HIGH SPEED FIELD MAPPING DEVICE AT FERMILAB

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SUMMARY

An automatic field mapping device has been made for large high energy experimental magnets at Fermilab. A set of three mutually perpendicular search coils on a "Ziptrack" are moved continuously at a speed of one-half meter per second. Coil voltages are integrated and digitized by fast ADC circuits in a CAMAC system. The data are processed by an on-line PDP-11/05 computer, displayed on a graphics terminal and stored on cassette tapes. The moving parts of the Ziptrack are made of non-metallic material. The overall characteristics and general performance are discussed.

INTRODUCTION

At Fermilab, we now have an increasing demand for a general purpose device to do point-by-point field mapping for high energy experimental magnets. The typical sizes of the magnetic field volume to be measured are 8" high, 24" wide and 13' long for BM109 magnets; 2' high, 4' wide and 10' long for superconducting magnets. We have developed a field mapping device, Ziptrack, which is primarily used for smaller aperture magnets (BM109) which requires manual positioning of the search coils in the transverse dimensions. In the future a manipulator will be added to provide automatic three-dimensional movement of the search coil.

The main feature of our device is the fast speed with which we can take data, and programming flexibility. In our device we take data while the probe is in motion. This permits us to take data at a high rate. Furthermore, the points at which we take data are determined by software and hence are quite easily changed to fit the particular magnet being mapped. Typically, a magnet can be mapped in twelve hours including the time required to align the Ziptrack and to do 100 runs through the magnet with points taken every 1/2 inch along the track. Similar devices at other laboratories are reported elsewhere.[1,2,3] In these devices the probes are required to be stationary during data taking.

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1. APPARATUS

The system is composed of two major parts: the Ziptrack, and a data acquisition system composed of CAMAC modules and a computer. As a magnetic field sensor, we use a three-dimensional search coil assembly. The output of each coil is integrated by an individual integrator and fed into a Kinetic Systems 3520 12-bit fast ADC CAMAC module. The overall absolute accuracy of 0.1% has been achieved. The data are stored into core and written on a cassette tape after each run. The block diagram of the system is shown in Fig. 1.

1.1 Ziptrack

The Ziptrack is basically a long straight aluminum beam over which a non-metallic cart moves over a fifteen-foot region. The cart is driven by a DC motor controlled by a CAMAC module, along the Y axis. In our coordinate system, X is right/left, Y is along the Ziptrack, and Z is up/down. The motor end of the Ziptrack is shown in Fig. 2 with the cart in place. The cart includes a large template, mounted perpendicular to the direction of motion, which is filled with holes on a precision one-inch grid. The search coil assembly can be mounted onto any of these holes. After each run the position of the search coil is relocated manually.

The search coil assembly contains three mutually perpendicular Garrett-compensated coils which have a common center. The induced voltage in each of these coils is integrated by electronic integrators. As the cart translates the search coils from one point to another, the change in voltage is proportional to the change in magnetic field between the two points, thus giving a direct measure of the field at that point. The magnetic fields at initial points are checked by a Hall gauss-meter.

The cart is connected to an optical shaft encoder by a 5 mil thick, 5/16 inch wide stainless steel ribbon to measure the position of the cart along the Ziptrack. The cart is pulled along the aluminum beam by a separate Kevlar drive cable roughly a half meter per second. The three components of the field are read out on the fly whenever the shaft encoder determines that the cart has moved an additional 64 encoder counts (about a half inch) away from Y = 0, using a Fermilab 044 CAMAC module. The number of counts between readings can be changed easily for any configuration.

1.2 Data Acquisition System

The whole operation is controlled through a PDP-11/05 mini-computer and a CAMAC system. The computer system consists of a CPU with 24k core memory, a dual cassette drive unit, which is used for program storage and data taking, a Tektronix 4010 display terminal and a hard copy unit. This data acquisition system is shown in Fig. 3.

