GEODETIC MEASUREMENTS FOR THE HERA PROTON RING, THE NEW EXPERIMENTS AND THE TESLA TEST FACILITY - A STATUS REPORT

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Abstract

The HERA proton machine has been operating since 1991. Only parts of this accelerator have been measured in that period. This report gives an overview of the results, which show the movements of the magnets and the reproducibility of the geodetic measurements.

The measurements which were necessary for the installation of two additional detectors are also described. Finally an outlook on the alignment of the components of the TESLA Test Facility (TTF) Linac is presented.

1 INTRODUCTION

The accelerator survey at DESY is done by applying angle - and distance measurements as shown in the accelerator workshops 1989 and 1990 [1] [2] [3] [4] [5]. The first complete alignment of HERA based on such measurements was done in December 1990 just before commissioning of the proton machine.

While overall measurements and the necessary realignment could be carried out in 1991/1992 for the electron accelerator that was not possible for the proton machine. Only certain parts of the proton ring could be measured allowing an overview of the behaviour of the magnets and the accuracy of the geodetic measurements.

2 THE HERA P-MACHINE

2.1 BETWEEN NORTH HALL AND EAST HALL

In January 1992 and November 1993 the superconducting part of the machine between north hall and east hall was surveyed. The three dimensional coordinates of the survey platforms were evaluated from a free least square adjustment of the observations related to the nominal values. From the coordinate differences the radial and vertical deviations from nominal position were derived. Systematic deviations of the radial values from the nominal position were removed by a least square fit with respect to an eighth order polynominal function. Fig.1 and Fig.2 show the results. There were 43 out of 290 radial deviations in 1992 which were between 0.5 and 1.0 mm, only 6 exceeded 1.0 mm with the maximum value being -1.5 mm. All the other deviations were smaller than 0.5 mm.

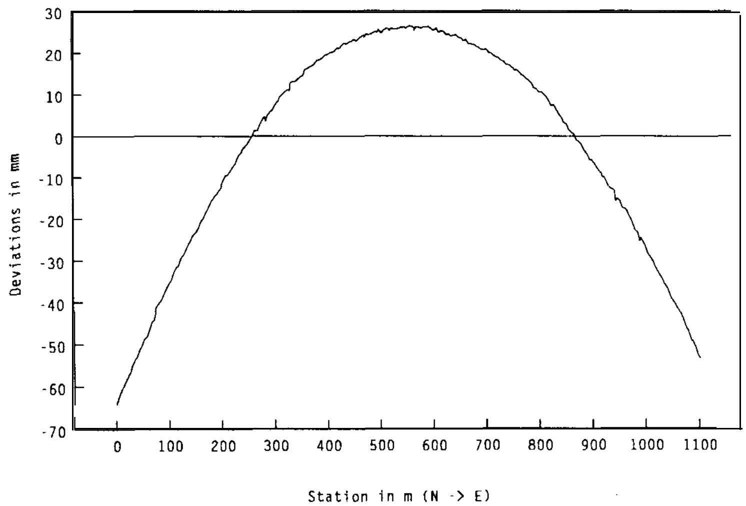

Figure 1. Radial deviations dr from nominal position-January 1992

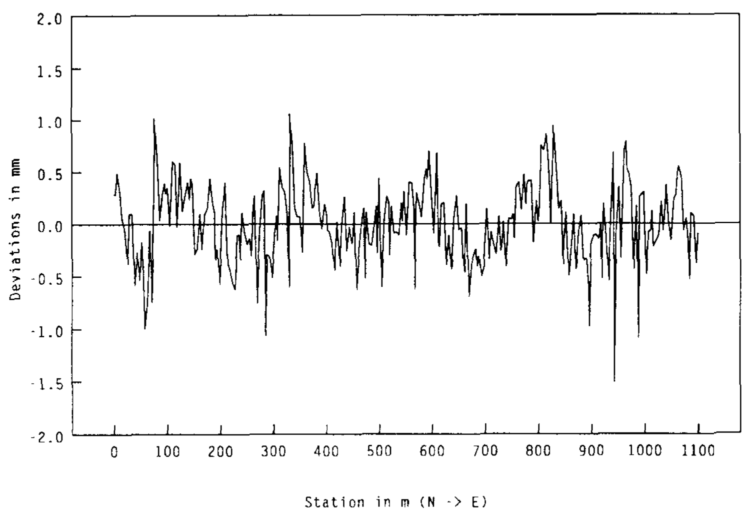

Figure 2. Relative radial deviations dR–January 1992

The results obtained in 1993 were very similar. The mean square values of the deviations for both years were the same (± 0.35 mm) if values of 1.0 and more are neglected.

The reproducibility of the measurements can be derived from the differences between both sets of measurements, which are shown in Fig.3. Here only five magnets (10 values) showed significant differences, which were caused by instabilities of the magnet supports. For the other magnets the reproducibility of the measurements stayed within ±0.12 mm (mean square value of the differences), which was consistent with a standard deviation of the radial measurements in 1992 and 1993 of ±0.08 mm.

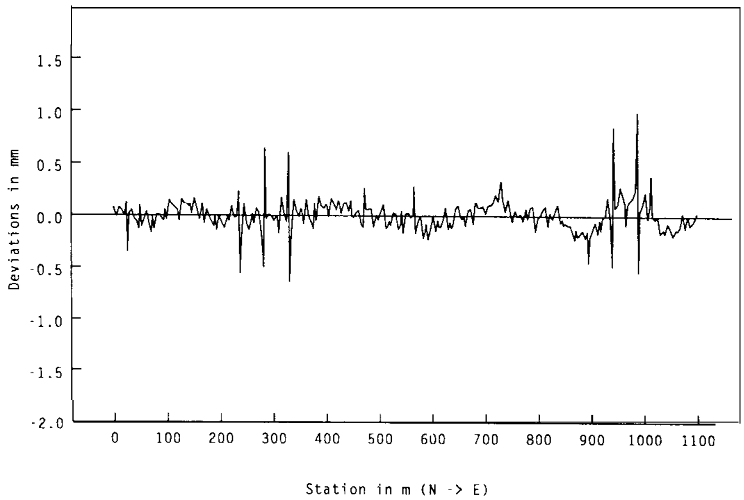

Figure 3. Differences of the relative radial deviations dDR (Nov. 93–Jan. 92)

Similar results were obtained for the height measurements. Fig.4 gives the vertical deviations measured in 1992. Here 67 values out of 290 were in the region 0.5 to 1.0 mm, only 4 deviations exceeded 1.0 mm with a maximum of -1.2 mm. All other vertical deviations were smaller than 0.5 mm. The vertical deviations in 1993 were comparable. The mean square values were ±0.40 in 1992 and ±0.35 mm in 1993, if deviations of 1.0 mm or more are not taken into account. The differences between the vertical deviations measured in 1992 and 1993 are shown in Fig.5. Significant values exist for four magnets, which were obvious already from their radial movements. For all other magnets the differences corresponded to the surveying accuracy of the radial measurements, if systematic effects are eliminated.

