION OF SUPERCONDUCTING CABLE DURING MANUFACTURING

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INTRODUCTION

The downstream failure of cable during winding, insulating, coil winding, and coil assembly is a significant issue in magnet production. The impact of these failures are costly both financially, and from the time to recover from this downstream failure. The current approach to cabling has been to visually inspect the cable for any gross defects during cabling. To date this has been effective in finding small defects such as crossovers for example, which drastically reduce the mechanical integrity of the strand, and thus the cable itself. But because of the large volume of cable which will be manufactured an automated flaw detection system which can inspect the cable and detect these type of defects will be needed. We have recently done an on-line experiment using an Eddy current system, and specialized Eddy current probes to inspect cable during manufacturing.

We will present the results of our inspection demonstrating detection of crossovers, and cold welds. And this will include a description of the instrumentation, probe drawings, and their setup, and a synopsis of the experiments performed at LBL to obtain these results.

EXPERIMENTAL OBJECTIVES

1. To evaluate the signal to noise ratio of the Smart Eddy system, and specialized Eddy current probes in situ during a cabling run.

2. To determine the sensitivity of the Eddy current probes, that is to say their physical resolution.

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The present work utilized this smart EDDY 3.0 System, and an iterated probe design which FaA engineered for this application.

The Eddy current system, smartEDDY 3.0, which is available from SE Systems, Inc. of Hayward, CA, combines specially designed software programs with internally-mounted, eddy-current instrument modules to convernt any PC-based computer, including 80486 computers, into a test, measurement, and imaging system. The smartEDDY 3.0 system provides multiple-frequency, low noise detection of cracks, corrosion, and other defects in metallic components, as well as measurements of thickness, magnetic permeability, hardness, and physical dimensions. The system is ideally suited for production line applications.

50mm Outer Cable Experiments. The first studies were done on cable driven by a pair of motorized take up spools. It was extremely difficult to evaluate the signal to noise ratio of the system, and the systems sensitivity because of a rather high background noise. We feel that the source of this noise was due to a "jerkiness" in the tension applied to the cable by the take up spools. The tension in the cable causes the individual strands to lie in a very uniform geometric position, giving a very periodic structure to the cable. But when the tension changes this periodic structure is disturbed. These effects could show up in the Eddy current signal as large indications. We assume the transverse conductivity across the wide face of the cable is very dependent on the compaction of the strands, and the lesser the tension the lesser the compaction, and therefore the poorer the conductivity from strand to strand. Therefore, an increase in the cable tension causes a major change in the conductivity of the cable, resulting in a large disturbance in the Eddy current fields and a large change in the Eddy current signal. The variation of the tension caused the Eddy current signal to be very noisy, and to generate false indications. Since the tension between the Turk's head and the cable measuring machine is quite constant, we decided to conduct another series of measurements with the Eddy current system mounted on the cabling machine. This also allowed us to verify that no new noise sources would be generated by the cabling machine itself.

We modified the probes used in the previous LBL experiment to allow complete coverage of a single strand. Refering to Figure 1, each probe element was 2.5 mm in diameter, and there were four elements in each probe. We aligned the probe elements parallel with the pitch of the strand, to improve signal to noise ratio, within each of the probe holders.

The probe elements were wired in series and then the probes were wired in a differential fashion.

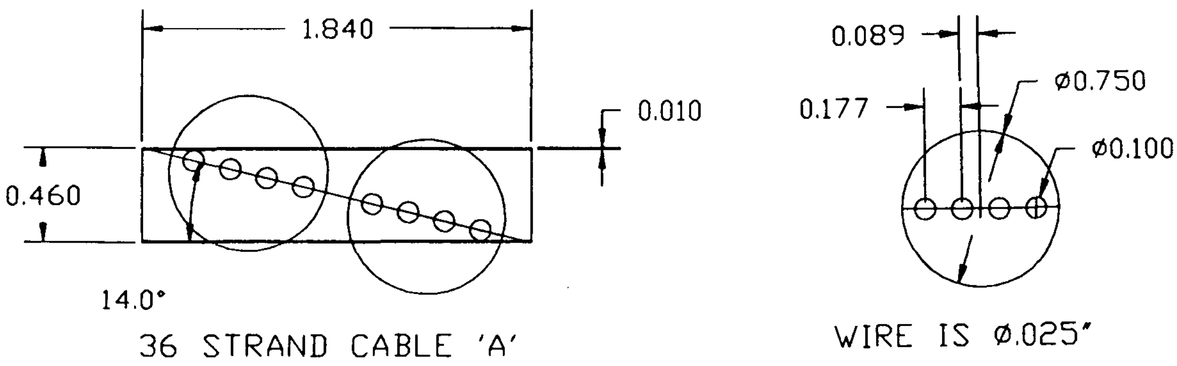

Figure 1. Eddy current probe diagram.

