KERNFORSCHUNGSZENTRUM

KARLSRUHE

May 1970 KFK 1220

Institut für Experimentelle Kernphysik
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An Arrangement for Automatic Magnetic Field Measurements+

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GESELLSCHAFT FÜR KERNFORSCHUNG MBH., KARLSRUHE

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Zusammenfassung

Es wurde eine Apparatur zur automatischen Ausmessung von Magnetfeldern entwickelt. Diese kann für die Ausmessung von Biege-, Quadrupol- und Gradientenmagneten bis zu Feldstärken von 50 kΓ mit einer Genauigkeit von 1‰ verwendet werden. Die Feldstärke wird mit Hallsonden, Spulen oder magnetfeldabhängigen Widerständen gemessen. Die Sonden werden durch eine spezielle Meßmaschine im Feld mit einer Genauigkeit von ± 10μm positioniert. Alle Gleitlager der Maschine sind zur Wahrung der Genauigkeit und zur Vermeidung des Stick-slip-Effektes statische Luftlager. Zur Steuerung der Maschine und zur Verarbeitung der Daten ist diese im On-line-Betrieb an einen TR86 Rechner angeschlossen.

An Arrangement for Automatic Magnetic Field Measurements

J. Brandes, G. Friesinger, A. Ulbricht

Kernforschungszentrum Karlsruhe

Abstract

An arrangement for automatic magnetic field measurements is developed. It can be used for bending, quadrupol and gradient magnets with field strength up to 50 kG within 0.1 % and assists the development of synchrotron and beam transport magnets. The measurement is done with Hall probes, coils or field depending resistors. The magnetic field sensors are positioned by a specially constructed measuring machine within ± 10 μm. All slide bearings are static air bearings to avoid stick slip and wear and tear. For automatic acquisition of the high quantities of data and for on-line control of the measurements, the measuring system is connected to a TR 86 computer.

I. Introduction

For the development of synchrotron and beam transport magnets an arrangement is developed for measuring the field distribution of bending, quadrupol and gradient magnets (1,2,3). The magnetic field is measured point by point and all necessary derivations, gradients, differences etc. are computed from the obtained data. The apparatus, which is connected to a TR 86 computer for on-line data acquisition and control, consists of three parts: The measuring device, the driving mechanism for positioning the magnetic field sensors, and the electronical equipment for data transmission and control of the measuring process.

II. Magnetic Field Sensors

The magnetic field sensors are Hall plates or magnetic field depending resistors for static and coils for dynamic field measurements. A temperature stabilized Hall plate with a precision current source (stability $2 \cdot 10^{-5}$ in 8 hours) yields together with an analog-to-digital converter an accuracy of 10^{-4}. The coils for dynamic measurements are described in a proceeding paper (4).
The magnetic field sensor is mounted on the top of the arm of the measuring machine (fig.1). The measurements are point measurements and all further computations are done by a computer. This presents a considerable flexibility for the various measurements of quadrupole, bending and gradient magnets. With the high accuracy of the measurements required, the strong gradients of the fringing fields and the magnetic fields themselves demand some effort for positioning the probe precisely enough in the field. Requiring an accuracy of 2 Gauss at gradients in the order of 3 kGauss/cm the probe must be positioned with an accuracy better than ± 10 μm.

III. The Positioning Machine

Frequently used positioning machines make use of turning lathes and milling tables. Their guiding accuracy is given by ± 20 μm (5). On account of stick slip the positioning of the probe within an accuracy of ± 10 μm is more delicious. To get rid off these friction effects in a satisfactory manner an air film is generated between the sliding guidance in the here described construction. The now very small friction, about 100 times better than with a conventional guidance, allows use of stepping motors for moving the measuring machine. Digital steering is possible in a