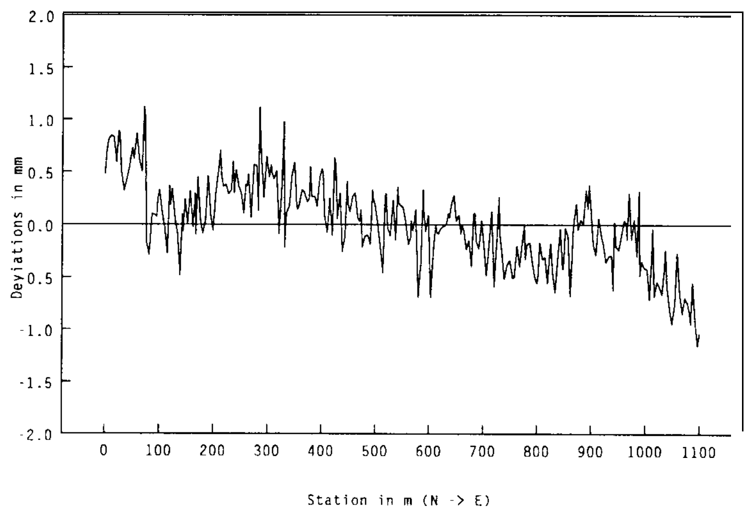

Figure 4. Vertical deviations dh from nominal position-January 1992

During both measurements in the 1992 and 1993 surveying periods the roll of the magnets was also determined. The differences are given in Fig.6 which shows that they were smaller than 0.3 mrad.

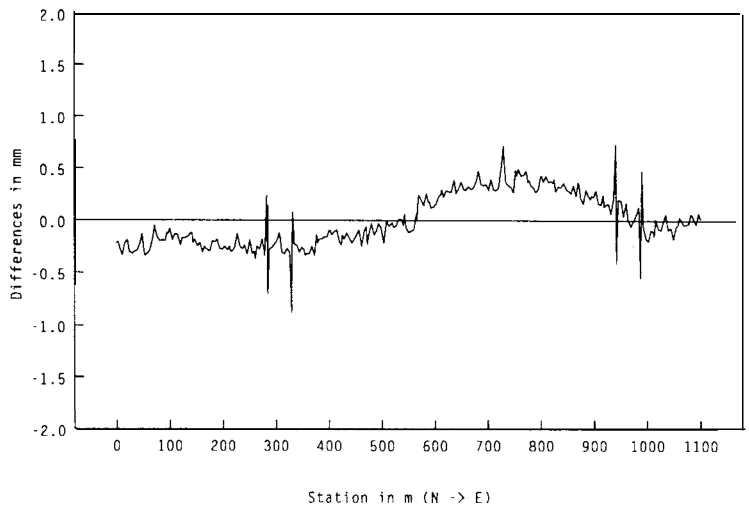

Figure 5. Differences of the vertical deviations (Nov. 93–Jan. 92)

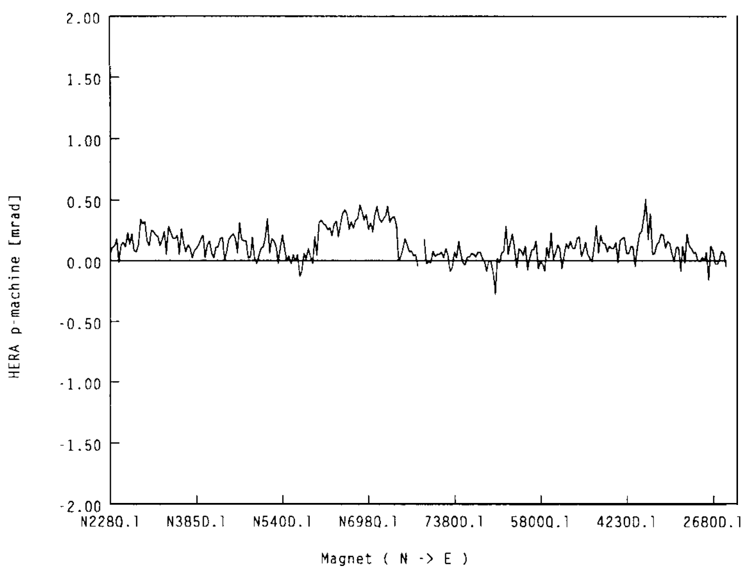

Figure 6. Differences of roll measurements (Nov. 93–Jan. 92)

2.2 BETWEEN NORTH HALL AND SOUTH HALL

In December 1994 a resurvey of the superconducting parts of the proton machine between north hall and south hall was carried out including the normal conducting straight section in east hall. The survey program was slightly changed compared to former sessions. The theodolite is now mounted on the survey platforms of the superconducting quadrupoles, which means less instrument stations are necessary for the measurements than with the old scheme. Only the two dipoles at the vertex of the magnet ring are still used as stations (Fig.7). Furthermore the TC 2002 Leica total station was used for angle and distance measurements, instead of the theodolite Kern E2 for angle and the Kern ME 5000 for distance measurements. The necessary time for the survey thus could be reduced significantly.

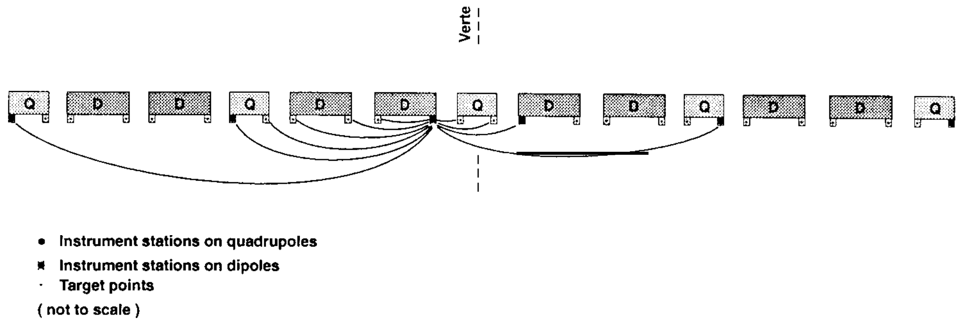

Figure 7. Survey scheme for Hera-p

The three dimensional coordinates were evaluated by a free least square adjustment of the observations related to the nominal values of three points of the traverse and the center of the coordinate system. By comparing the actual coordinates of each survey platform with their nominal value the radial(dr), vertical(dh) and azimutal(dt) deviations could be determined. Because of systematic influences during the measurements the size of dr varied between +10.8 mm and -23.8 mm, that of dh between +1.8 mm and -2.1 mm (Fig.8) and that of dt between -22.4 mm and +16.6 mm (Fig.9). The systematic parts of the deviations could be evaluated using cubic spline functions and were subtracted from the original values in order to get the relative deviations DR, DH and DT. The maximum values of DR were then ±2.6 mm with 81% less than 0.7 mm and a mean square value of ±0.34 mm (Fig.10). For DH the extremes were i-l.6 and -1.2 mm with 95’% less than 0.7 mm and a mean square value of ±0.31 mm (Fig.11). This agrees with the 1992 and 1993 measurements.

