# REFERENCING THE MAGNETIC AXIS FOR HERA'S SUPERCONDUCTING MAGNETS

F. LÖFFLER

*Deutsches Elektronen Synchrotron*

*Hamburg, Germany*

Abstract

For the alignment of the superconducting magnets of HERA the survey datums have to be referenced to the magnetic axis and the direction of the magnetic field. The necessary measurements are described in the following.

## 1 Definition of the survey datums

For the alignment of the superconducting magnets of HER-1/1/ each magnet can be equipped with two survey platforms. They are attached to the side of the magnets (Fig. 1). Reference points for these platforms are screws. which are prealigned by the manufacturer (Fig.2). Three radial screws define a plane, which gives the position of the surveypoint with respect to the geometrical axis and the roll and yaw of the survey platform. Two vertical screws, on which the platform rests upon? provide the fixed-points for the height and the pitch of the survey platform. The azimuthal orientation is achieved by two horizontal screws, which locate a finger of the platform.

## 2 Optical control measurements

The position and the inclination of the survey platforms with respect to the geometrical axis and the reference planes of the magnet have to be controlled after delivery to DESY. This is performed on "Optical Control Stands", which consist of two steel supports with horizontal machined surfaces at both ends of a magnet,. Each of them carries two conical baseplates. on top of which Taylor-Hobson alignment telescopes or spherical targets can be mounted. The four baseplates of a control stand form a rectangle. The distances of the two plates of each support are set to the nominal value of the distance between the geometrical axis of the superconducting magnet and a spherical Taylor-Hobson target on top of its survey platforms. The connecting lines between corresponding base plates at each end of the magnet are therefore parallel and within the same horizontal plane. These reference lines are represented by the centers of the mounting sphere of an aligment telescope at one end and respectively a spherical target at the other. Fig. 3 shows the centering fixtures for the telescopes at one end of a magnet, Fig. 4 the corresponding base plates at. the other end of the magnet with a spherical target.

The magnet. between the two supports has to be aligned with respect, to the first reference line. First the roll of the magnet, is eliminated by reading coincidence levels on top of the two survey platforms while using jacks for the correction. If the readings of the levels show differences within some tenths of a millirad the average value is chosen. Then the magnet is moved by jacks and guide rods in vertical and radial position until the spherical targets on top of the two survey platforms are on the line of sight of the telescope. Remaining offsets are measured with the optical micrometers of the alignment telescope.

After this alignment the second reference line can be used for controlling the geometrical axis of the magnet. For the superconducting quadrupoles (Fig. 5) it has the nominal distance of 635.00 mm from the first reference axis and the survey platforms respectively. By inserting a special self centering target in the beampipe of the magnet its vertical and radial deviations with respect to the reference axis can be measured with the micrometer of the alignment telescope. With the offsets $\Delta r_2$ and $\Delta h_2$ for the beampipe and respectively $\Delta r_1$ and $\Delta h_1$ for the targets on the survey platforms their distance and height with respect to the beampipe axis can be calculated

$$\begin{aligned} dr &= 635.00 + \Delta r_2 - \Delta r_1 \\ dh &= \Delta h_1 - \Delta h_2 \end{aligned}$$

In addition to the control measurements for the position of the spherical targets on top of the survey platforms the roll of the magnet with respect to the reference bars of the survey platforms has to be determined. The reference plane of the quadrupole is marked by the manufacturer by scribed lines on the endflanges. They should be horizontal after the described alignment of the magnet. Deviations can be easily measured with a precision leveling instrument.

For the superconducting dipoles the second reference line can be set at two additional distances from the first reference axis and the survey platforms respectively. The first position has the nominal distance of 630.83 mm, the second is 640.35 mm (Fig. 6). The second value defines the vertex “b” of the magnet axis, the first a point “a”, which lies 3343 mm left of the vertex. A third point a’ lies symmetrically 3343 mm right of the vertex. Its distance from the first reference axis is 630.74 mm The difference between the two values for “a” and a’ is caused by the asymmetric position of the survey platforms: One is fixed 2507.5 mm left of the vertex. the other 2392.5 mm right of the vertex, while their nominal distance from the magnet is still 635.00 mm. The points a, a’ and b once more are represented by self centering targets. which are inserted in the beampipe of the magnet. Their radial and vertical deviations are measured with the micrometer of the alignment telescope: for a and a’ from the first position of the reference axis, for b from the second position. With this data and the measured offsets of the targets on the survey platforms their actual distance from the magnet axis can be calculated as well as their height.

The roll of the magnet with respect to the survey platforms in this case is measured by a frame level, referenced to two pins at the magnet end. Like the scribed lines of the quadrupole these pins define the average reference plane of the magnet.

If the deviations from the nominal radial, vertical and inclination values are within some tenths of a millimeter and respectively of a millirad and if other control data. such as flange positions and so on, are within the demanded tolerances the magnet is accepted for further use at DESY. If they are too large, the magnet is send back to the factory for improvement. If possible the necessary corrections are done by DESY itself, while the magnet is still on the “Optical Control Stand”.

## 3 Magnetic measurements[1]

After the optical measurements the magnets are mounted on “Magnetic Measuring Stands”. These stands are very similar to the “Optical Stands”. On each end of the magnet a steel support with a horizontal machined surface is mounted. In this case they are equipped with only one Taylor-Hobson baseplate (Fig. 7). The baseplates on the two supports define the reference axis for the alignment of the magnet: one carries the alignment telescope, he other the spherical target. The aligning procedure for the

[1] The devices described in this paragraph have been developed by the group PMES at DESY which is in charge of all cold magnet. tests

quadrupoles and the dipoles is the same as described for the "Optical Control Stands". Remaining offsets of the reference spheres on top of the survey platforms of the magnets are measured with the micrometer of the aligment telescope. Additionally the actual inclinations $\beta$ of the two reference bars on top of the survey platforms are measured.

After the alignment. the magnet is connected to the He-system and cooled down. Then the magnetic field measurements can be performed. For the quadrupoles the magnetic axis and the direction of the magnetic field have to be determined.

Therefore a Stretched Wire System is used. A single wire is supported by precise quartz cylinders at both ends of the magnet. They are attached to high precision carriages? which are mounted on top of the two steel supports and allow a movement in radial and vertical direction with a reading of better than 0.01 mm. The radial direction is perpendicular to the reference axis. the horizontal and vertical movement guaranteed by a precise adjustment of the carriages.