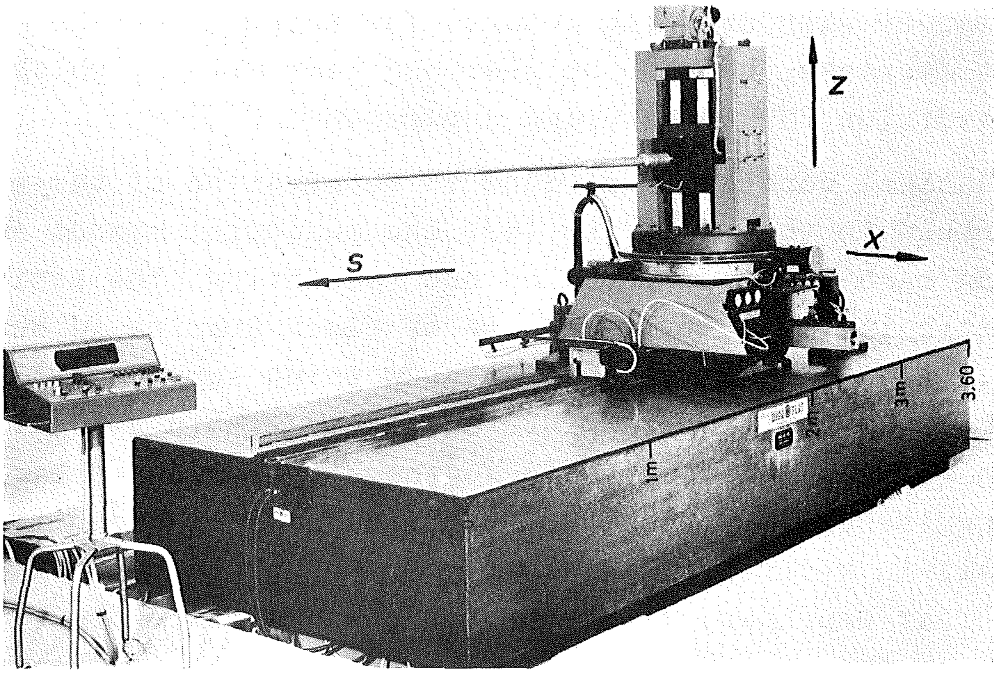

Fig.1

The positioning machine with the manual control desk.

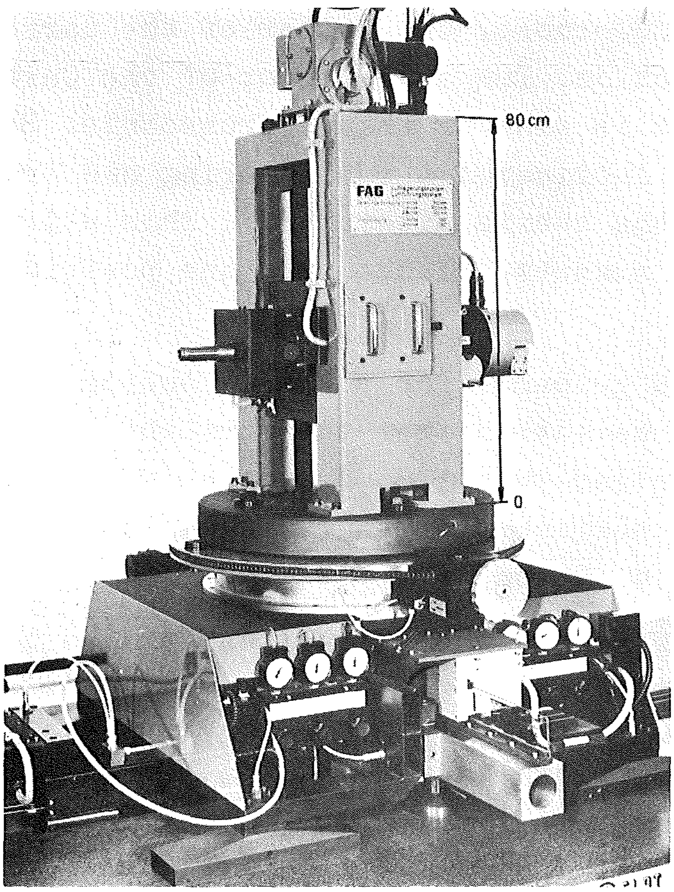

Fig.2

The carriage with mounted z-pillar supported on four air lubricated flat bearings.

simple manner with stepping motors. The accuracy of the guidance does not decrease, because no wear and tear arises, which in an ideal condition for a measuring apparatus.

