Threedimensional Alignment Methods for the HERA Superconducting Magnets

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Abstract

For the alignment of the 646 superconducting magnets of the HERA proton accelerator a special measuring method based on a threedimensional centering system was developed. This paper shows how this large amount of work can be done with the help of modern electronic equipment like electronic theodolites, inclinometers, CCD-cameras and handheld computers in a most effective way.

1 The Magnets

Since the maximum energy of the protons in the machine is very high (820 GeV), all magnets in the 4 arcs of the machine (422 dipols and 224 quadrupoles) are superconducting. This means that the magnet itself is surrounded by a insulated tank and cooled down by liquid helium.

Each of the 9.8m long dipole magnets and the 4.0m long quadrupoles has at the side of its tank two sets of reference screws, which are used to fix a measurement-platform in a defined position (Fig. 1). A pre-tensioned spring presses the platform against the screws with a defined force. So deformations of the platforms are negligible.

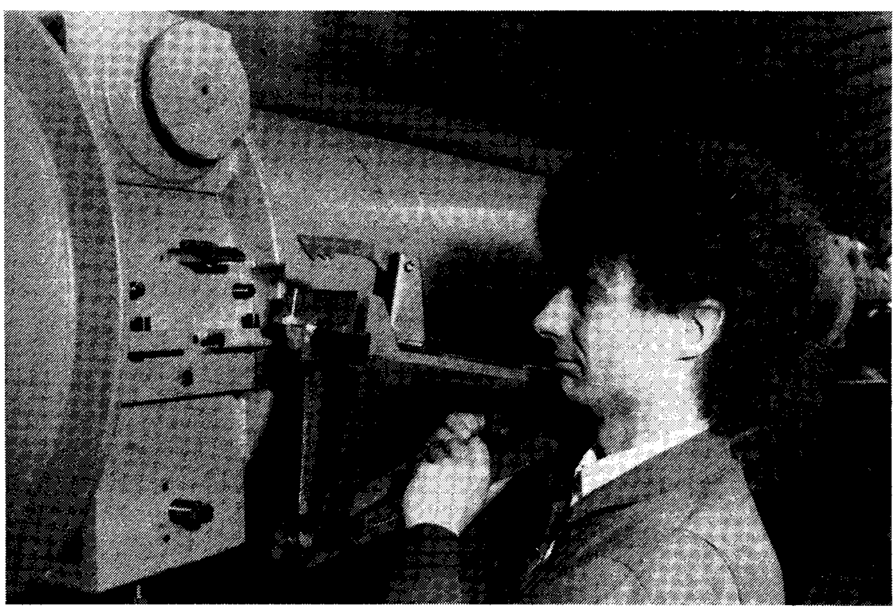

Figure 1: Survey platform

In the middle of the platform is a conical centering-surface for the Taylor-Hohson-Sphere with a diameter of 88.9 mm (Fig. 5 and 9). The center of this sphere defines the threedimensional measurement-point with an offset from the beamline of 635 mm. With two of these points height, radial position, yaw and pitch of the magnet are fixed.

The roll of the magnet is measured on a shaft which is mounted on the right side of each platform. It must be measured on both ends of the magnet because it may be twisted during the alignment procedure.

A cylindrical bore with a diameter of 12 mm eccentrically mounted on the platform allows distance-measurements with a steel tape to the next platforms without removing the Taylor-Hobson-Sphere. So the tangential position can be measured too.

The relation between the inner vacuum-pipe and the magnetic field vector is measured on a special measurement stand by the magnet-measurement-group /1/. The results of these measurements are given as corrections to the theoretical offsets of the platforms on a data set on the IBM mainframe computer which is connected by Ethernet to the PC's in the office. So the final co-ordinates in the earth system can be calculated.

2 Installing the magnets

2.1 The adjustment devices

Each magnet has four screws to allow movements in the vertical direction and to adjust the roll. Guide-rods for the radial movement and a device for the tangential alignment make it possible to move the magnet 25 mm in each direction (Fig. 2)