Fig. 8 shows the principle of the Stretched Wire System. The position of the wire is defined by a groove on the quartz cylinder. By changing the position of the quartz cylinders on both sides simultaneously one can shift the wire parallel from A to B. By this movement voltage is induced in the wire by the magnetic field. Since the wire forms a closed circuit the

$$\int_A^B U_{ind}\,dt = \Delta\,\Phi$$

can be measured via an amplifier ($\Delta\,\Phi$ = change of the magnetic flux).

By moving the wire up and down one can find voltages $U_1$ and $U_2$, where $U_1 = -U_2$. The vertical position of the magnetic axis then is exactly in the middle between the two corresponding height, readings. The radial position can be determined similarly by horizontal movements of the wire. Here the two positions have to be found, where $U_3 = -U_4$.

The vertical measurements are made in several positions of the horizontal carriage and vice versa for the horizontal measurements. Thus the magnetic axis and the inclination $\alpha$ of the magnetic field are defined with respect to the carriage readings.

The connection between the carriage-readings and the reference axis is achieved by optical measurements. The distance between the wire and the reference axis can be directly measured with a precision rule, which is held against the end of the quartz cylinder. It can be read from the alignment telescope at the other end of the magnet (Fig. 7). Since the distance of the wire from the end of the cylinder is well known from manufacturing, the distance from the reference axis then is determined also.

The height of the stretched wire can be measured on both sides with a precise leveling instrument. with respect to the adjacent reference sphere.

Both measurements are made in a position of the wire near the nominal magnet axis. The corresponding readings of the carriages give the reference for any position of the wire.

These reference measurements are made regularly. The results can be reproduced within 0.03 mm.

The overall accuracy of the determination of the magnetic axis with respect to the reference axis is about. 0.1 mm, that of the field direction 0.2 mrad. To refer this data to the survey platforms of the magnet, it is very important, that the remaining offsets of their spheres are measured carefully. Then the radial distance and the height of the magnetic axis with respect to the magnet spheres can be determined. The obtained values have to be transformed into the coordinate system of the magnet,. The origin of this system is given by the magnetic axis, one coordinate axis by the direction of the magnetic field.

This data has to be used for the alignment of the magnet in the tunnel. Additionally the measured field direction a and the actual inclinations $\beta$ of the survey platforms during the field measurements have to be taken into account (Fig. 7).

Fig.9 shows the precision carriages for the Stretched Wire System and the Taylor-Hobson target at one end of the magnet.

The magnetic measurements for the dipoles have to check mainly the field integral and the field direction. The first point is solved by a NMR-probe (Nuclear Magnetic Resonance). The field direction, which is much more important for us. can be measured by a combination of two hallprobes with a tilt sensor. The hallprobes are mounted perpendicular to each other and rigidly fixed to the tilt. sensor. The whole assembly is supported like a pendulum, so that one hallprobe is almost vertical, the other almost horizontal. The signal of the vertical hallprobe is zero as long as the field is parallel to it. The other then gives maximum signal. If the field has an angle $\gamma$ with respect to the hallprobe the induced voltage

$$U_H \sim B \sin\gamma$$

is used to derive the value of $\gamma$. With the additional reading from the tilt sensor the field direction can be referenced to gravity.

Fig. 10 shows the measuring device, which has been developed by the DESY-magnet-devision. It is mounted in a cylindrical carriage, which centers itself by special wheels in the vacuumpipe of the magnet. It is moved from one end of the magnet to the other by a synchronous toothed belt,. Measurements are made in well defined positions along the magnet. axis, which are established by a step up motor and angle decoders at each end of the magnet (Fig. 11).

The results of the inclination measurements for one magnet are shown in Fig. 12. Looking from left to right the field is inclined clockwise. Obviously there is a twist to the other side in the last part of the magnet.

The magnetic measurements were repeated several times. The reproducibility was within some hundreds of a mrad. The average value for the inclination of the whole magnet, was $< \varphi > = -0.64$mrad. The mechanical adjustment of the magnet by reading the level on top of the survey platforms was set to -1.5mrad. So the difference between mechanical and magnetic measurement was -0.86 mrad.

As a control for the accuracy of the measurements the magnet was rotated by +3.04 mrad. The magnetic measurements then gave the same magnet twist and an average value for the inclination of $< \varphi > = +2.43$ mrad. That. means that $\Delta\varphi_{measured} = +3.07$mrad. The mechanical rotation of the magnet could be reproduced exactly by the magnetic measurements. That. confirms, that the actual inclinations $\beta$ of the reference bars on top of the survey platforms have to be measured in conjunction with the magnetic measurements. For the alignment in the tunnel the differences $\Delta = \beta - \gamma$ then have to be considered.

For the radial and vertical positioning of a dipole in the tunnel the results of the optical measurements have to be used. Nevertheless these values first have to be transformed to the measured field direction.

Overall 246 quadrupoles and 453 dipoles have to be measured on both the optical and magnetic control stands. Therefore a special hall was constructed, where several Magnetic Measuring Stands were installed. Fig. 13 shows this part of the hall with four stands for quadrupoles and four for dipoles.

After the magnetic measurements each magnet, is controlled once more on the optical stand. Only when the values from the first measurement can be reproduced the magnet. will be taken to the tunnel.

## 4 References

/1/ **Löffler, F.:** The Geodetic Approach for HERA. First. International Workshop on Accelerator Alignment, S1-2 / S2-4, July / Aug. 1989