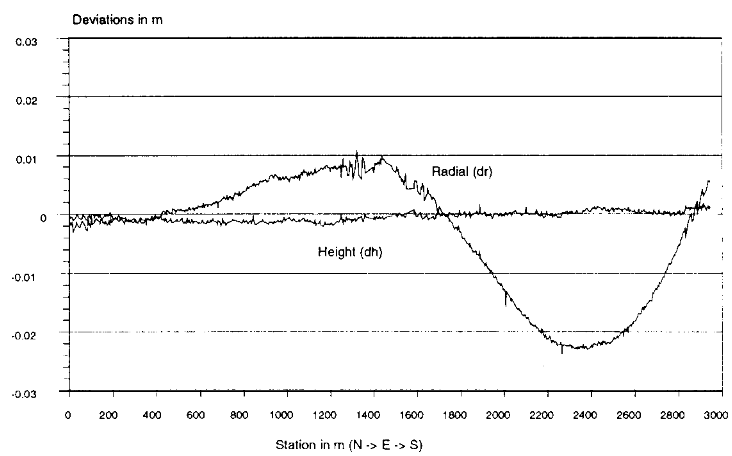

Figure 8. Radial and vertical deviations from nominal position-December 1994

The results for DT were significantly worse, as the extremes here were ±9.4 and -7.9 mm (Fig.12) with 71% less than 2.0 mm. The mean square value for these deviations was ±l.1 mm. Since the original alignment was done using steeltapes this figure is reasonable. The cause of the larger deviations of the remaining points has not yet been clarified.

The values DR, DH and DT can be directly compared with the first measurement made after the alignment in December 1990 (Tab.1 and 13, 14, 15). Only 36% of total 708 evaluated differences between the radial measurements of 1994 and 1990 were smaller than 0.3 mm with a mean square value of ±0.17 mm. For the height measurements 54% were within this margin with a mean square value of ±0.15 mm. These particular magnets obviously have not changed their radial and vertical position within the period of four years.

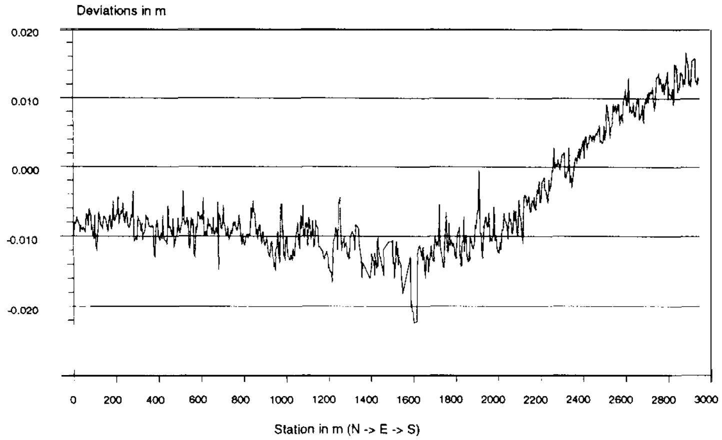

Figure 9. Azimutal deviations dt from nominal position–December 1994

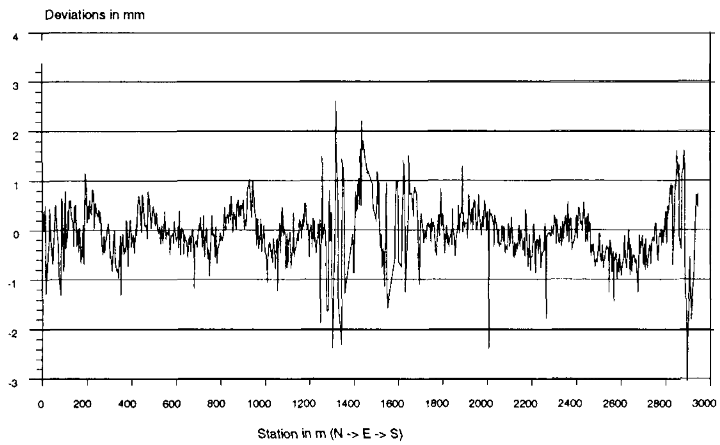

Figure 10. Relative radial deviations dR–December 1994

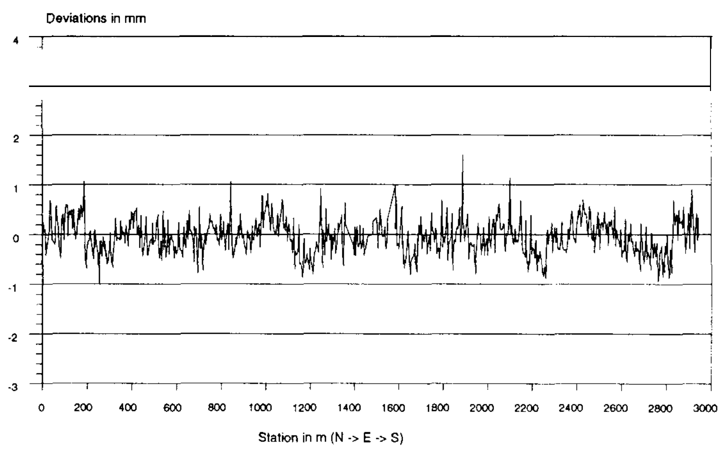

Figure 11. Relative vertical deviations DH–December1994

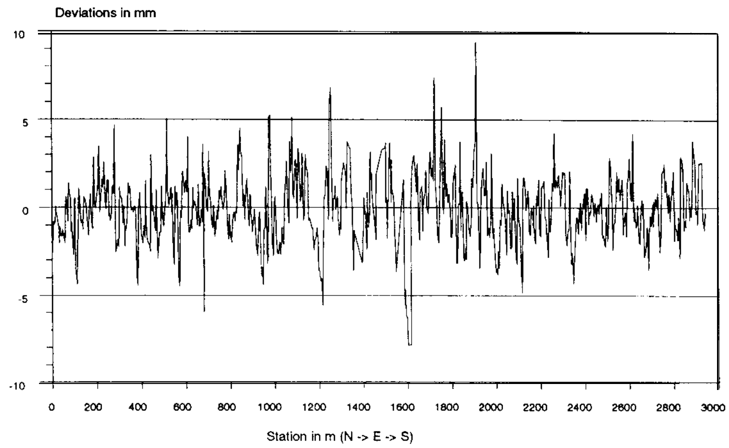

Figure 12. Relative azimutal deviations dT–December 1994

Table 1. Number and size of radial and vertical differences

Size (mm)	Number of differences dDR=DR94-DR90	Number of differences dDH=DH94-DH90
0.0 - 0.2	257	382
0.3 - 0.4	151	149
0.5 - 0.9	198	146
1.0 - 1.4	66	28
1.5 - 1.9	22	1
2.0 - 2.4	8	0
2.5 - 2.9	5	1
3.0 - 3.4	0	1
3.5 - 3.9	1	0

