KERNFORSCHUNGSZENTRUM

KARLSRUHE

Oktober 1972   KFK 1645

Institut für Experimentelle Kernphysik

Zur Abhängigkeit des Oberflächenwiderstandes anodisierter Niob-Resonatoren von der Hochfrequenz-Feldstärke zwischen 2 und 4 GHz

P. Kneisel
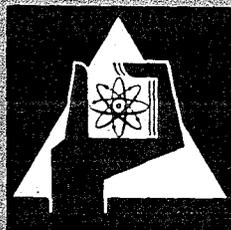
KERNFORSCHUNGSZENTRUM KARLSRUHE

August 1972   KFK 1644

Institut für Datenverarbeitung in der Technik
Institut für Experimentelle Kernphysik (*)

A system for control and interactive data reduction
for a magnetic field measuring arrangement

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Zusammenfassung

Es wird das Programmsystem für eine Magnetfeld-Meßapparatur
beschrieben. Die Apparatur ist seit zwei Jahren in Betrieb (1)
und ist über Datenkanäle mit einem TR-86-A Prozeßrechner ver-
bunden, der mit einem Betriebssystem für Vielfachzugriff aus-
gerüstet ist und an den weitere Experimente angeschlossen sind.

Das Programmsystem ist aus zwei Modulen aufgebaut, der erste
Modul besteht aus Datenerfassungs- und Steuerroutinen, der zwei-
te aus Auswerteroutinen zur interaktiven Datenreduktion. Die
Steuerprogramme werden für Punktmessungen magnetischer Felder be-
nötigt und verfahren eine Meßsonde längs Geraden, Kreisen, Ebenen
und Zylinderflächen. Die Auswerteroutinen berechnen physikalische
Parameter und Funktionen wie z.B. die Abhängigkeit magnetischer
Feldstärken vom Ort der Meßsonde, Integrationen oder Ableitungen
von Meßkurven.

Eine Reihe von Anwendungen dieser Programme auf z.B. Zuverlässig-
keitsprüfungen von Gerätekomponenten, Messungen der Feldverteilung
von Quadrupol- oder Dipolmagneten, sowie Erregungskurven sollen
den Grad der erreichten Laborautomation veranschaulichen.

Entwurf, Kodierung und Test des Programmsystems erforderten
etwa zwei Mannjahre.

Abstract

The program system for a magnetic field measuring system in opera-
tion since two years is described. The experimental system (1)
is connected via data channels to a TR-86-A computer and utilizes
an operating system for multi-access serving also several other
experiments.

The program system is divided into two moduls, one modul con-
sisting of data acquisition and control routines and the other
one of the evaluation routines for interactive data reduction.
The control routines are used for point to point measurements
of magnetic fields and to drive a field sensor along straight
lines and circles and across flat planes and cylindrical sur-

faces. The evaluation routines calculate and display physical
parameters and relations such as magnetic field strengths as
a function of sensor position or differentiated and integrated
measured curves.

Several applications of the control and evaluation routines to
e. g. tests of device components, to measurements of field
distributions of dipol and quadrupol magnets and excitation cur-
ves illustrate the degree of automatic data acquisition and ana-
lysis.

The time required for designing, coding and testing the program
system was about two man years.

Contents

I. Introduction

For the automation of laboratory performance at the Kern-
forschungszentrum Karlsruhe a central automation system
CALAS (computer aided laboratory automation system)was
developed (2), (4) which allows coupling of several ex-
perimental systems. Some of them are represented in (3),
(5) in this article the programming package for another
experimental system, an arrangement for automatic magnetic
field measurements with interactive data analysis is to be
described.

The operation and construction of the arrangement for auto-
matic magnetic field measurements, the characteristics of
its electronical equipment and its first measuring results
are detailed in (1). The following paper states more preci-
sely the developed control and interactive analysis routines,
which are in use for more than one year, and will show, how
the experimenter is freed from routine work in data acquisition
and how CRT display of reduced and transformed measuring results
suggests further measuring methods and a more complicated or
even another data analysis on a larger computer system.

II. The abstract machine for the application programs and the main requirements by the users of the magnetic field measuring system

The experimental station for the magnetic field measurements it-
self is described in (1). In the following the further environ-
ment for the programming system, the hardware and operating
system characteristics, known as abstract machine, and the re-
quirements imposed by the users and their goals are discussed.

The machine equipment of the Calas laborautomation system (4)
consists of

the TR-86-A computer (cycle time 0.9µs, 64 k 24 bit

words core store, at least 12 program interrupt channels, but
no floating point arithmetic),

two disk storage units SSP 300 with drum characteristics,
two magnetic tape units and the usual slow peripheral

standard units (console teletypewriter, card reader, high speed
printer and puncher)

a real time clock with an alarm arrangement,
up to 64 display units (four different modes - character,

incremental and vector mode and a special two dimensional mode -,
512x512 or 256x256 screen point display, display repetition fre-
quency max 24 Hz and several possibilities of hardware manipu-
lation of spectra displayed in incremental mode),

up to 64 command units for parameter and control

information input by the experimenters, and

the process channel. The process channel has a tested

maximum input rate of 600 kwords/s and a maximum output rate of
400 kwords/s. By use of multiplexors it is divided into different
kinds of subchannels, connected to modems with maximum transfer
rates of 3 kwords/s (bit serial) and 15 kwords/s or 50 kwords/s
(byte serial). The subchannels and modems are connected with a
standard interface to the different experimental stations (s. Fig.4).
The Calas operating system is designed for centralized multiaccess
and allows data acquisition and analysis in parallel for all con-
nected experimental stations. The storage allocation schema is
variable for control and data acquisition programs of different
types of experiments (high transfer rates, own larger buffers etc).
The operating system provides two different program priority classes
with a higher and a lower response time. The first one is designed
for time critical tasks in real time problems and the second one
for interactive data analysis routines using the display units.
The utilities support disk transfer, output to magnetic tape in
a format compatible with a larger computer system,picture display
and manipulation of the parameter records from the command units.

For the experimental system considered a section of 50 k words is
reserved on the disk unit for absolut coded control and evaluation

routines, and for measuring results.

The main restrictions of this operating system are the few test utilities and the absense of compilers for higher programming languages, such as ALGOL or Fortran, generating object code routines less than 4 k.

Using the above described abstract machine, the following requirements by the experimenters have to be fulfilled as far as practicable.

The users of the magnetic field measurement system are mainly interested in the development of magnets for particle accelerators, but not in computer science. Therefore the first task is to construct a program system for easy use without knowledge about the computer system behind, with a general formal construction, such as similar parameter records for all routines, and with a sufficient documentation.

A further requirement is to guarantee a safe operation of the system. This could be achieved by supervising the measuring process as far as possible and by monitoring the parameter input to prevent especially input of values which would cause a crashing of the field sensor against the magnet boundaries.

The main requirement results from the aims of the experimenters themselves, the examination of conventional iron and supraconducting magnets for particle accelerators and beam transport, especially quadrupol and bending magnets (7). The study of their field distributions requires control programs for driving the field sensor and measuring point by point along arbitrary curves, in particular circles and straight lines.

Besides this, it is desired to test automatically the apparatus and certain parts of it, such as long time stability of power supplies and linearity of calibration curves.

Last but not least, interactive data reduction and analysis is required as far as possible, even highly sophisticated analysis of the measuring results by including error dependencies of higher order. This is necessary e.g. for the empirical determination of

an optimal shimming and searching for suited end faces of
beam transport magnets. Since the Calas system supports
two different priority levels of user programs, interactive
display manipulation and magnetic tape output compatible with
the IBM 360/65 system of the KFK computer centre, the pro-
gramming system for the magnetic field measurement was divi-
ded into three parts, discussed in detail in the following
paragraphs: The control routines for control, test and data
acquisition, the evaluation routines for interactive data
reduction and analysis and those, which serve for a more
complicated or even another analysis on a larger, off-line
IBM computer system. (s. Fig. 1)

The information flow between the experimenter, the
control and evaluation routines, the experimental
system and the Calas operating system
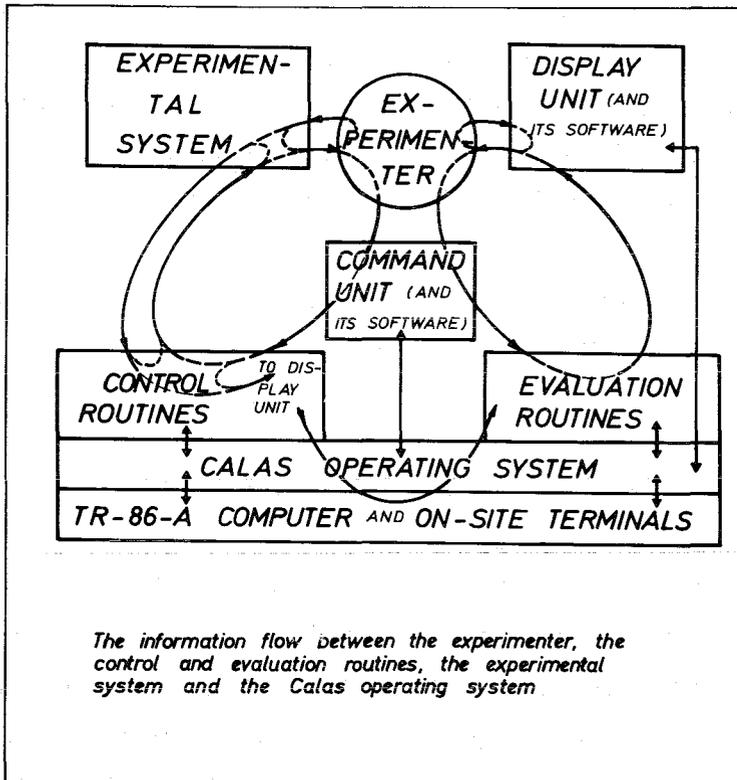
Figure 1

III. The control and gauge routines of the magnetic field measuring system

The task of the control routines (8) consists in
(a) controlling the movement of a field sensor(located within
the aperture of a magnet) along certain geometrical paths;

(b) transferring data collected by the field sensor and
    other devices to the TR-86 computer, and subsequently
    storing them on magnetic tape and intermediately on a
    disk.

The control routines consist of two parts. In the first part,
the geometrical paths and point sequences for the field sensor
are calculated. In the second part, the trajectories obtained
from part 1 are translated into control commands for the measu-
ring machine. In analogy to EXAPT-routines controlling numerical
tool machines the second part is called the postprocessor.The
calculation of geometrical paths and point sequences for the
field sensor can be easily accomplished by using a higher language
such as EXAPT or ALGOL. Therefore a program library is desirable,
consisting of subroutines written in these languages which may
be called, together with the postprocessor, during the measuring
phase. But adequate compilers generating object code routines
short enough are not available. Thus, all geometrical programs
had to be written in the TR-86 assembly language.

Consequently a detailed analysis of those measuring programs
expected to be used most frequently was necessary. We obtained
the following result from this investigation:

Accelerator and beam transport magnets are mainly normal and
supraconducting quadrupol and bending magnets. Important items
are the quality of the field distribution over the aperture,
the field strength and the gradients themselves, the determina-
tion of the real length of the magnetic field, the influence
of mechanical tolerances in larger series of magnets, and the
determination of the magnet axes for positioning the magnet
in a beam line. To determine these properties, point measure-
ments of the magnetic fields are necessary across flat planes
and cylindrical surfaces as well as along straight lines, circles
and arbitrary curves. (The last point can only be realized by
means of a more elaborate parameter input from the command unit
during the measurement).

This resulted in the following three control programs:

(a) The meander program, driving the field sensor along straight lines or within planes,

(b) the circular program, driving the field sensor along circular lines or across cylindrical planes and

(c) the curve program for measurements at arbitrary points, lines or planes.

The gauge routine is used to connect the measured Hall voltages of the field sensors and the magnetic field strength B. This is discussed in III.4.

III.1. The geometrical formulas and the flow chart of the control routines

In this chapter, the parameters, geometrical formulas, and the flow chart of the control routines are discussed in detail. The postprocessor subroutine managing the output of commands to and the data input from the experimental system, and the methods of storing data on magnetic tape and disk are described in III.2. and III.3.

The flowchart for the control routines (Fig.2) consists of nine phases. Each phase is activated by a special parameter record sent from the command unit. In phase 1 and 2, the starting parameters for the whole routine are transferred, such as

program identification
number of measurement,
type of measuring magnet,
number of channels of the ADC-multiplexor,
the various scanning frequencies of the channels,
their physical dimensions,
coordinates of the origin of the coordinate system,
required accuracy G of field sensor position,

and, in particular for the different control programs

BEGIN

PARAMETER INPUT

PHASE NUMBER P

ADJUSTMENT PHASE 1,2

P=1,2

CONTROL PARAM. ACCEPTABLE ? — NO → DISPLAY OF ERROR MESSAGE → END 1

YES

PARAMETER DISPLAY

END 1

ADJUSTMENT PHASE 3,4,5 POSITION $P_1=MP_1$, $P_2=MP_2$, $P_3=P_{st}$

P=3,4,5

OUTPUT OF READ-COMMANDS

INPUT: CONTENT OF S,X,Z,φ REGIS.