## 5 Figure captions

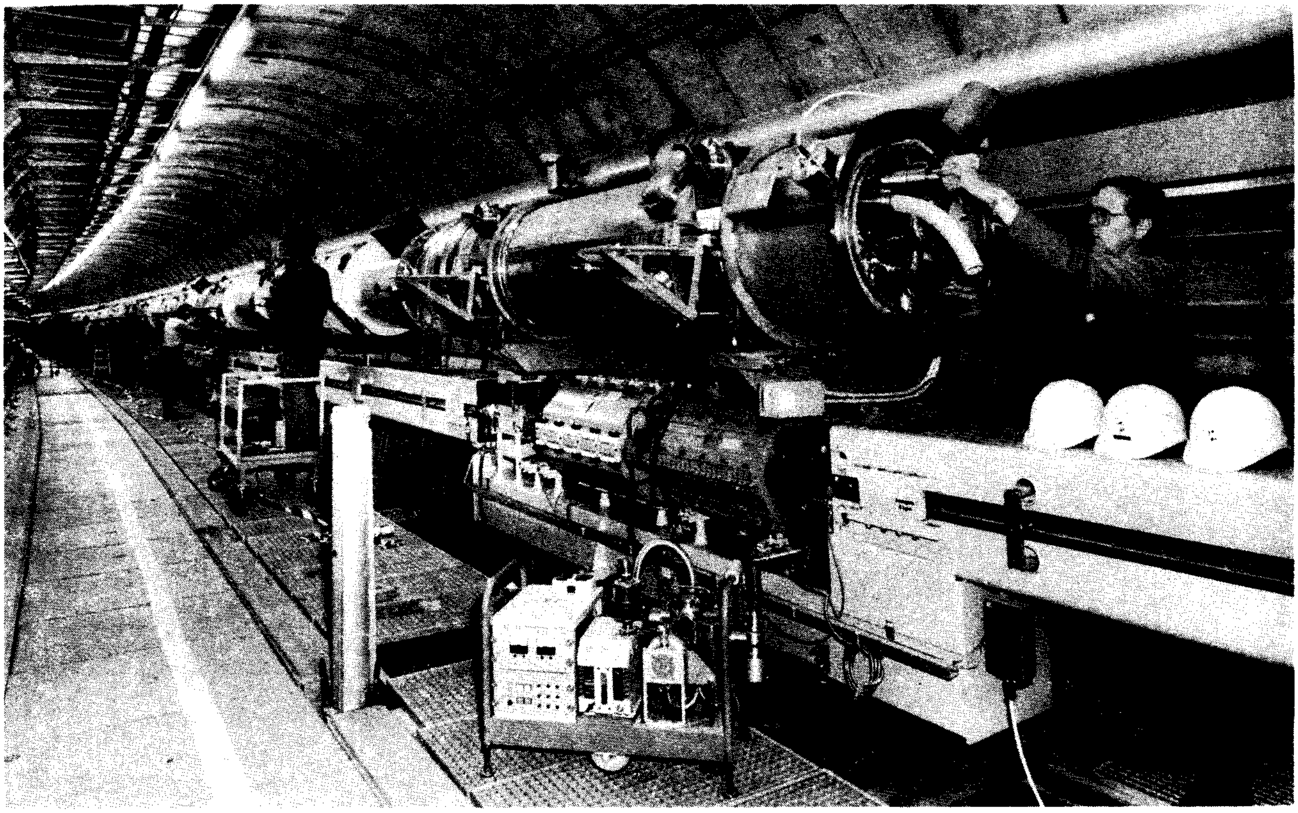


Fig. 1

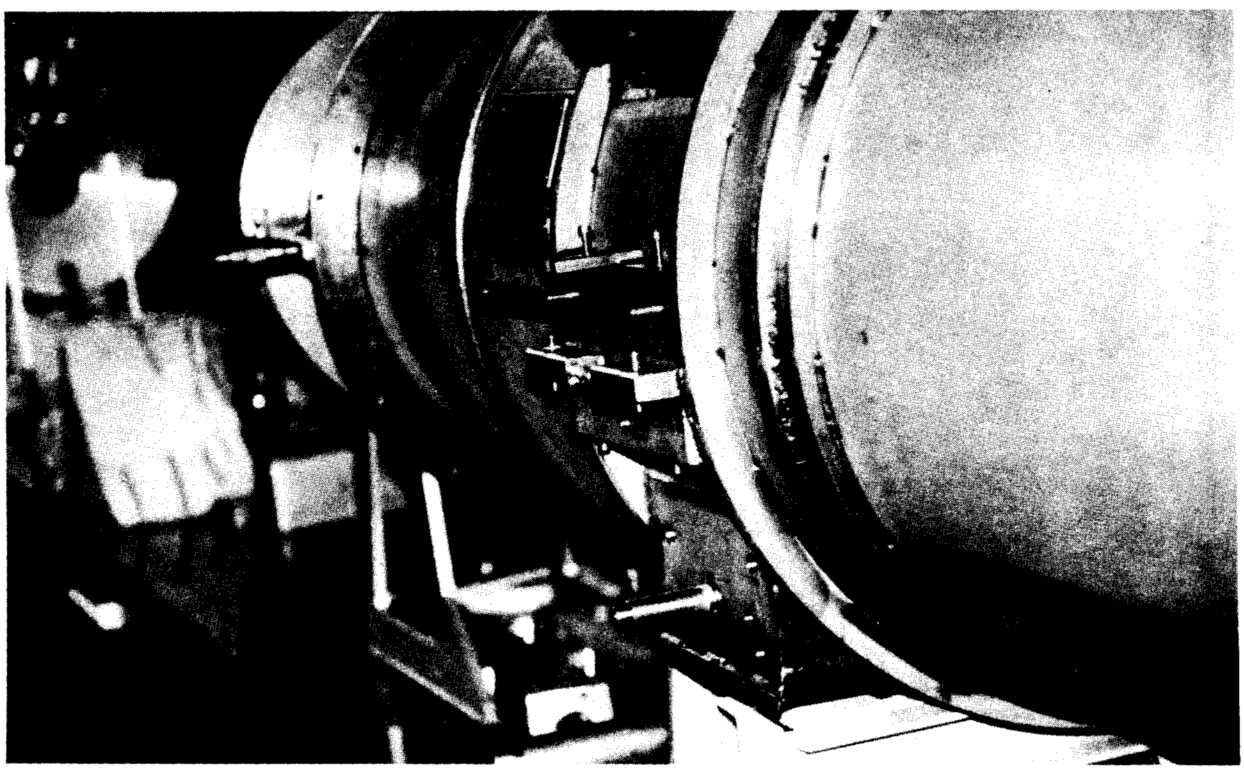


Fig. 2

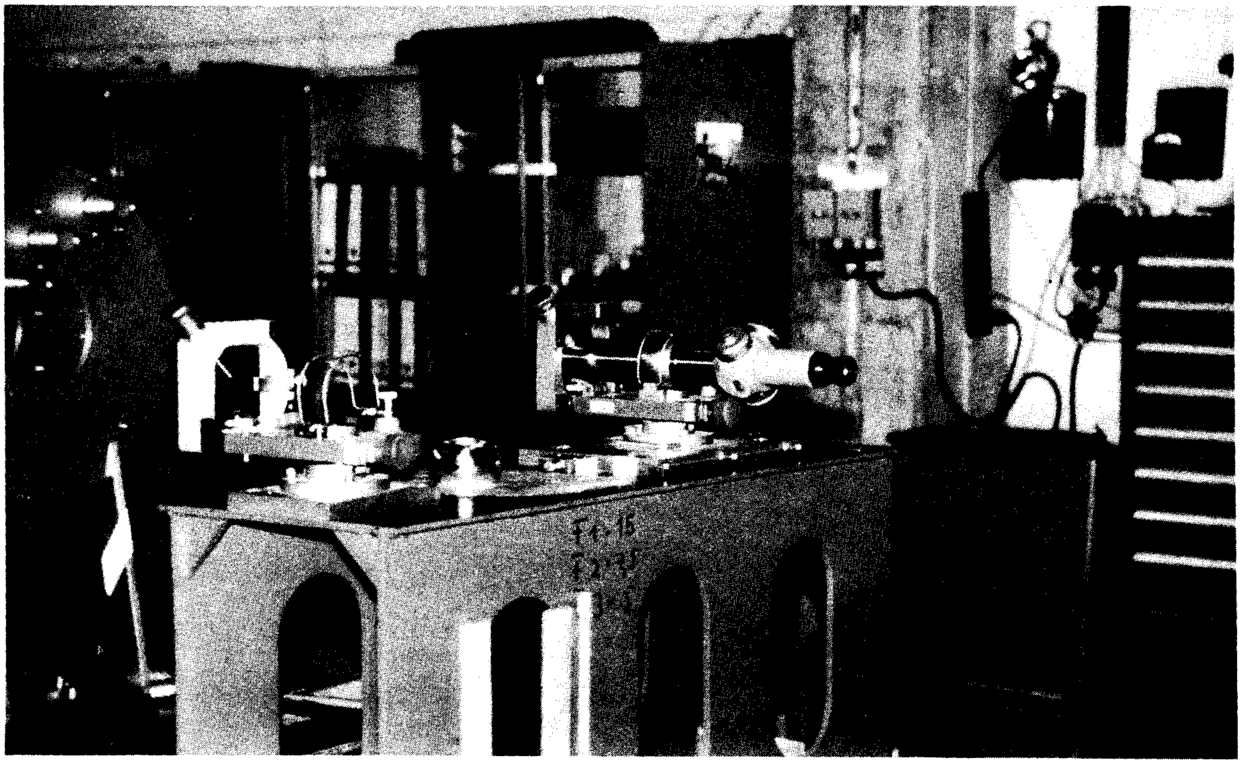


Fig. 3

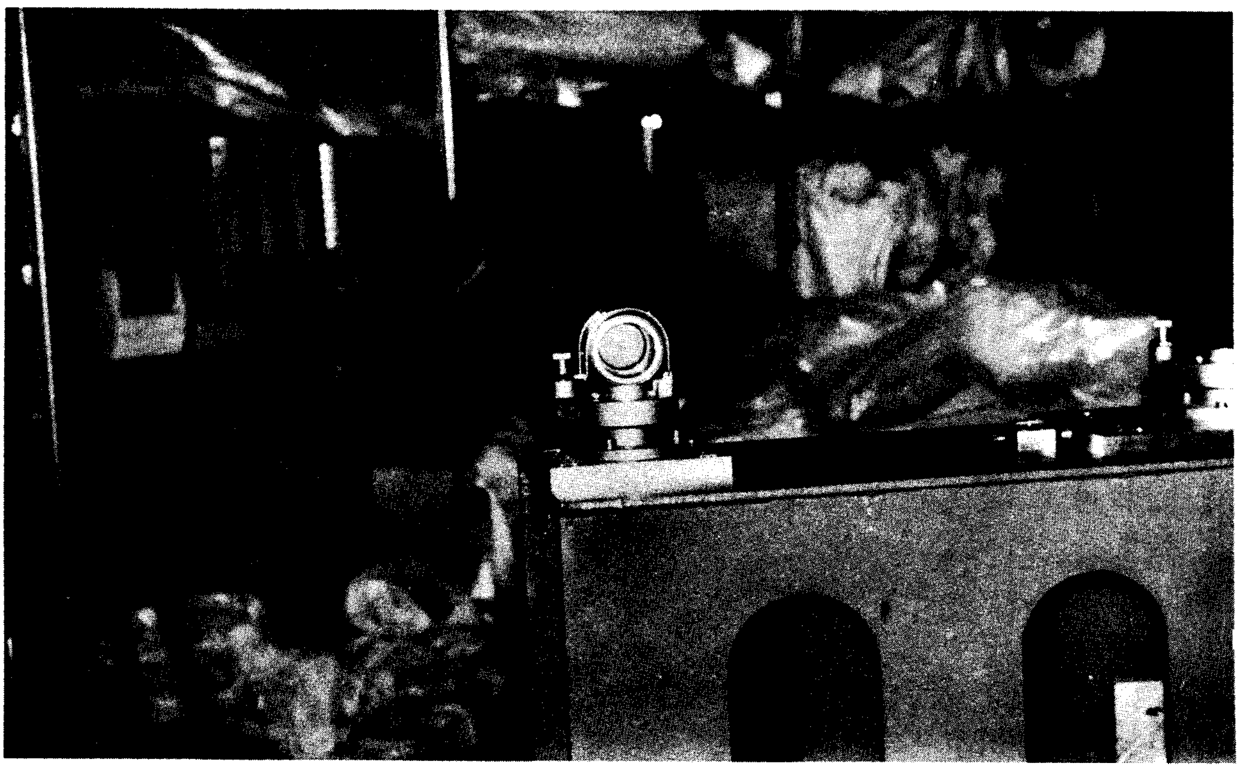
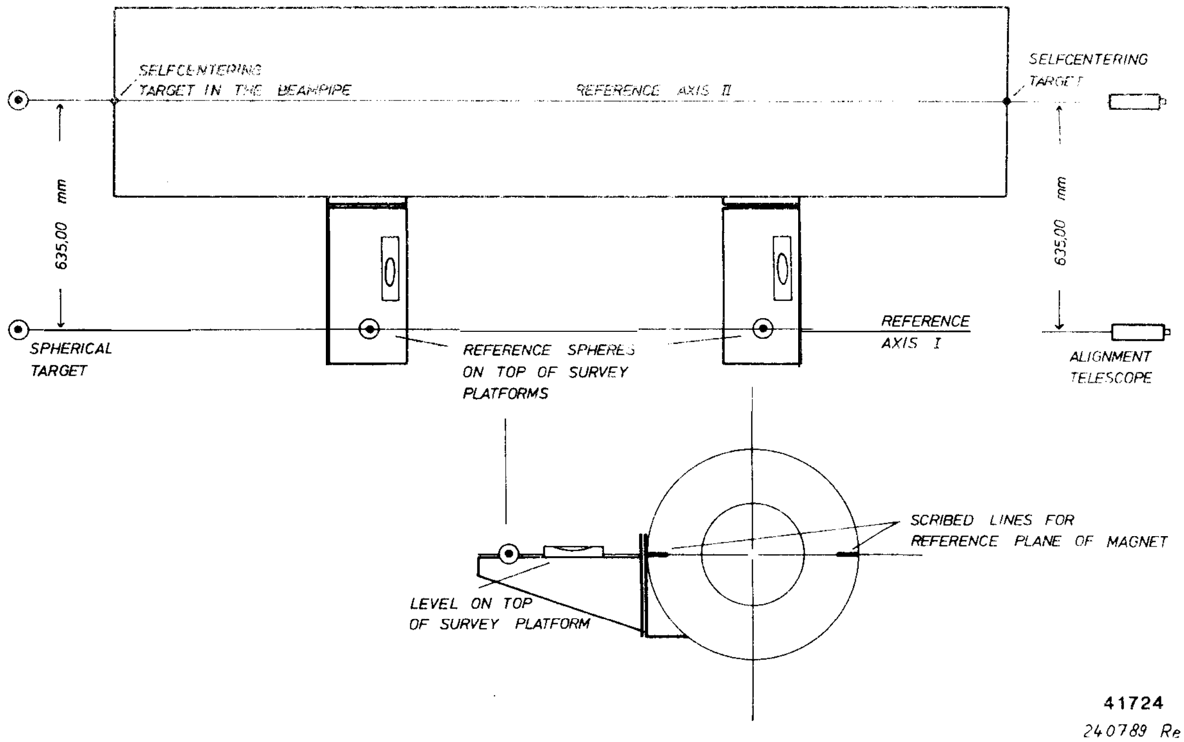