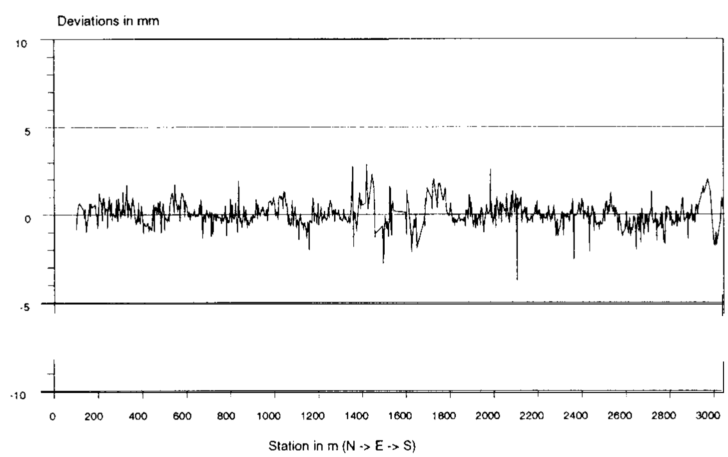

Figure 13. Differences of the relative radial deviations dDR (Dec. 94–Dec.90)

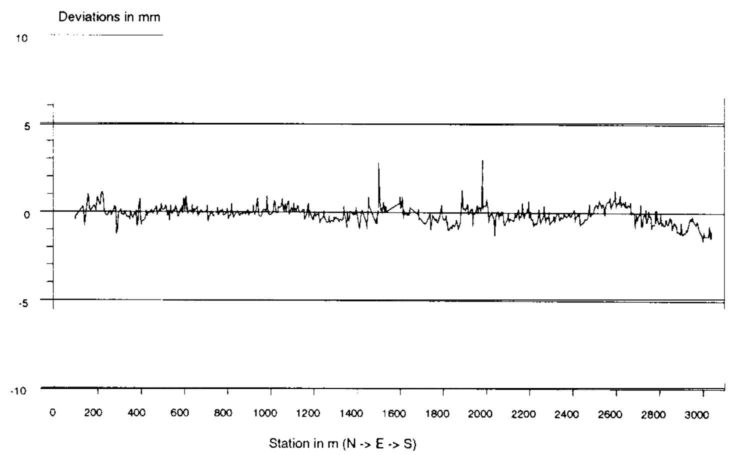

Figure 14. Differences of the relative vertical deviations dDH (Dec. 94-Dec. 90)

The comparison of the azimutal measurements of the survey platforms is shown in the following table (Tab.2). In this case 73% of the azimutal measurements were reproducible within ±1 mm with a mean square value of 30.50 mm which means that the corresponding magnets have only slightly moved, if at all, in this direction.

Table 2. Number and size of the azimutal differences

Size (mm)	Number of Differences dDT=DT94-DT90
0.0 - 0.2	200
0.3 - 0.9	315
1.0 - 1.9	151
2.0 - 2.9	27
3.0 - 3.9	7
4.0 - 4.9	7
5.0 - 5.9	1

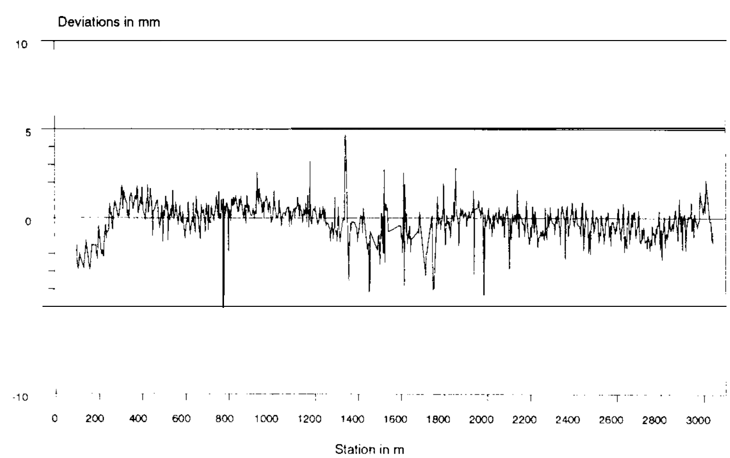

Figure 15. Differences of the relative azimutal deviations dDT (Dec. 94-Dec. 90)

The other magnets have obviously changed their azimutal position. These movements most probably were caused by the heavy forces which were generated by vacuum breakdowns, quenches and instabilities of the magnet supports which occurred mainly during the first year of operation.

3 INFLUENCES FROM OUTSIDE ON THE HERA - MACHINES

It, is obvious that civil engineering work on the surface near the tunnel axis influences the HERA-machines. In the summer of 1992 the excavation of the construction pit for a new office building between south hall and west hall outside the DESY-area caused an elevation of the HERA-ttunnel of about 7 mm. That was discovered in January 1993, by a measurement of the height, of the electron accelerator, because it had become extremely difficult to run the machine in this region (Fig.16). The deviations were eliminated by an alignment of the electron magnets and the result was, that the accelerator ran well again.

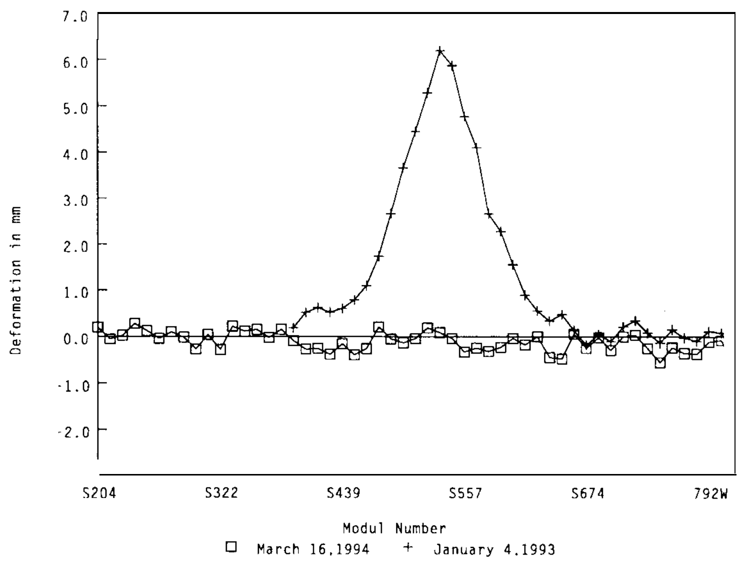

Figure 16. Influence of a civil engineering project on the height of the Hera e-machine between south hall and west hall

In January 1994 a second adjustment was necessary, this time in the opposite direction, since the electron machine had moved about 2 mm down due to the weight of the building even though special foundations had been constructed to prevent this effect.

Though the proton machine suffered the same movements as the electron machine it could be operated without bigger problems. Its position was only measured in December 1994. The results confirmed those obtained from the electron accelerator (Fig.l7), so that the proton magnets in that area were realigned vertically in January 1995. The alignment was done in several small steps, because the superconducting magnets are connected to each other with very stiff fixing sleeves, so that they form a compact string of magnets. Small shifts in radial or vertical direction of less than 0.5 mm are possible for the individual magnet without opening of the magnet connections. but it is not possible to make roll corrections in these conditions.