COMPUTATION OF POSITION P_i

DISPLAY: P_i COORD. OUTP. ON MAGN. TAPE

END 2

MEASUREMENT PHASE

P=6

PARAMETER OUTPUT ON MAGN. TAPE

SU BGE $\emptyset$ COMPUTATION OF THE DUTY STEPS $N_{1,2}^0$ AND OF THE VECTOR COMPONENTS OF ΔMP (OR ΔS) (S. TEXT) → 1

P=7

STOP MEASUREMENT → END

P=8

CONTINUE MEASUREMENT

P=9

CONTINUE MEASUREMENT AFTER UNDEF. BREADOWN

1

$N_1 := -N_1^0$ $N_2 := 0$

READ POS.

3

$N_2 = N_2^0$ — YES → END 4

NO

$N_2 := N_2 + 1$

CALCULATION OF THEOR. POS.

2

$N_1 := N_1 + 1$

$N_1 \leq 0$ — NO → $N := N_1^0 - N_1$

YES → $N := N_1^0 + N_1$

CALCULATION OF THEOR. POS. (S. TEXT)

NUMBER OF DRIVING STEPS = THEOR. POS. - REAL POS.

(*) OUTPUT: DRIVING COMMANDS, COMMANDS FOR ADC AND ADC SCANNER, READ REGISTER COMMANDS

INPUT CONTENT OF S-, X-, Z-,φ- AND ADC - REGISTERS

COMPUTATION OF REAL POSITION

REAL POS. EQUAL TO THEOR. POS. ? — NO →

YES

COMPUTATION OF ADC VALUES

OUTPUT PROBE POSITION AND ADC-VALUES ON MAGN. TAPE U_{HALL} VALUES ON DISK

2

$N_1 = 0$ — NO → $N_1 = N_1^0$ — NO →

YES → 3

YES → $N_1 := -N_1^0$ → 3

s. text

Fig. 2 Flow chart of the control routines for the field measuring system { *) postprocessor subroutine }

$$\left.\begin{array}{c}\Delta MP \\ \Delta\phi\end{array}\right\} \text{ see Fig.3,}$$

rotation direction of the field sensor,

driving direction along a given circle,

N_1^o (see below)

for the circular routine,

$$\left.\begin{array}{c}D_1 \\ D_2\end{array}\right\} \text{ step widths, see Fig.6 in (1),}$$

for the meander routine, and

N_1^o, the number of curve points,

for the curve program.

The meaning of the geometrical parameters can be seen from the formulas given below, parameter G serves as an automatic correction of the field sensor position if the condition

|theoretical position - real position| > 2^G-1 [5μm]

is true.

In the phases 3 to 5 the position of the field sensor is read automatically by the TR 86 computer and is interpreted as

P_i, i = 1, 2, 3, defining the meandering plane,

or as MP_1, MP_2, MP_{st}, defining the cylindrical plane, (see Fig. 3) or for P=3 as starting point of an arbitrary curve.

In this way of specifying the input, the experimenter is forced to drive the field sensor by hand to the border points of the measuring plane to prevent crashing of the field sensor against the magnet boundaries if wrong parameters during the measuring phase were given.

Phase 6 is the actual measuring phase. It starts with output of the parameters from phases 1-5 on magnetic tape and continues with calculation of the geometrical parameters N_1^o, N_2^o, $\Delta x_{1,2}^i$ in SU BGEO, using the formulas below. Then for each of the (N_1^o+1)x (N_2^o+1) measurements the theoretical position is computed and the field sensor transported for a number of steps, proportional to

the difference from the theoretical and real position. Then, the contents of the ADC and s,x,z,ϕ registers are read, and, if the theoretical and real position agrees within given limits, transferred to magnetic tape and disk. When the last of the $(N_1^O+1) \times (N_2^O+1)$ measuring points is reached, the measurement is stopped.

The geometrical parameters of the circular routine
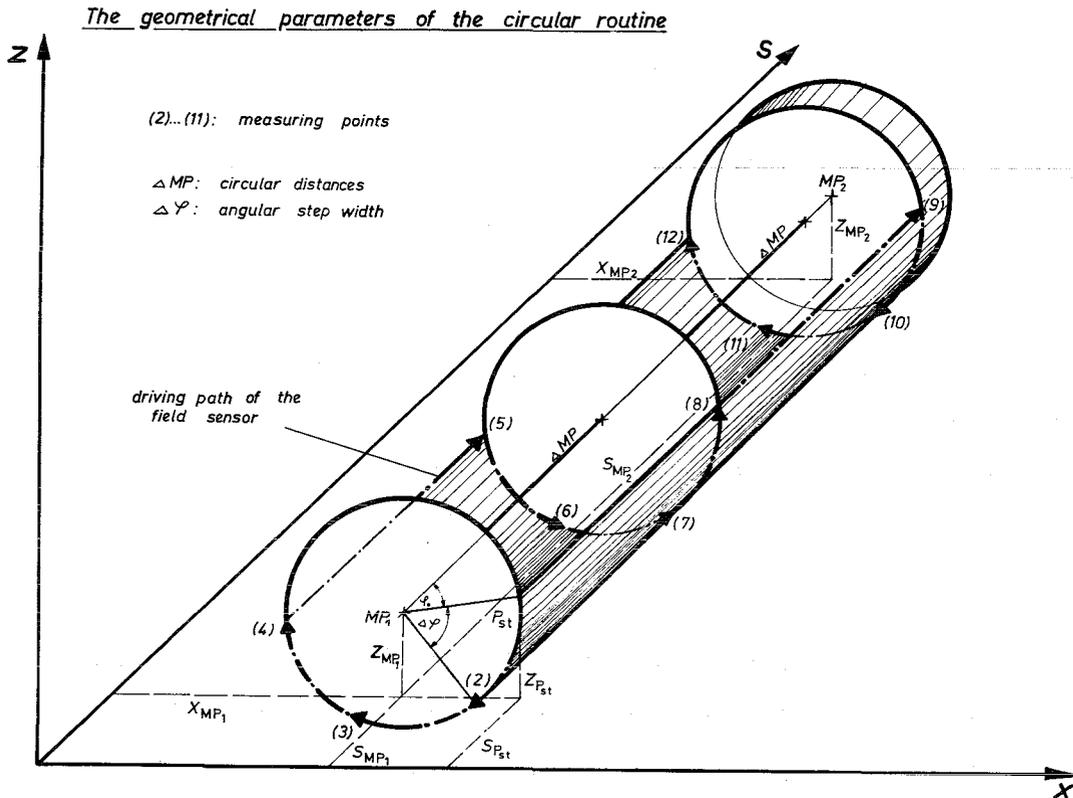
Fig. 3

Phase 7 and 8 are used for stopping and continuing the measurement at arbitrary times, while phase 9 allows to restart a measurement after an undefined breakdown, especially of the CALAS operating system. This program part is realized by saving all important parameters during every driving period of the field sensor, and is well proven during long measuring periods, especially with Helium cooled magnets, being too costly and time consuming to be repeated because of system failures.

The geometrical calculations of the control programs use the following formulas.

1. The meander routine computes with the parameters as represented in Fig.6 of (1) the number $N^O_{1,2}$ of duty steps the field sensor has to drive into the directions $\overline{P_1P_2}$ and $\overline{P_2P_3}$ of the meander plane by

$$(1) \quad N^O_i = \text{entire } (\overline{P_i\,P_{i+1}}/D_i), \quad i = 1,2$$

and also the step components $(\Delta S_i, \Delta Z_i, \Delta X_i) = (\Delta x^j_i)$, i=1,2, j=1,2,3, as

$$(2) \quad \Delta x^j_i = D_i\,(x^j_{i+1}-x^j_i)/\overline{P_{i+1}\,P_i}, \quad i=1,2, \ j=1,2,3,$$

with

$$\overline{P_i\,P_{i+1}} = \sum_{j=1}^{3}\,(x^j_{i+1}-x^j_i)^2$$

and $D_{1,2}$ = step widths in direction $\overline{P_1\,P_2}$ and $\overline{P_2\,P_3}$,

$P_i = (x^j_i)$, j=1,2,3.

By (1) and (2), the theoretical position of the field sensor is calculated as shown in the flow chart for the meander routine in (1).

2. The geometrical properties of the possible circular curves and the geometrical parameters of the circular program are illustrated in Fig. 3. All measuring points are allowed which arise, if an arbitrary meandering plane is placed partly or several times around a cylindrical plane with a given radius, as far as $\overline{P_2\,P_3}$ is parallel to the cylindrical axis and both are parallel to the x- or s- axis.

As Fig. 3 shows, the cylindrical plane is defined by the circular centers MP_1, MP_2 and the starting point $P_{st}=(X_{st},\ Z_{st},\ S_{st},\ \phi_{st})$ of the field sensor. The theoretical position (S,X,Z,ϕ) of the N-th measuring point is calculated for the special case with the cylindrical axis beeing parallel to the x-axis by the following formulas:

$$(3) \quad \phi = N_1\times\Delta\phi+\phi_{st}$$
$$(4) \quad S = S_{MP1}+N_2\times\Delta\,MP,$$
$$(5) \quad X = X_{MP1}+ \Delta X'$$
$$(6) \quad Z = Z_{MP1}+ \Delta Z'$$

with $\quad \Delta X' = \Delta X \cos (N_1 \, \Delta\phi) - \Delta Z \sin (N_1 \, \Delta\phi)$,

$\qquad \Delta Z' = \Delta X \sin (N_1 \, \Delta\phi) + \Delta Z \cos (N_1 \, \Delta\phi)$,

$\qquad \Delta X \;\; = X_{Pst} - X_{MP_1}$,

$\qquad \Delta Z \;\; = Z_{Pst} - Z_{MP_1}$.

$\qquad N_2^O = \text{entire} \; (\overline{MP_1 \; MP_2} / \, \Delta MP) \;$ and

N_1^O is equal to the number of duty steps on the circular curves and N_1 and N_2 are given by the ALGOL-like statements

$\qquad N_2 := \text{entier} \; ((N-1) \, / (N_1^O + 1))$,

$\qquad N_1 := 1 + \underline{if} \; N_2 \equiv 0 \; \text{mod} \; 2 \; \underline{then} \; (N-1) \; \text{mod} \; (N_1^O + 1)$

$\qquad\qquad\qquad\qquad\qquad \underline{else} \; -N \; \text{mod} \; (N_1^O + 1)$.

3. In the curve routine phase 6 has to be called repeatedly by the user, passing the relative or absolute coordinates to the next theoretical position as parameters. Therefore, the theoretical position is easily calculated. The measurement stops after N_1^O starts of phase 6. The program is more elaborative for the user, but as fast as others, because the change of the parameter records is possible during the driving period of the machine.

III. 2. The postprocessor

The postprocessor is a subroutine used by all control routines and the gauge routine. It builds up the connection between the TR-86-A computer and the experimental system, and causes transfer of commands to and of data from the experimental system.

The input parameters are:

> field sensor coordinates to be read,
> field sensor coordinates to be changed,
> its number,
> values of the required coordinate changes,
> ADC channels to be read,
> mask for experimental interrupts.

The output values are:

the required coordinates of the field sensor position and the measured values from the required ADC channels.

The following two warnings are possibly displayed on the console teletypewriter and on the experimental display unit:

errorneous command transfer or interrupt and
errorneous data transfer

They cause interruption of the measurement, with restart with phase 9 beeing possible.