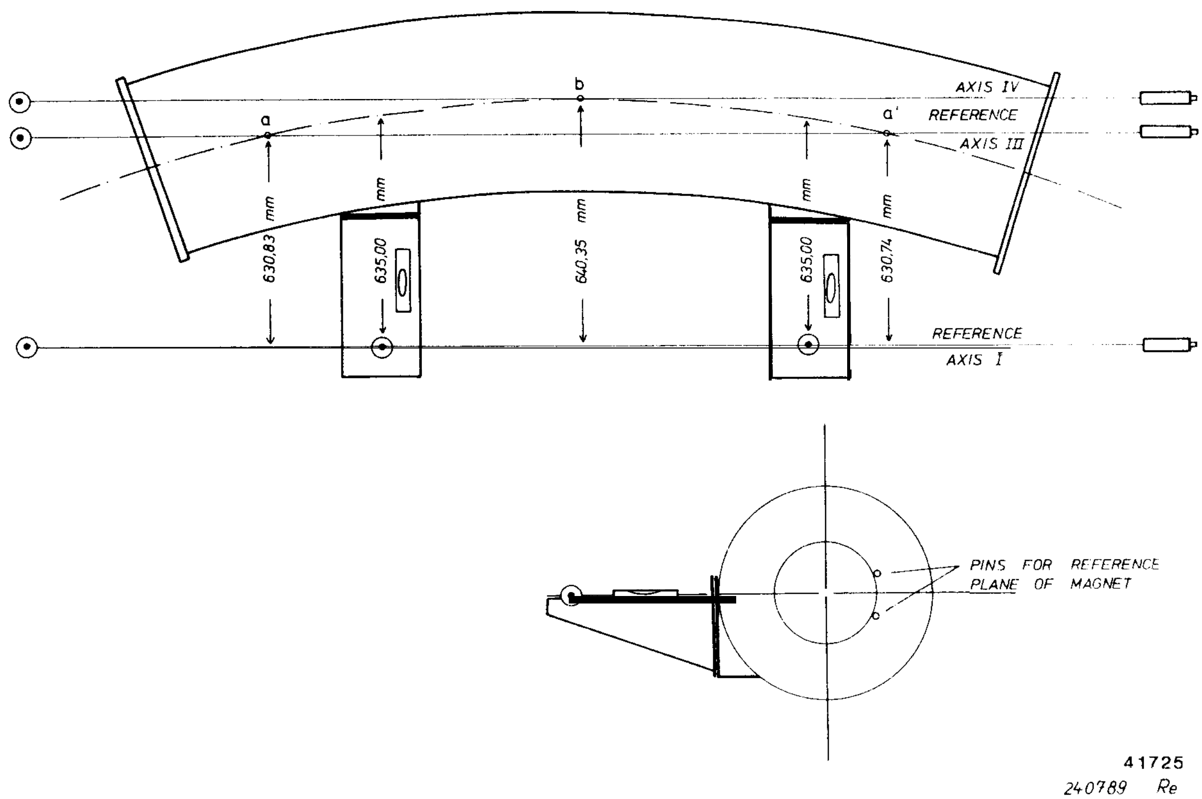


Fig. 4



SELFCENTERING TARGET IN THE BEAMPIPE
REFERENCE AXIS II
SELFCENTERING TARGET
635,00 mm
635,00 mm
SPHERICAL TARGET
REFERENCE SPHERES ON TOP OF SURVEY PLATFORMS
REFERENCE AXIS I
ALIGNMENT TELESCOPE
SCRIBED LINES FOR REFERENCE PLANE OF MAGNET
LEVEL ON TOP OF SURVEY PLATFORM
41724
240789 Re


Fig. 5



b
a
a'
AXIS IV
REFERENCE
AXIS III
630,83 mm
635,00 mm
640,35 mm
635,00 mm
630,74 mm
REFERENCE
AXIS I
PINS FOR REFERENCE PLANE OF MAGNET
41725
240789 Re