The results of this alignment will be seen in the winter shut down of 95/96, when a first resurvey of the complete proton ring is planned to take place.

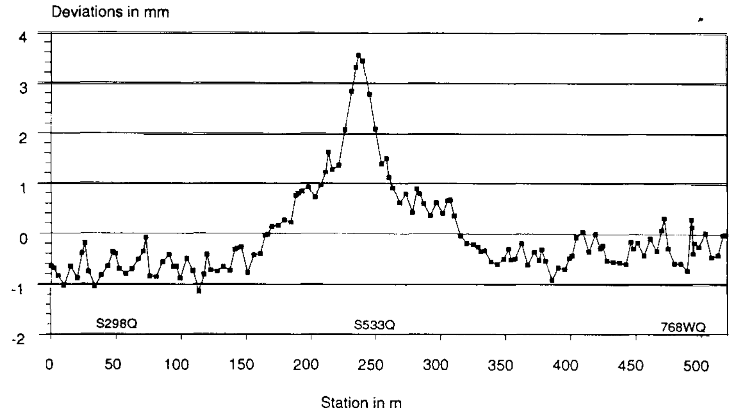

Figure 17. Influence of a civil engineering project on the height of the p-machine between south hall and west hall (Dec. 1994)

4 NEW EXPERIMENTS

4.1 THE HERMES-EXPERIMENT

Two experiments were installed in HERA at the very beginning, ZEUS in south hall and Al in north hall [6] [7].

Since spring 1995 a third experiment called HERMES became operational in east hall (Fig.18). Its aim is the research of the spin structure of the nucleon. The components of the detector were mounted in 1994 in the hall area and installed in the electron beam line in the shut down 1994/1995.

Standard geodetic methods were applied to align the various parts of the experiment (magnet, vertex chambers, forward chambers, magnet chambers and backward chambers, Cerenkov counters, TRD, hodoscopes and calorimeter). The chambers behind the detector magnet were only accessible from the sides of the experiment. They were therefore equipped with appropriate survey points attached to the frame of each chamber. There were two on each side which were at a known position to the beam axis (Fig.19). The position of these survey points with respect, to the detector axis could be determined by polar measurements from datum points (Kern centering plates). They were installed temporarily during the mounting phase in east hall on both sides of the detector and on the detector axis mounted on concrete blocks (Fig.20). The coordinates of these datum points with respect to the beam were defined by angle- and distance measurements using the Kern E2 and the Mekometer ME 5000. The chambers were aligned from the datum points by angle and distance measurements with the TC 2002 Leica total station using reflecting foils attached to the targets. The measurement of four points on each chamber provided an easy control of the quality of the alignment.

Only the target chamber and the vertex chambers in front of the detector magnet were fitted with the standard reference sockets, for Taylor Hobson spheres, as used in the HERA tunnel and with reference points for roll measurements. They were aligned directly from the beam axis as it was done with the detector magnet itself. It carries a number of reference sockets which define the magnet geometry.

The calorimeter at the end of the experiment was fitted with two Taylor Hobson sockets, one on each side. They were not only used for the alignment of the calorimeter itself. but also for the

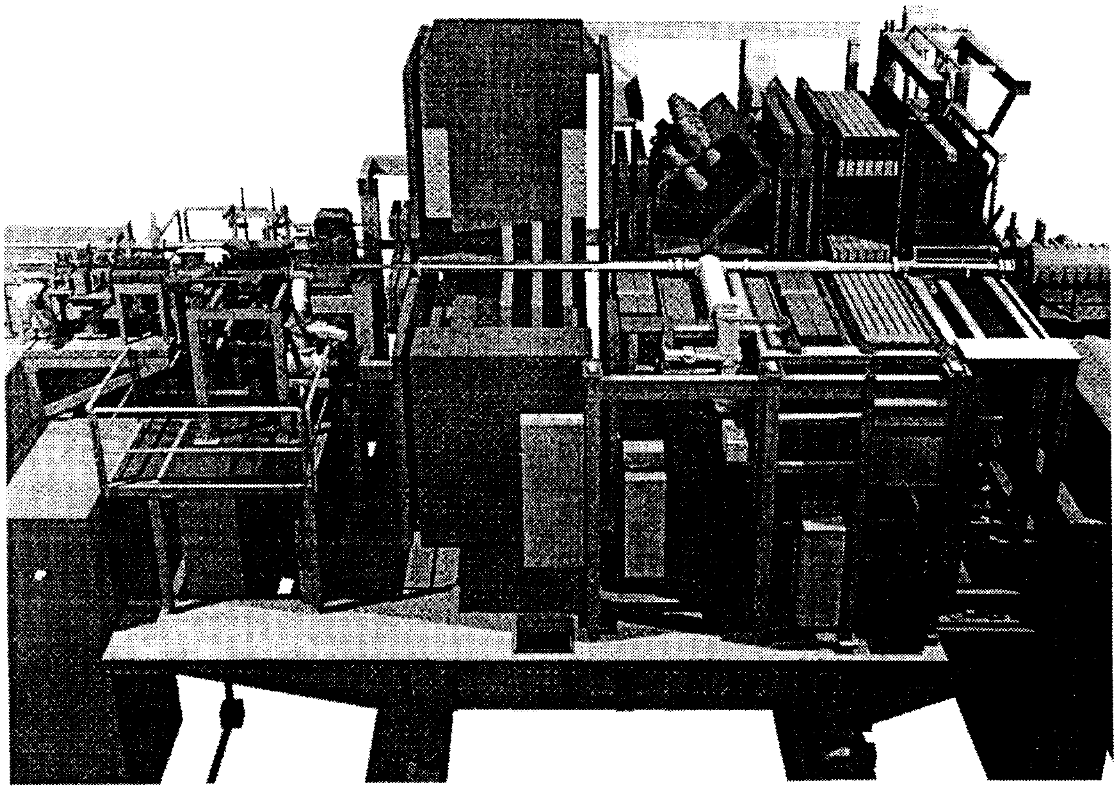

Figure 18. HERMES-Isometric-Cut

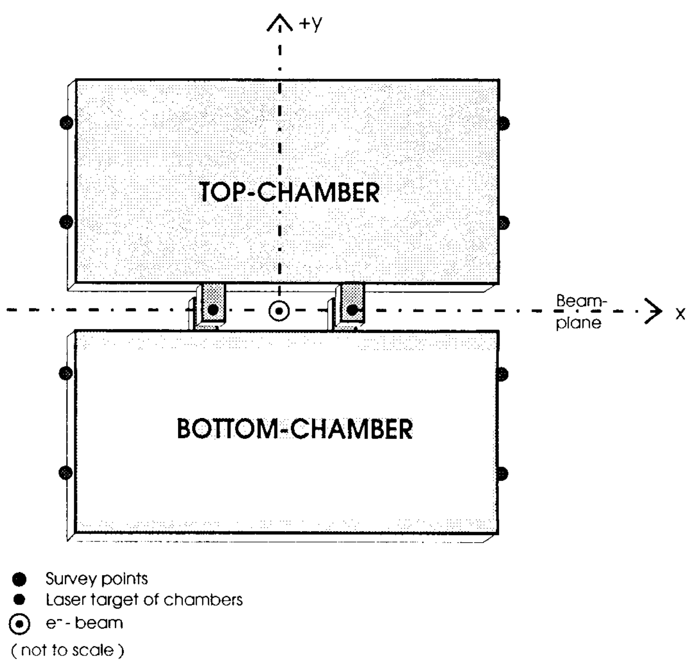

Figure 19. Position of the reference points at the Hermes-chambers

positioning of the experiment when it was moved from its parking position in the hall to the final beam position. The Taylor Hobson spheres of the calorimeter on one end and those on the target chamber on the other could be directly pointed at from neighboring accelerator magnets and so