The mechanical construction, done in cooperation of three firms, is described in the following (6). The measuring magnet and the measuring machine are mounted on one foundation. The basis of the positioning machine is a plate of black granite (dimensions: 3,6 x 1,5 x 0,45 m^3) placed on a three point support (7) (fig.1). The surface of the granite plate is lapped within ± 6 μm. The guidance for the s-direction is a groove in which one bar of a rectangular cross slides. The other bar of the cross is the guide rail in x-direction. A carriage, supported on four air lubricated flat bearings, slides on the stone surface and is guided by the bars of the rectangular cross to every point in the s-x-plane (fig.2). A quadratic pillar is mounted on the carriage. The movement in the third dimension, the z-direction, is done by a sleeve sliding on the pillar. A spindle rests in a circular air bearing which is mounted on the sleeve. The probe holder is fastened with clamps at the top of the spindle. The spindle and therefore the probe is able to be rotated around its longitudinal axis about an optional angle within ± 20 arcsec. The pillar of the carriage is adjustable in the z-direction. The angle error of the Carthesian coordinate system s,x,z is smaller than 2 arcseconds. Besides this, the pillar has an air lubricated thrust bearing and from that it is turnable around the z-axis within 360°. This allows measurements with different magnets, placed near the positioning machine.

The measured accuracy of the guidance for the s-direction is within ± 6 μm (fig.3). The deviation from the straight line along the x-direction is smaller than ± 6 μm in the vertical plane and ± 0,15 μm in the horizontal plane. The deviation of the z-direction is within ± 0,15 μm (fig.4).

The positions of the probe are read photoelectrically by a binary coded measuring device with an accuracy of ± 5 μm (9). One step of the stepping motors corresponds to a movement of about 1,5 μm along one coordinate (max.stepping rate 3200 puls./sec and 2000 steps/rev.) (8).
The probe itself can be positioned in a volume of 2,0 x 0,5 x 0,3 m^3.
The measuring room is air conditioned at (22,0 ± 0,5)°C.

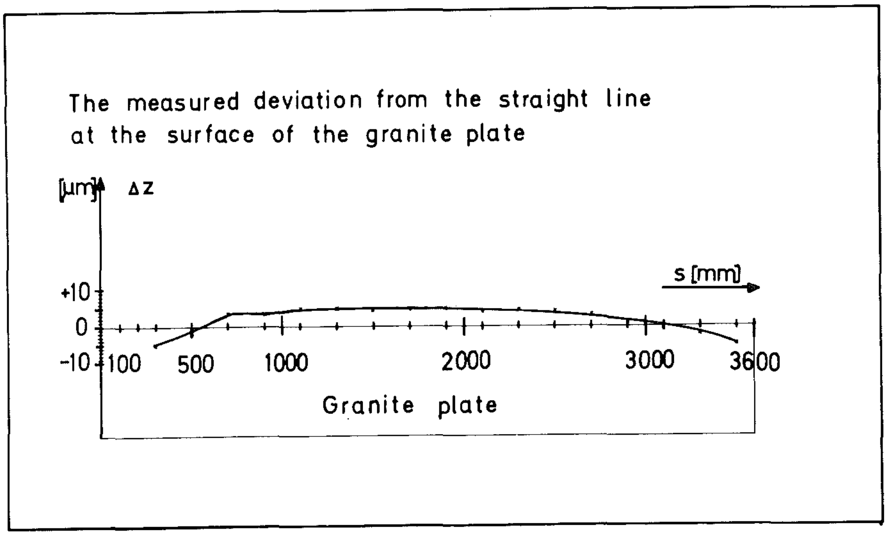
The measured deviation from the straight line
at the surface of the granite plate
[µm] Δz
s [mm]
+10
0
-10
100
500
1000
2000
3000
3600
Granite plate

