Concept for the Alignment of the planned Linear Collider at DESY

Willfried Schwarz
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

1 INTRODUCTION

High-energy e^+e^--colliders have been essential instruments in the search for fundamental constituents of matter and their interactions. The intention is to have collisions by energy range up to the TeV scale. This requires further development of collider technologies. A possible solution consists of two opposing linear accelerators with more than 30 km. At present around the world different studies are under way to gain experience for the realisation of this. At DESY two different collider concepts are studied, one is the TESLA project. In the TESLA project superconducting cavities will be used. At DESY a Test Facility is under construction. The alignment of the TESLA Test Facility is described in [2]. In the following for the TESLA Linear Collider the alignment concept will be described.

2 GENERAL LAYOUT OF THE TESLA LINEAR COLLIDER

A sketch of the overall layout of the TESLA Linear Collider is given in Fig. 1. More information about the TESLA layout are given in [1].

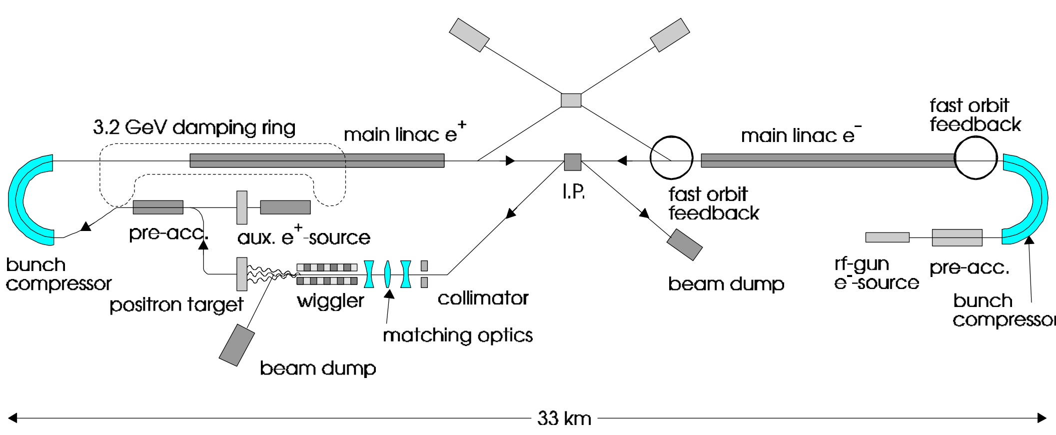

Figure 1 . Sketch of the overall Layout of TESLA