Block diagramm of electronical equipments used by the postprocessor
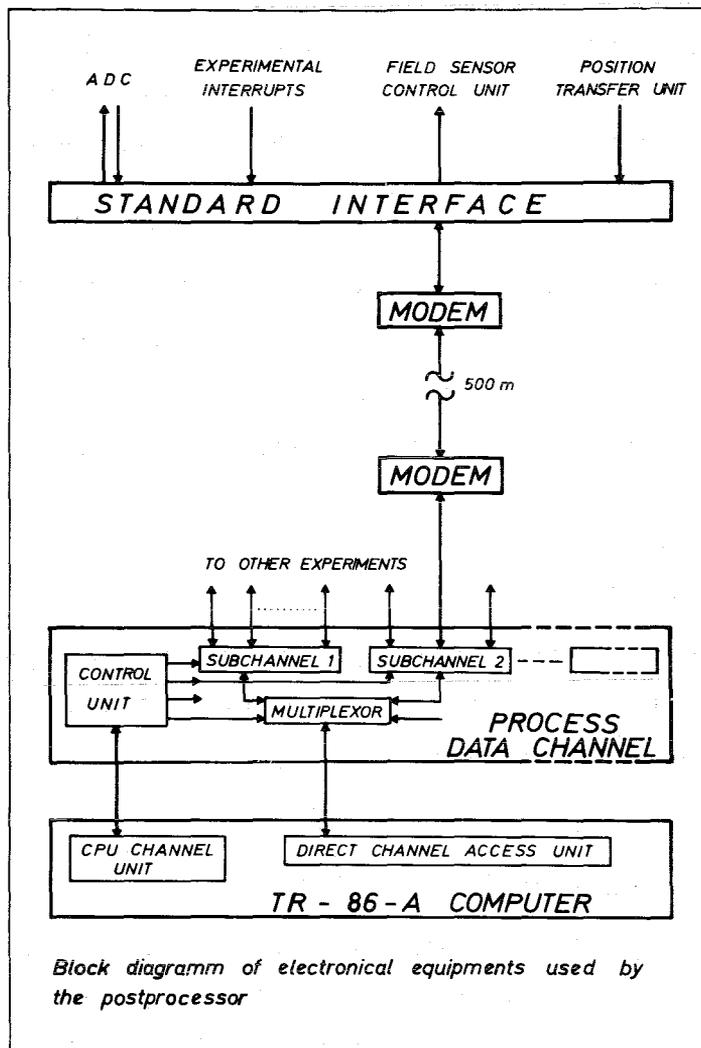
Fig. 4

The hardware used by the postprocessor is illustrated in
Fig. 4. The electronic equipment of the magnetic field mea-
suring system is connected to the TR-86 computer via the stan-
dard interface, the modems and one of the subchannels for
serial data transfer of the process channel.

The electronic units are controlled by three different types of
commands

    the commands for the control unit of the process data channel,

    the commands for the standard interface, and

    the commands for the unique experimental electronical devices.

The control unit instructions are on a higher level then all
others, as they initiate the subchannel to transfer the inter-
face and experimental command code from certain storage cells
to the units specified.

The commands for the control unit of the process data channel are:

    initiate transfer of code for experimental commands,

    "   "   of the code "start data input",

    "   "   of the code "stop data input",

    clear subchannel

    clear all interrupts,

    clear all subchannels.

The last two commands are used only by the operating system,
"clear subchannel" normalizes the electronical devices after
undefined breakdown of the measurement.

The first instruction above is most frequently used. It allows
transfer of the following standard interface codes

    selection (builds up the connection to the experimental system),

    disconnection (cuts the connection to the experimental system),

    half disconnection (cuts the connection partly, only inter-
    rupt messages remaining possible),

and of the following special experimental codes

      allow reading of field sensor position,

set ADC control register into mode 1,2 or 3
(defines the ADC channels to be read before or after driving the
field sensor),

set coordinate counter (contains the number of coordinates
to be changed)

set s - coordinate of field sensor,

" x -   "   "   ,

" z -   "   "   ,

" ϕ -   "   "   ,

clear experimental interrupt,

set mask register for interrupts, and

set data way mask.

The remaining two control unit instructions initiate start and
stop of data transfer. The first one initiates transfer of the
standard command "start data transfer" to the experimental in-
terface, and transfer of the buffer address and buffer length
to the subchannel. The control unit instruction for stop trans-
fer iniates transfer of the standard command "stop data trans-
fer" to the interface and input of the last data transfer address
from the subchannel into a certain cell in core.

Every transfer of commands to the standard interface and the ex-
perimental system by the subchannel is acknowledged by a program
interrupt with typical status words. Normally, the successful ana-
lysis of these status words causes output of the next command,
except in two cases:

After"set s, x, z or ϕ coordinate "it is waited additionally for
an experimental interrupt, telling that the required position has
been reached by the field sensor, and

after "start data input" it is waited additionally for an interrupt
"end of record".

Therefore the command flow through the subchannel is as follows:

At the beginning of the measurement:

clear subchannel,

selection,

set mask register for interrupts,

set data way mask,

and, repeatedly for every new position:

allow reading of sensor position,

set ADC control register in mode 1, 2 or 3 (defining

the ADC channels to be interrogated before or after driving of
the field sensor),

set coordinate counter,

set s coordinate of field sensor,

set x coordinate of field sensor,

set z coordinate of field sensor,

set ϕ coordinate of field sensor,

half connection (waiting for new position beeing

reached and ADC beeing ready),

selection,

clear experimental interrupt,

start data input (of position and ADC data),

stop data input,

and at the end of a measurement:

disconnection

Each command is issued by initiating the control unit in the
manner mentioned above after the interrupt of the previous
command is received.

III.3. The representation of the measured results on magnetic tape and disk, error messages and transfer rates.

The measured results are recorded on magnetic tape in blocks of
34 words. The labels and end-of-file marks are compatible with
the requirements of the large IBM computer system of the Daten-
verarbeitungszentrale at the Kernforschungszentrum. The first
ten words are similar for all blocks and contain the program
and user identification, block number, date and time of recor-
ding.

The first two blocks contain the above described input parameters
and geometrical parameters to allow a comparison of the theoreti-
cal and real positions of the field sensor. The following blocks,

one for every measure point, contain the real position s, x, z, φ
of the field sensor and its ADC values (up to six).

The end of measurement is marked by a special block. (-1 in word
11).

The disk storage is limited for this experiment to 150 segments
of 33 1/3 words each and is used for intermediately storing
measurement values and absolut coded control and evaluation rou-
tines.

The data stored on disk are parameters such as measurement identi-
fication, number of measurement points and step widths and up
to 10 x 1050 measured values of the first two ADC channels.

All error messages are displayed on the CRT terminal and nor-
mally the field sensor is stopped, until restarted by the ex-
perimenter. The recognizable error situations are errorneous
or abnormal interrupts, data transfer troubles, overflow of
the backward counter, output to disk or magnetic tape, im-
possible and senseless input parameters.

The maximum transfer rate of the process channel for this experi-
mental system is about 3 k words/s, the time required for executing
one channel command ~500 μs. Therefore, the calculated time neces-
sary for command and data transfer for one measuring point is
~10 ms. Including conversion time of the ADC (20 ms), CPU time
(3 ms), output to tape (4 ms without starting time) and to disk
(20 ms), at least 50 ms are necessary.

The measured values, incl. the time used by the operating system,
are 150 ms/measuring point, if the field sensor is not moved.
This time is far below the time necessary for driving the field
sensor as shown in Fig. 5, taking a minimum of about 5s per mea-
suring point.

— 20 —

DRIVING TIME IN S- AND X-DIRECTION VERSUS STEP WIDTH D

ACCURACY: ± 40 µm (± 80 µm for s ≤ 5 cm), t = 150 msec for D = 0
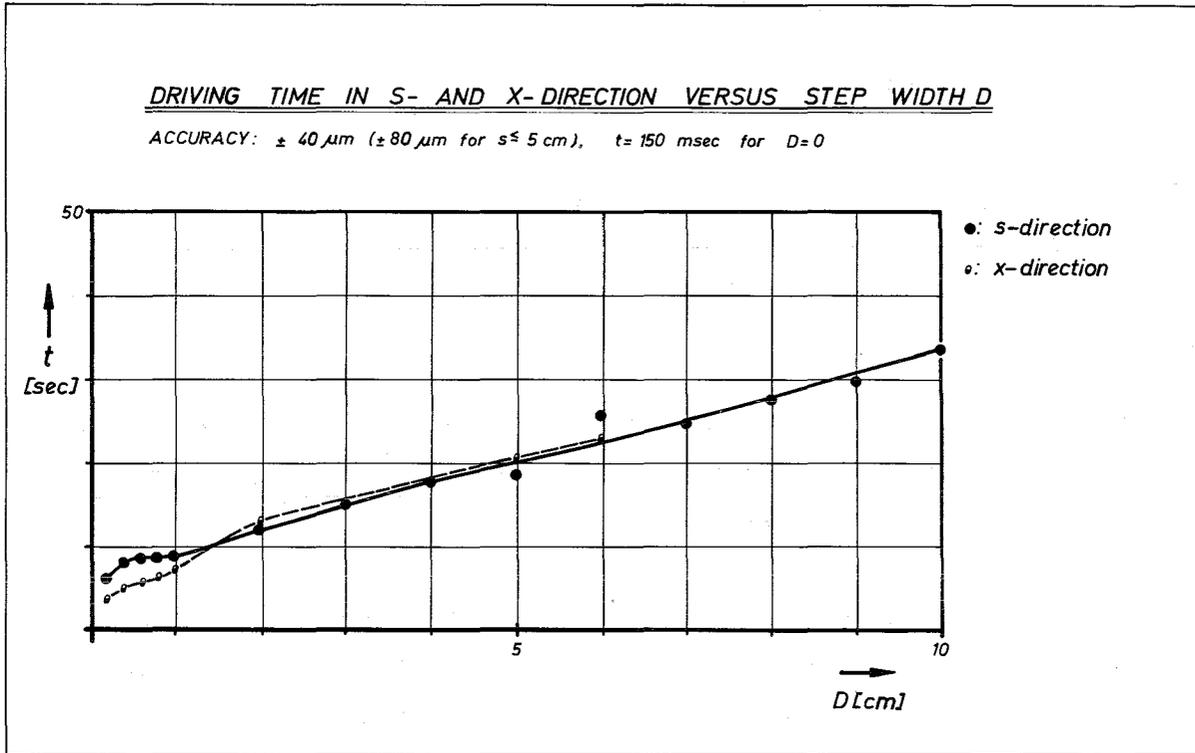
Fig. 5

III. 4. The gauge routine

When using the gauge routine, an arbitrary gauge function of the form

$$U_H = f \ (B)$$

is stored on magnetic tape for evaluating the measured data on a larger computer and on disk for evaluating them on-line using the display unit.

U_H is the Hall voltage generated by the magnetic field strength B or corresponds to a field dependend resistance value. Normally, the field sensor whose characteristic is to be measured is placed into the gauge magnet, and, together with inputting the B-value via the command unit, the corresponding U_H -value of the field sensor is automatically transferred into the computer.

Input parameters are

> program identification,
> gauge function identification,
> starting value B_o,
> increment ΔB.

Up to 200 measured values are possible. They are transferred
using the postprocessor similar to the flow chart in Fig.2.

IV. Interactive reduction and analysis of the measured data

All evaluation routines (9) for the analysis and interactive
reduction of measured data are written in the assembly language
of the TR-86-A computer, too. Because these programs are not
time-critical, they have a lower internal priority than the
control routines and are serviced by the central unit in a
time-scliced manner.

The routines placed at disposal compute and display the mea-
sured Hall voltages, the magnetic field values, the quotients
of the measured values of ADC channel 1 and 2, as well as their
differentiations and integrations as a function of the field
sensor position. The reasons for this are now discussed in detail.

There are two goals in the design of the evaluation routines which
should be fulfilled:

1. They should permit immediate surveillance of the measured data
to detect major faults of the measuring apparatus and its use,
and they should illustrate the results, especially during test
runs.

2. Almost during the measuring phase it should be possible to get
an idea about the scientific importance of the measured data.Both
as far as there are algorithmic methods for evaluating magnetic
field measurements being coded in the TAS assembly language in a
reasonable amount of time.

The interactive analysis of the measured data is supported by the
operating system by utilities for the display and command unit.

The command unit is constructed for parameter input and
initiating the routines, and allows input of decimal or
octal numbers of five digits (a more comfortable keyboard
is being tested). The operating system understands several
macro commands for manipulation, start, display and inter-
mediately storing parameter records constructed by use of
the command unit.

More important for the evaluation of measuring data are the
properties of the display unit which operates in four different
modes: The character, incremental, vector, and another special
mode. In the primarily used incremental mode, which is the fastest
one the contents of a contiguous number of storage cells is
displayed as a function of their relative address. Besides this,
the display unit has the properies of a multi-channel analyser
allowing by hardware different accuracy, isometric display and
superposition of spectra and parts of them.

With these auxiliary means and to reach a fast supervision of
the measurements it was at least necessary to calculate and
display the Hall voltages U_H and field strength values B. Then,
it was desired to display the quotients

$$U_H/I_{mag} \qquad and \qquad B/I_{mag}$$

I_{mag} = magnet current, to eliminate deviations of the magnetic
field distribution caused by instable power supplies. Slightly
generalised the functions

$$A_i^j = f(x_i), \quad i = 1, 2, \ldots 8,$$

are calculated.

A_i^j is one of the eight following modes,

x_i = i-th position of field sensor,

y_i^1 = i-th measuring value of ADC channel 1,

y_i^2 = i-th measuring value of ADC channel 2.

