4.8 Survey and Alignment

4.8.1 Network on the Surface of the Earth

First, the coordinates of reference points along the linear collider have to be determined with respect to the existing coordinate system at the respective site (in case of DESY, this would be the HERA coordinate system). The reference points are the base to mark out the planned halls. The demanded global accuracy (standard deviation) of the reference points should be better than 5 mm over the whole area of the linear collider of about 30 km. Today the coordinates will be measured by the satellite system GPS (GPS = Global Position System). With points on the top of the halls the coordinates have to be transferred into the tunnel to control the tunnel boring machine and later on to mark out the supports of the components of the beam transport system. With a precision levelling a vertical network also has to be established.

4.8.2 Requirements for the Aligment of the Components

In the groundplan the tunnel axis is a straight line approximately. In the vertical plane the axis of the tunnel follows the earth curvature except for the first 6.5 km. Then the height of the tunnel in this area is constant everywhere. The heights are referenced to the geoid. Therefore it is possible that the earth radius for the tunnel axis is not constant. Depending on the gravity of earth small changes in the radius are possible.

In the tunnel there are 5 separate beam lines to be aligned. The components of each beam line have to be aligned with a high accuracy. The standard deviation of any point over a range of 400 m (this is the maximum betatron wave length) in the transverse direction should be better than 0.5 mm horizontally and 0.1 mm vertically.

Therefore it is too inefficient to align each beam line separately. It will be more efficient to have only one alignment (basic alignment). Then the components of each beam line have to be connected to the basic alignment.

4.8.3 Basic Alignment

The reference points for the basic alignment are fixed on the tunnel wall. They are only target points, not suitable to put geodetic instruments on. The distances between the points are between 25 m to 50 m. The geodetic instruments will be set on a moveable carriage (Fig. **??**). The carriage rolls on beams mounted on the tunnel wall above the causeway. The carriage can be fixed to the tunnel wall at any position with clamps.

The basic alignment can be carried out with Precision Total Stations (Tachymeters). A Tachymeter measures the horizontal angle, the vertical angle and the distance to the target point simultaneously. These measurements can be carried out either manually or automatically. The targets are Taylor–Hobson–Spheres for the manual and prisms in Taylor–Hobson–Spheres for the automatic methods. "Automatic" means that a computer controls the instrument, and the target recognition will be done automatically. The accuracy is for both instruments

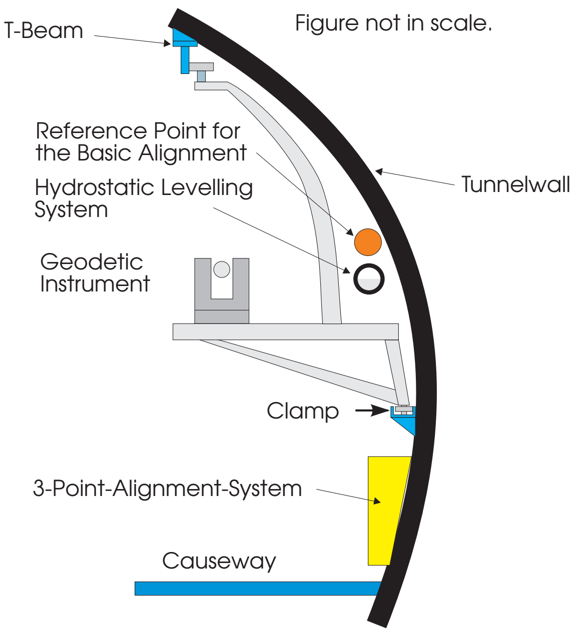

Figure 4.8.1: *Movable Carriage for the Geodetic Instruments and Locations of different Measuring Devices*

- horizontal direction 0.2 mgon (3 μrad),
- vertical angle 0.2 mgon (3 μrad) and
- distance 0.1 mm.

To coordinate the reference points on the tunnel wall the movable carriage with the Tachymeter can be set in front of each reference point. Now one can measure to several reference points, for example to two or three points back– and forward. How many points are to be measured is a question of the demanded accuracy. Fig. **??** shows the expected accuracy of a point in the middle of a 600 m long area in dependence on the number of measured target points and of the distances between the target points. The required accuracy can be achieved by using at least 3 reference points.

In the calculation only random errors are taken into account. What are the effects of systematic errors (for instance the refraction of air)?