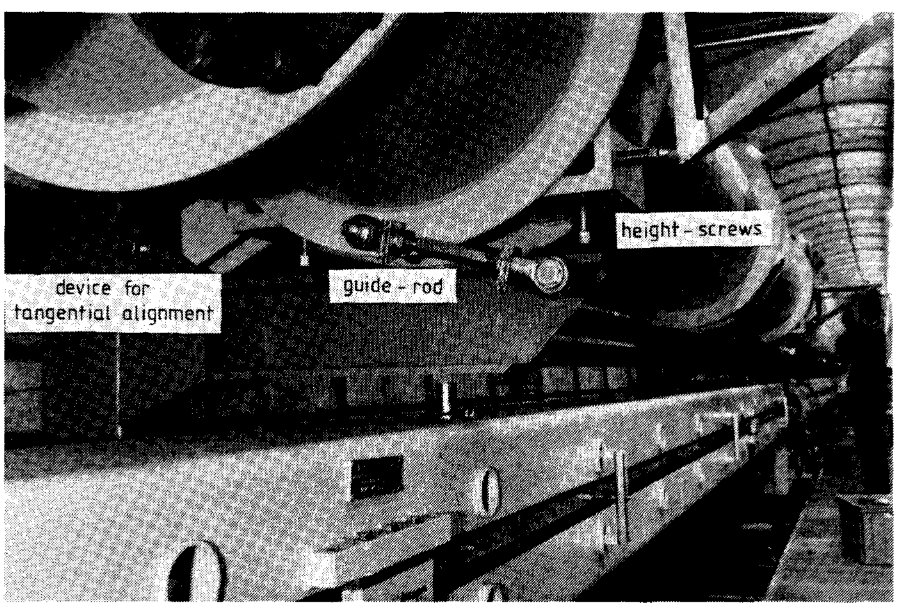

Figure 2: Alignment devices at a dipole magnet

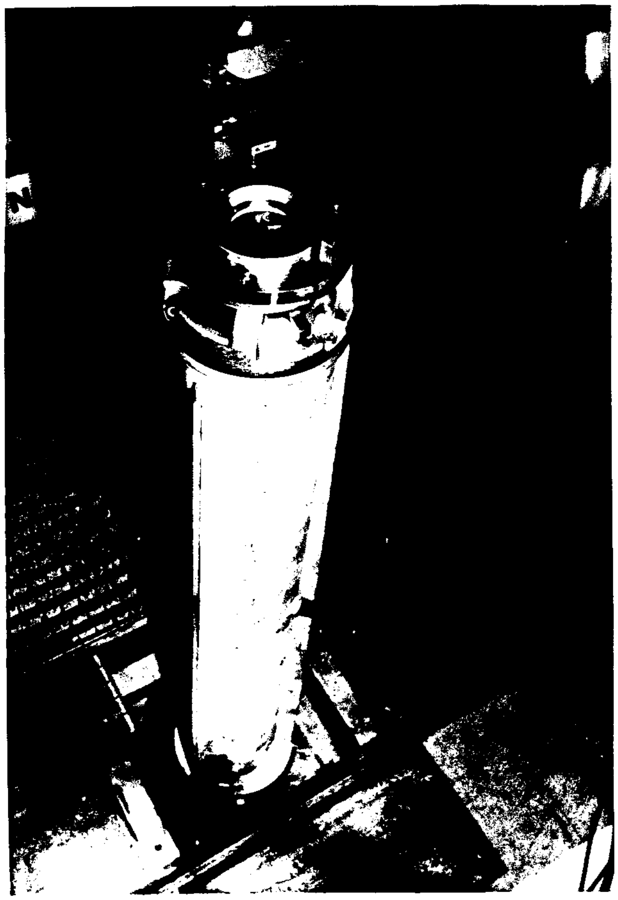

Figure 3: Survey pillar with adapter for Taylor-Hobson-Sphere

2.2 The Tolerances

For the first alignment the tolerances are given by mechanical constraints. They are :

radial :	±0.7 mm
height :	±0.7 mm
tangential :	±2.0 mm
roll :	±0.4 mrad

The roll must be good because it influences the height by a factor of 0.64.

For running the accelerator the accuracy must be much better. The standard deviations for the height and the radial position should be better than 0.1 mm. All these tolerances and accuracies are not absolute but relative with respect to the neighbouring magnets /6/.

2.3 The Reference System

The reference system is given by pillars which are mounted on steel plates inserted in the concrete wall of the tunnel every 35.2 m (Fig. 3/4). On top of these pillars are adapters with the same threedimensional centering system as on the platforms.

The co-ordinates of the pillars are determined by a threedimensional traverse with overlapping lines measured with an E2-Theodolite and a Mekometer ME 5000. This underground traverse is connected to the geodetic network on the surface by trigonometric plumbing /l/ /2/ /3/ /4/.