Fig. 6

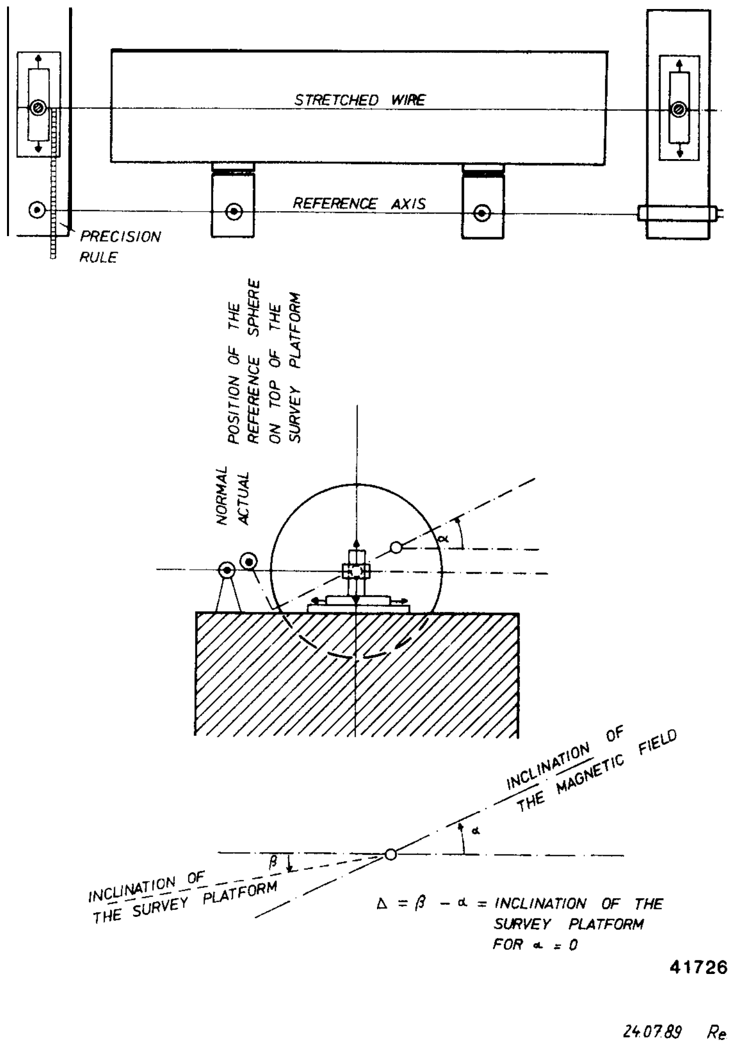

STRETCHED WIRE
REFERENCE AXIS
PRECISION RULE
POSITION OF THE REFERENCE SPHERE ON TOP OF THE SURVEY PLATFORM
NORMAL
ACTUAL
INCLINATION OF THE MAGNETIC FIELD
INCLINATION OF THE SURVEY PLATFORM
Δ = β − α = INCLINATION OF THE SURVEY PLATFORM FOR α = 0
41726
24.07.89 Re

Fig. 7

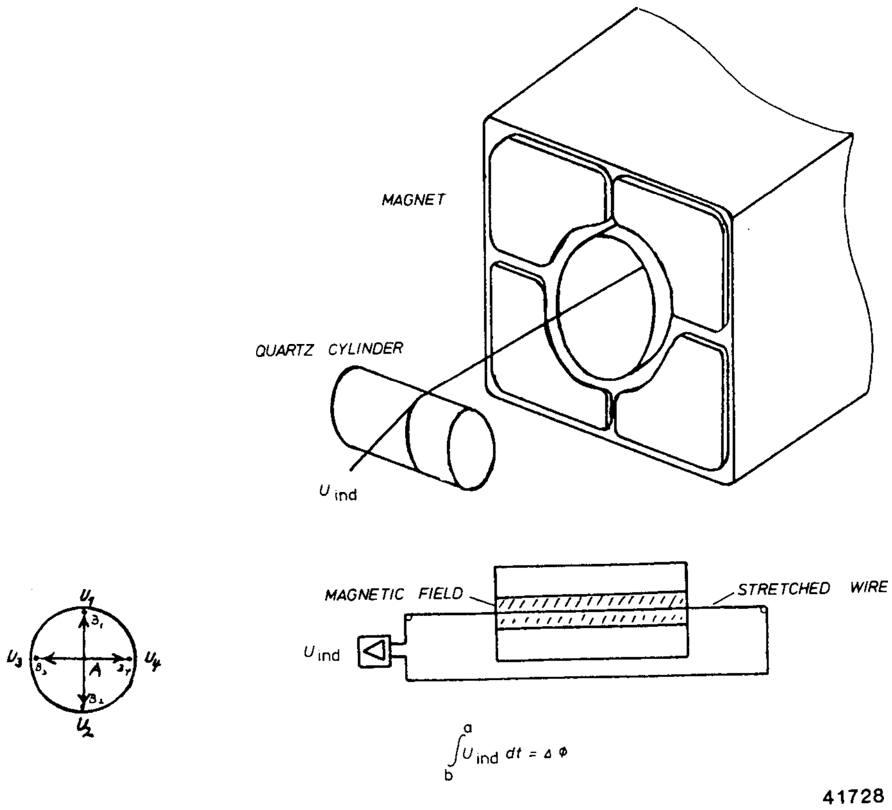

MAGNET
QUARTZ CYLINDER
$U_{ind}$
MAGNETIC FIELD
STRETCHED WIRE
$U_{ind}$
$\int_b^a U_{ind}\, dt = \Delta \Phi$
41728