Fig.3

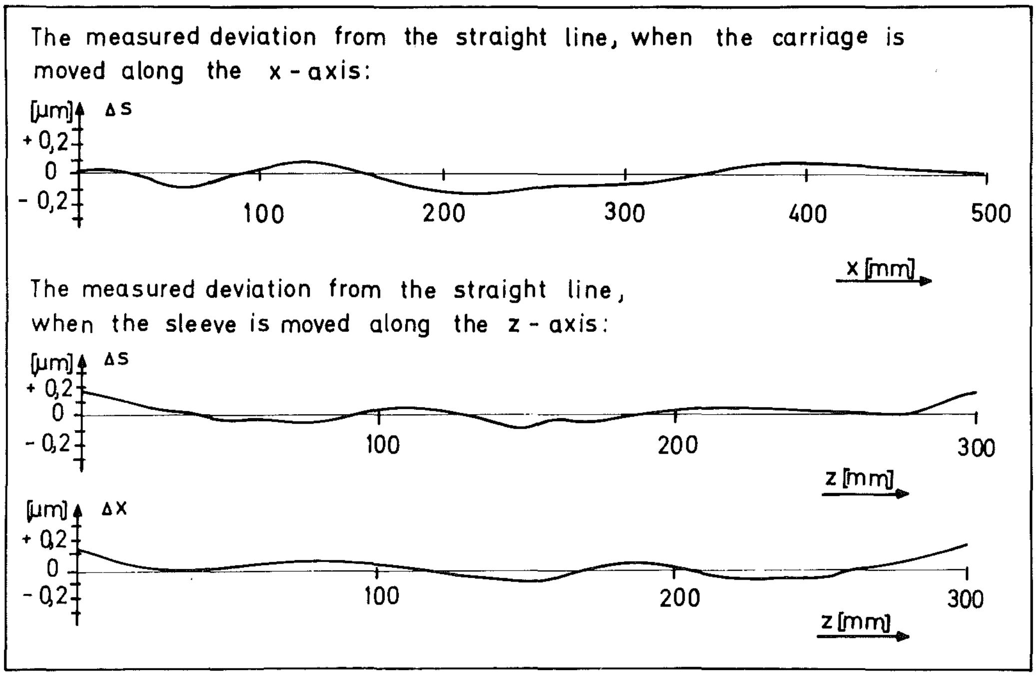
The measured deviation from the straight line, when the carriage is moved along the x-axis:
[µm] Δs
+ 0,2
0
- 0,2
100
200
300
400
500
x [mm]
The measured deviation from the straight line, when the sleeve is moved along the z-axis:
[µm] Δs
+ 0,2
0
- 0,2
100
200
300
z [mm]
[µm] Δx
+ 0,2
0
- 0,2
100
200
300
z [mm]

Fig.4

IV. The Electronical Equipment for On-Line Control and Data Acquisition

For the on-line control and the data acquisition of the magnetic field measuring system a TR 86 computer configuration is used. The TR 86 system is planed for serving several other experiments by time sharing, too, and consists of an usual computer configuration with peripheral standard units completed by a data channel and CRT display facilities (10).

The data channel is developed for transmission of commands and data with rates up to 2.5 kHz towards the special electronical equipment of the experiment.

The experimental electronics (fig.5) consists of a HP 2402 ADC, the ADC scanner to serve up to 6 measuring places, the scanner unit to adress the s,x,z and φ registers, which contain the information about the probe position, and the units to drive the probe in the s,x,z and φ directions (11) (12). A wanted position is reached, when a preset register is counted down. This causes a program interrupt in the TR 86 computer. In the same way the end of conversion of the ADC is signaled to the computer via the data channel.

The command unit enables the experimentator to start certain programs as well as to input required parameters. Because the operating system of the TR 86 allows time slicing, it is possible to run several routines together.

Adjusting operations can be carried out by a manual control desk. The desk allows driving of the magnetic sensors by hand and displays its position on numeral indicator tubes as decimal numbers (14).

V. Software of the Automatic Field Measurements

The tasks, the software has to achieve, are to control the measuring device, to transput the measurement values and to store them on magnetic tape and disk, as well as further data processing and display.