4.8.4 Systematic Effects: Refraction of Air

Refraction of air means that if the density of the air is not constant then the line of sight to the target point is not a straight line exactly. The density depends mainly on the temperature of air. If there is a constant gradient in temperature for example of 0.1 degrees/m, a line of sight with a length of 600 m will follow a circular curve with an offset of 4.5 mm. These effects exceed the demanded accuracy by far and it is very difficult to determine their actual amounts. But there are some techniques available to reduce the effects of refraction of air:

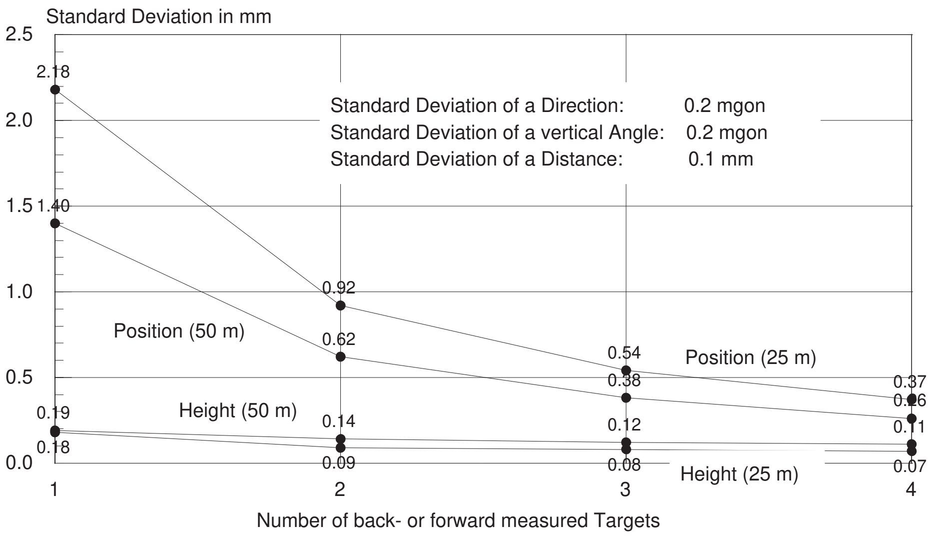

Figure 4.8.2: *Expected Accuracy in the Middle of a 600 m long section*

- hydrostatic levelling system for the vertical position,
- angle measurements without the effects of refraction (under development),
- Heelsche Alignment System (It does not work here, because the collider is not a straight line. In the vertical it follows the earth curvature.),
- stretched wires in an overlapping manner for the horizontal position,
- 3–point–alignment–technique for the horizontal position.

In the following the hydrostatic levelling system and the 3–point–alignment–technique will be described in detail.

4.8.5 Hydrostatic Levelling System

In the part of the tunnel which is horizontal, it is possible to install a pipe filled half with water. The pipe is mounted along the tunnel wall, so that the reference points are directly above the pipe (Fig. **??**). A movable device with a capacitive distance sensor can be set in the reference point to measure the height of the reference point in respect to the water level. The water level is horizontal but it is not a curve with a constant radius. The accuracy of the sensor is better than 5 μm und therefore it seems possible to measure the heights of the reference points over a length of about 600 m better than 0.1 mm. If the water level makes vibrations one can reduce this effekt by breakwaters which are mounted in the pipe.

4.8.6 3–Point–Alignment–System

A technique to reduce the effects of refraction of air will be given by the "3–point–technique". For example there are mounted reference plates on the tunnel wall in

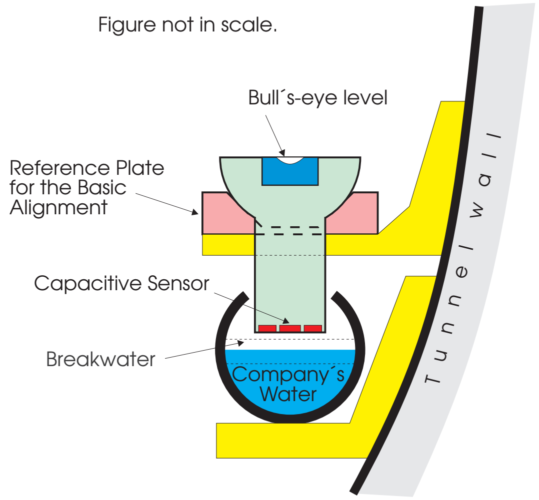

Figure 4.8.3: *Hydrostatic Levelling System*

regular distances (1 m oder 2 m). From a movable bar in each position the distances will be measured to the 3 opposite reference points (Fig. **??**) to better than 1 μm by capacitive sensors. The distances are very small, about 0.5 mm. The distances define the horizontal angle of the reference point in the middle to the both other neighbouring points. Therefore a traverse is measured and the displacements of each reference point in respect to a reference line can be calculated. The accuracy depends mainly on the stiffness of the bar. If the accuracy of the distance sensor is 0.1 μm, over an area