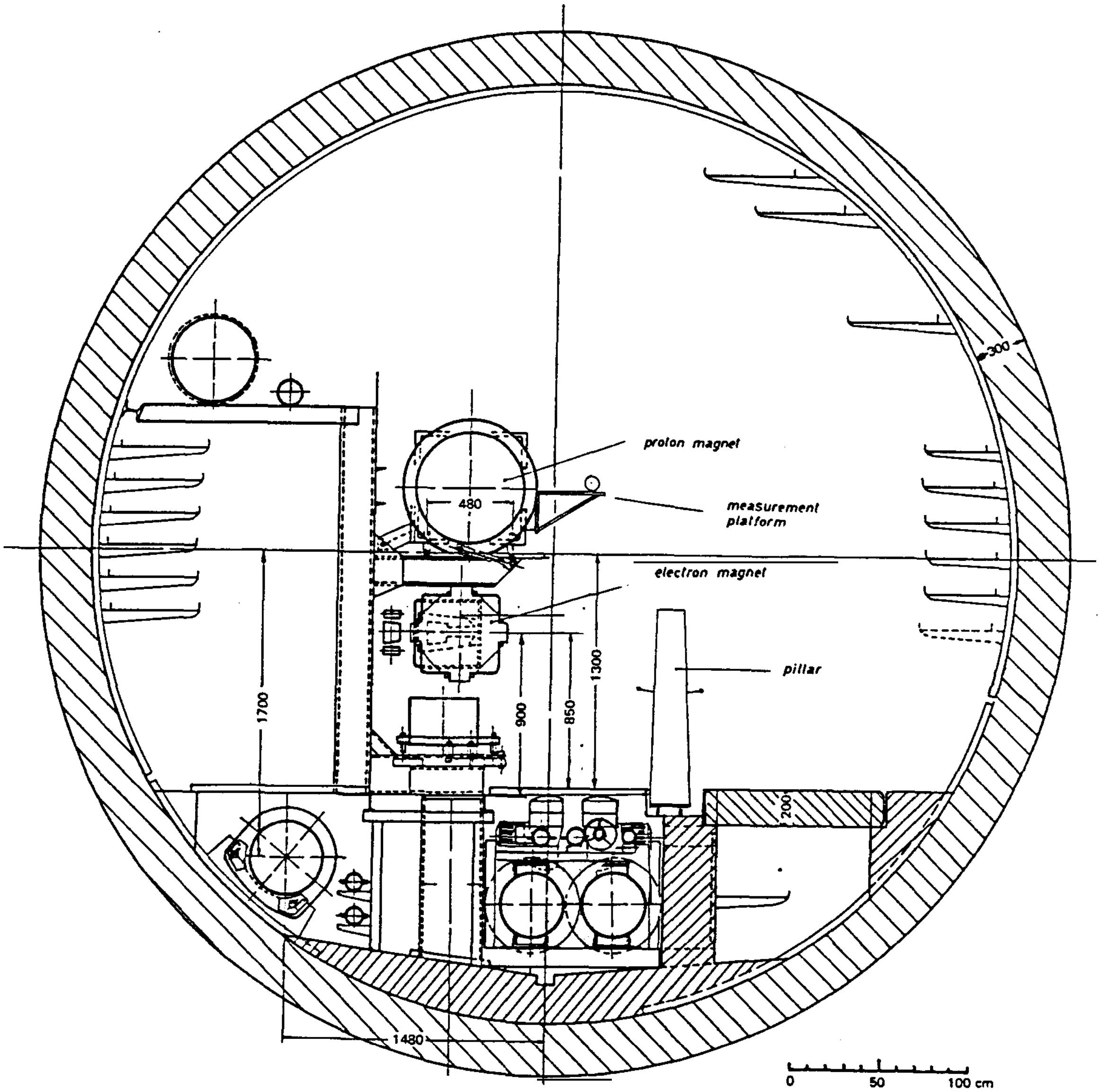

Figure 4: Tunnel cross-section

2.4 The Centering System

The HERA-machine is tilted against gravity by 1%, which means that the maximum height difference is 20.5 m. Since all geodetic instruments work with respect to the gravity, all three components of the position are connected and can not be adjusted separately like at the older machines DESY, DORIS, PETRA.

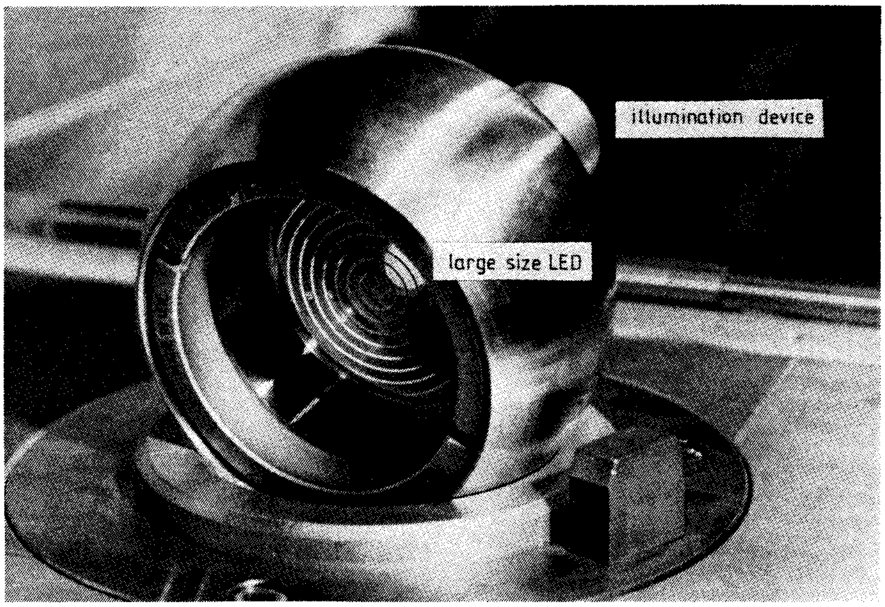

Figure 5: Taylor-Hobson-Sphere with illumination device

A solution for this problem is a threedimensional centering system using the Taylor–Hobson–Sphere on the target side (Fig. 5). Another advantage of this device is that you only have to lay it in the conical baseplate and no adjustment has to be done. This results in saving a lot of time.