Normally, y_i^1 represents Hall voltages U_H and y_i^2 magnet currents. The eight possible modes are:

$$A_i^1 = y_i^1 \tag{1}$$

$$A_i^2 = B_i \tag{2}$$

$$A_i^3 = y_i^1 / y_i^2 \tag{3}$$

$$A_i^4 = B_i/y_i^2 \tag{4}$$

$$A_i^5 = (y_i^1 - y_{io}^1)/y_{io}^1 \tag{5}$$

$$A_i^6 = (B_i - B_{io})/B_{io} \tag{6}$$

$$A_i^7 = (y_i^1/y_i^2 - y_{io}^1/y_{io}^2)/(y_{io}^1/y_{io}^2) \tag{7}$$

$$A_i^8 = (B_i/y_i^2 - B_{io}/y_{io}^2)/(B_{io}/y_{io}^2). \tag{8}$$

As mentioned in chapter III, the measured values of the first two ADC channels are stored on disk during the control of the magnetic field sensor and the (B, U_H) value pairs, used to get e.g. $B_i = f(x_i)$, are stored on disk by the gauge routine.

For checks of the linearity of measured values, e.g. of quadrupol fields, current field characteristics, and end fields formed by a magnetic mirror plate, it is recommended to represent the deviation from a linear function. Normally a line of best fit

$$\tilde{y} = a_1 + b_1 \tilde{x},$$

defined by minimizing the sum Q of the squares of the deviations

$$Q = \sum_{i=1}^{N} (y_i - \tilde{y}_i)^2$$

is applied. But especially for some errorneous measured points "eye fit" is a better method. Therefore, the experimenter has to input the start and final values (y_1, x_1), (y_2, x_2) (or in another notation: (A_a^j, x_a), $A_e^j, x_e)$) defining the line of best fit himself.

Calculating the deviation ΔA_i^j is possible for all eight functions above using the formulas

$$\Delta A_i^j = A_i^j - \frac{A_a^j - A_e^j}{x_e - x_a} (x_i - x_a) - A_a^j, \quad j=1, 2,..8.$$

For determination of the gradients in quadropole fields and of the slope of linear functions, and for a better estimation of the shape of the end pole faces of the magnets the differentiation and for calculation of the effective length the integration of the functions above is required. Therefore for all functions A_i^j it is possible to display their differentiated, D_i^j, or integrated, I_i^j, curves:

$$D_i^j = \frac{d\, A_i^j}{dx_i} = f'\,(x_i) \quad \text{and}$$

$$I_i^j = \int_{-\infty}^{+\infty} A_i^j\, dx_i = \tilde{f}\,(x_i), \quad j = 1, 2,...8.$$

More precisely, the differences

$$D_i^j = \frac{A_{i+1}^j - A_i^j}{x_{i+1} - x_i}$$

and the summations

$$I_i^j = \sum_{i=1}^{N} A_i^j\, (x_{i+1} - x_i) \quad \text{are displayed.}$$

N = number of measurement points of one measurement.

All internal calculations are done, if necessary, with software floating point arithmetic, the mantissa being twenty two bits and the dual exponent twenty-four bits long. The rounding errors are considerably beyond the measured accuracy and all results are represented on the display unit modulo 2^{16}. Especially for scaling and output of negative results, a factor a and summand b are needed. They are contained in the following parameter record used to initiate evaluation routines:

1. routine number
2. mode number
3. summand b
4. factor a
5. number P of measurement parts
6. parameters for specifying the measurement records being used on the disk unit and their lengths N
7. gauge record number
8. constant (A_a^j, x_a^j), (A_e^j, x_e^j) for the line of best fit.

On account of the values a, b the displayed curves consist of P measured sections of the form

$$a \times f(x_i) + b, \quad i=1,\ldots.N,$$

with $f(x_i) = A_i^j, \Delta A_i^j, D_i^j$ oder I_i^j, respectively. All measurement parts may be compared by superposition. (For different types of functions $f(x_i)$ up to four of than may be overlayed by use of special commands, supported by the operating system.)

Applications of the evaluation routines above discussed are given in chapter VI; the possibilities of off-line calculation of the measured results is discussed in the next paragraph.

V. Routines for a detailed analysis on a larger computer

For another or a more sophisticated analysis of the measured results the use of higher programming languages, such as ALGOL, Fortran, or PL/1, is recommended. Therefore all measured values are stored by the control routines and the operating system on magnetic tape compatible with the requirements of the large IBM 360/65 computer system of the Datenverarbeitungszentrale at the KFZ. The routines desirable for another more complicated analysis are perhaps routines of different or new theoretical approaches, or for eliminating measuring errors, caused by the

mechanical and electrical parts of the magnetic field
arrangement. Since in these cases it is not really known
now, which routines become standard ones, it is assumed
to be task of the different users to write these programs
in a higher language for themselves. This is only backed
by a Fortran routine, which reads all measured values
and input parameters from the TR-86 magnetic tape and
writes them out on the standard high speed printer unit
sorted on date, measuring set, magnet type or number.

VI. Applications of the control and interactive evaluation routines to magnetic field measurements

In this part of the paper some examples of measurements will
be given using the preceding display and control routines.
Shown are measurements concerning field sensors, the stabili-
ty of power supplies, the elimination of current shifts, the
determination of current shifts, the determination of the
magnetic center and measurements of field distributions and
excitation curves.

VI.1. Measurements concerning field sensors and the stability of power supplies

The first problem of our field measurements is that the com-
monly used field sensor, a Hall probe, has a non linear cha-
racteristic. The measured voltage is not proportional to the
magnetic field strength for measurements which require accura-
cies in the range of 10^{-4} [10, 135 ff].Therefore a calibration
of the probe against an NMR or rotating coil Gaussmeter in a
homogeneous field is needed. The distance of the calibration
points must be chosen small enough to allow a linear inter-
polation without reducing the measuring accuracy. The cali-
brations are done with the gauge routine and the characteristics
of the Hall plate are analysed with the evaluation routines.
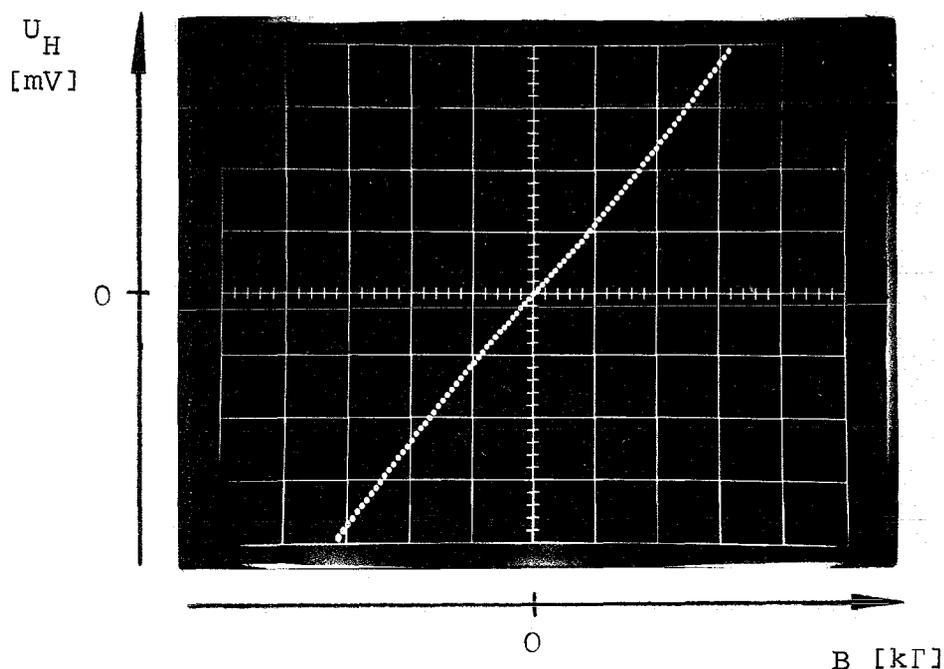
Figure 6   Hall plate characteristic (Type FC 32 Siemens)
between -22 kGauss and 22 kGauss

Vertical: 90 mV/Div., Horizontal: 6,7 K Γ /Div.
Point to point 500 Γ

Display of the results allows estimating the different Hall
plates. A typical Hall plate characteristic (Type FC 32 Siemens)
is presented in Figure 6, the output of evaluation routine A_2^1.
Further analysis of the characteristic is shown in figure 2.

The upper part of figure (7a), generated by the routines D_i^1
and A_i^3, gives a comparison between the differential and the
absolute sensitivity. Figure 2b is the result displaying ΔA_i^1
and presents the difference between an ideal straight line
through the first and last point of the characteristic and the
characteristic itself. These results are important for estimating
the different Hall plates, and also for finding an optimal
load resistance for the linearisation of the characteristic
[10, 135 ff], which is done in figure 8. The first curve of this
figure presents the differential sensitivity of a Hall plate

$$\frac{d\ U_H}{d\ B}, \frac{U_H}{B}$$

$[\mu V/\Gamma]$

1

2

a)

13,7

ΔU_H

[mV]

0

b)

O

B $[k\Gamma]$
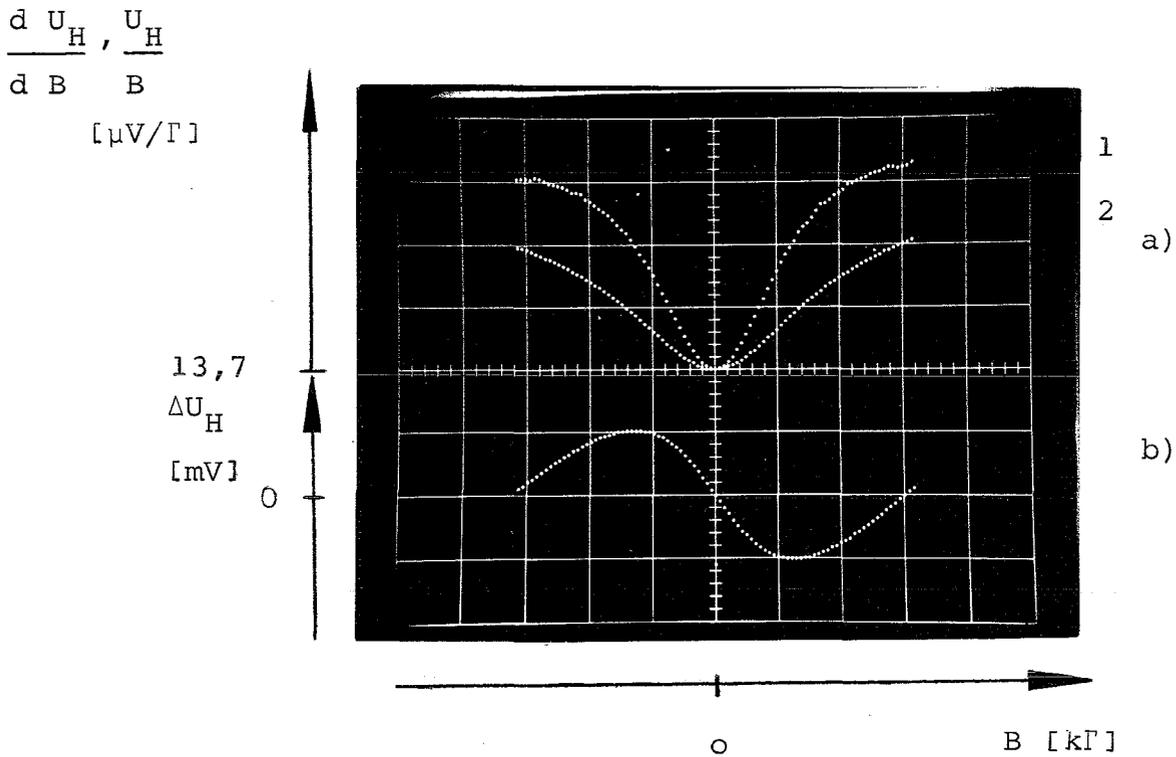
Figure 7   a.1) differential⎫ sensitivity of the Hall plate
            a.2) absolute   ⎭ (Type FC 32 Siemens)

            b.) The differences of the measured Hall voltages
                from a linear function through the first and
                last point of the measured characteristic

            Vertical: a.1), a.2) 1.1 μ V/Div or 8,3 %/Div
                      (refered to sensitivity 13,7 μV/Γ at B=0)

                      b.) 10,5 mV/Div (3%/Div refered to 22 KΓ)

            Horizontal: a.), b.) 7 kΓ /Div (500 Γ point to point)

(type FC 32 Siemens), and the third curve the differential
sensitivity of the same Hall plate coupled with a load resistor
for getting better linearity [10, 135 ff]. The differential
linearity of the Hall plate type SBV 579 (Siemens) is given
by the median curve. This Hall plate is a new type with its
plate material being formed like a cross. This shows, that the
nonlinearities of the conventional Hall plates are heavily
caused by the punctiform Hall voltage terminal.