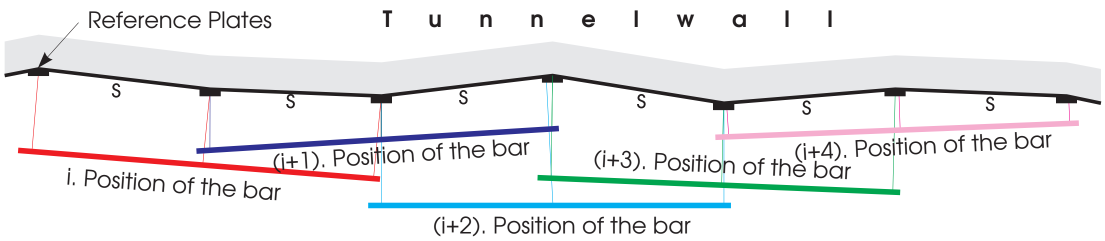

Figure 4.8.4: *Straightness measurements with the "3–Point–Technique"*

of 600 m the displacements of the straightness can be measured better than 0.5 mm (Fig. **??**). In this calculation the distances between the reference plates are 1 m and 2 m. Now it is possible to have bars with lenghts up to 10 m or 20 m. But in this case the bars are not stable enough by themselves. With a stretched wire and a differential diode mounted in the bar the stiffness of the bar can be controlled. A 26 m long test assembly with reference plates in 1 m distance has shown that the calculated accuracy will be achieved.

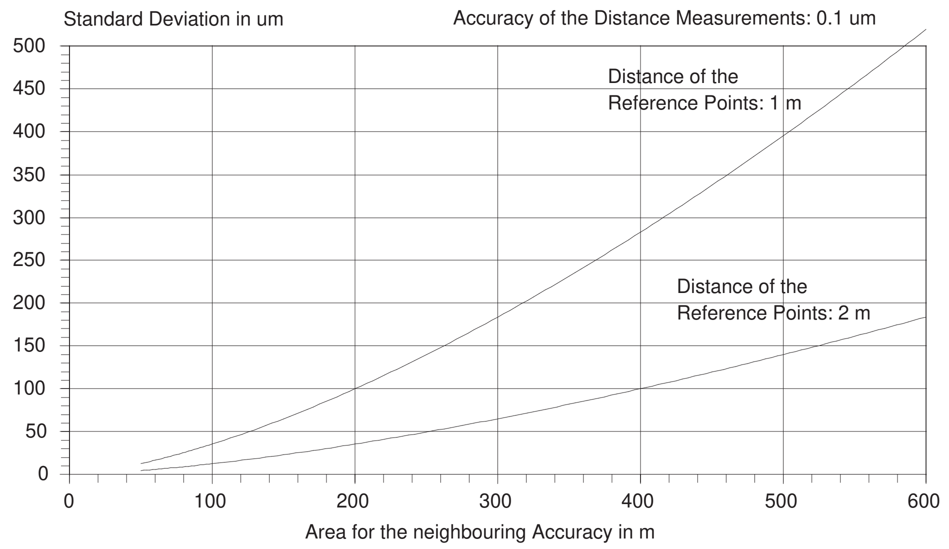

Figure 4.8.5: *Expected neighbouring accuracy for straightness measurements with the "3–Point–Technique"*

4.8.7 Transfering the Coordinates

After performing the measurements as discussed above, the coordinates of the reference points on the tunnel wall are available with the demanded accuracy. In the next step the coordinates of the reference points have to be transferred to the components of each beam line. For this each magnet should have two reference plates for targets and a support to measure the roll. The movable carriage is positioned at any place so that the neighbouring reference points and the points of the component which has to be aligned can be pointed out. The measurements to the reference points define the coordinates of the point on the movable carriage. Then the alignment of the component can start. For this one can use the following geodetic instruments

- Precision Total Stations (Tachymeters),
- Lasertracker and
- new instruments (under development).

The alignment will be carried out for each component individually. To control the adjustment it is advisable to make a control measurement in which the reference points and the magnet points are included simultaneously. To have a good redundancy each magnet point is measured twice from the neighbouring instrument station of the geodetic instrument.