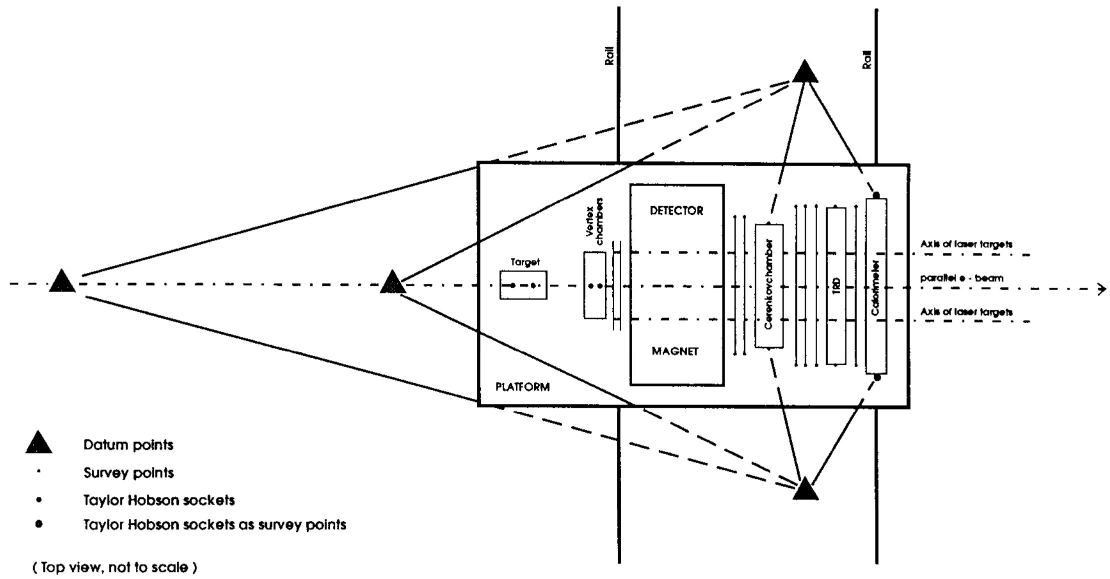

Figure 20. Survey scheme for the alignment of the Hermes-detector in parking position

be moved to their nominal position. The roll of the experiment was determined by simultaneously measuring the height differences of the two spheres on the calorimeter. Since it changed as the experiment was moved to beam position it had to be restored by adjusting the support platform using the hydraulic carriages.

The relative position of the chambers can be controlled during operation of the experiment by a laser system, which was developed and installed by Japanese members of the HERMES-collaboration. Therefore, each chamber was additionally equipped with two laser targets at the level of the beam plane (Fig.19). Their positions with respect to the beam axis and beam plane were determined before installation by the DESY survey group, in a similar way to the survey points. These laser targets define the radial and vertical positions of the HERMES chambers and their roll. During the installation phase they could therefore be used by the survey group for an additional control of the alignment. The deviations of the targets from a straight line were determined by angle measurements with theodolites, which were adjusted on the two laser lines. It could be demonstrated by these measurements that all chambers had been positioned to within 0.4 mm in radial and 0.8 mm in vertical directions with a reproducibility of better than 0.1 mm.

4.2 THE HERA-B EXPERIMENT

A fourth experiment, HERA-B will be installed in the future in the west hall. It will study CP violation in the B system using an internal target in the proton ring. The main detector components are shown in Fig.21. They are the silicon vertex detector, the main tracking system with a dipole magnet, TRD and RICH counters for particle identification, the electromagnetic calorimeter and the muon system. The detector will be mounted on movable platforms, in order to provide access to the tunnel for the HERA tram and the alignment of the accelerators.

At the end of the 1995/1996 winter shut down the first components are planned to be installed in the proton beam (detector magnet and muon iron). Therefore a modification of the accelerator lattice is necessary which means, that many machine components have first to be shifted or replaced by new elements in the region of the experiment.

The mounting of the detector magnet and the iron absorber of the muon chambers will take place