$$\frac{d\ U_H}{d\ B}$$

$[\mu V/\Gamma]$

a)

b)

c)

O

B [kΓ]
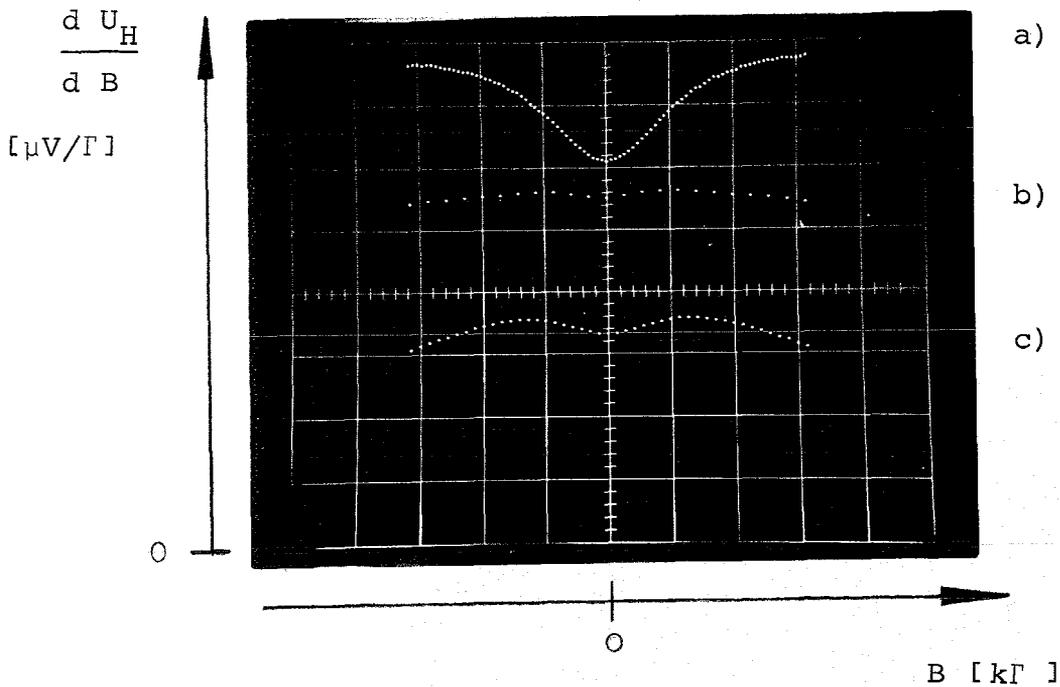
Figure 8:   a) FC 32 not loaded

b) SBV 579 not loaded

c) FC 32 with load resistor

Vertical: 2,25 µV/Γ , Horizontal: 7 kΓ /Div.

(500 Γ point to point)

Besides Hall probes, coils are used as magnetic field sensors.
For coils the integral of the induced voltage $\int_{t_0}^{t_1} U\,dt$ is proportio-
nal to the change ΔB of the magnetic field:

$$\int_{t_0}^{t_1} U\ dt = F \times \Delta B.$$

F is the winding area of the coil and is calculated with suffi-
cient accuracy from the following measuring results by use of
display routine I_i^1.

The coil is mounted in a homogeneous magnetic field, which changes
within t seconds for ΔB. A high impedance digital voltmeter mea-
sures directly the induced voltage of the coil n times within
time t. The voltage data are transfered to the computer by the
circular control routine , which allows as a special case to

measure the voltages arbitrary often without moving the
field sensor. The number of measurements per second is
adjusted by a delay circuit. The result of the measurements
is displayed in figure 9, integrated over the increasing
and decreasing parts by use of routine I_2^1 results in winding
area F with accuracy of some 10^{-3}.
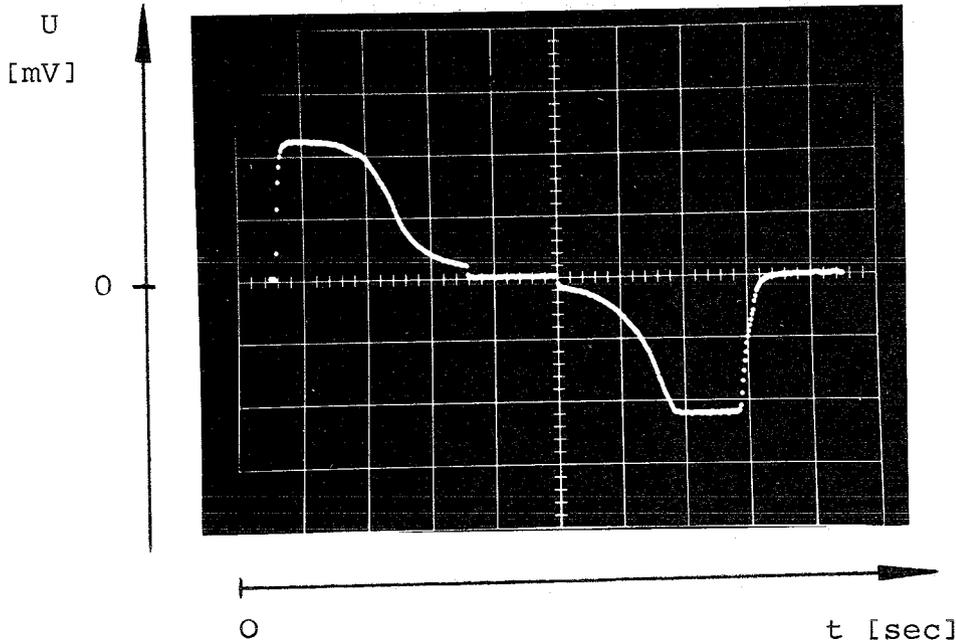
Figure 9: The measured induced voltage as a function
of time t for an increasing and decreasing
magnetic field
Vertical: 2,33 mV/Div   Horizontal: 20,4 sec/Div

Also, the stability of magnetic fields and the stability of
power supplies can be checked by means of the same special
case of the circular routine as shown in figure 10.

VI.2 Measurements of field distributions and determination of the sextupol coefficient in a dipol magnet

A typical example for using the meander routine is the measure-
ment of the field distribution in dipol magnets. They are used
for beam optics in particle accelerators and have to fulfill

$\frac{\Delta I}{I}$

[1]

a)

$\frac{\Delta I}{I}$

[1]

b)

t [sec]
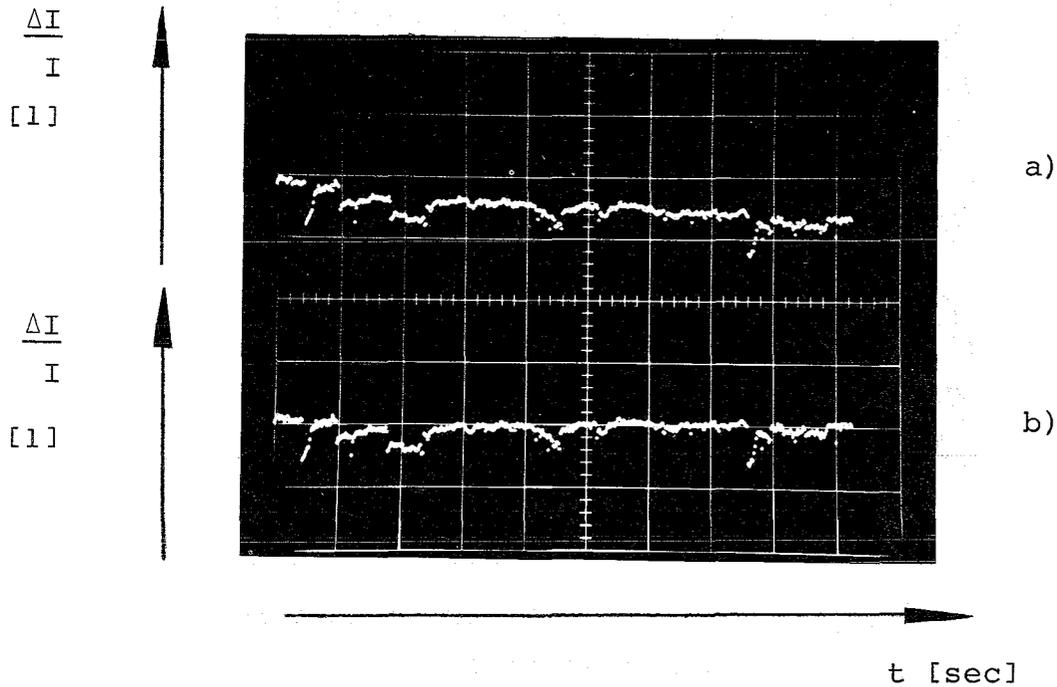
Figure 10   Stability of a thyristor controlled high current
(3000 Amp.) power supply over a period of 9 minutes.
The long time current drift in a) is in b) eliminated
by means of routine ΔA_i^1.

Vertical: 2×10^{-3} /Div. Horizontal: 60 sec/Div

several specifications. Especially the degree of homogenity,
the decrease of the magnetic field at the end of the magnet and
the integrated length of the magnetic field have to be proved.

To do this, a meandering plane is layed in the median plane of
the magnet with the longitudinal axis in parallel to the magnet
axis. The result of such a measurement is presented in the follo-
wing figures.

Figure 11   Display of the parameter input before the
            meander routine is started
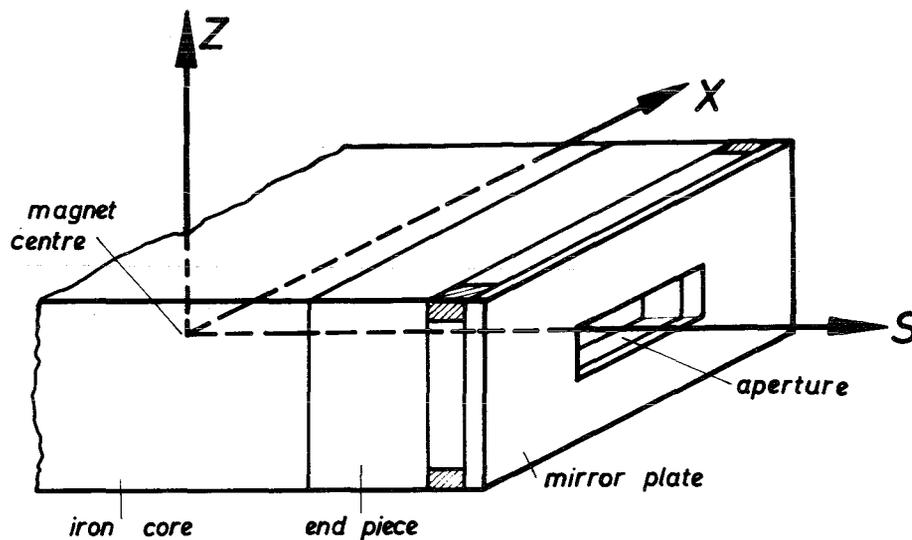
Figure 12   Bending magnet with coordinate system
            (field strength B is parallel to Z axes)
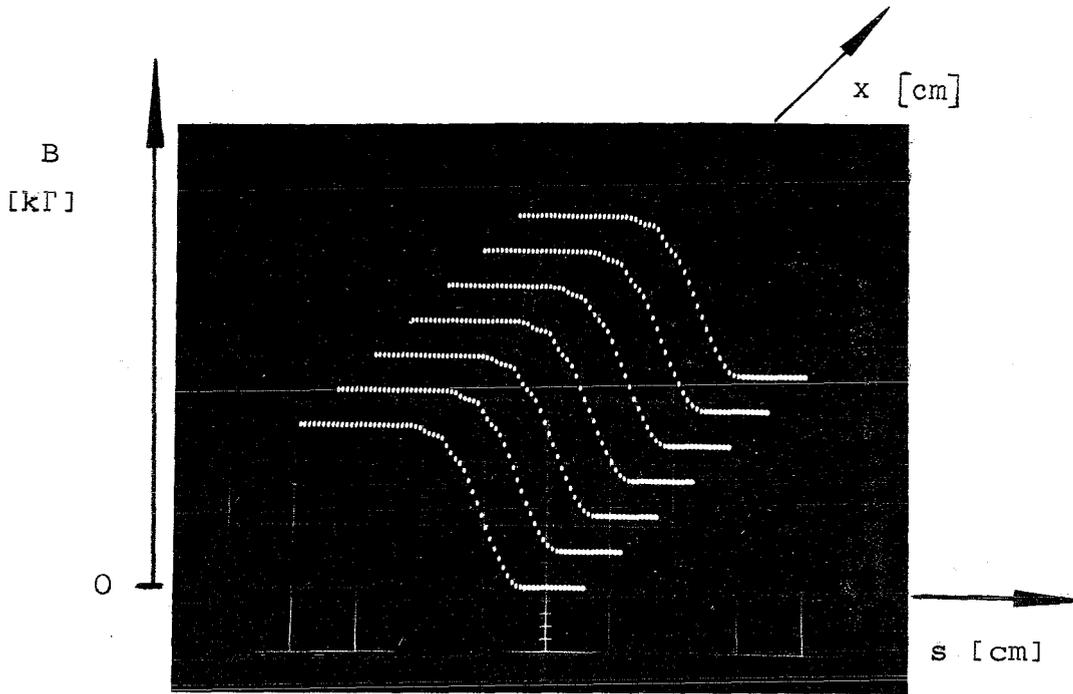
Figure 13   B = f (x, s), an isometrical representation of
the field B within a bending magnet, measured
with the meander routine and displayed by the
evaluation routine A_i^2.