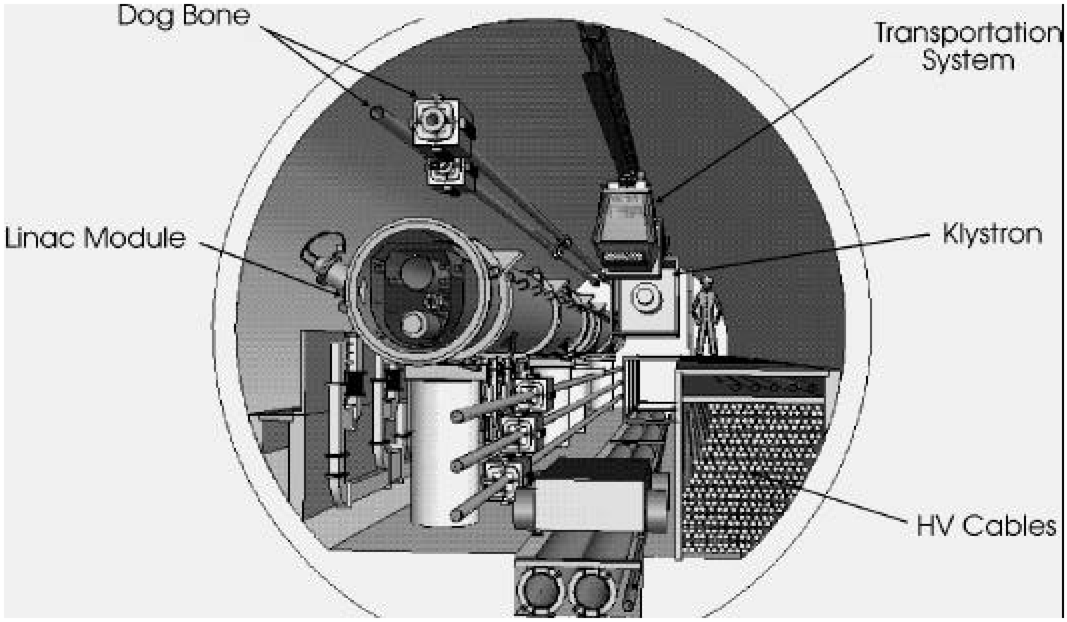

Figure 2. Sketch of the TESLA Linac Tunnel

The Linear Collider will be built in a tunnel at a depth of about 15 m. The tunnel with an inner diameter of 5.20 m starts on the existing DESY area next to the HERA Hall West in north-north-western direction (Fig. 3). The tunnel is straight in plan view up to the end station. In side

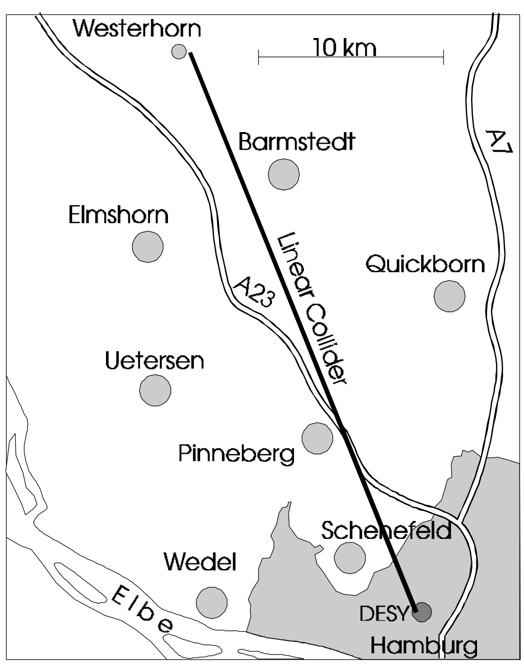

Figure 3. Overall view of the Linear Collider site at DESY

elevation the tunnel is mainly horizontal and follows the earth curvature. Within the first 6.5 km section the change, in the elevation, from the existing HERA to the Linear Collider will be done (Fig. 4). In a single bay distance of about 5 km halls are planned for the cryogenics.

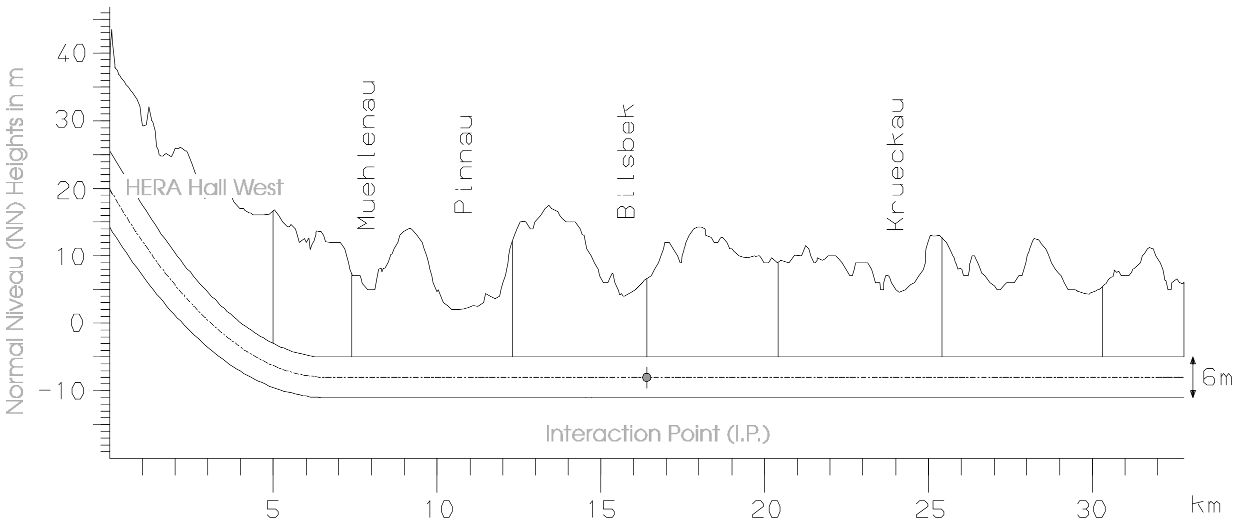

Figure 4. Elevation of the Linear Collider

3 REQUIREMENTS FOR THE ALIGNMENT

In the groundplan the tunnel axis is a straight line approximately. In the vertical plan the axis of the tunnel follows the earth curvature except for the first 6.5 km. Then the elevation 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 several 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 the maximum betatron wave length (= 576 m) in the transverse direction should be better than

