STATUS OF MAGNETIC MEASUREMENTS OF ENERGY DOUBLER MAGNETS

F. T. Cole and D. A. Gross

December 20, 1978

Introduction

A detailed study is made of the field and loss characteristics of every Energy Doubler magnet as the penultimate stage of its manufacture. This report describes these measurements, both their present status and plans for improvement.

A room-temperature measurement system has been developed by R. E. Peters. This system measures the magnetic field in the collared coils (before insertion in the cryostat and yoke) at low current as a function of radius, using a planar coil array. The correspondence of these room-temperature measurements and the more complete cold measurements discussed here has been studied in detail by A. V. Tollestrup, who finds that there is a fixed relative increase in the dipole component and a fixed sextupole component coming from the yoke. All other multipoles are closely the same. This correspondence is important in meeting the purpose of the room-temperature measurements, which is to give rapid feedback to the production line on the effects of design and manufacturing changes on final magnetic fields.

Magnet Test Facility

Magnetic tests are carried out on 6 test stands in Industrial Building 1, 5 dipole stands and 1 quadrupole stand. Cooling for all stands is provided by a CTI 1500-W helium refrigerator. There are some differences in instrumentation and stand 1 is usually utilized for development of measurement systems.

The beam tube of Energy Doubler magnets is cold in operation and an insulated double-wall warm-bore tube is inserted to give a room-temperature volume for the measuring apparatus. As the later stands were commissioned, during the fall of 1978, it was found that small glitches in field were measured with all warm-bore tubes except the original one, apparently because of lack of annealing after welding up the longitudinal seam inner stainless-steel pipe. New warm-bore tubes have now been procured and are being put into operation. Care was taken in the interim to carry out all measurements sensitive to field glitches with the good tube.

Liquid helium is provided by a CTI-1500 refrigerator, capable of producing 330 ℓ of liquid helium per hour at 4.4 K as a liquefier or to cool approximately 1800 W at 4.8 K as a refrigerator. It is planned that the excess capacity of this system will eventually be used to produce liquid helium for use in experiments, but this use will be of lower priority than magnet testing.

Venting of helium during quench tests was making difficulty for other groups carrying out leak detecting in the building, so a temporary exterior exhaust system was constructed. A permanent recovery system is now being constructed and installed to conserve helium.

Magnets are energized by a Transrex power supply controlled by a ramp generator. The power circuits are interlocked for safety. The ramp rate can be varied from 0 to 120 GeV/sec.

Operation and monitoring of the test stands, safety circuits and helium distribution is carried out by an LSI-11 microprocessor and CAMAC system and a 5TI sequencer. Each of the measurement programs described below is operated through a computer program on a PDP-11 interfaced by a CAMAC system. All data for a particular magnet are put on a tape and are transferred to accessible files in the PDP-10. Until now, this transfer has been accomplished manually by carrying the tape to the Central Laboratory, but components have been ordered for a system to interface from the PDP-11 system to the PDP-10 and transfer the data directly from the Industrial Building.

Approximately 8 hours is needed to install a magnet on a test stand, leak check and pump it, then purge and cool it. A full set of magnetic tests required 10 to 12 hours. Another 8 hours is needed to warm up the magnet and remove it from the stand. The times given here should be viewed as minimum times. If any unusual problems occur, the times will be longer.

Test Programs

The dipole program includes the following measurements:

1. Quenches

   a. A series of quenches is carried out to train the magnet up to a maximum current of 4400 A. In the standard measurements, most of the stored energy in the magnet is dumped into a shorting resistor. A series of special tests has been carried out, dumping the full stored energy in the coil of a magnet with special instrumentation to measure internal pressure and a redesigned relief tube. With this tube, the internal pressure rise in a full-energy quench is approximately 100 psi.

b. The ramp-rate dependence of maximum quench current is measured for ramp rates up to 500 A/sec.

The computer program calculates energy loss in the magnet and dump resistor and maximum quench temperature.

2. <u>AC Loss</u>

The dependence of ac loss on ramp rate and maximum current is measured for ramp rates up to 4000 A.

3. <u>DC Excitation</u>

A stretched wire loop extends through the entire magnet. It can be rotated by stepping motors at both ends. The remanent field is measured first by rotating the loop through 180°. Then the magnet is slowly ramped and the loop signal integrated to give the field up to 4000 A.

4. <u>Vertical Plane</u>

In the standard measurements, the same stretched wire loop is utilized. Ramps are done with the loop at several angles to find the position of null signal. The measurement is carried out at currents of 500, 1000, and 4000 A.

This is an extremely difficult measurement. The precision required is very high. We believe from reproducibility that the vertical-plane measurements are precise to 0.2 - 0.3 milliradians.

Many special tests have been carried out to try to measure dependence of the vertical plane on quenching history and on warmup and cooldown history. It appears that there is little change of vertical plane with quenching.

In the warmup and cooldown measurements, an attempt has been made to improve the precision of measuring changes in the vertical plane by fixing the loop and measuring the voltage induced during a ramp. Here there are problems with the wire oscillating. The yoke loop installed for alignment of the cryostat in the yoke has been utilized in the same method. There appears to be a good correspondence between the stretched-wire and yoke-loop results, even though there are saturation effects in the yoke. The magnet tested had changes in the vertical plane in a heat cycle of more than 1 milliradian when tested with the stepping-motor system. With the other systems, the changes have been less than 0.5 milliradian. We do not yet know whether this is a real "damping" of the changes or an effect of the different measurement.

A high-precision system is in the process of being built.

5. Harmonic Measurements

A harmonic coil is rotated in the field to measure normal and skew components. The probe is 8 ft long and so measurements of the ends and body are made separately. The total harmonic content can be found by appropriate summing. It is also of interest to consider the body and ends separately, since the body sextupole is tuning by adjusting the coil angles to compensate the natural sextupole arising from the magnet ends.

Measurements are carried out at a series of dc excitations from 200 to 4000 A. Harmonics of the remanent field are measured separately. AC harmonics are also measured on the ramp. They are usually in good agreement with the dc harmonics and it is not clear that separate ac measurements should be continued indefinitely in production testing.

6. NMR

The central field is measured by moving a proton sample manually through the warm-bore tube, making measurements at 6-in. intervals. The purposes are to measure field homogeneity and transfer function (gauss/amp). The measurement is done at 2000 A. An automatic system is being developed to give an absolute measurement of the integral central field.

Several QA quadrupoles were measured in the past using the dipole stands. The quadrupole stand (3) has now been commissioned and the first completed QB quadrupole has been installed and partly measured. It is planned to measure quenches, gradient length, excitation, symmetry planes and harmonics for quadrupoles as part of production testing, but we are still learning about some aspects of these measurements.

Development Work

At the time of writing, work is in progress to investigate a number of phenomena. Among these studies are:

(i) Maximum field as a function of subcooling and flow rates

(ii) Maximum field as a function of single-phase temperature

(iii) Further studies of pressure rise during quenches

(iv) Further studies of vertical-plane motion during warmup cycles

(v) Studies of the effects of yoke twists

(vi) Evaluation of steel-saving laminations.

A number of items of work are also in progress to improve the facility itself. Among these are

(i) Improvement in vertical-plane measurement

(ii) Improvements to make absolute measurement of integral field length

(iii) Improvements in the control room to avoid measurement errors

(iv) Improvements in data storage and presentation

(v) Development of a system of heat-loss measurements, to become part of the routine production measurements.