A Kinetic Systems 3911A unibus controller module is used for the CAMAC system. Two Kinetic Systems 3520 dual channel 12-bit ADC's are used for data taking. Three channels are used for X, Y, and Z components of the field, and the remaining channel is used as a monitor of the field via a Hall probe or can be used for monitoring magnet current. A Fermilab 044 position controller module and an interrupt module are used for positioning the cart through the optical shaft encoder. The count from the shaft encoder is registered through these modules and the position of the cart is determined. They send a strobe signal to ADC's whenever a predetermined number is registered.

The main program is written in the language, BASIC, for easy program development and change. The data taking part of the program is written as a subroutine in assembly language for speed. A flow chart is shown in Fig. 4. BASIC is fast enough for the main programming in this kind of operation, and DEC has full software support for it through the cassette system. A separate program is written for diagnostics of every operation of the system which proved very useful during development. Cassette tapes are used for both program and data storage.

2. RUN PROCEDURE

There are several calibration procedures for the system which were performed prior to actually mapping a magnet. The whole system, including search coils, integrators, and ADC's, was calibrated using a standard magnet and an NMR gaussmeter. This procedure provides calibration constants for each axis. The linearity of each axis system was checked using the NMR and the experimental magnet.

The coil misalignment was measured at the center of a BM109 magnet. This was done by taking runs with the coil assembly oriented along each of the three axes. Since the direction of the field is known at the center of the magnet the true B_x, B_y, B_z can be unfolded from the three components which were actually measured. The coils do not quite lie along the XYZ axes, due to the imperfections of the coil and due to the misalignment of the coil relative to the magnet. With this measurement the fine adjustments needed in coil alignment can be made with software.

The field mapping is started by typing calibration constants. Each run is initiated by typing run parameters and adjusting drifts of integrators using a graphics display and resetting them, as is shown in Fig. 4.

During each run the computer collects hopefully identical sets of data on the way out and on the way back. At the end of the run each of the three components of the field can be displayed as a function of distance Y, as shown in Fig. 5A, where the vertical component B_z is shown. The differences between the data taken on the way out and on the way back may be displayed also, as shown in Fig. 5B for B_z, where the main difference is in the least significant bit. If the differences are small enough for all axes, the data are stored on DEC cassette tapes, which are later transferred to a regular magnetic tape off-line. A typical run summary sheet is shown in Fig. 6.

3. OPERATIONAL CHARACTERISTICS

3.1 Speed of Search Coil Movement

The speed of the cart on the Ziptrack is about 0.5 meter/sec, which corresponds to 50 μs/mil. When taking data, the four ADC's are strobed every 4 μs in succession. The reading time of ADC's is 25 μs, thus the relative positioning accuracy of the search coil can be ± 0.3 mil. In this respect, the cart could be moved faster if we had a better driving and braking system.

3.2 Positioning Accuracy of Search Coils

The present encoder has a sensitivity of 1024 counts/revolution, and the diameter of the wheel is 2.5 inches. This gives a potential positioning sensitivity of 7.6 mils/count. The pulse width of the shaft encoder is 2.5 μs and the relative positioning accuracy could then be better than 1 mil for a run in one direction.

3.3 Experienced Positioning Accuracy for the First Use of the Ziptrack

The major problem encountered in the first actual use of this device was slippage between the tape and the wheel of the encoder. During this mapping the actual positioning accuracy obtained was ± 40 mil. This large slippage seems to have been related to both the abrupt motion of the cart and to electrical pickup in the encoder. We expect to come close to attaining the potential positioning accuracy stated in the last section. To this end several modifications are being tried with some success.

3.4 Eddy Current Effect

For the Ziptrack, all the stationary parts of the apparatus are made of non-magnetic material (mostly aluminum), while all the moving parts are non-metallic (mostly G-10). The only exceptions to this are the coils, coil leads with their shielding braid, and the encoder drive tape all of which are metallic but non-magnetic. The shielding braid around the coil leads is made of dozens of tiny strands of insulated wire. In order to experimentally investigate possible eddy current effects we took two runs, one at the full speed of about 0.5 meter per second and one at one-fifth speed. No noticeable eddy current effects were observed.