Vertical: 18,5 kГ /Div   Horizontal: 13 cm/Div
Point to point distance in x-direction: 1 cm
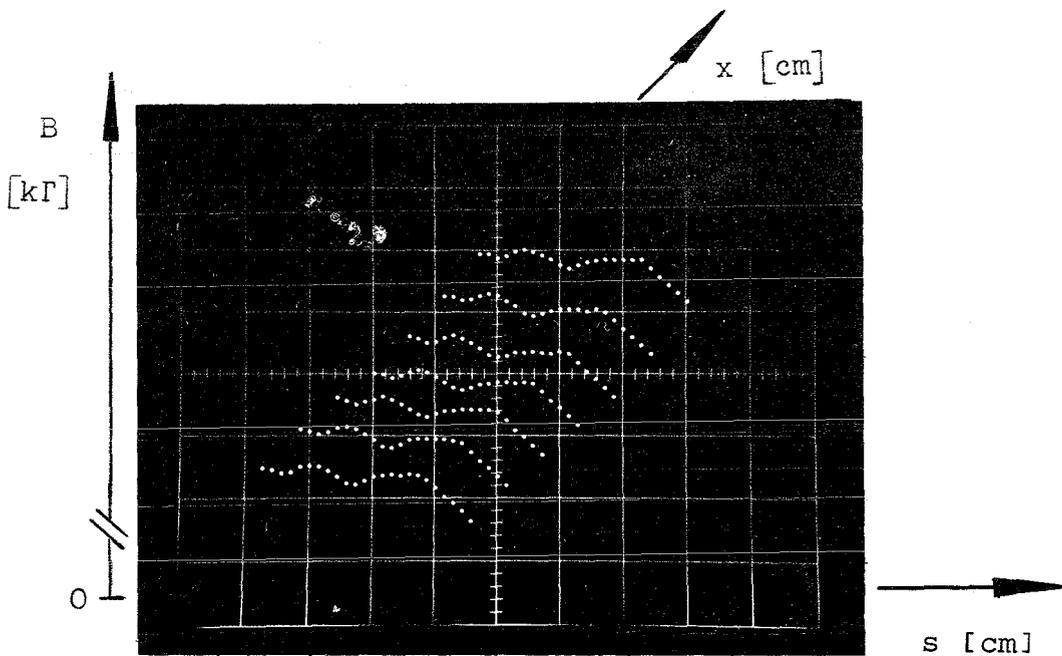
Figure 14   A cut out of figure 13. The plateaus of the
distribution above in larger scale.

Vertical: 65 Γ/Div   Horizontal: 13 cm/Div
Point to point distance in x-direction: 1cm

A special switching equipment of the display unit enables
the user to cut out interesting points along the magnet
axis like the beginning of the end pieces, the beginning
of the magnet mirror plate or the end of the iron core.
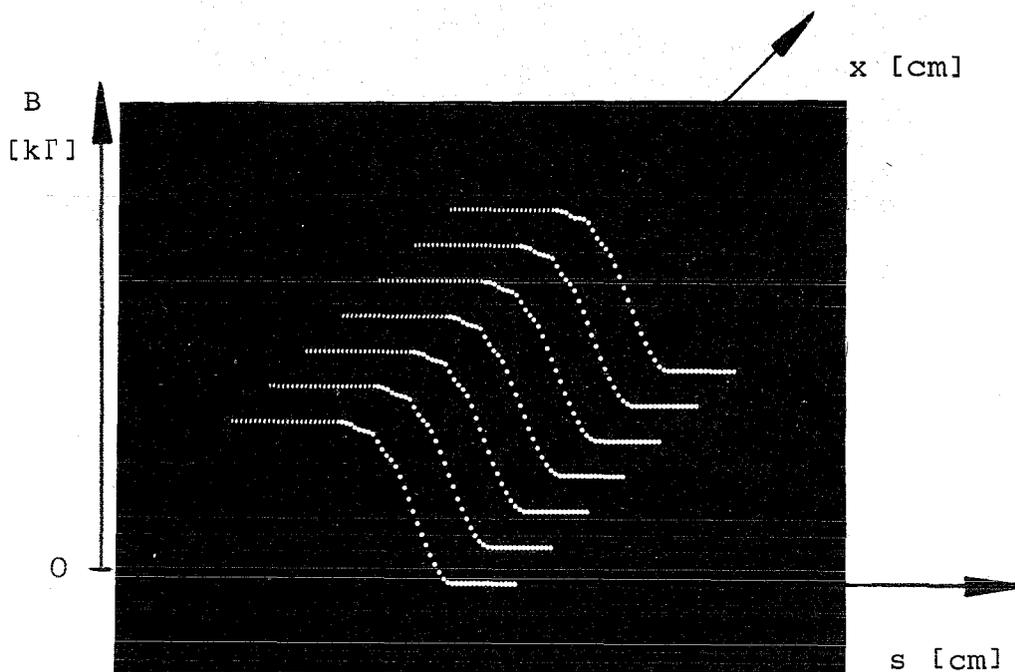
Figure 15   The beginning of the end pieces
            Vertical: 18,5 KΓ/Div; Horizontal: 13 cm/Div
            Point to point distance in x-direction: 1cm
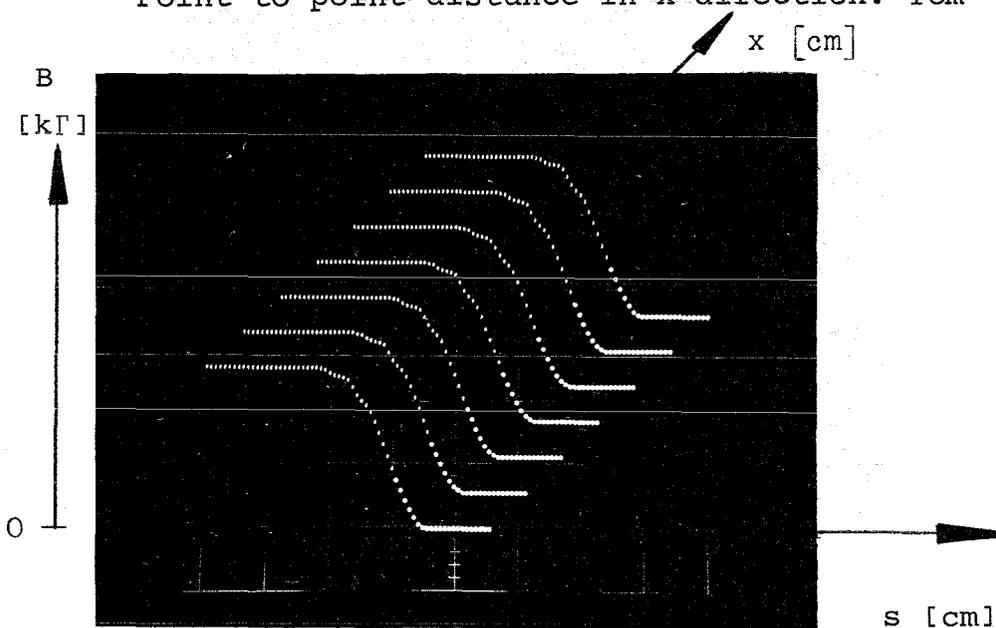
Figure 16   The end of the iron core
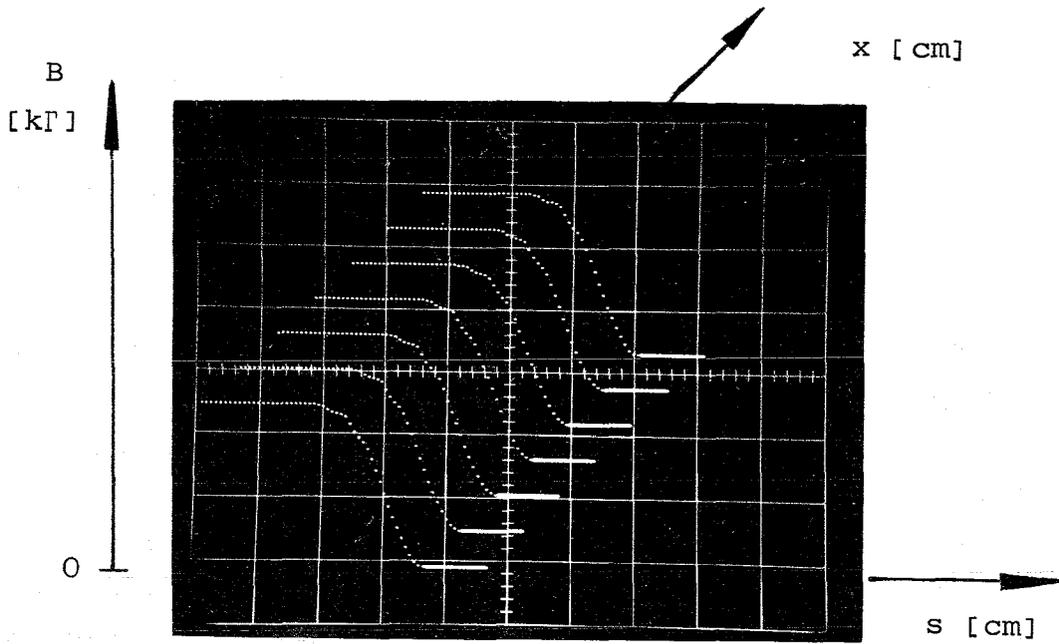
Figure 17   The beginning of the mirror plate

The finite integral $\int_0^{+\infty}$ Bds =L B_0 of each of the curves in figure 13 is represented by the seven point curve displayed in figure 18, B_0 = field strength in the middle of the mag-net, L = magnetic length. From this integration the real magnetic length can be computed which is important for all calculations of beam trajectories.
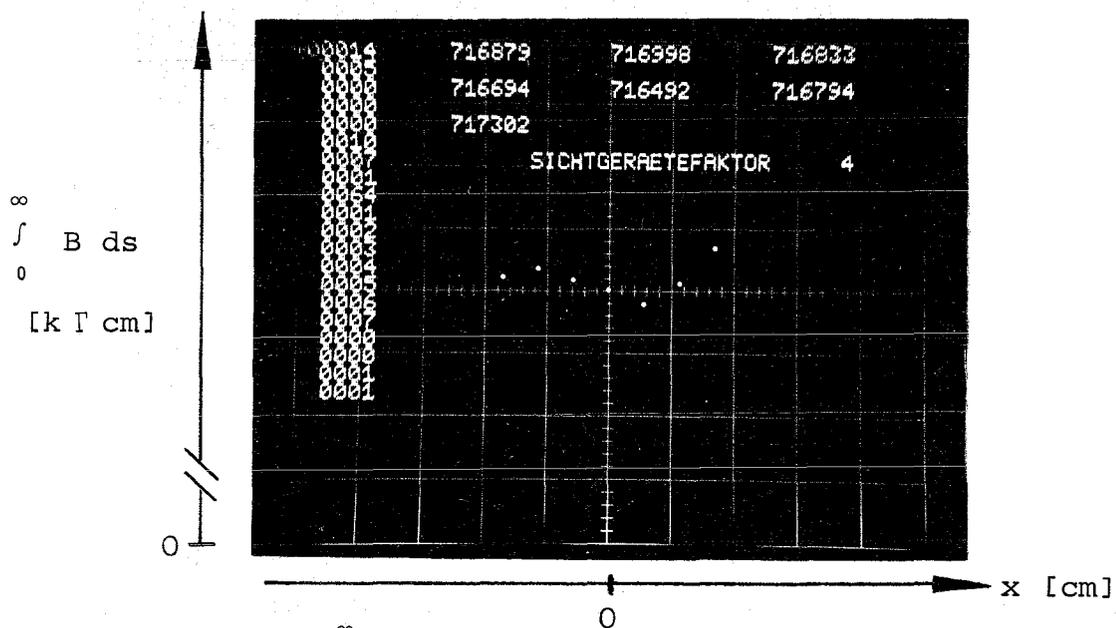
Figure 18 $\int_0^{\infty}$ Bds over the aperture of the magnet. On the left side the parameter record for the

evaluation routine I_i^2. (The numbers in the upper part are the numerical values of integrals $\int_0^\infty Bds$ incl. summand and factor for further calculations)

Vertical: O, 87kΓ cm/Div   Horizontal: 1,8 cm/Div or 1 cm point to point, magnet current 5000 Amp.