The required hardware is described above. Besides this a complete TR 86 operating system for multi access exists, which contains

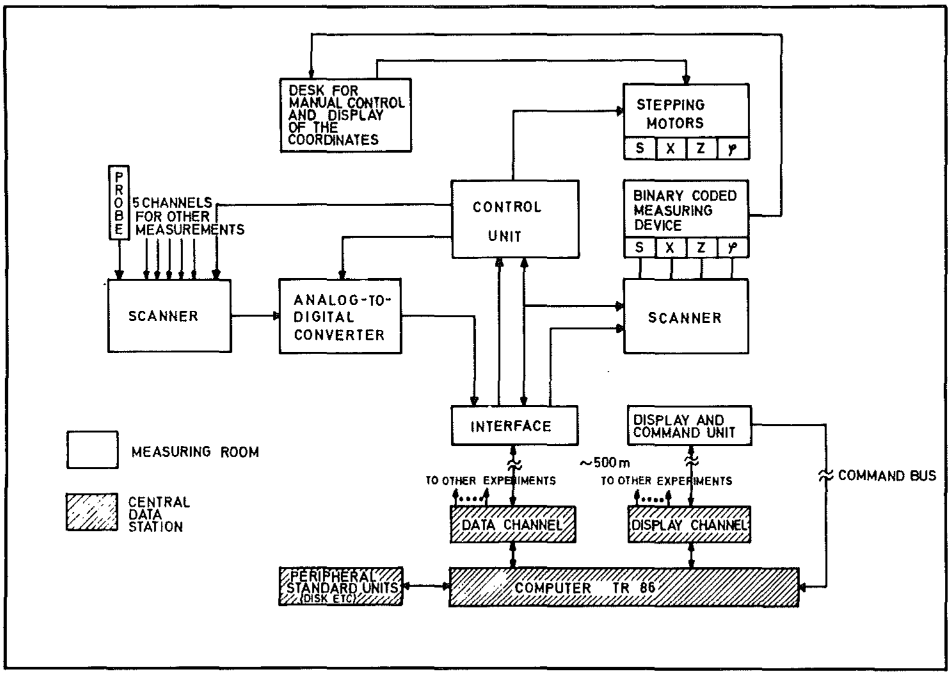

Fig.5

Block diagram of the electronical equipment.

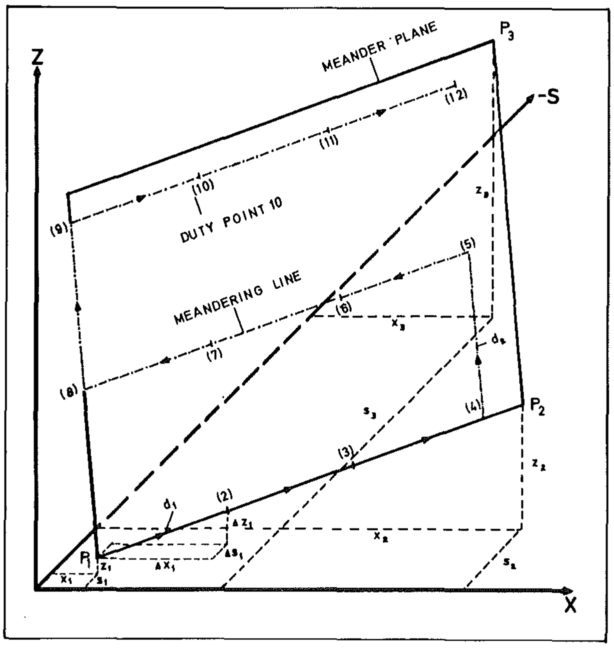

Fig.6

Geometrical parameters of the meander routine.