- *0.5 mm horizontally* and
- *0.1 mm vertically*.

For a linear collider the area is essentially larger over which the accuracy demands have to be realized in comparision with a circular accelerator. It is too inefficient to measure each beam line separately. It will be more efficient to have only one measurement (basic measurement). Then the components of each beam line have to be connected to the basic measurement.

4 BASIC MEASUREMENT

First, the coordinates of reference points along the linear collider have to be determined with respect to the existing coordinate system on DESY area (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 Positioning System). With points on the top of the halls the coordinates have to be transfered 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. By precision levelling a vertical network also has to be established.

4.1 Optical Measurement

The reference points for the basic measurement 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. 5). 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 measurement can be carried out with Precision Total Stations (Tachymeters). A Tachymeter measures simultaneously the horizontal angle, the vertical angle and the distance to the target point. 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 instuments

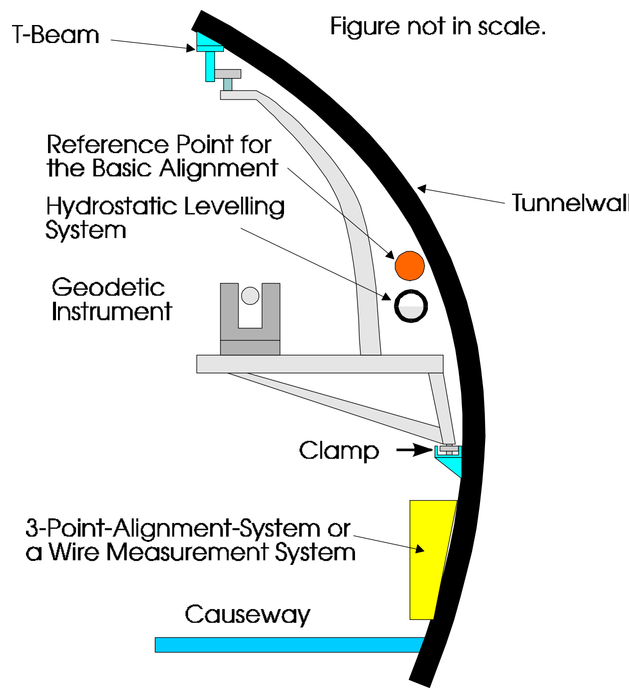

Figure 5. Moveable Carriage for the Geodetic Instruments and Locations of different Measuring Devices

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

To coordinate the reference points on the tunnel wall the moveable carriage with the Tachymeter can be set in front of each reference point. This allows to measure to several reference points, for example to two or three points back- and forward. The number of points to be measured depends on the demanded accuracy. Fig. 6 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 if from each station the measurements are carried out to three reference points (Fig. 6).