3.5 Accuracy of ADC

The ADC's have a 12-bit capacity when operated in the unipolar mode (0 to 10v) or 11-bits plus a sign bit for bipolar operation (-5 to +5v). Therefore, the maximum sensitivity is 0.03% for full scale.

3.6 Drift of Integrators

The amount of drift of the integrators is given by 10/R mV/sec, where R is the input resistance of the integrators in ohms. Typically R is 10 kΩ and it takes about 20 seconds to travel the Ziptrack. The amount of drift is 20 μV.

3.7 Search Coils

The effective areas of the search coils are 248, 1124, and 912 cm^2 for X, Y, and Z coil respectively.

4. FUTURE EXPANSION - MANIPULATOR

For large aperture magnets the Ziptrack itself is moved in two dimensions by a manipulator. The system is now being built. At both sides of the magnet we install a stand. The stand has a frame structure, and its movable aperture for the Ziptrack is five-feet wide and four-feet high.

The Ziptrack is made from an aluminum beam so there is an eddy current effect when it is moved in a magnetic field causing field distortion and magnetic force. Therefore, the movement is done by stepping motors and the field measurement is done after it is in position. The horizontal and vertical speed of the Ziptrack movement is 12 and 6 in/min. respectively. The total weight of the Ziptrack is counter-balanced at both stands to reduce the load for the stepping motor. When this manipulator is used, the large template on the cart of Ziptrack will be replaced by a small one.

ACKNOWLEDGEMENT

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(2) W. Gajewski et al., "Magnetic Measurements for π^--e Experiment at 50 GeV", Dubna Internal Report E13-6659, 1972.

(3) J. K. Cobb at SLAC, private communications.

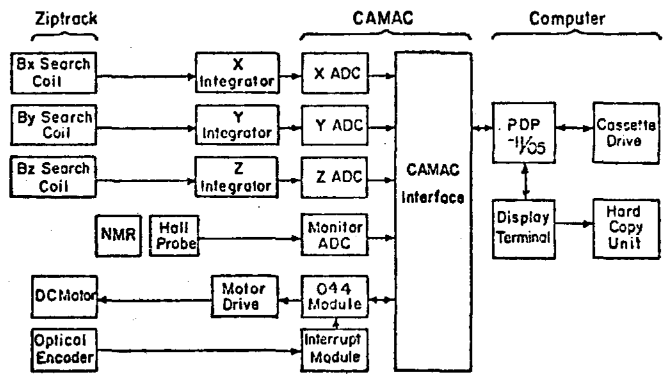

Fig. 1 Block Diagram of Data Acquisition System

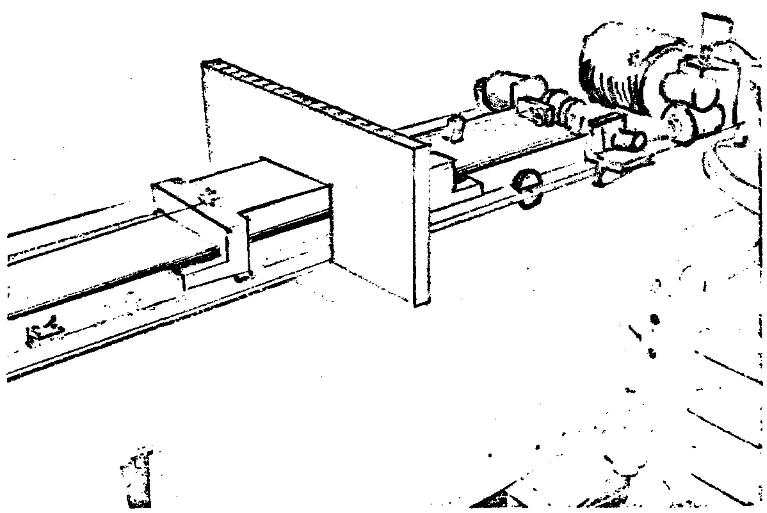

Figure 2. Motor End of Ziptrack with Template Cart.