This bridge configuration allowed us to inspect an entire strand, and if there was some difference in the signal seen by either of the probes an output occured across the bridge indicating some type of defect. This configuration was used for both the top and the bottom set of probes. The probe holders were made out of Delrin with a shallow recess made for the cable to run through. In addition there were thru holes for the probes to be mounted in, with a pair of tapped holes drilled perpendicular to these thru holes for screws to hold the probes at a fixed stand off. We used a probe stand off distance of 0.1 mm which gave us an adequate signal to noise ratio, but left us with acceptable sensitivity.

In the first attempt to use the inspection system we placed the probes as shown in Figure 2 directly behind the caterpiller, and before the Cable Measurement Machine.

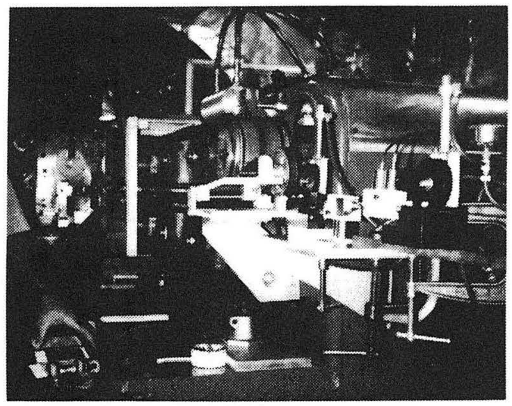

Figure 2. Probes behind caterpiller

To provide additional stability we placed the probes between the Delrin rollers which were clamped into position by small pneumatic cylinders, which applied around 10 PSI to the cable. Initially we had the probes mounted on the top and bottom of the cable directly facing each other. However, we had to install the probes in a staggered fashion as shown in Figure 3 because we found that the Eddy current fields generated by the probes had deep enough penetration into the cable to cause interference between their signals.

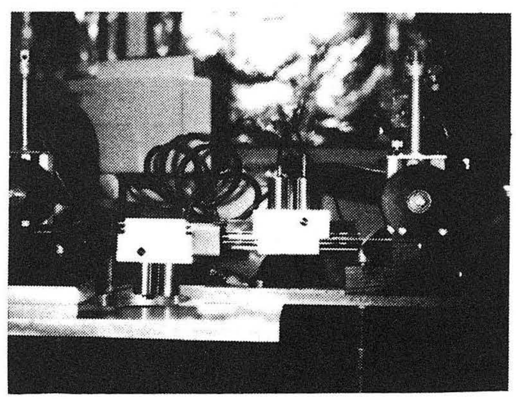

Figure 3. Staggered probe set up.

We found that the cable's position oscillated, as did the cable's tension, perhaps due to the Cable Measurement Machine, giving us a rather noisy signal.

We then moved the transducer banks between the turks head and the caterpiller. The tension in this region was very constant, of the order of 200 pounds. which resulted in a very steady Eddy current background signal. The set-up, with staggered probe position, is shown in Figure 4.

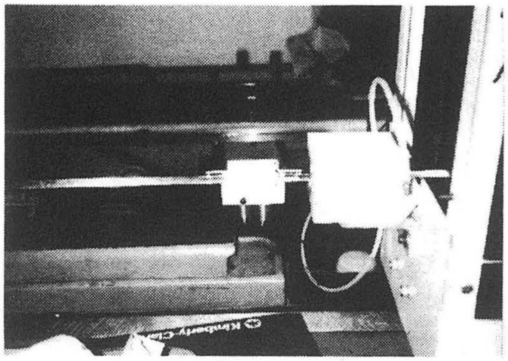

Figure 4. Probe arrangement between turk's head and caterpiller.

The probes were initially arranged this way without the proper mechanical fixturing, but with the transducer holders "riding" on the oscillating cable they performed surprisingly well. The holders were not held by any rigid fixture, but only supported by the cable itself, and constrained to move with any oscillation of the cable. In this orientation we began to obtain a low - noise signal output, and it became evident that cold welds also could be detected.