The scattering of the points in figure 19 is caused by insta-bilities of the magnet current during the run of the measure-ment. This drifting can be corrected by routine I_i^4. Every mea-sured field value is divided by the magnet current measured some parts of seconds later. This eliminates the error, be-cause the magnetic field is proportional to its excitation current. The corrected measurements are presented in figure 19.

$$\frac{\Delta \int_0^\infty B \, ds}{\left(\int_0^\infty B \, ds \right)_{x=0}}$$

[1]
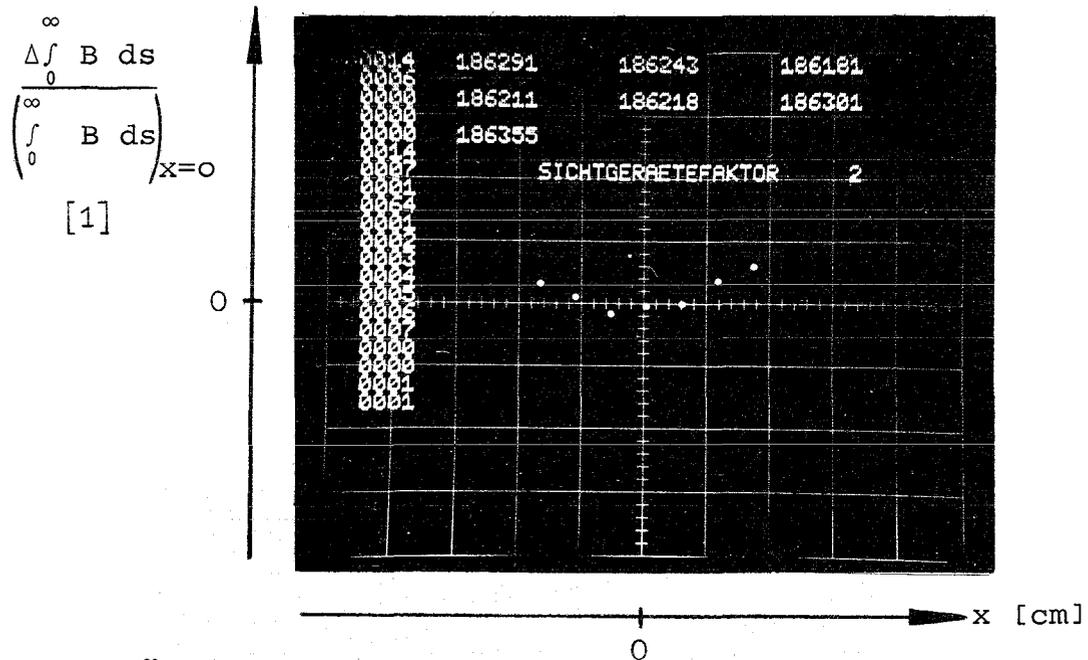
Figure 19 $\int_0^\infty$ Bds after elimination of the magnet current drifting

Vertical:1,3 %o/Div   Horizontal: 1,8 cm/Div or point to point distance 1 cm.

For a study of the two dimensional field in the middle of the magnet the field distribution over the aperture at different excitation currents is shown (Fig. 20). These measurements are important, because they allow a comparison between

calculated and measured values. As before, those measured
data in figure 20 being errorneous on account of drifting cur-
rents are corrected in figure 21 by calculation of the
quotient B/I.
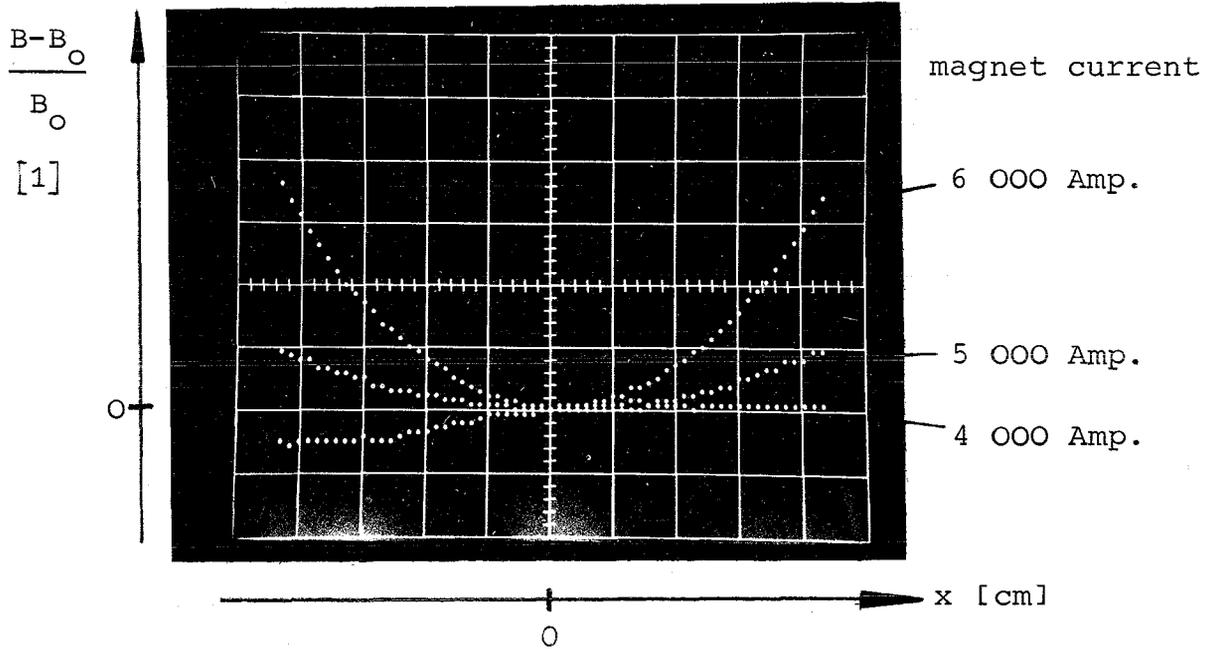
Figure 20   The field distribution (B-Bo)/Bo over the magnet
             aperture with Bo equal to the field strength at
             the magnet center. The nonlinearity of the lower
             curve is caused by a drifting magnet current.

             Vertical: 6×10^{-4}/Div   Horizontal: 0,7cm/Div
                                                  or distance point to
                                                  point 1 mm

For a dipol magnet the field variation over the aperture is
given by

$$B = Bo + \frac{1}{2} ax^2 + \ldots\ldots$$

Bo: field strength in the magnet center, a: sextupol coefficient,
x: coordinate over the aperture [6, 81 ff]. The quadratic law
can be proved by the derivation of the curves in figure 20 and
21 using the evaluation routine D_i^8. The result is shown in fi-
gure 22.

$$\frac{(B/I)-(B_o/I_o)}{(B_o/I_o)}$$

$$= \delta (B/I)$$

[1]

magnet current

— 6 000 Amp.

— 5 000 Amp.

— 4 000 Amp.

0

x [cm]
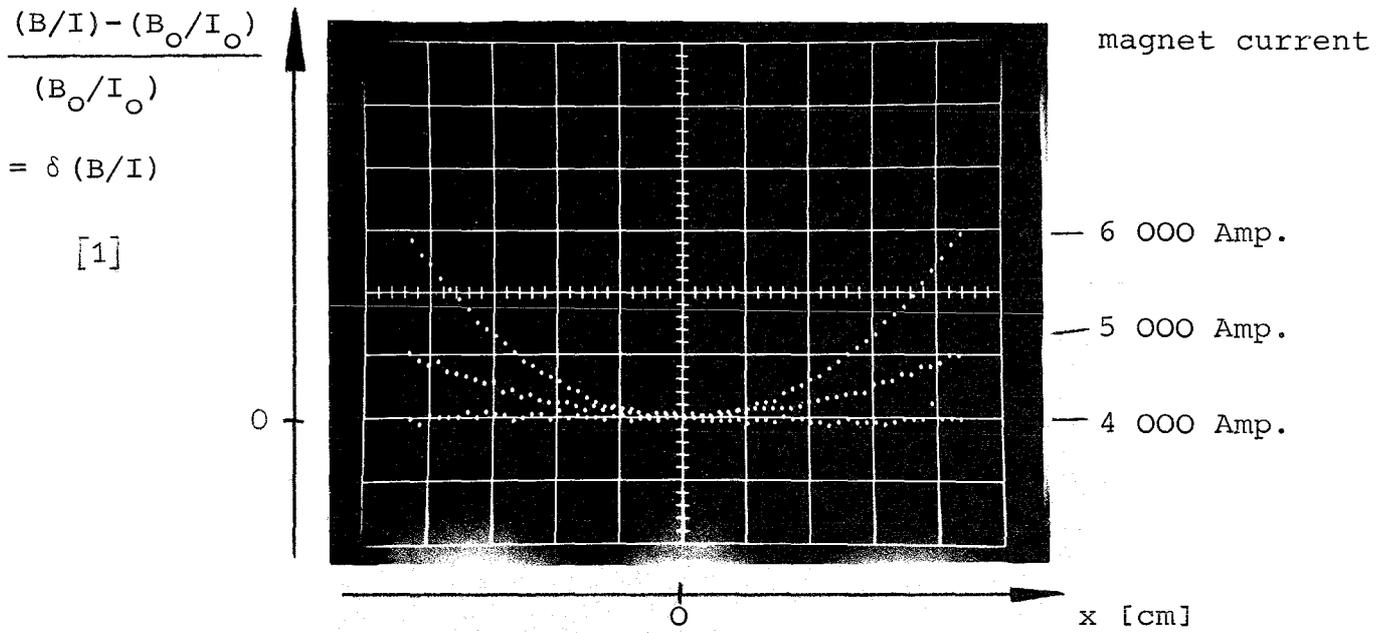
Figure 21   The display of the curves in figure 20 by the evaluation routine A_i^4 for elimination of the current drift.

Vertical: 8×10^{-4}/Div   Horizontal: 0,7 cm/Div
or distance point to point
1 mm

$$\frac{d(\delta (B/I))}{dx}$$

[1/cm]

magnet current

— 6 000 Amp.

— 5 000 Amp.

— 4 000 Amp.

0

x [cm]
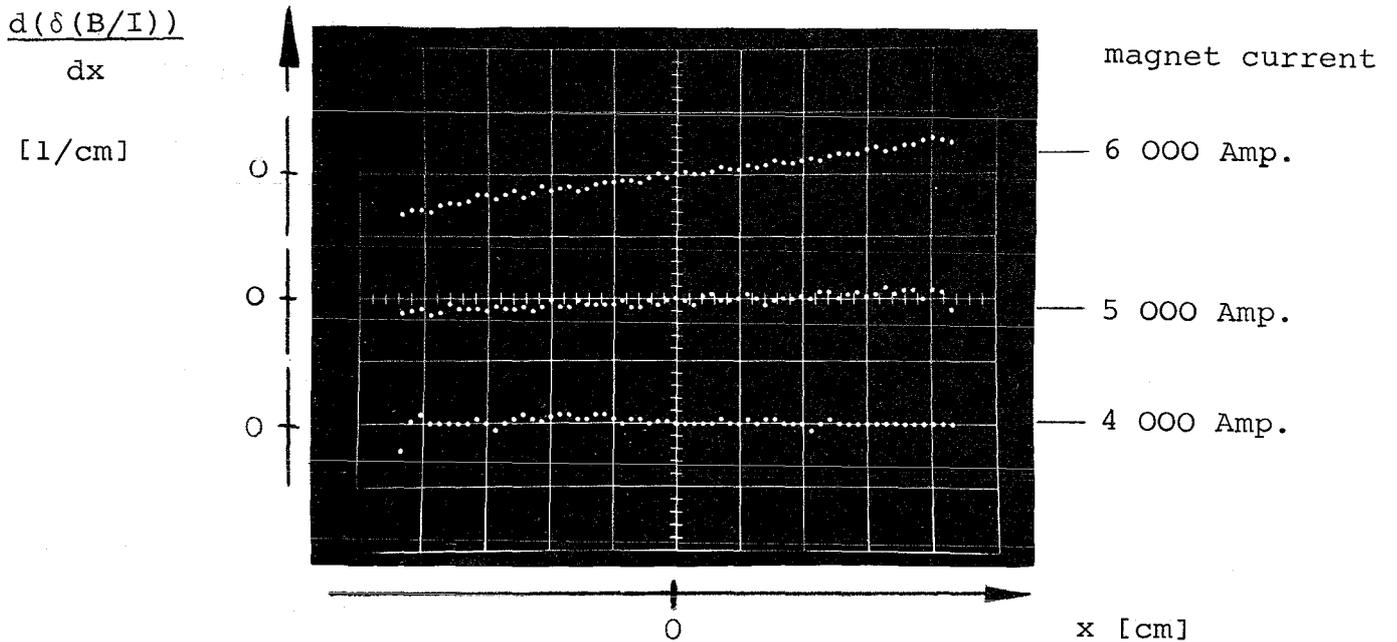
Figure 22   The check of the quadratic law. The derivation of the curves from figure 21
Vertical: $2,3 \times 10^{-4}$/cm /Div   Horizontal: 0,7 cm/Div

From the slope the coefficient "a" can be calculated. This
coefficient depends on the excitation current and must not
exceed a certain value to avoid serious problems in beam optics
[11].