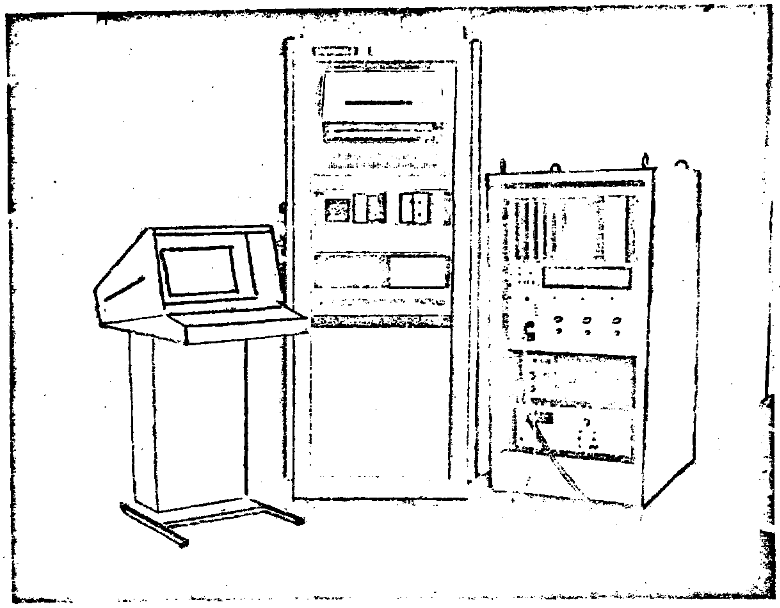

Fig. 3. Data Acquisition System

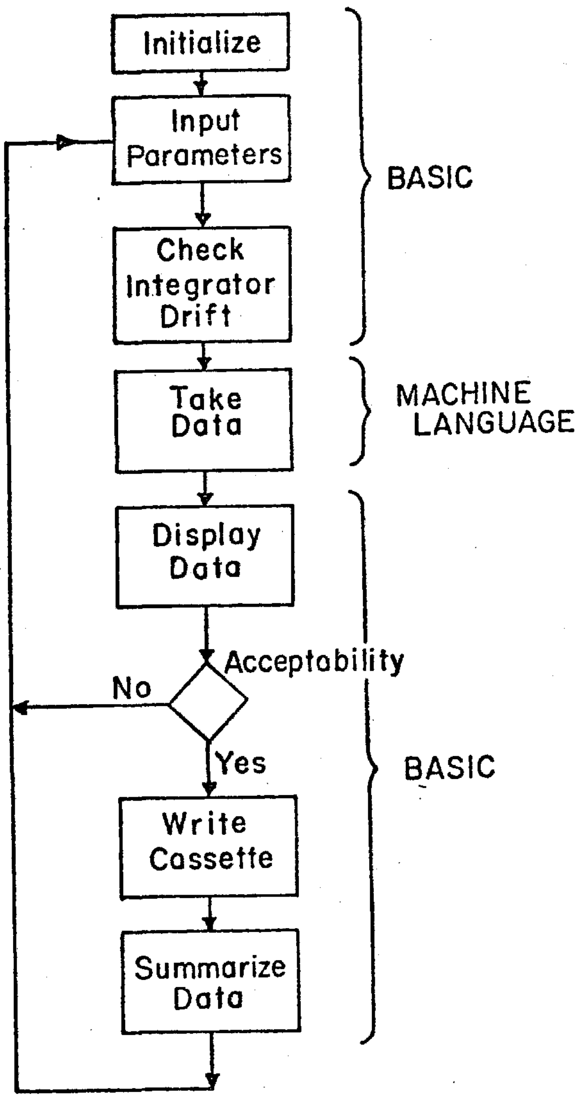

Fig. 4 Flow Chart of Program

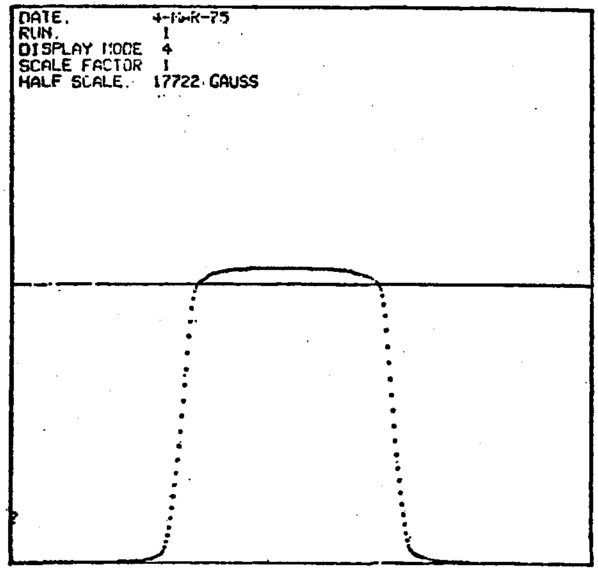

Fig. 5a Typical display of field component(B_z) as a function of distance(Y).

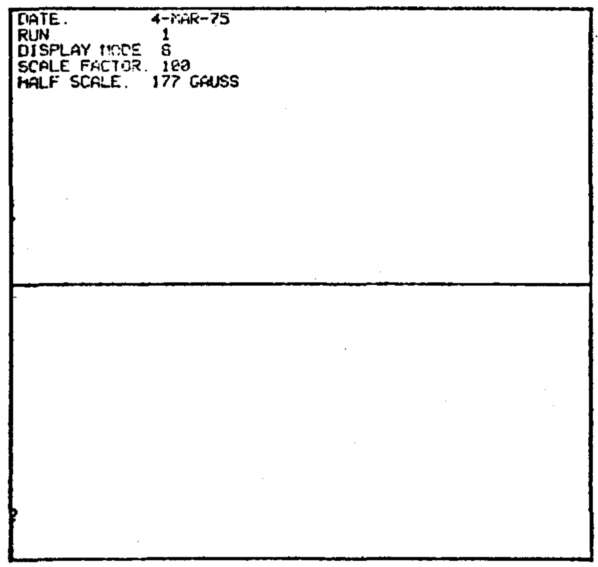

Fig.5b Differences in data taken in forward and reverse runs.

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FIELD MAPPING DATA SUMMARY SHEET.                    RUN 1         4-MAR-75

X PROBE POSITION.                                    1
Z PROBE POSITION.                                    1

CALIBRATION CONSTANT OF NORMAL.                      1
CALIBRATION CONSTANT OF X COIL.                      6.62692
CALIBRATION CONSTANT OF Y COIL.                      .36123
CALIBRATION CONSTANT OF Z COIL.                      .28214

DRIFT          L1(BUF1)       L2(BUF1)       L2(BUF2)       L1(BUF2)

                0              0              0              0
               -6              10             10             0
                5              5              5              0
                5              9              9              0

PEAKS          MIN (BUF1)     MAX (BUF1)     MIN (BUF2)     MAX (BUF2)
MAX LOC 328
LOCATION        328            328            328            328
VALUE           0              0              0              0

LOCATION        105            135            106            135
VALUE          -17             90            -20             88

LOCATION        270            121            270            121
VALUE          -599            616           -599            616

LOCATION        24             205            3              205
VALUE           5              2169           0              2169

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Fig. 6 Typical Run Summary Sheet.