Fig. 8

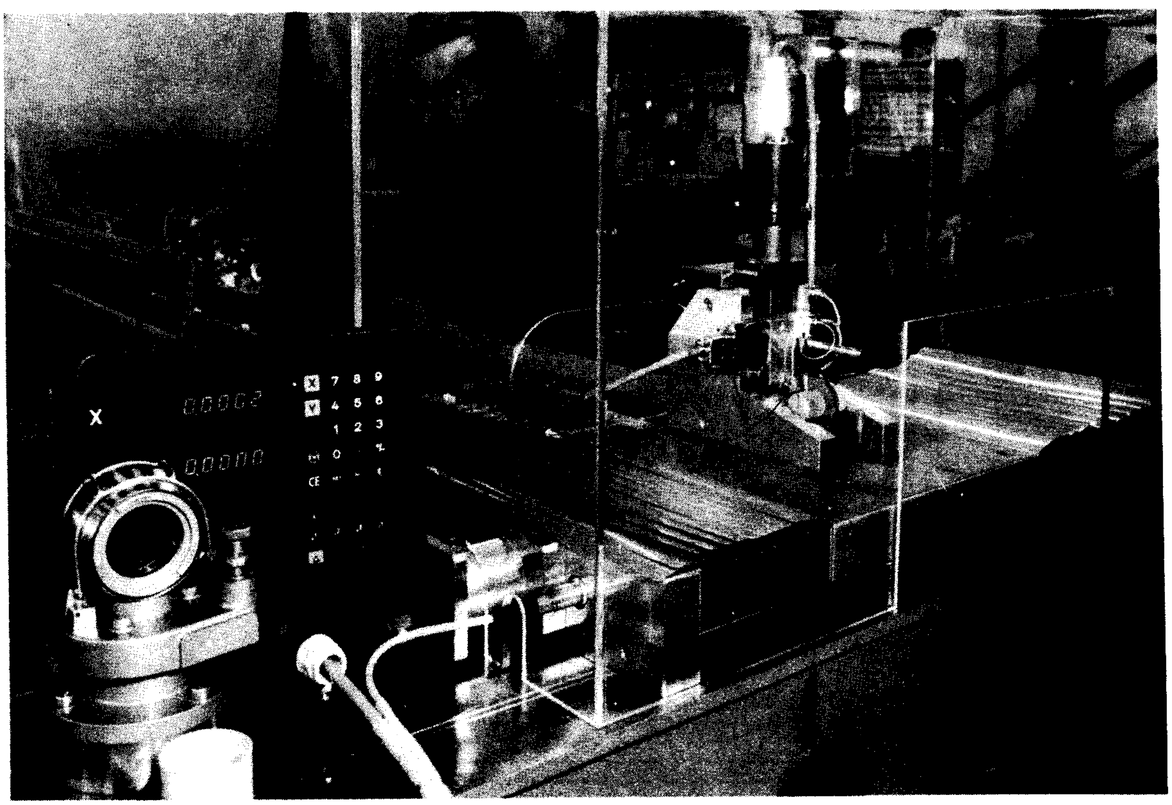

X
7 8 9
4 5 6
1 2 3

Fig. 9

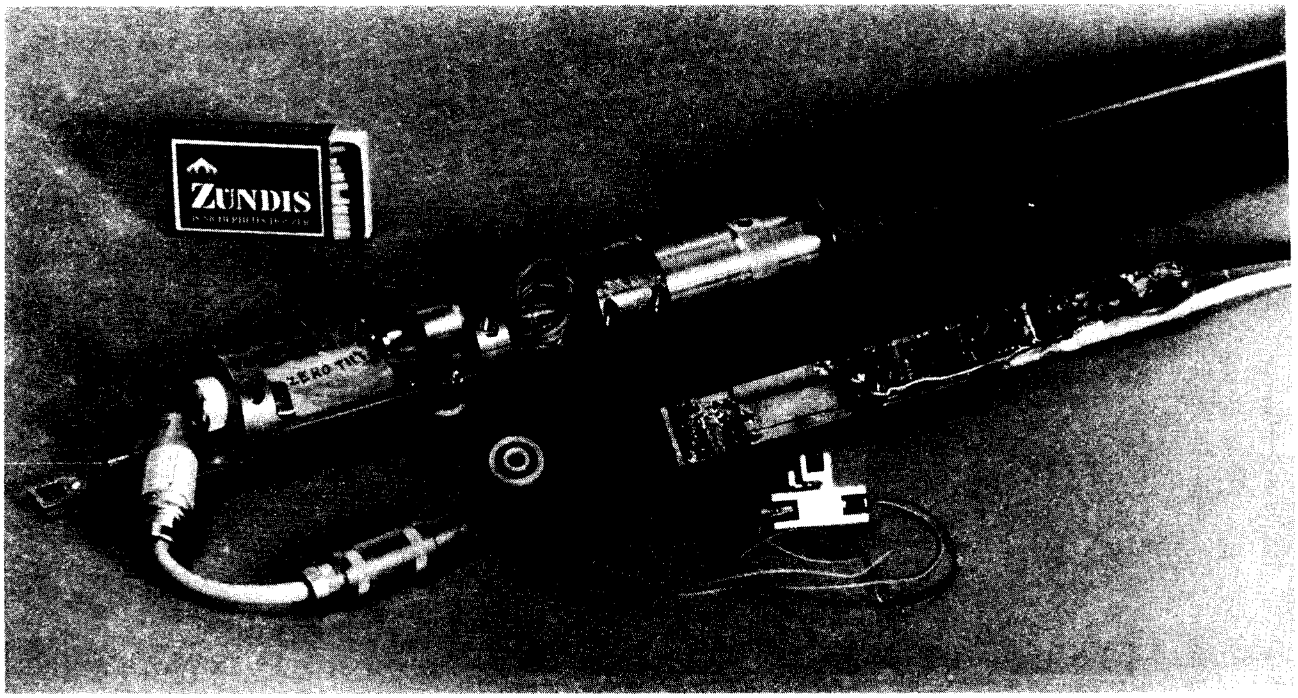

ZÜNDIS
ZERO TEX

Fig. 10

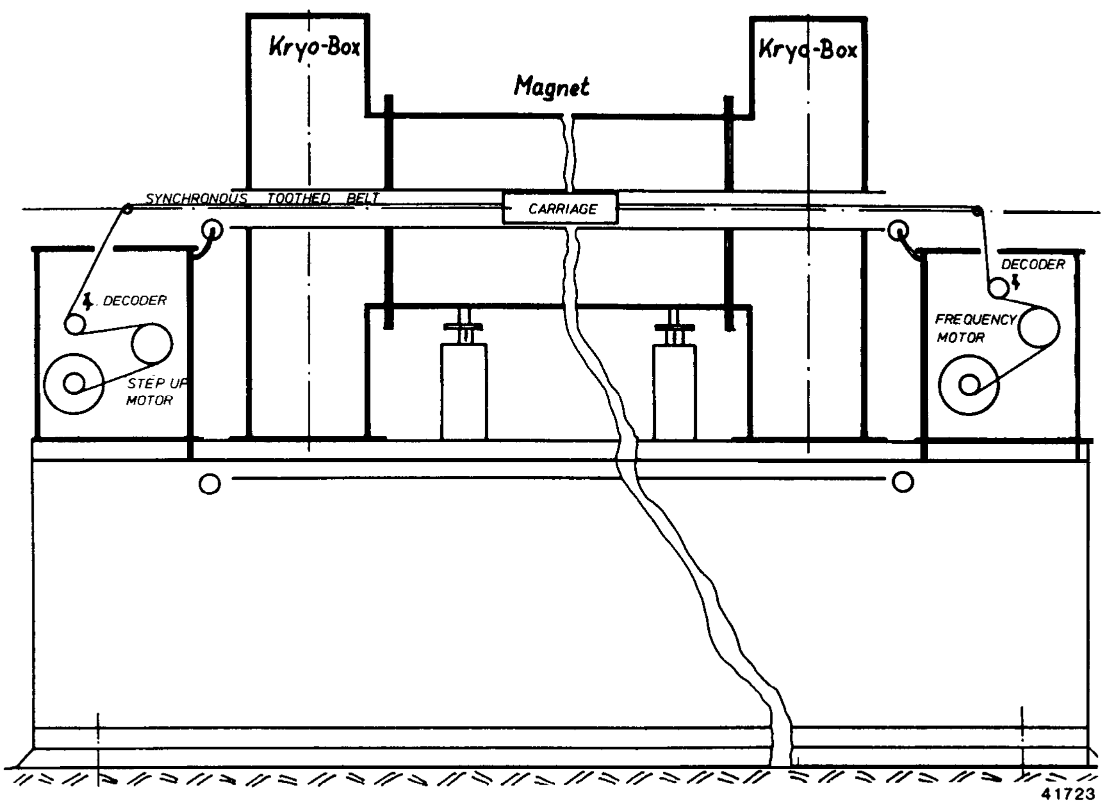
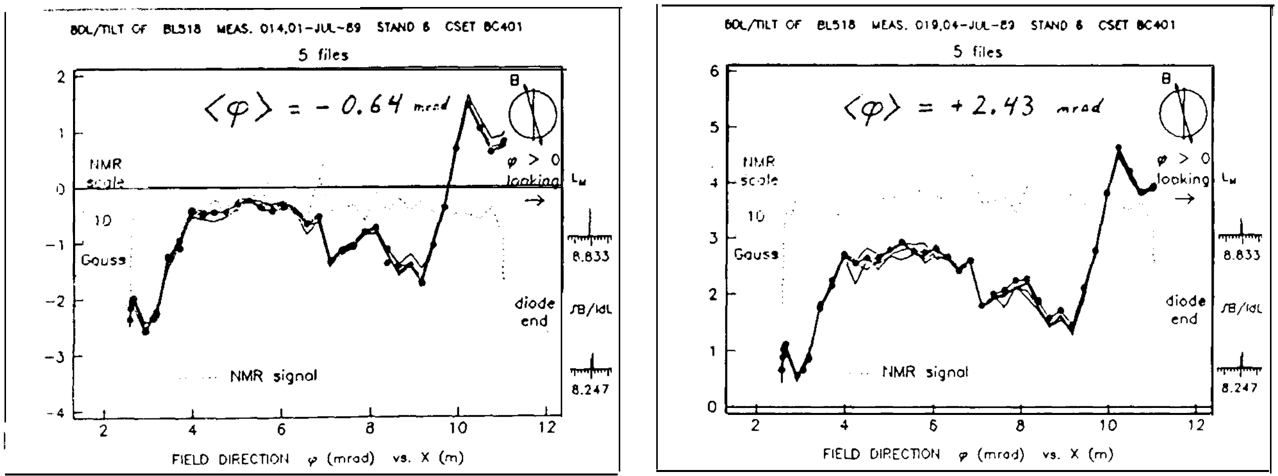

Kryo-Box
Kryo-Box
Magnet
SYNCHRONOUS TOOTHED BELT
CARRIAGE
DECODER
