THE EFFECT OF AXIAL STRESS ON YBCO COILS

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Abstract

A spiral wound “pancake” coil made from YBCO coated conductor has been stressed to a pressure of 100MPa in the axial direction at 77K. In this case axial refers to the coil so that the force is applied to the edge of the conductor. The effect on the critical current was small and completely reversible. Repeatedly cycling the pressure had no measureable permanent effect on the coil. The small current change observed exhibited a slight hysteretic behaviour during the loading cycle.

INTRODUCTION

The large aspect ratio of typical YBCO conductors makes them ideal for constructing solenoids from pancake style coils. An advantage of this method is that each subunit can be tested before assembly into the finished magnet. The fact that conductors are available in relatively short lengths is another reason for using such a fabrication technique. The principal drawback is the large number of joints required to connect the coils together. When very high field solenoids such as those contemplated for the muon collider [1, 2] are built in this way the magnetic forces between pancakes can be very large. Extensive measurements have been made on the effect of stress on short lengths of conductor [3, 4], but there is little or no data on the effect of intercoil loading. The experiment described in this paper was designed to test the ability of YBCO coils to withstand these forces.

EXPERIMENTAL SETUP

An apparatus originally built to calibrate strain gauges at low temperatures was modified to apply pressure to a small winding while immersed in a liquid nitrogen bath. A schematic diagram of this device is shown in Fig.1and a photo in Fig.3.The hydraulic cylinder pulls up on the lower jaw against a fixed upper jaw to apply force on the test fixture.

The test coil is non-inductively wound from 6m of Superpower YBCO conductor. Voltage taps are situated every meter so that three sections are on each spiral. This configuration minimizes magnetic field effects and positions the current leads at the outer radius. The size of the coil is dictated by the maximum total force that can be applied. If the coil is too small it will not be truly representative of the solenoid windings, and if it is too large the maximum pressure will be low. With the existing equipment a 5cm coil can be loaded to just over 100MPa. After being wound the coil was placed in a stainless steel fixture (see Fig.2, photo Fig.4). Stycast 1850FT was used to even out irregularities in the surface so that the load is distributed evenly over all 42 turns in the coil (see Fig. 5).

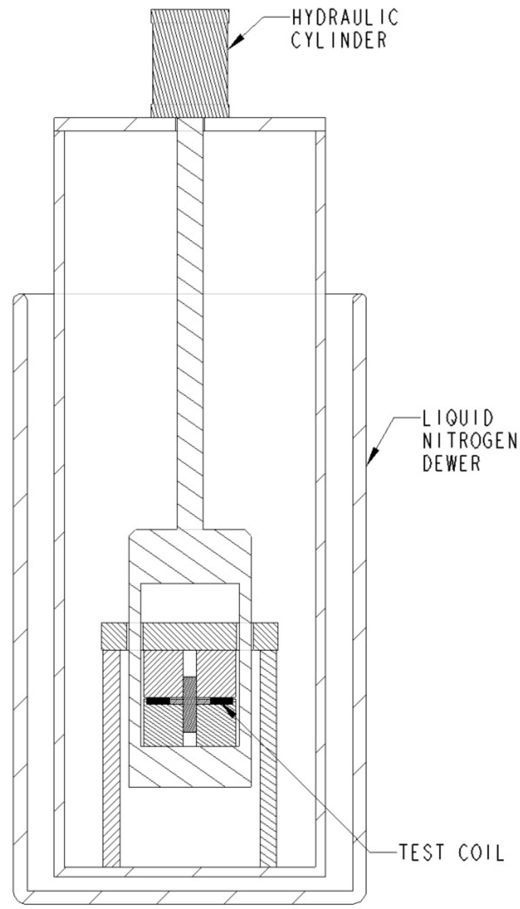

Figure 1: Schematic drawing of the low temperature loading apparatus.

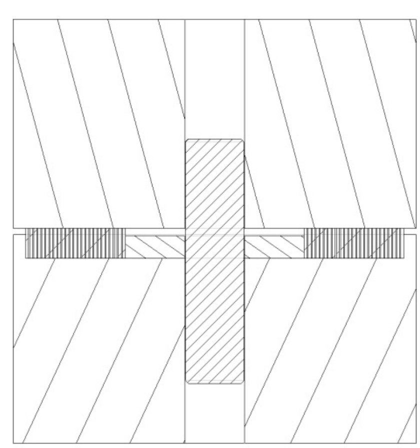

Figure 2: Diagram of the loading fixture. The center pin is used for alignment and to insure that the force is applied uniformly over the coil.