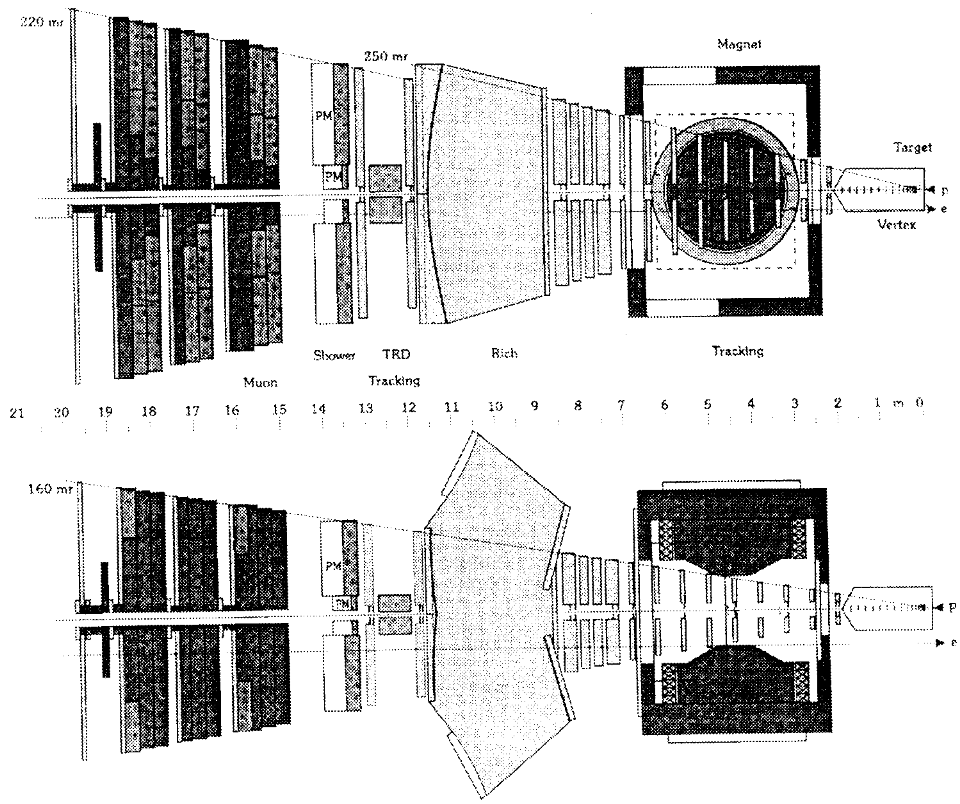

Figure 21. Top- and Sideview of Hera-B

in the hall area before. The magnet is equipped with a number of reference sockets on the outside. which were machined at defined positions during the manufacture of the iron parts of the yoke. They allow DESY standard targets to be inserted for geodetic measurements, so that all these sockets can be related to the geometrical axis of the magnet after it has been completely mounted. Then these sockets can also be used as reference points for the magnetic field measurements. which have to be carried out before the magnet is moved to the beam position. The final alignment of the magnet in the beam position will be based on these reference points and will be done from neighboring accelerator magnets as instrument stations. The positioning of the muon absorber will be carried out in a similar way.

5 THE TESLA TEST FACILITY

Two research facilities for future linear colliders are under construction at DESY. One uses conventional travelling wave accelerating structures at 3 GHz (S-band) and g = 17 MV/m, the other one superconducting Nb standing wave accelerating structures at 1.3 GHz (L-band) and is aiming for an accelerating gradient “g” above 15 MV/m.

Details on the first collider study (SBLC) are given by W. Schwarz in reference [8]. Some aspects of the second project (TTF-Tesla Test Facility) will be discussed in the following section.

The layout of the TTF is shown in Fig.22. Its main objective is to process and test industrially fabricated Nb cavities and demonstrate that they have stable operation with a gradient of at least 15 MV/m. The infrastructure includes facilities for chemical etching and high pressure rinsing, heat treatment in an UHV oven and high peak power processing of the cavities. The TTF-linac consists of an injector including its gun, a capture cavity and a diagnostic section, followed by a first cryomodule and a warm section (for the later installation of a magnetic bunch compressor) and three more cryomodules. The linac facility is completed by a diagnostic area for beam experiments. Each of the four linac modules houses eight superconducting cavities of 1 m length, which are assembled as a string. The last elements of the string are a beam position monitor and a superconducting quadrupole doublet. Every cavity has its own helium vessel and the whole string is supported by a long helium gas return pipe (Fig.23). The operating temperature is 1.8 K.

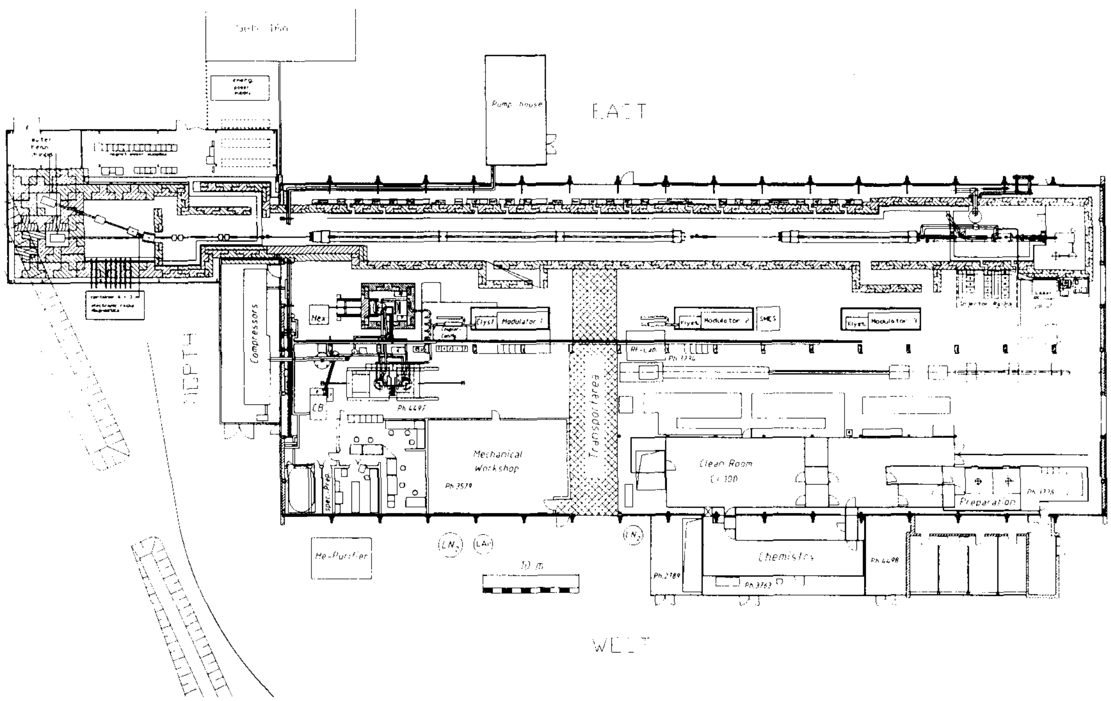

Figure 22. Layout of the Tesla Test Facility

The cavities are assembled and connected to a string in a class 100 cleanroom in order to avoid contamination of the cavity surface. The transverse position of the cavities during this procedure is fixed by a support structure which is well aligned by a machined guiding rail. Only the roll of every cavity must be corrected separately using the input coupler flanges as a reference. The final assembly of the string is done outside the cleanroom at the end position on the guiding rail.

Before the string can be inserted into the cryostat tank it has to be moved to the so called “Installation Area”, where three supports simulate the final attachment of the helium gas return pipe to the cryostat. In this position the eight cavities and the quadrupole doublet must be aligned in the correct transverse positions with respect to the return pipe. Each element therefore has been equipped with four optical targets, two at each end, which give the reference position with respect to the beam axis together with the input coupler (Fig.24). With these targets the alignment can be accomplished using vertical and horizontal angular measurements with two theodolites, which are positioned on the nominal axes of the targets (Fig.25).

After this alignment the cavity string is inserted in the cryostat tank and fixed to the three final supports. The return pipe should then be in its nominal position with respect to the tank and the beam. Small adjustments are still possible if necessary. They have to be carried out using measurements made with Taylor Hobson sockets and spheres for roll which are mounted on top of the support structures of the pipe.