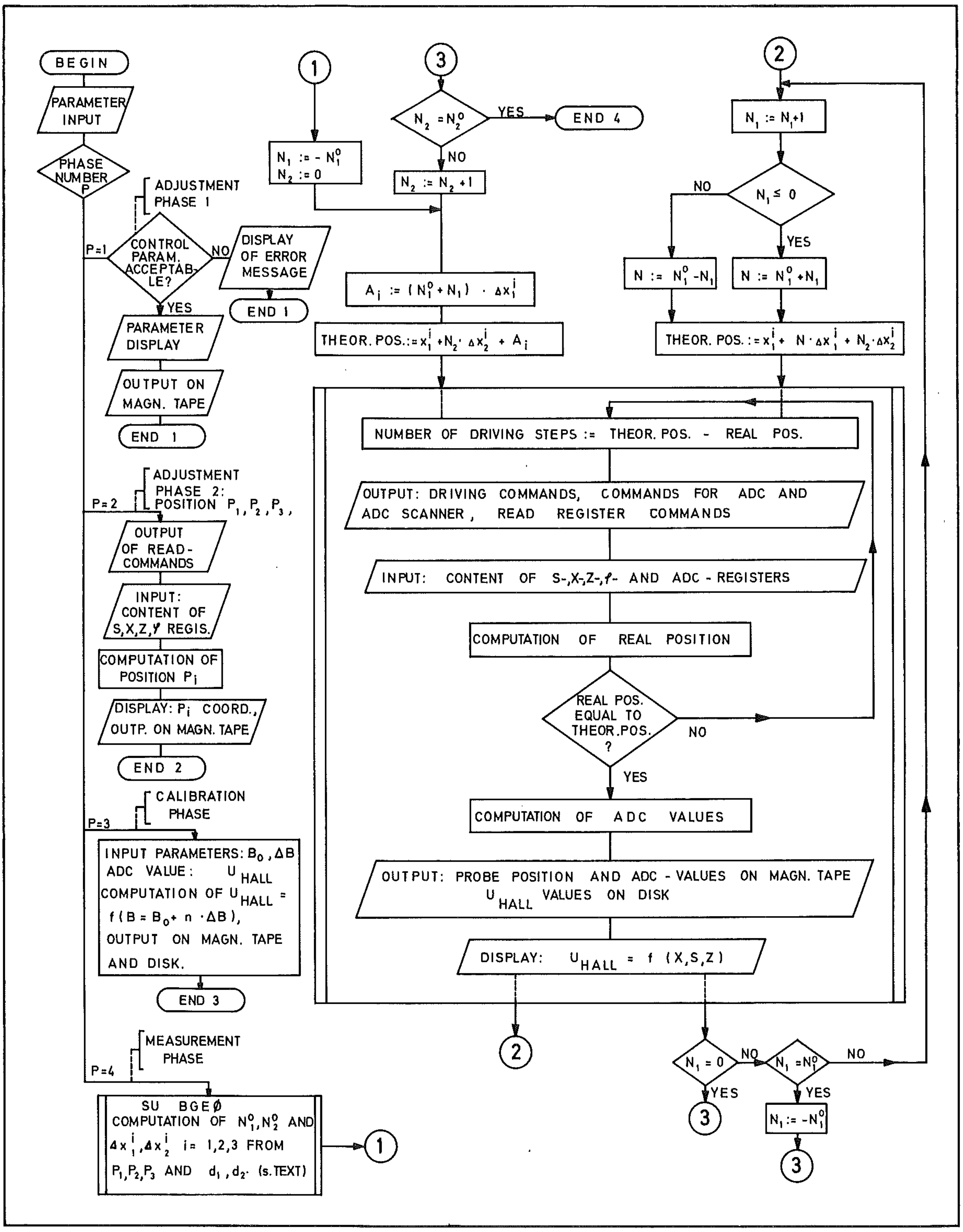

Fig.7

Flowchart of the meander routine.

macro-instructions for the peripheral standard units (10) (13). Therefore the data output on magnetic tape (for further processing on the IBM 360/65) and the transput on disk (for further processing on the TR 86) is quite easy, but about 2000 TR 86 commands are required for driving the Hall probe on a meandering line.

The complete software consists of three driving programs (the meander program, below described in detail, and two circular programs) with a calibration and measurement phase, several analysis routines with CRT display of the results, and later on the software for more sophisticated analysis with the IBM 360/65.