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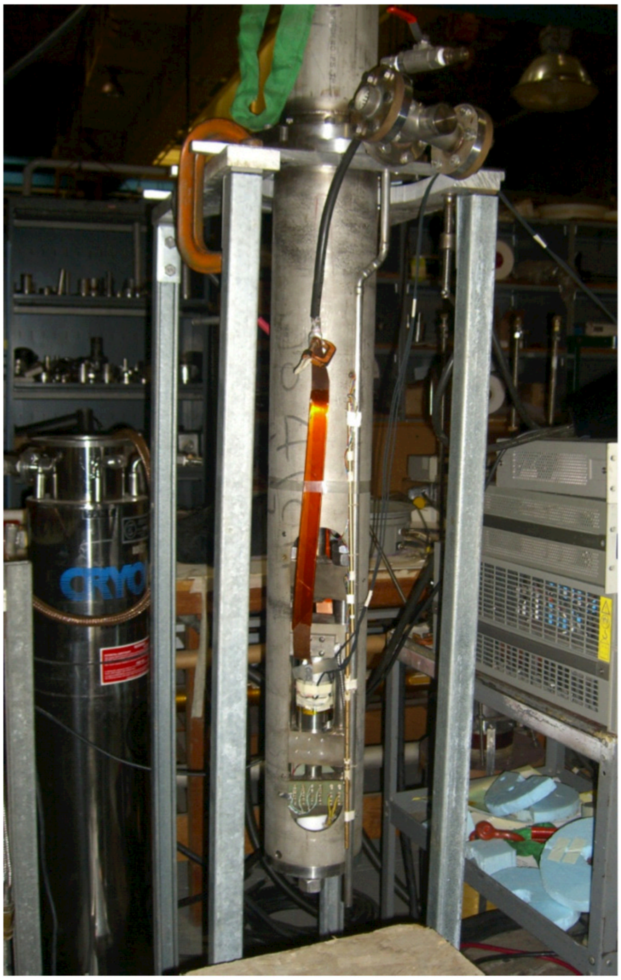

Figure 3: Photograph of the low temperature loading apparatus.

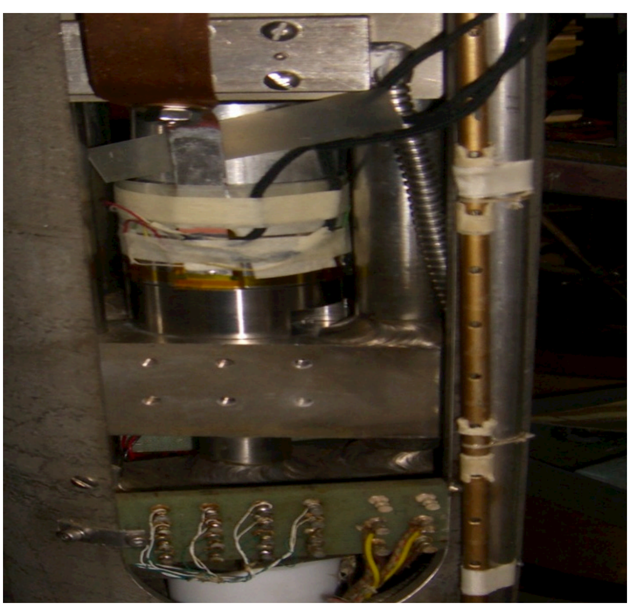

Figure 4: Photograph of the loading fixture showing the upper and lower jaws of the stress machine.

EXPERIMENTAL RESULTS

Table 1 gives the measured values for the critical current (1µV/cm) before any stress was applied to the windings, and Fig. 5 shows a typical V-I transition. All sections had approximately the same critical current and an n value greater than 30. The pressure was first cycled to 25MPa and back to zero, and the critical current remeasured. This was repeated at 50, 75 and 100MPa. There was no observable change in the critical current.

Figure 5: A picture of a test coil. The blue color is due to the epoxy used to fill small surface irregularities.

Table 1: Measured Values of Critical Current before Stress Applied to Windings

Section	Critical Current	"n" value
1	79.3A	32
2	80.8A	34
3	81.5A	32
4	79.1A	32
5	79.2A	32
6	81.3A	31

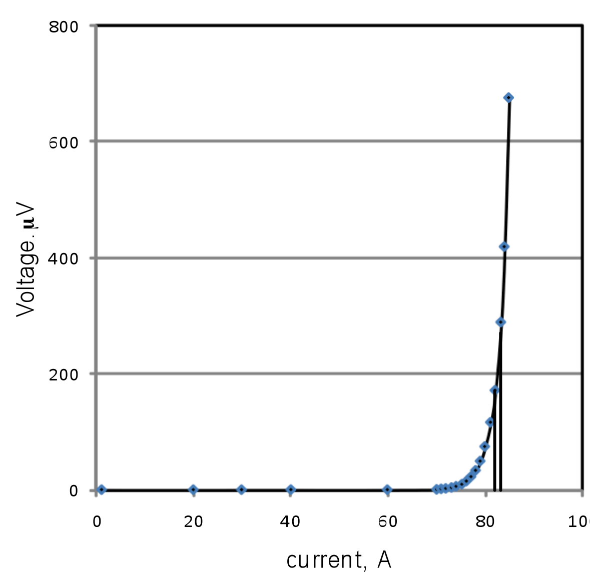

Figure 6: Typical V-I curve for a 1 m section.