VI.3. Excitation curves of magnets and the determination of the magnetic center

Often in the daily laboratory work functions of one variable
are varying at equidistant steps. An example is the excitation
curve of a magnet. In Figure 23 such a function is measured
for a quadrupol magnet. Because the field sensor is positioned
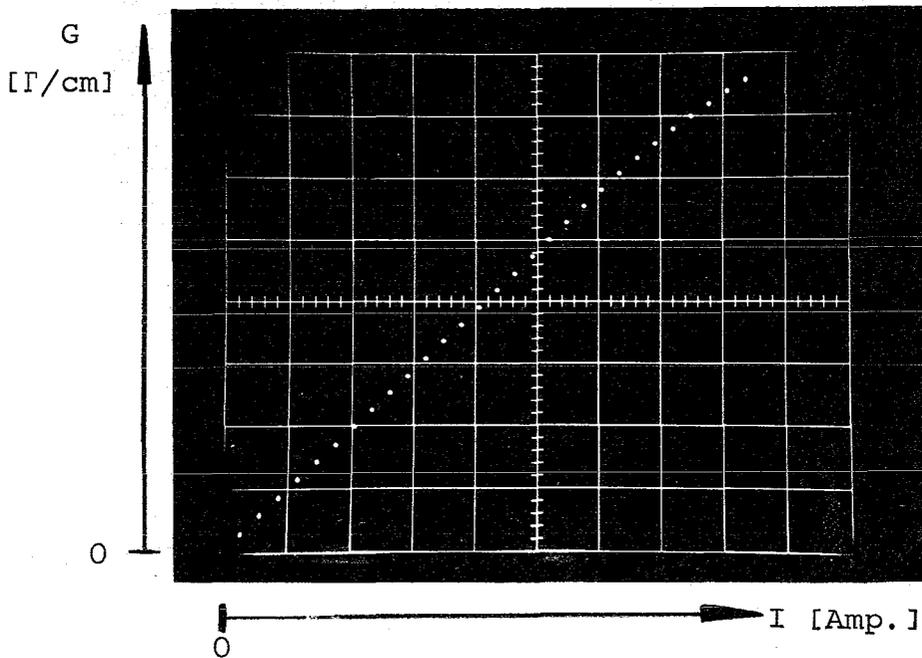
Figure 23   The Gradient G of a quadrupol magnet measured as
a function of the excitation current I

Vertical: 447 Γ /cm/Div   Horizontal: 345 A/Div
or distance point to point
100 A

in the medium plane of the magnet 1 cm apart from the
magnet axis, the gradient G of the magnet as a function
of the excitation current I is determined. The extent of
saturation of the iron yoke at high excitation currents
is illustrated by display of the deviation from a straight
line using evaluation routine ΔA_i^2 (Figure 24).
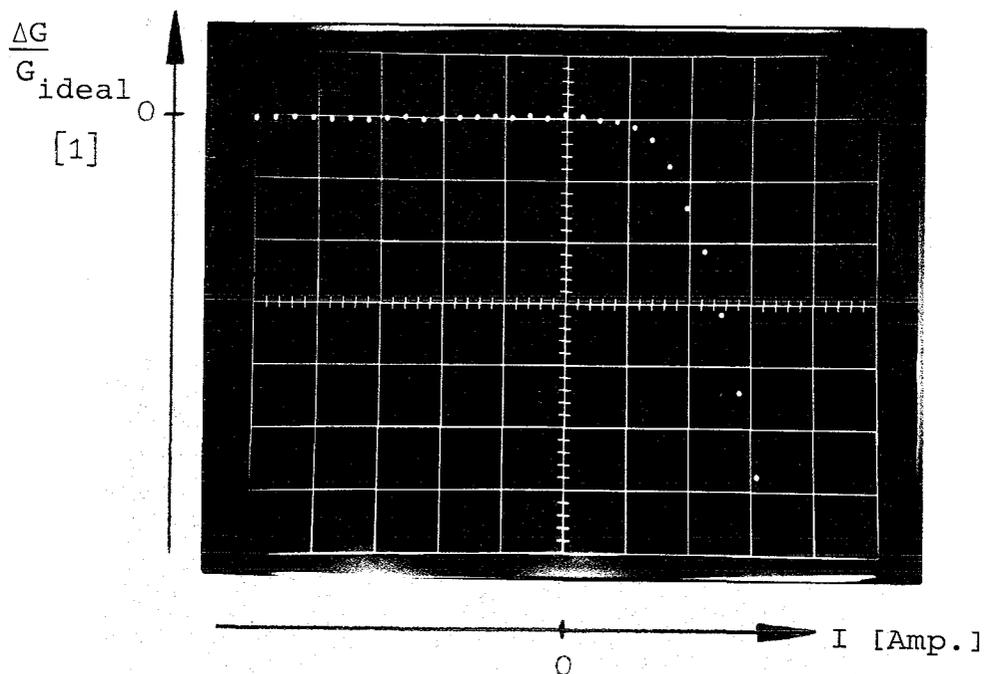
Figure 24   The difference between the ideal and a measured
             excitation curve.

             Vertical: 1%/Div.   Horizontal: 350 Amp/Div
                                              or 100 Amp. point to point

             G_{ideal}: 3,61 kΓ/cm at 2 900 Amp.

A method for finding the magnetic center of a quadrupol lens
is to rotate the Hall plate around its longitudinal axes. A
rotation at an arbitrary point in the aperture of the quadru-
pole gives a sinusoidal wave of the field strength. When the
Hall plate is in the center of the quadrupol the field is zero.
Figure 25 shows these measurements,when the Hall plate is dri-
ven along the magnet axis. The distance from the magnetic cen-
ter can be calculated by the gradient and by the amplitude of
the sinusoidal wave. The accuracy of this method is a about
$\pm$ 50 μm, which is sufficient for mounting a magnet in a beam
transfer system.
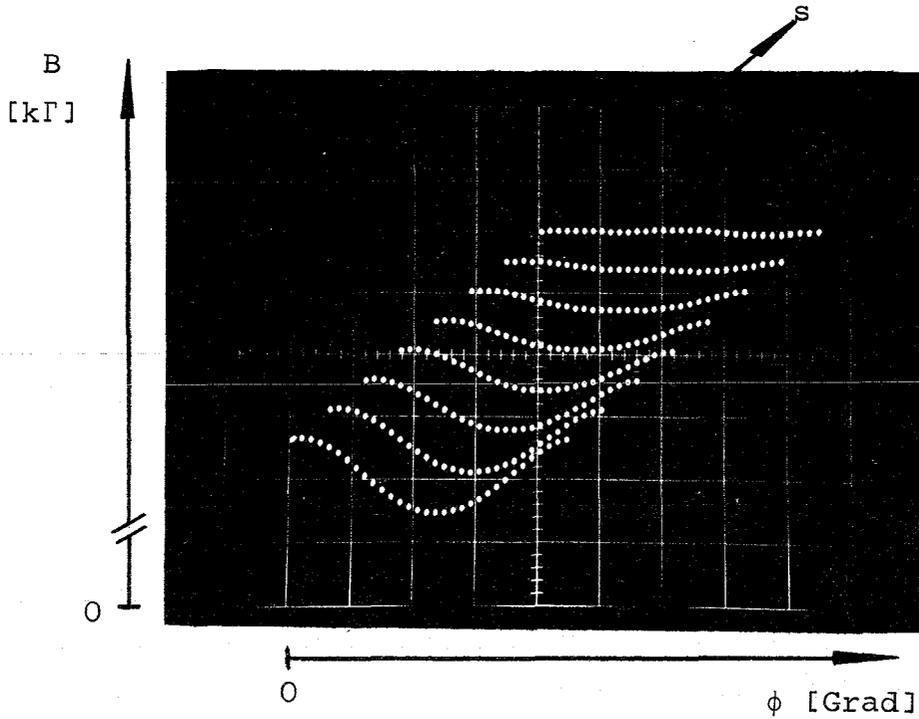
Figure 25 The field strength as a function of the rotation
angle ϕ at different places of the axis s.

Vertical: 1.7 kΓ/Div   Horizontal: 77°/Div
Distance curve to curve in S-direction: 5 cm

VI. 4. Desirable future developments

After the magnetic field measuring arrangement is being used
since two years, only few extensions of the system are desirab-
le. These are a more comfortable parameter input, display of
the cursor register in decimal digits (in preparation) and more
accessible disk segments for measured data. Also, an interac-
tive Fourier analysis of the measured magnetic fields should be
provided for calculating the multipol field components.

As shown in examples above, though not originally planned,the
measuring devices are used for daily laboratory work and not
only for magnetic field measurements. To extend this application
the data of all six ADC channels should be stored on disk with
simple arithmetic operations between them being possible.

VII. Programming efforts

The automatic magnetic field measuring arrangement was developed by several groups - the hardware groups for the special electronic equipment and for the control devices of the system, the group for planning and organization of the whole experimental system and the software group, whose efforts were described in this article (and besides this, the Calas hardware and software group).

The amount of software, all written in assembler language, is about 13.5 k words; the control routines need 9 k, the interactive analysis programs 4.5 k words core store, but the really different code is about 3.5 k and 1.5 k words, respectivly.

For the design, test and documentation of the control software during 2 years about 50 % of one man's working time was needed, including the time necessary for making o.s. thoroughly acquainted with the Calas hardware and software system. 2/3 of the time was spent for testing - 1/3 for searching own programming errors, 1/3 on account of those within the hardware and software of the Calas system, which was in its proving phase.

The coding, test and documentation of the interactive analysis routines occupied a programmer about one year. Assistance in designing and especially testing the programming system by the planning and organization group took 1/3 man years. Thus, we obtain a total of 2 1/3 man years, two-thirds of it used for testing - a not unknown situation in real time systems programming.

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Acknowledgement

References

(1) J. Brandes, G. Friesinger, A. Ulbricht,
     An arrangement for automatic magnetic field measurements,
     KFK-Bericht 1220 (May 1970).

(2) G. Krüger,
     Ein Betriebssystem für den Vielfachzugriff in der Labor-
     automatisierung,
     KFK-Bericht 929 (Jan. 1969)

(3) G. Gagel, H. Herbstreith, K. Rietzschel,
     Automatische Führung eines Kernresonanzspektrometers
     durch einen Prozeßrechner,
     Atompraxis 15 (1969), Direktinformationen 1/69, Informatik

(4) G. Gagel, G. Hepke, H. Herbstreith, J. Nehmer,
     Calas 68 - ein computergestütztes Vielfachzugriffssystem
     zur Laborautomatisierung,
     Externer Bericht 19/69 - 1 (Nov. 1970)

(5) R. Mache, K. Rietzschel, G. Gagel,
     On-line Datenerfassung und Datenreduktion für eine Kopp-
     lung Gaschromatograph - Massenspektrometer mit Calas.
     KFK-Bericht 1396 (Juli 1971)

(6) K.G. Steffen, High energy beam optics,
     Interscience Publishers, New York, London, Sidney (1965),
     pp 56

(7) F. Arendt, H. Brechna, J. Erb, N. Fessler, G. Hartwig,
     W. Heinz, K.P. Jüngst, W. Maurer, G. Merle, G. Ries,
     W. Schauer, J. von Schaewen, C. Schmidt, P. Turowski,
     A. Ulbricht and G. Krafft,
     Developments in Cyrogenic and Superconducting Magnets,
     KFK-Bericht 1396 (November 1970)

(8)   J. Brandes, A. Ulbricht,
      Beschreibungen der Steuerprogramme, Dez. 1970, April 1971
      (unpublished)

(9)   W. Lembach,
      Beschreibungen der Auswerteprogramme,
      März 1971 (unpublished)

(10) F. Kurth, H.J. Lippmann,
      Hallgeneratoren
      Springer-Verlag, Berlin, Heidelberg, New York (1968)

(11) J. Erb, G. Merle
      Some Results of Computations Concerning the Influence
      of Bending Field Errors on Resonant Extraction
      External Report 3/69-26 (March 1970)