For mounting a theodolite on the platforms a new support was developed which makes it possible to measure the height by vertical angles. This means that the height of the tilt-axis of the theodolite above the center of the Taylor–Hobson–Sphere must be well defined. This support consists of a KERN–centering– plate and a half-sphere with the same diameter as the Taylor–Hobson–Sphere underneath (Fig. 6).

With two footscrews it can be made horizontal, while those of the theodolite are not used. They are locked so that the theodolite-axis is perpendicular to the KERN–reference–plate. Therefore the height of the center of the theodolite does not change during the horizontal alignment.

Beneath the footscrews there is a adjustable spring-leg which keeps the support under tension. It is locked against rotation by a finger on the platform or the adapter on the pillars. A plastic-screw presses the support against it while small ball bearings prevent canting.

2.5 The Alignment Procedure

With the knowledge of the threedimensional co-ordinates of the pillars and the platforms it would be possible to do the alignment by setting out the horizontal and vertical angles and the distance from the pillars. But this method is not the best because the directions of the measurement-elements are not parallel to those of the guide-rods and screws of the magnet.

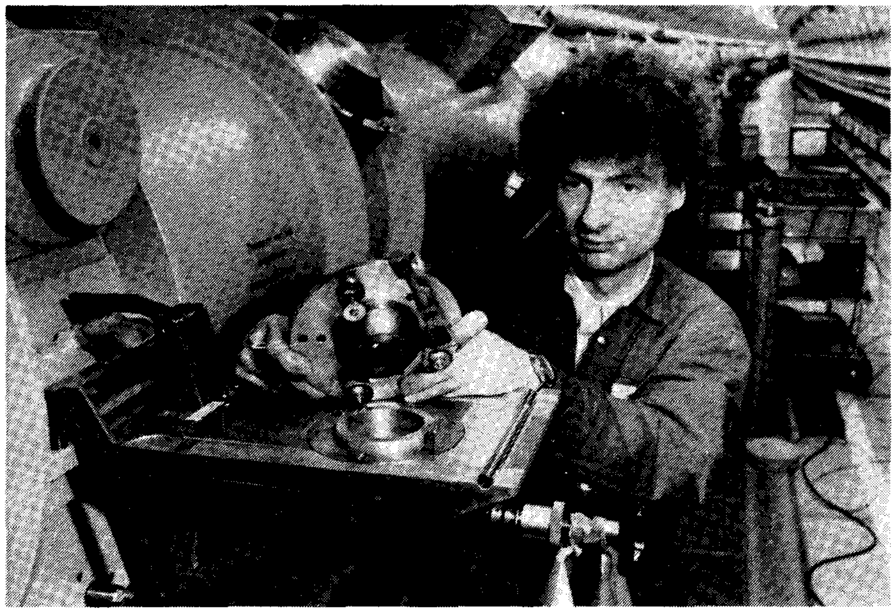

Figure 6: Support for the theodolite

So all three measuring-elements are changed while moving the magnet in one direction. This is unfavourable because the tolerances for the adjustment directions are very different.

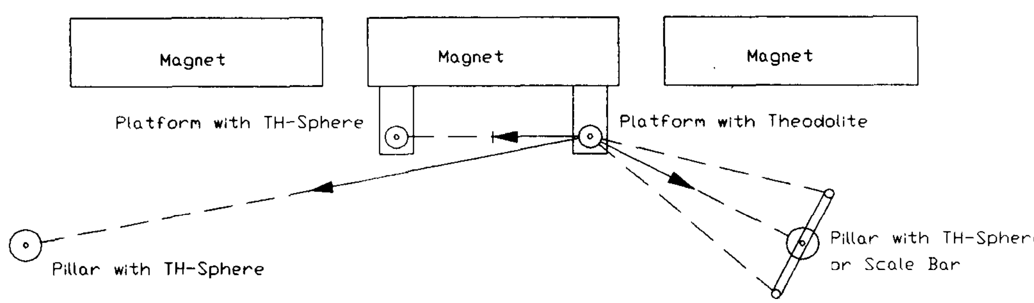

Figure 7: Measurement scheme for co-ordinate determination

All these disadvantages can be eliminated by taking the standpoint on a magnet between those which shall be adjusted. The threedimensional co-ordinates of this point are determined by measuring the horizontal and vertical directions to the fixpoints on both sides. Additionally the horizontal distance to the nearest fixpoint is measured with the help of a 1 m-scale bar of invar with an accuracy better than 0.5 mm. The second platform on the same magnet is also determined during this procedure by polar measurement.