The current was then set at 81A (i.e., well into the resistive zone), and the voltage measured as the pressure was increased. Changes in voltage of approximately 100μV were observed. This voltage change can be expressed as a decrease in critical current of approximately 1Amp as illustrated in Fig.7 where the curve of Fig.3 is enlarged to show the current change required to produce the observed voltage difference. The steepness of the V-I curve amplifies this rather small effect. This voltage change is reversible with stress, but exhibits some time delay so that a cycle to maximum pressure gives slightly different values on the up and down legs (Fig. 8). In addition, the voltage will creep up when the pressure is held steady so that the hysteretic loops vary depending on the time spent at each pressure. The relaxation time after a pressure cycle is of the order of a few minutes. The larger loop shown in Fig. 5 was obtained by waiting several minutes at 100MPa before reducing the pressure.

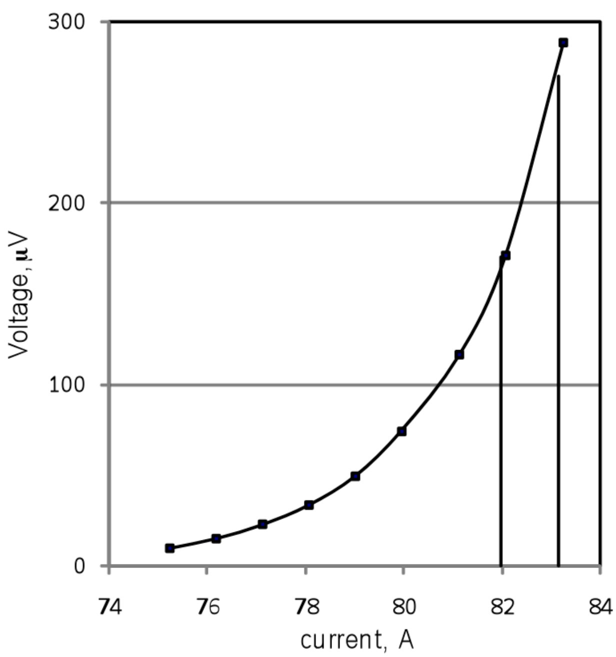

Figure 7: Expanded view of the region near the critical current. Illustrating how a small change in current can produce the 100μV signal.

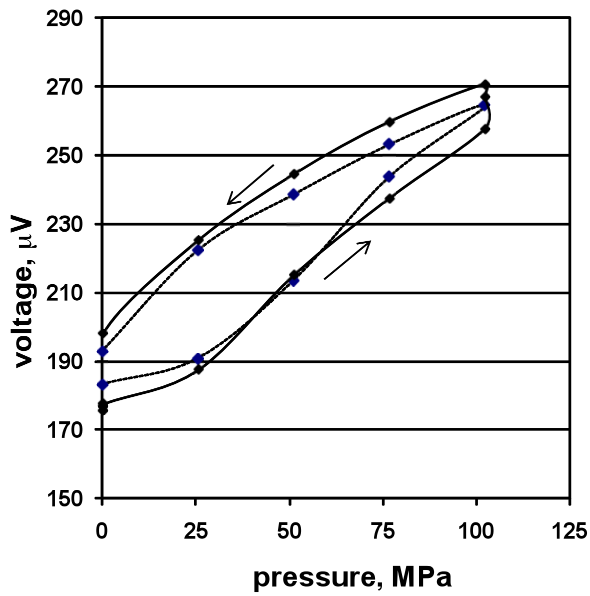

Figure 8: Hysteretic effects due to a pressure cycle. The dotted curve was made with no pause at the maximum pressure. The solid curve had a 3 minute pause at 100MPa

To test for any possible fatigue effects the pressure cycle to 100MPa was repeated for one hundred cycles with no change observed in the critical current.

CONCLUSIONS

Superpower YBCO pancake coils tolerate simulated coil to coil forces very well, at least up to 100MPa.The small changes in critical current observed seem to be completely reversible and there was no indication of susceptibility to multiple cycles. Additional experiments are planned to higher stress levels to establish a limit on inter-coil forces.

REFERENCES

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