Measuring the Magnetic Field in Steel Using Flux Loops

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***Summary*—Flux loops have been installed on select segments of the steel flux return for the 4 T solenoid of the Compact Muon Solenoid (CMS) detector [1] under construction at CERN. This steel also serves as part of the muon detection system of CMS and accurate characterization of the magnetic flux density inside the steel is necessary. Voltages induced in these loops during fast discharge of the solenoid will be sampled and integrated to measure the change in average flux density in the steel due to the discharge. The results of laboratory studies using model iron blocks equipped with flux loops and magnetized with a controlled power supply, are reported.**

I. INTRODUCTION

A three-dimensional calculation [2] of the magnetic-field of the CMS magnet has been made with the program TOSCA [3], which relies on the use of "averaged" permeability values measured in many samples taken from the steel plates of the CMS flux return yoke. The plates are up to 630 mm thick and also comprise the absorber plates of the muon detection system.

It is desirable to provide a direct measurement of the magnetic flux density in select portions of the muon steel to help reduce the uncertainty in the measurement of the momenta of muons which penetrate the steel during operation of the detector. For this purpose, multi-turn flux loops have been installed around select segments of the CMS muon steel yoke plates to permit the measurement of magnetic flux density changes in the steel when the field in the solenoid is changed [4].

II. THE CMS FAST DISCHARGE AND FLUX LOOPS

The rapid discharge of the solenoid (approximately 300 seconds time constant), made possible by the protection system of the magnet, will induce significant voltages in the flux loops. This protection system will be tested during the commissioning of the magnet system, providing an opportunity to measure magnetic flux changes in the CMS steel yoke by an integration technique. Because rapid discharge of the CMS solenoid will cause quenching of the superconducting coil, the calculated discharge (Fig. 1) departs modestly from a simple L/R decay of an inductor into a fixed resistance [5].

This discharge results in flux changes in various parts of the steel yoke of the system, and from calculations of the flux densities in representative steel blocks at 9 successive currents during the discharge, average voltages induced in flux loops around these blocks is calculated, $V = \Delta\Phi/\Delta t$ (Fig. 2).

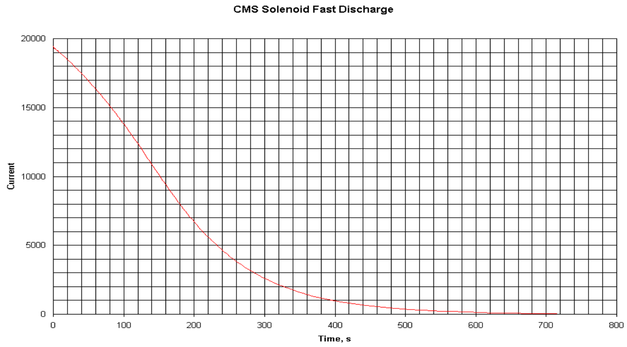

Fig. 1 CMS Coil Fast Discharge

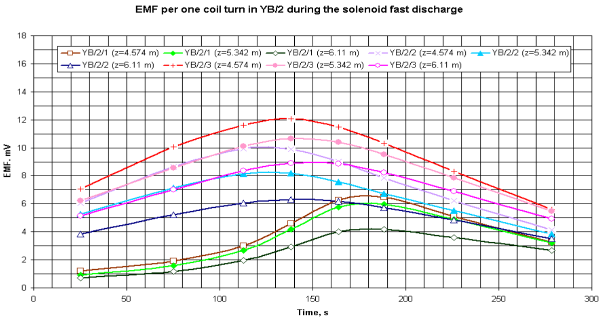

Fig. 2. EMF per On-Turn Flux Loop in End Cap Plates 1 & 2

The CMS flux loops each consist of a 400-turn coil (made of a few-turn ribbon cable with conductors connected in offset to yield 400 turns in series) embedded in a shallow groove machined into the peripheral surfaces of the steel plate that is to be sampled. It is the goal of this study to determine if these voltages can be integrated over the entire discharge with sufficient accuracy to provide a measurement of the initial flux density in the steel to a few percent uncertainty. It is anticipated that the value of the remanent field in the steel may be required to fully characterize the field value at full operating field of the solenoid.

III. FLUX COIL EXPERIMENTAL APPROACH

A commercial precision voltage sampling data acquisition system [6] was connected to a 994-turn model flux coil which was mounted between the flat steel pole tips of a laboratory standard magnet. The magnet was charged and discharged at a number of different rates under software control and the voltages from the flux coil recorded and integrated off line to measure the flux changes in the coil. A TOSCA model for the laboratory standard magnet was prepared to guide the interpretation of the data obtained from the flux coil.