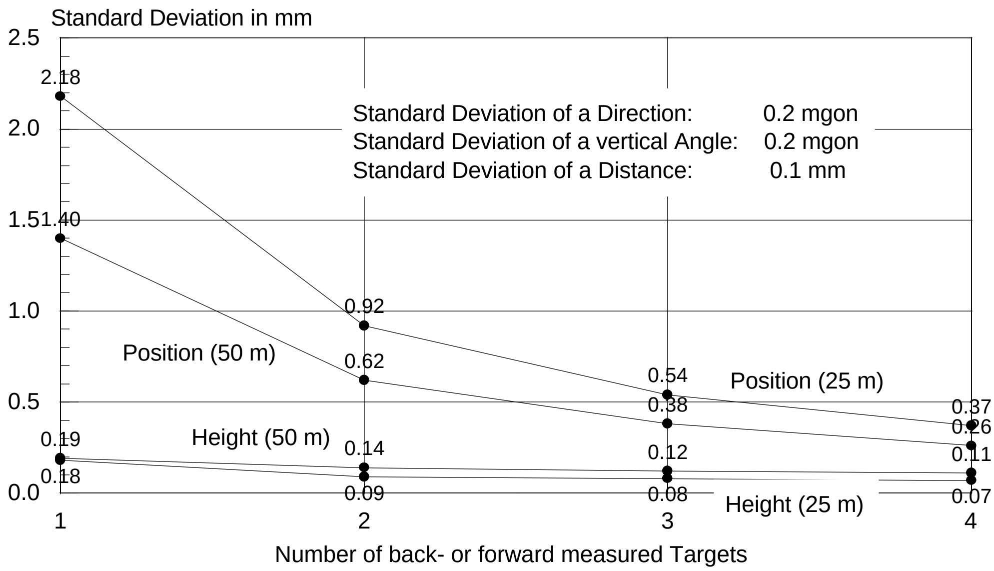

Figure 6. Expected Accuracy in the Middle of a 600 m long Area

In the calculation only random errors are taken into account. We must also look at the effects of systematic errors, for instance the refraction of air?

4.2 Systematic Effect: 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 exactly a straight line. The density depends mainly on the temperature of air. If there is for example a constant gradient in temperature the line of sight will follow a circular curve (Fig. 7). The deviation angle γ is given by

$$\gamma = \int_{x=0}^{x=l} \frac{\partial n}{\partial y} \cdot dx$$

with n = refraction index of air.

Is $\partial n / \partial y = const = a$, it follows

$$\gamma = a \cdot l \quad \text{and}$$

$$z = \frac{l^2}{8} \cdot a$$

z : maximum offset of the line of sight

By approximation it is

$$\frac{\partial n}{\partial y} = -10^{-6} \cdot \frac{\partial T}{\partial y} = a$$

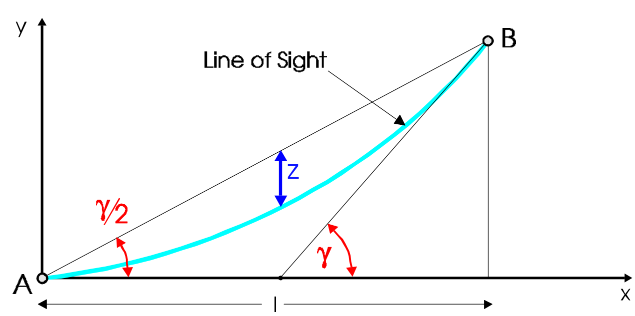

Figure 7. Refraction of air

$\frac{\partial n}{\partial y}$: Gradient in refraction index

$\frac{\partial T}{\partial y}$: Gradient in temperature of air

Is there for example a gradient in temperature of only 0.1 degree/m the maximum offset of the line of sight with a length of 600 m is 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:

- angle measurements without the effects of refraction (under development),
- hydrostatic levelling system for the vertical position,
- Heelsches 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 more detail.

4.3 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. 8). A moveable 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 effects by breakwaters which are mounted in the pipe.

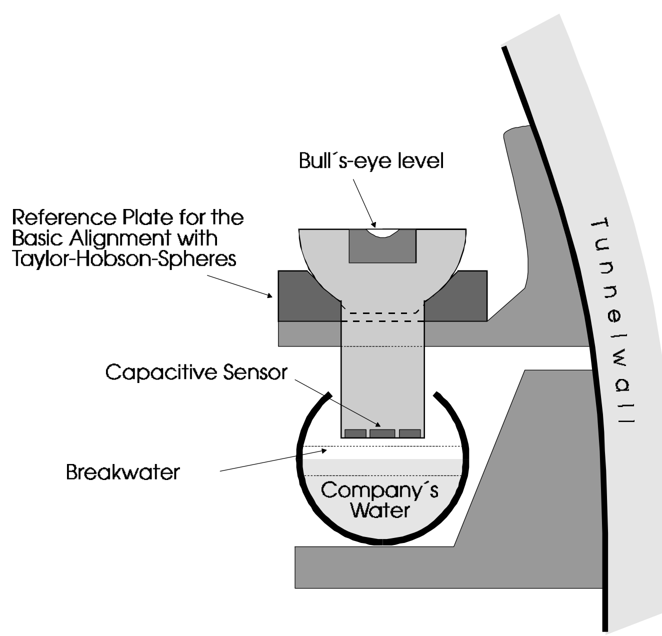

Figure 8. Hydrostatic Levelling System

4.4 3-Point-Alignment-System

A technique to reduce the effects of refraction of air will be given by the „3-point-alignment-technique“. For example there are mounted reference plates on the tunnel wall in regular distances