The readings of the theodolite KERN E2 are automatically registered by a handheld computer Husky Hawk 8/16 or a laptop computer Compaq SLT 286, which calculates the co-ordinates of both platforms immediately and stores the result on a special file. The repeatability of this procedure is within some tenth of a millimeter (Fig. 7/8).

Now the alignment of the neigbouring magnets can be done. The computer calculates the setting-out-elements and compares it constantly with the reading of the theodolite. The difference is shown on the display of the E2. So the operator only has to move the screws

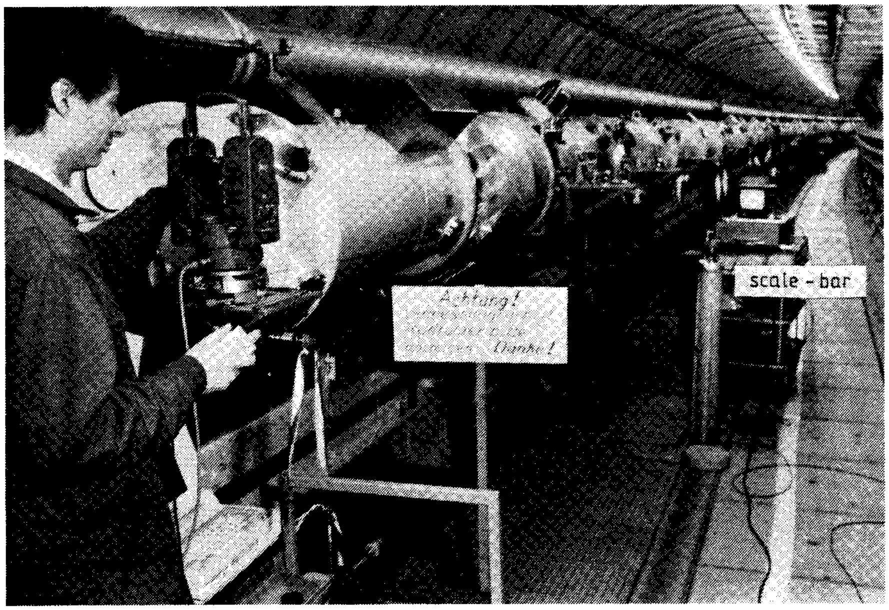

Figure 8: Distance measurement with scale-bar

until the readings are zero. The pointing-axis of the theodolite gives the height and the radial position of the platform. The tangential position is given by a steel tape as described before. The theoretical reading is shown on the display of the computer.

The roll of the magnet is measured by electronic inclinometers Schaevitz LSOC $\pm 1^\circ$ on both platforms. The analog output of these instruments are sent to a electronic-box developed by the geodetic institute of RWTH Aachen which transforms it into signals of the ASB-system of KERN /5/. These signals are given into a Husky handheld computer which calculates immediately the difference to the theoretical values and displays them in large numerals (Fig. 10). The aim is to make these numbers zero, so that there is little chance in mis-reading.

It is very important that the people who turn the screws at the magnet can see what they are doing especially because the platforms are mounted eccentrically on the magnet so that the movements influence each other. The solution for this is a CCD-camera mounted behind the eye-piece of the theodolite which transfers the image of the Taylor-Hobson-Sphere and the crosshair to a monitor beside the magnet (Fig.11-13). So all movements can be seen at the monitor and the handheld computer which are mounted together on a carriage.

The magnet on which the theodolite stands during this procedure can be adjusted relative to any other magnet using the co-ordinates stored in the computer before.

2.6 Results

After aligning a block of normally 9 magnets they are contolled by measuring a threedimensional traverse with overlapping lines. The standpoints are always the platform of a dipole which is near to a quadrupole (Fig. 14). If a pillar is nearby the directions and the distance to it are also measured. To the other platforms polar measurements are made always from two standpoints so that the measurement is controlled internally.

The distances to the pillar are measured by the invar scale bar, those between the platforms by steel tape.