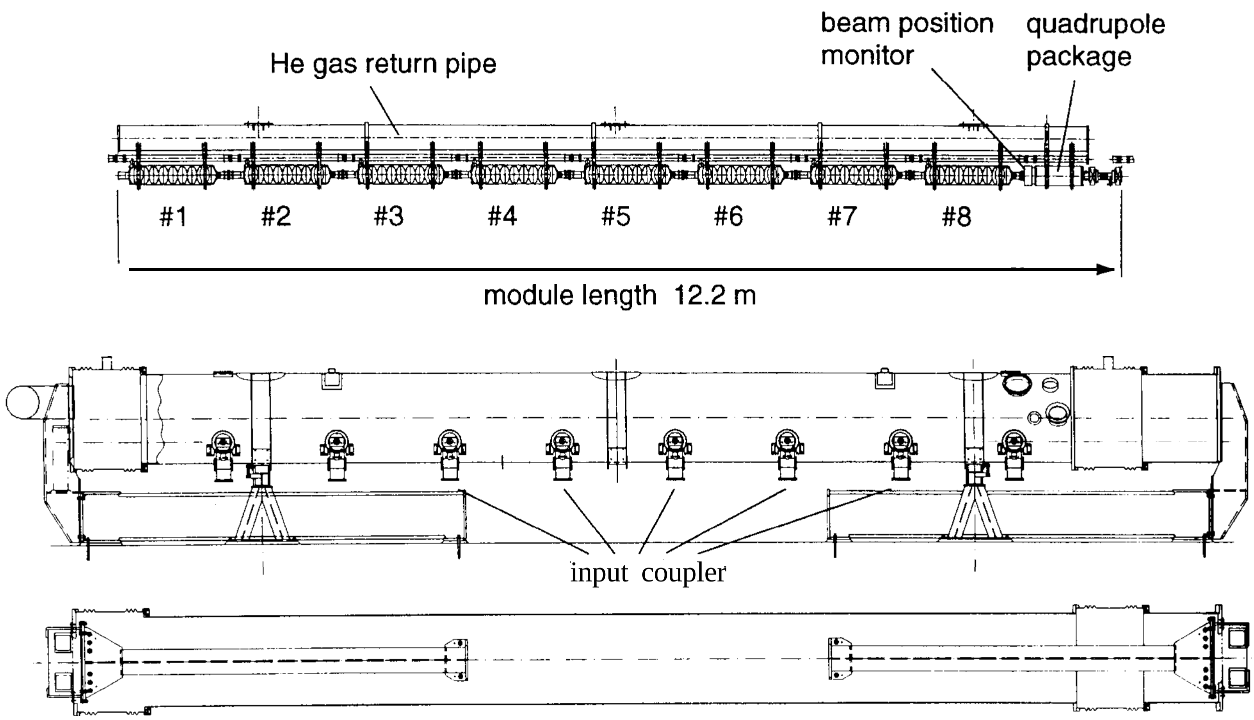

Figure 23. Cryo module of the Tesla Test Facility

Additional measurements with theodolites then give the final position of the cavity and magnet targets. All these optical targets can be illuminated and are attached in such a way, that they can be pointed at with theodolites situated in front of the tank. If changes with respect to the positions in the “Installation Area” can be found they have to be taken into account as coordinate corrections for the corresponding elements.

Each tank is equipped with two reference plates on the side, which carry the centering sockets for Taylor Hobson spheres and additionally reference spheres for roll measurements, as it is standard for the HERA proton ring. The coordinates of these survey points are determined simultaneously with those of the optical targets during the control measurements after insertion of the cavity string in the cryotank. The alignment of the cryomodules in their final location in the linac lattice can then be carried out in a similar way to the methods known for the HERA accelerators.

It will be interesting to get information on the stability of the cavities during cool down. It’s planned to observe the behaviour of the first module by optical measurements of the target positions. This should be possible by pointing through optical windows, which are installed in the endcaps in front of the optical targets. Additionally it is planned to install a stretched wire system inside the tank, which will be able to indicate movements of the cavities immediately. The necessary sensors will have to be aligned after the optical alignment of the cavities in the “Installation Area”. If the two methods will definitely work has to be shown yet. Up to now no complete string of cavities is available for tests.

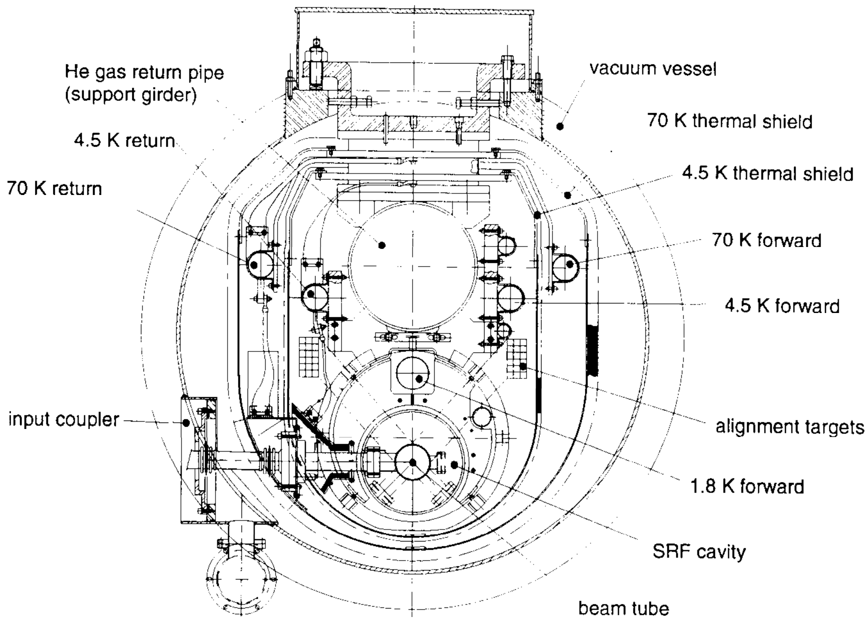

Figure 24. Cross Section of the Cryo module

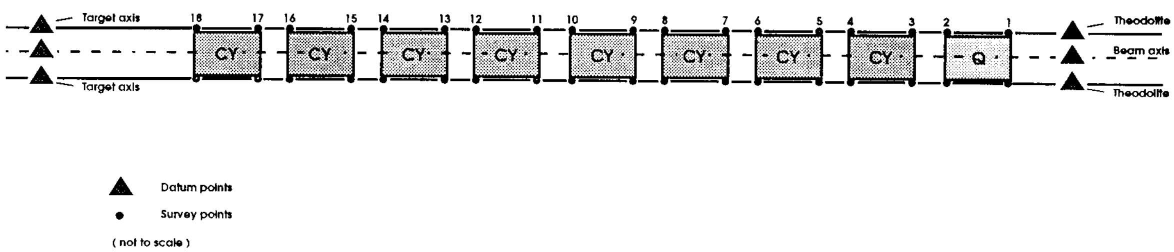

Figure 25. Survey scheme for the transverse alignment of the TTF-cavities

6 CONCLUSION

The results of the geodetic measurements of the proton ring show, that the desired surveying accuracy can be reached without problems. The stability of the magnets is worse than expected but this has, until now, had no serious effects on the operation of the machine. The alignment of the experiments HERMES and HERA-B and that of the components of the TTF linac are standard geodetic tasks. Control measurements of the superconducting cavities during cool down by pointing with a theodolite however will depend on the behaviour of the optical windows and the target illumination under vacuum and low temperature. Thorough tests will only be possible, if a working cryomodule is available. This is also the case for the stretched wire system inside the cryotank, which will be installed by the manufacturer of the tanks.

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