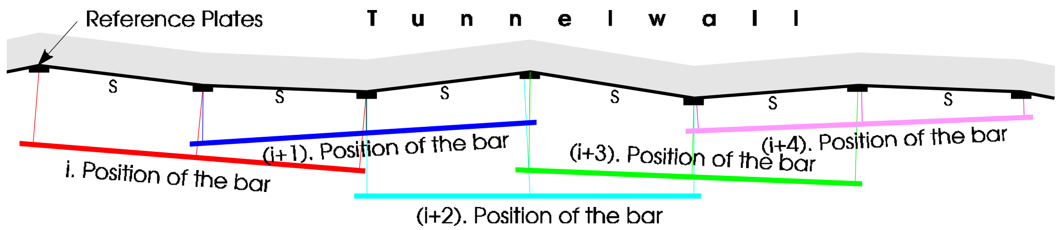

Figure 9. Straightness Measurement with the "3-Point-Technique"

(1 m oder 2 m). From a moveable bar in each position the distances will be measured to the three opposite reference points (Fig. 9) 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 of the point in the middle of the area is given by [3]

$$s_q = s_a \cdot \sqrt{n^3 + n/2}$$

With s_q : Standard deviation of the offset of the point in the middle of the area,
s_a : Standard deviation of a distance measurement to the reference plate,
n : Number of the traverse lines from the beginning to the middle of the area.

If the accuracy of the distance sensor is 0.1 µm, over an area of 600 m the displacements to the straightness can be measured better than 0.5 mm (Fig. 10).

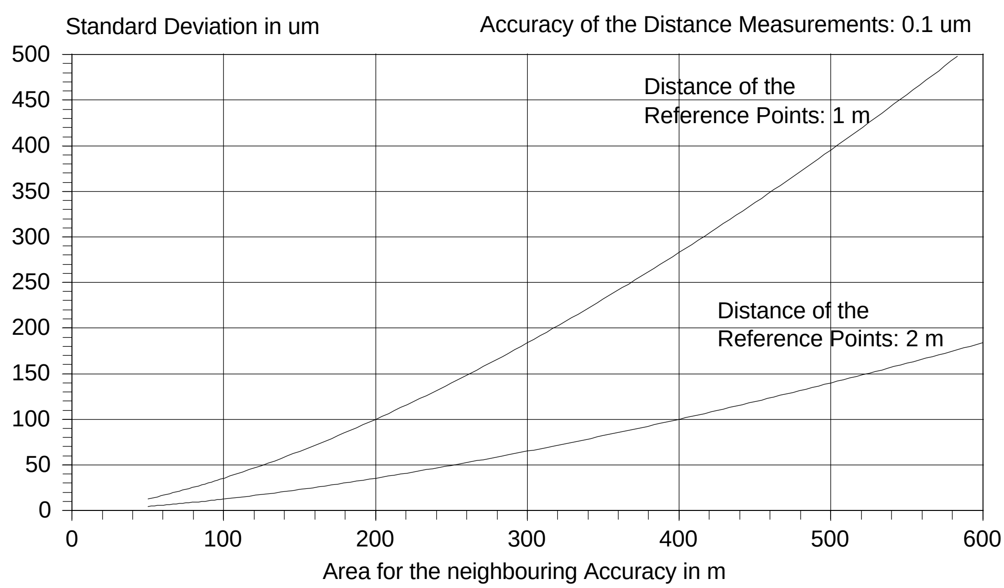

Figure 10. Expected neighbouring Accuracy for Straightness Measurements
with the "3-Point-Alignment-Technique"

Besides the accuracy of the distance sensor, the accuracy depends mainly on the stiffness of the bar. In this calculation the distances between the reference plates are 1 m and 2 m. Now it is possible to have bars with lengths 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.