IV. DATA FROM THE MODEL FLUX COIL

The flux coil was inserted in the standard magnet and the magnet charged to full current as shown in Fig. 3 at a charge rate of 2.5 A/s. After a pause, the current was decreased as shown at the same rate to zero. The voltage on the flux coil was sampled at 40 msec intervals (25 Hz sampling rate), and integrated off-line by multiplying the average voltage in each time interval by the length of the time interval.The same procedure was made with a disc of (high carbon) steel inserted in the bore of the flux coil, as seen in Fig. 4. The rapid initial magnetization of the steel disc yields a large transient voltage on the flux coil in the first few seconds of the chargeup.

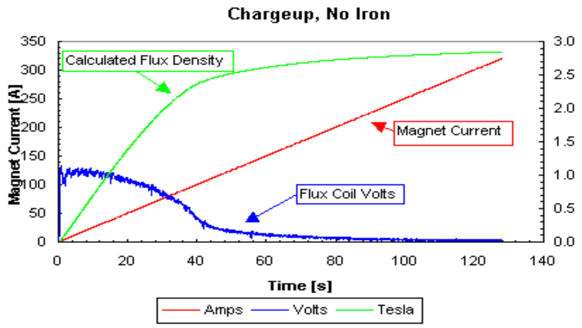

Fig. 3 Flux Coil in Airgap, Chargeup

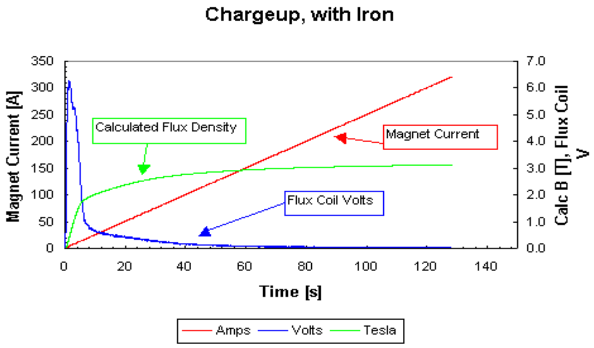

Fig. 4 Flux Coil with Steel Disc, Chargeup

The integral over time of the voltage during charge or discharge is just the total flux change in the coil, 40.5 ± 0.5 Webers in the case of no iron (which normalized by the area and number of turns in the coil, is 2.85 T average flux density, close to the value predicted by TOSCA). The discharge must be monitored for 2 –3 seconds after the magnet current reaches zero to permit the pole tips to demagnetize, in order to compare the charge and discharge flux changes. With the iron disc in place the flux density reaches 3.1 T in the steel disc, and up to 15 seconds is required for the disc to spontaneously demagnetize after the magnet current reaches zero. The equivalence of the charge and discharge values, and the corroboration with the TOSCA calculations, indicates a precision of 2% or better in the technique. Studies were made with an aluminum disc in the flux coil to assure that eddy currents were not significant, and the influence of the step-wise current changes of the current of the magnet (which will not be present in the CMS discharges) on the flux coil voltages was examined.

V. CONCLUSIONS & ACKNOWLEDGEMENT

The initial results of our experimental program indicate that the increase of flux density in a steel object magnetized by an external source can be measured with good precision using the techniques chosen. Ongoing laboratory work will focus on studying the characteristics of such measurements using steel samples taken from the yoke pieces of the CMS magnet, and the demagnetization characteristics of the steel will be evaluated. This work was supported in part by the US Department of Energy under Contract No. DE-AC02-76CHO3000.

VI. REFERENCES

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[3] Vector Fields Ltd., 24 Bankside, Kidlington, Oxford OX5 1JE, England.
[4] V.I. Klioukhine, R.P. Smith, "On a Possibility to Measure the Magnetic Field Inside the CMS Yoke Elements", CMS Internal Note 2000/000, Nov 16, 2000, CERN, Geneva, Switzerland.
[5] B. Cure, C. Lesmond, "Synthesis on Fast Discharge Studies", DSM/DAPNIA/STCM Technical Report 5C 2100T – 1000 032 98, Nov 18, 1999, CEA Saclay, Saclay, France.
[6] National Instrument's DAQ Card 6012®, fully encapsulated on a standard PCMCIA Type II card providing 8 double-ended channels with 16-bit resolution, operating at up to 20 kHz, with absolute accuracy of the order 0.005%. The input impedance of the ADC is of the order of 10 G Ω in parallel with 100 pF.