In this test of the Eddy current inspection system there were no cross-overs to detect, and we were unable to manufacture any because of the shortage of outer cable. This run though did have numerous cold-welds which were readily detected. The second run, described below, gave us the opportunity to generate some cross-overs, and manufacture some cold-welds.

40mm Outer Cable Experiments. This cable run was for LBL quads, and it had no cold welds. The geometry of the orientation of the transducers is shown in Figure 5.

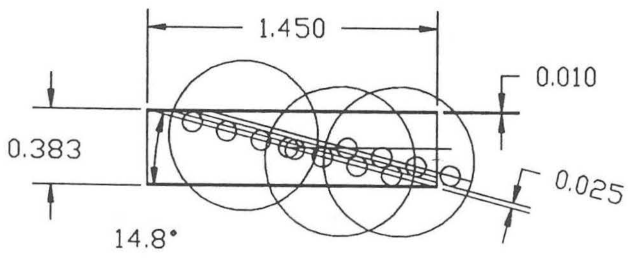

Figure 5. Orientation of Eddy current probes for inspection of 40mm cable

Our earlier run showed that the optimum position to locate the transducers was upstream of the caterpiller, and we built a simple rigid fixture to accomplish this. The arrangement is shown in the following photograph, Figure 6.

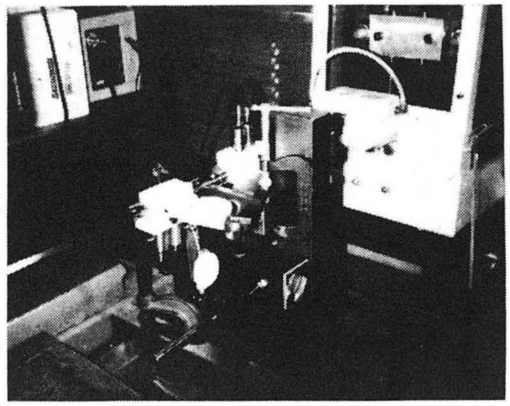

Figure 6. New probe locating fixture.

Again the probes were mounted in the carriers that were free to "ride" on the cable. The same stand off distance was used , 0.1 mm. And the probes were wired in the same fashion as in the first run.

The original positioning of the transducers again had to be modified as shown in the Figure 7.

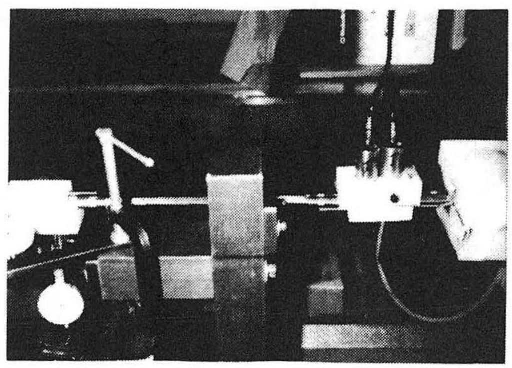

Figure 7. Final probe location.

As is shown the bottom transducer was situated in front of the mounting bar and the top transducer was situated riding against the back of the mounting bar. This seemed to give us an acceptable signal to noise ratio, and a uniform background signal. The mechanical fixturing still seems to be lacking, in that occasionally the cable seems to stick in the transducer holders causing an anomalous signal. In this run we were able to detect very small surface defects, such as scratches, and small galls in the strand of the cable of the order of the diameter of the individual probes themselves, which are 2.5mm in diameter, which the cognisant LBL personnel present asserted that these were insignificant flaws. This clearly demonstrated the sensitivity of the probes to even small defects. Further tests are needed to set the detection threshold levels to prevent false alarms from being generated by these small, allowable defects. After the cable run was complete there was a sufficient amount of strand left over to make some intentionally defective cable.

The cable was made with several cold welds and several cross-overs. A typical cross-over is shown in the following photograph, Figure 8. A typical cold weld is shown in Figure 9.

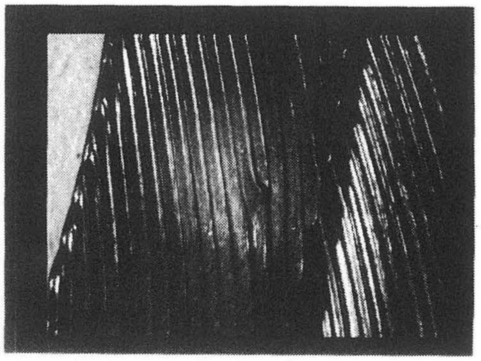

Figure 8. Typical cross-over.