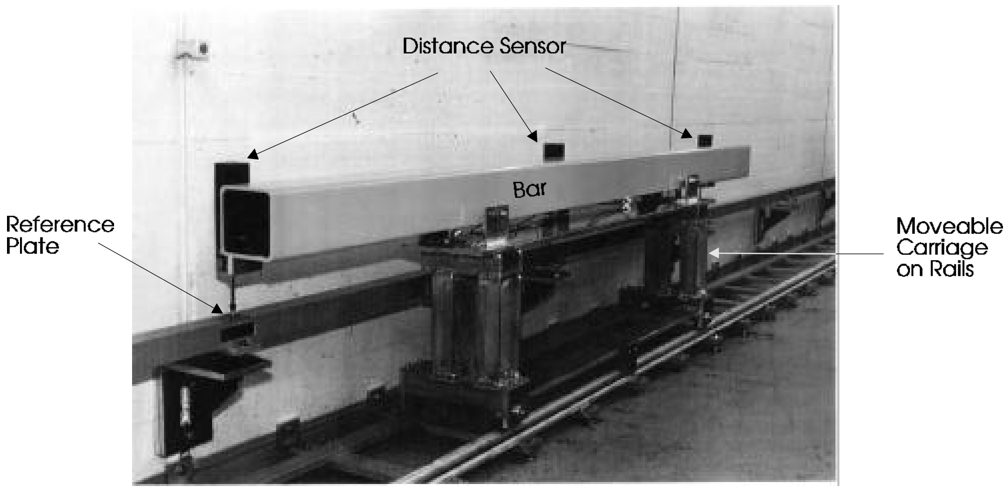

Figure 11. Test Facility for the "3-Point-Alignment-Technique"

In a test facility with a length of 26 m the accuracy of the „3-point-alignment-technique“ has been tested (Fig. 11). A bar with three distance sensors can be moved by a carriage on rails. At the wall the reference plates are mounted with a single bay distance of 1 m. In this test only digital length gauges (Heidenhain-Metro MT 60) are used. The accuracy of these sensors are about 1 µm. The disadvantage of these sensors is that they are not contactless. Later on sensors will be used that measure the distance contactless and have a higher accuracy.

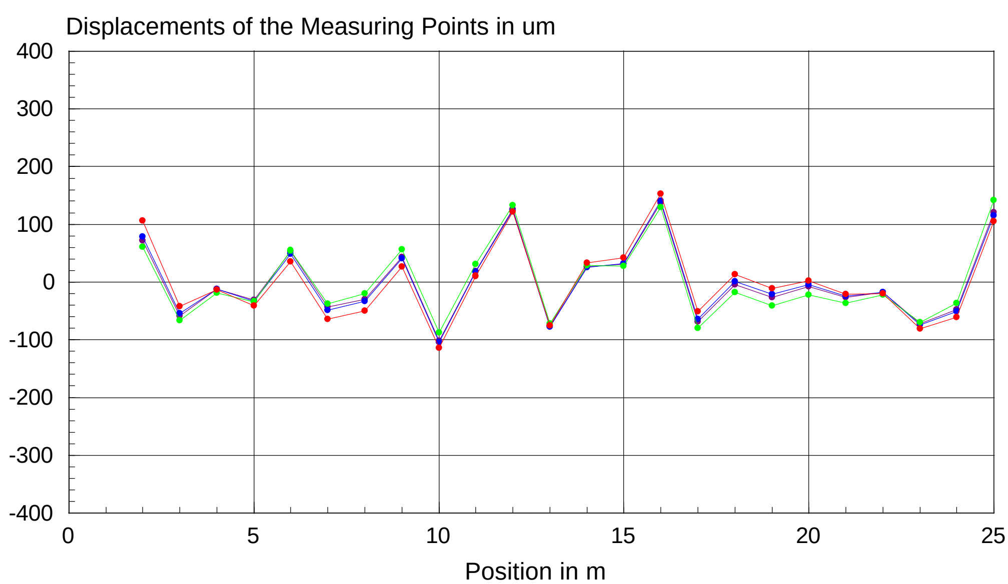

Figure 12. Measurements with the "3-Point-Alignment-Technique"

Fig. 12 shows the results of four measurements with this test equipment. The differences between the single measurements are usually smaller than 50 µm. Supposing that this value is in conformity with the standard deviation there is a general agreement with the calculated accuracy.