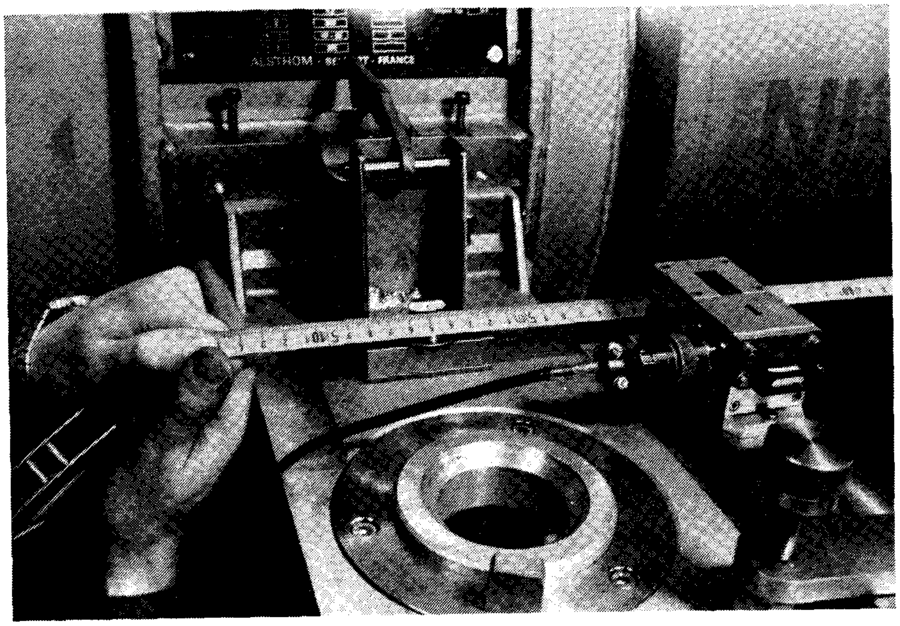

Figure 9: Survey platform with Schaevitz inclinometer and steel tape

Figure 10: Husky handheld computer with reading from inclinometer

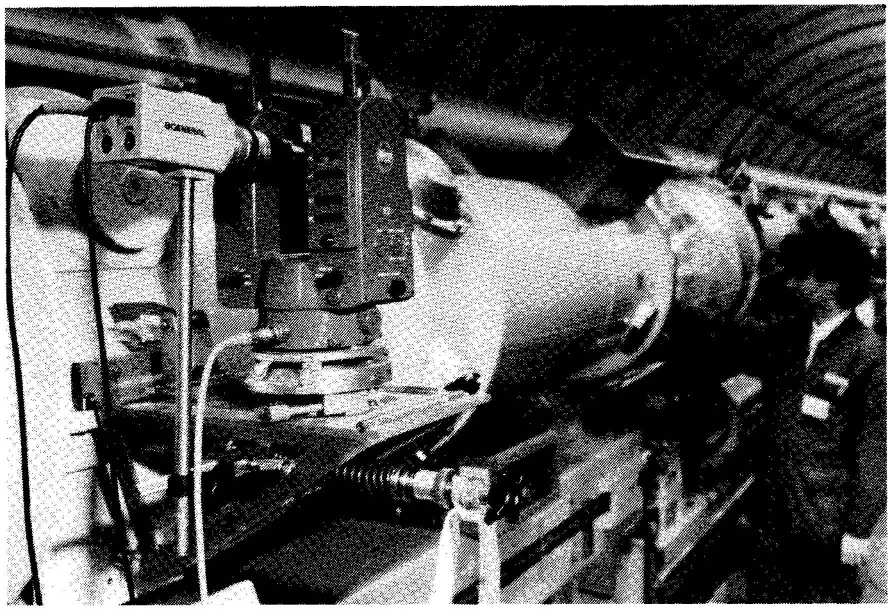

Figure 11: CCD-camera mounted at the theodolite

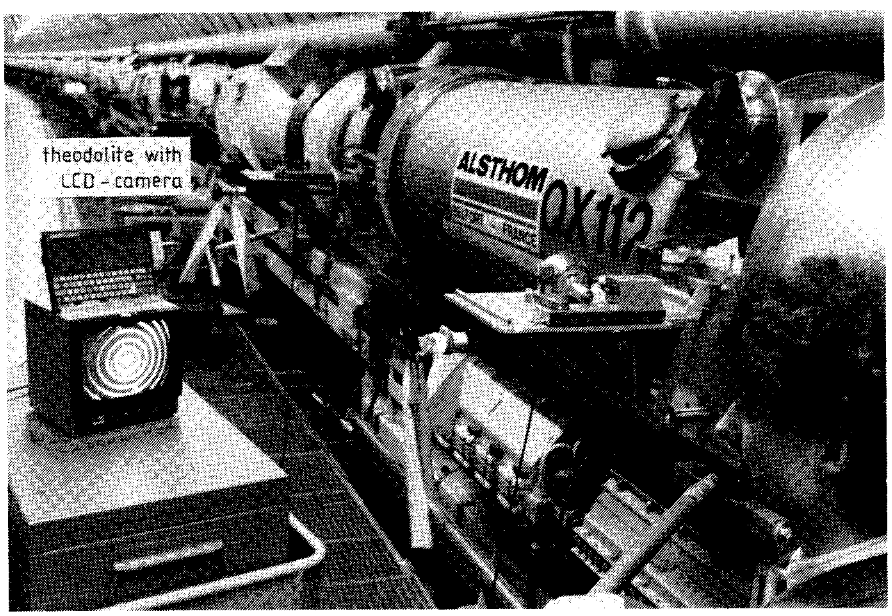

Figure 12: Aligning with target image on the monitor

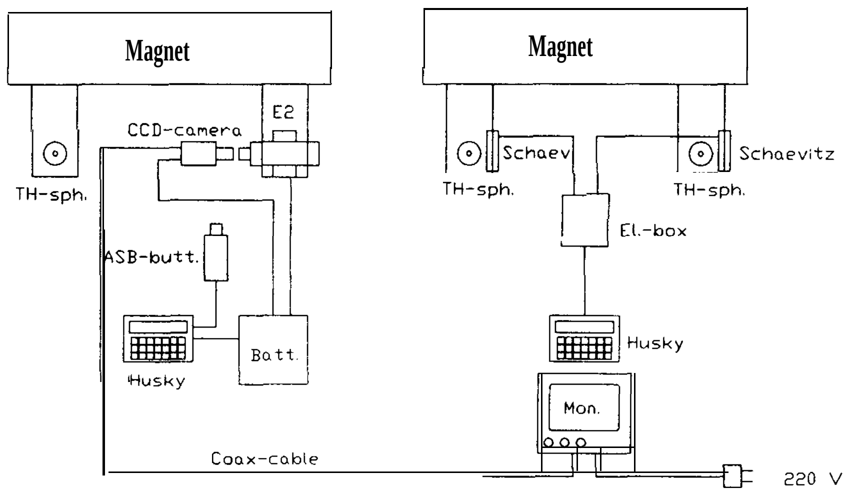

Figure 13: Block diagram

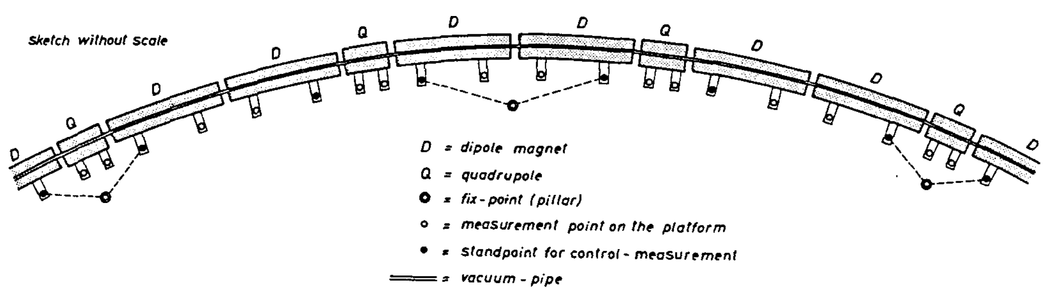

Figure 14: Measurement scheme for control-measurement

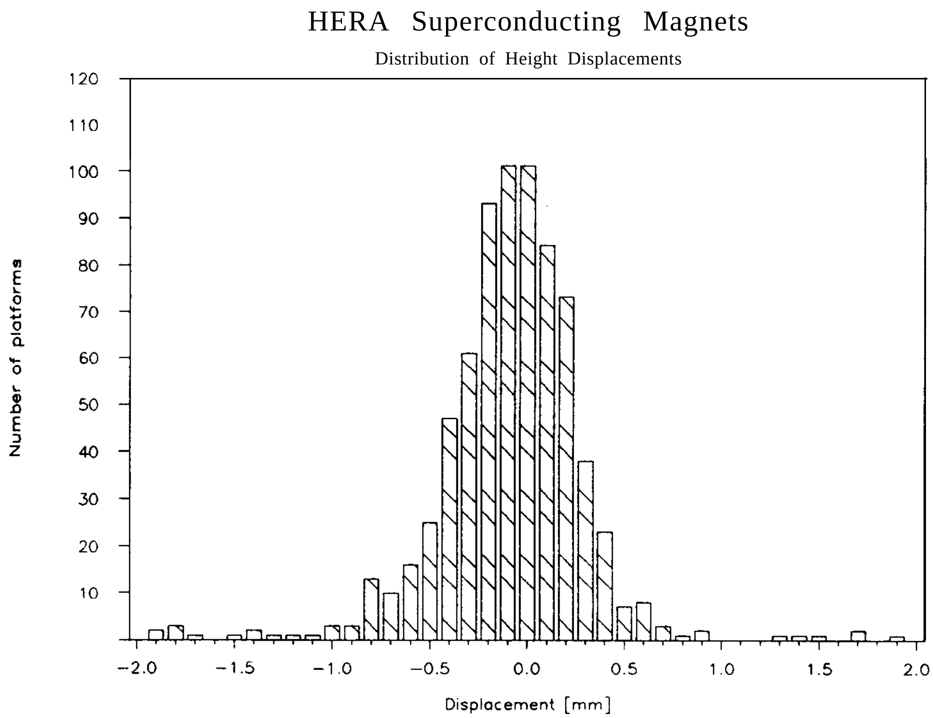

Figure 15: Distribution of height displacements