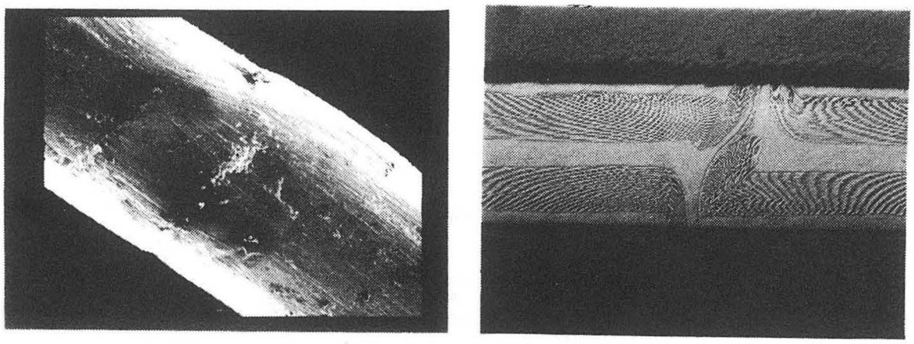

Figure 9. Typical cold weld.

These were then inspected and clear indications were detected using the smart EDDY 3.0 system, and our specialized probes. The output signal traces associated with the cross-overs, and cold welds, shown in Figures 10, and 11, respectively.

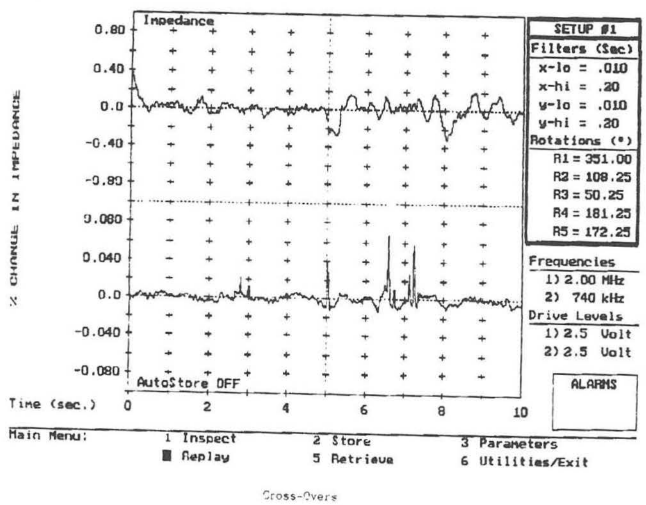

Figure 10. Trace indicating cross-over.

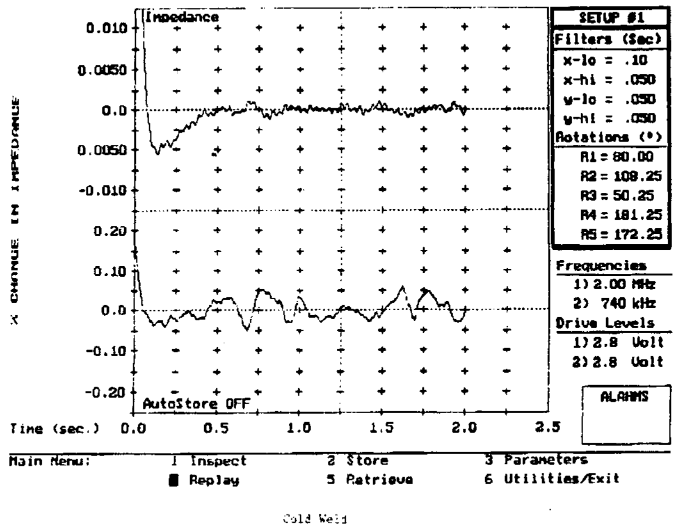

Figure 11. Trace indicating a cold weld.

CONCLUSION

The Eddy current system, and probes proved useful for inspection of the superconducting cable during manufacturing. The instrument, and probes clearly showed that the detection of cross-overs could be made with a signal to noise ratio of 4:1. While the cold weld indications occured with a signal to noise ratio of the order of 2:1, we need to improve this signal to noise ratio for reproducibility, and reliability of cold weld detection. The results suggest that we can implement the cross-over detection because of both: the satisfactory signal to noise ratio for theses defects, as well as, their cause of degradation of the mechanical integrity of the cable. Our future work will entail first optimization of the mechanical fixturing. Then working on better cold weld detection. And finally work on edge detection should be soon to follow.

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