In the next step the results of the „3-point-alignment-technique“ will be controlled by straightness measurements with the laser interferometer HP 5528 A. Instead of one distance sensor the wollaston prism is installed on a moveable shaft. The lower end of the shaft is in contact with the specific reference plate. Fig. 13 shows the results. The straightness measurements using a laser interferometer confirm perfectly the results of the „3-point-alignment-technique“.

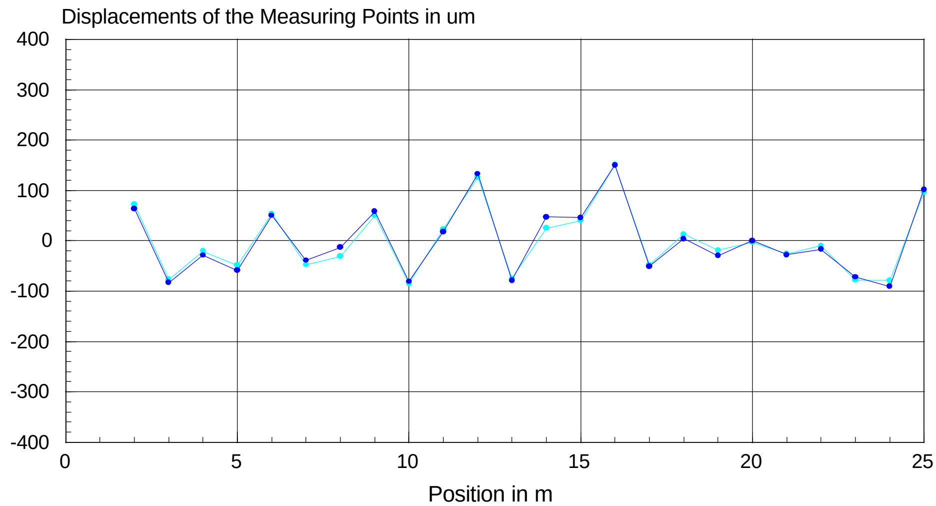

Figure 13. Straightness Measurements using a Laser Interferometer

5 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 transfered 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 moveable 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 at. The measurements to the reference points define the coordinates of the point of the moveable carriage. Then the alignment of the component can start. We 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 stations of the geodetic instrument.

6 SUMMARY

At DESY Linear Collider Concept for a collider with a length of about 30 km is discussed. In the vertical the axis of the tunnel follows the earth curvature except the first 6.5 km. In the tunnel there are five separate beam lines to be aligned. The components of each beam line have to be aligned in the transverse direction better than 0.5 mm and in the vertical better than 0.1 mm over a range of a betatron wave length (= 576 m). Therefore it is too inefficient to align each beam line separately. It will be more efficient to have only one basic measurement. Then the components of each beam line have to be connected to this reference system. In this report some ideas are discussed to align the components of the planned Linear Collider in respect of the required accuracy.

7 REFERENCES

[1] Brinkmann, R. a. o. : Conceptual Design of a 500 GeV e^+e^--Linear Collider with Integrated X-ray Laser Facility. DESY 1997-048, ECFA 1997-182, Hamburg 1997.

[2] Löffler, F.: Alignment of the Superconducting Cryostat for the Tesla Test Facility. Proceedings of the Fifth International Workshop on Accelerator Alignment, October 14-17,1997, Argonne National Laboratory (ANL), 9700 South Cass Avenue, Argonne, IL 60439 and Fermi National Accelerator Laboratory (FNAL), P.O.Box 500, Batavia, IL 60510.

[3] Schwarz, W.: Geodätische Aufgabenstellungen in der Grundlagenforschung der Hochenergiephysik. In: Ingenieurvermessung96, Beiträge zum XII. Internationalen Kurs für Ingenieurvermessung in Graz, 9.-14. September 1996, Ferd. Dümmler´s Verlag, Bonn 1996.

Address:
Dr.-Ing. Willfried Schwarz
Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, D-22603 Hamburg, Germany
e-Mail: willfried.schwarz@desy.de