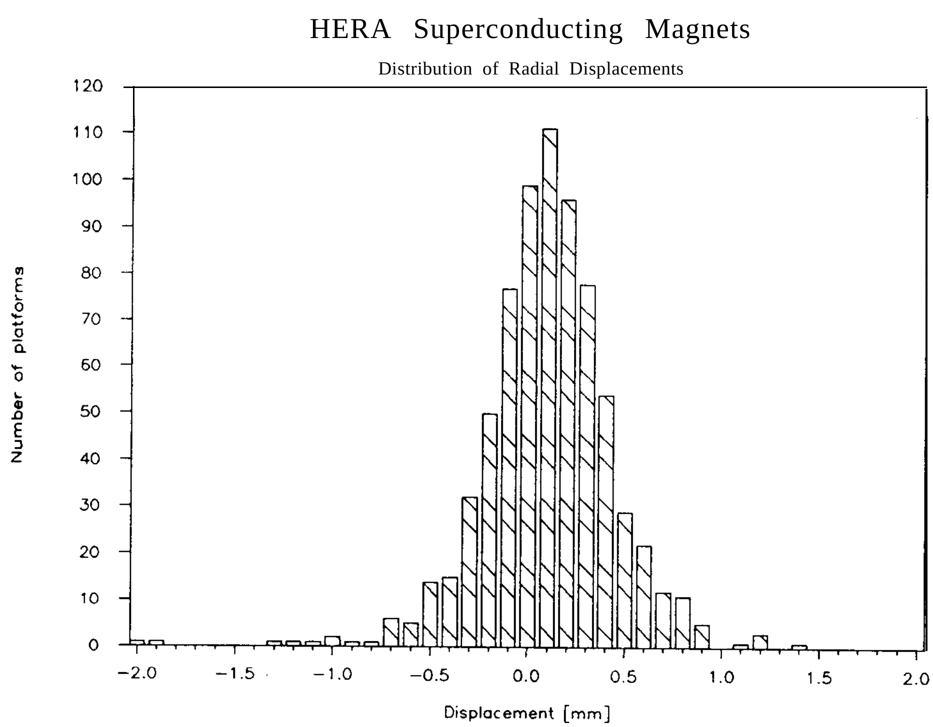

Figure 16: Distribution of radial displacements

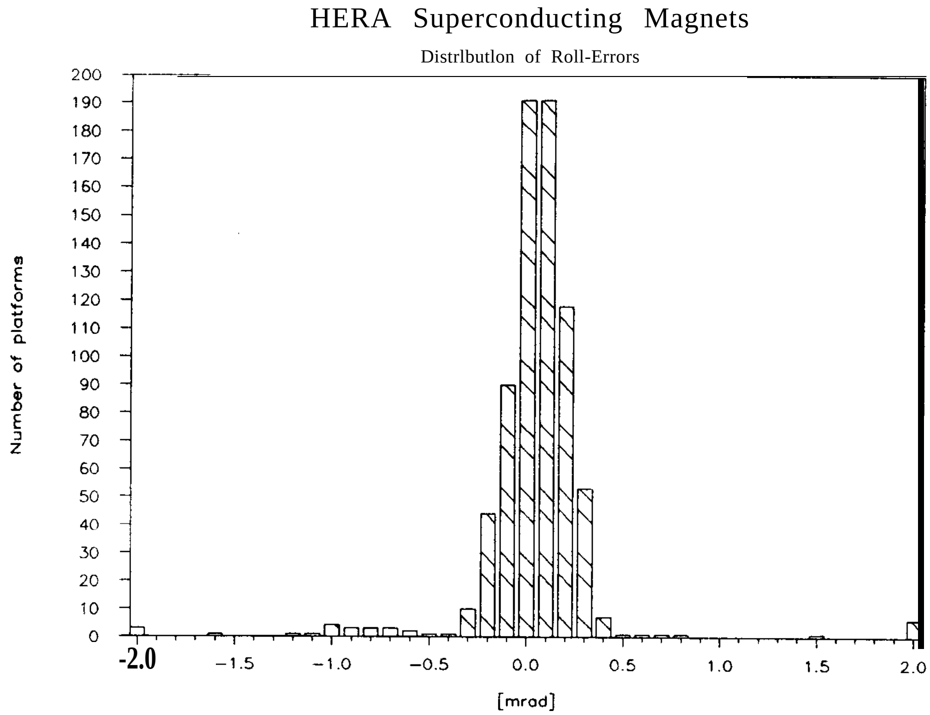

Figure 17: Distribution of roll errors

All values are registered on a laptop computer which calculates the displacements of the magnets immediately after measuring. The main part of the program-system which does the calculating is the geodetic adjustment program PAN of GEOTEC, the other parts are prograrmned at DESY. Now one can see on the display if the results are within the tolerances. If not corrections can be made at once, but as the results show, the first adjustment is normally within a few tenths of a millimeter (Fig. 15-17).

3 Conclusion

With the described method, based on electronic inclinometers, theodolites, computers and a threedimensional centering system it is possible to align up to 10 magnets per day by a survey group of 3 members (1 eng.,1 tech.,1 mech.) with an accuracy of some tenths of a millimeter.

A little increase of speed and accuracy could be achieved by using motorized theodolites with build in CCD cameras but the costs of such a system, at this moment are too high when compared with the benefits.

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