STEP UP MOTOR
DECODER
FREQUENCY MOTOR
41723

Fig.11




41722

Magnet mechanically positioned to ~ -1.5 mrad

Magnet mechanically rotated by +3.04 mrad

$\Delta\varphi_{measured}$ = + 3.07 mrad

Dipole magnets

Test for measurement of field direction

Fig. 12

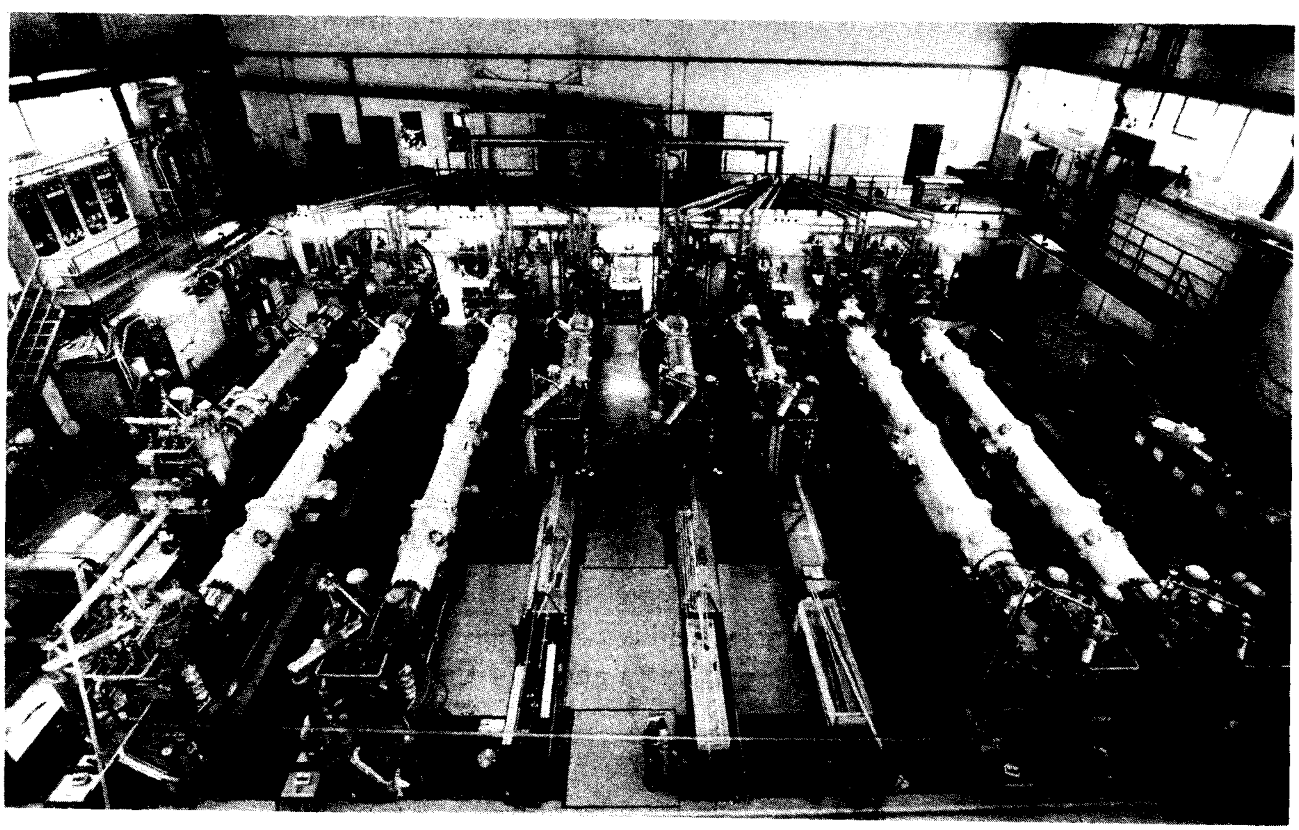


Fig. 13