The analysis programs of the TR 86 display the functions:

$$\frac{B_0 - B}{B_0} = f\,(s,x,z,\varphi) = f\,(x^i,\ i = 1...4)$$

$$\frac{dB}{dx^j} = f\,(x^i,\ i = 1...4),\ j = 1...3 \text{ and}$$

$$\frac{L_0 - L}{L_0} = f\,(x^i,\ i = 1...4)$$

with B = magnetic field, s,x,z,φ = the coordinates and $L = \frac{1}{B_0}\int_{-\infty}^{+\infty} B\, dx^i$.

The route points, the probe has to cross, are illustrated for the meander routine in fig.6. The flowchart of the meander routine is represented in fig.7. This routine requires five geometrical parameters:

The coordinates of P_1, P_2, P_3, which define the plane of the meandering line and d_1 and d_2, which fix the distance of the route points (s.fig.6). With these the subroutine BGEO computes the number N_1, N_2 of duty steps, the probe has to drive towards $\overline{P_1P_2}$ and $\overline{P_2P_3}$ as:

$$N_i = \text{entire}\,(P_i\ P_{i+1}/d_i),\ i = 1,2\ ,$$

and the components $(\Delta s, \Delta z, \Delta x) = (\Delta x^i,\ i = 1,2,3)$, which are necessary, because there are only driving commands in the s,z,x (and φ) directions. In fig.7 the adjustment phase 1 means the input of control parameters, like the number of ADC measuring points and their units. In adjustment phase 2 it is assumed, that

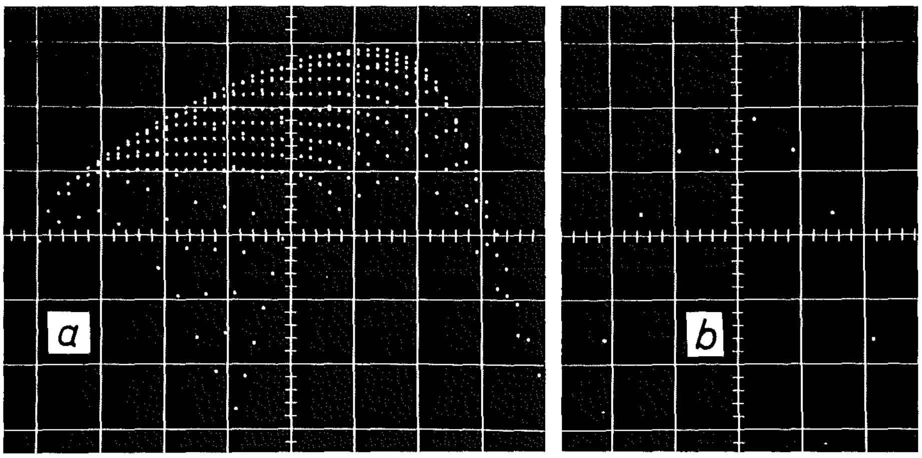

Fig.8

a) An isometric display of a measured field distribution in one half of a bending magnet with circular pole faces. The probe is driven along a meandering line which lies parallel to the pole faces in the middle of the air gap.
(vertical: field error $\delta B = (B_o - B)/B_o$, 7%/div.; horizontal: 3,6 cm/div.; distance of two curves: 0,9 cm; B_o = 22 kGauss)

b) The medium part of the first curve in Fig.8a) drawn in a larger scale. (vertical: field error δB, $7 \cdot 10^{-5}$/div.; horizontal: 0,94 cm/div.; B_o = 22 kGauss) the Hall probe is driven by hand to points P_1, P_2 and P_3, one after the other and the phase 2 started each time again.

The points P_i, i = 1...3, are optional; if two of them are identical, the probe is driven on a line. All further details can be seen from the flowchart.

Fig.8a) shows the isometric display of the field distribution in one half of a bending magnet with circular pole faces. The eight medium points of curve 1 are drawn in a larger scale in Fig.8b).

VI. Conclusions

The arrangement for automatic magnetic field measurements is described in its intermediate state. The connection of the apparatus to a TR 86 computer effects an highly flexible field measuring system. The software for on-line control and for data processing is designed for a lot of different measuring problems. By means of a display unit, the results of the measurements can be reviewed by the operator in the measuring room and therefore a continuous supervision of the measuring process is possible, which is important for the measurements of larger series of magnets.

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