Status Report on Survey and Alignment Efforts at DESY

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This report presents major projects and activities of the survey and alignment group at DESY during the period of 2004 to 2006. It focuses on planning and development of new alignment concepts for the two new synchrotron light sources to be built at DESY: PETRA III and XFEL. Besides that it describes some permanent measurement systems recently installed at DESY.

1. INTRODUCTION

The research activities of DESY are more and more focused on the two new projects PETRA III and XFEL. The last run of HERA II will be on June 30, 2007, after that the focus will shift more and more towards the synchrotron radiation science. After HERA II had its final shutdown, PETRA will not be used as pre-accelerator any more. From July 1, 2007 it is therefore reconstructed as a synchrotron light source.

According to these general aspects the main activities of the survey and alignment group at DESY were focused on the projects PETRA III and XFEL, too. For PETRA III the survey and alignment concept is being developed, including but not limited to the girder and undulator concept for the new 1/8th of the ring. For XFEL there was a lot of planning business to do, accompanied by settling down the basics of the survey and alignment concept for this new machine.

Besides that, normal maintenance surveys on the existing accelerators, mainly DESY, DORIS, HERA and FLASH are going on.

While the ILC/TESLA project is still postponed until an international agreement on technology and site is found, research activity for an efficient alignment of very large accelerators is going on with the LiCAS project. First test measurements on the DESY site are to be expected early 2007.

2. PETRA III

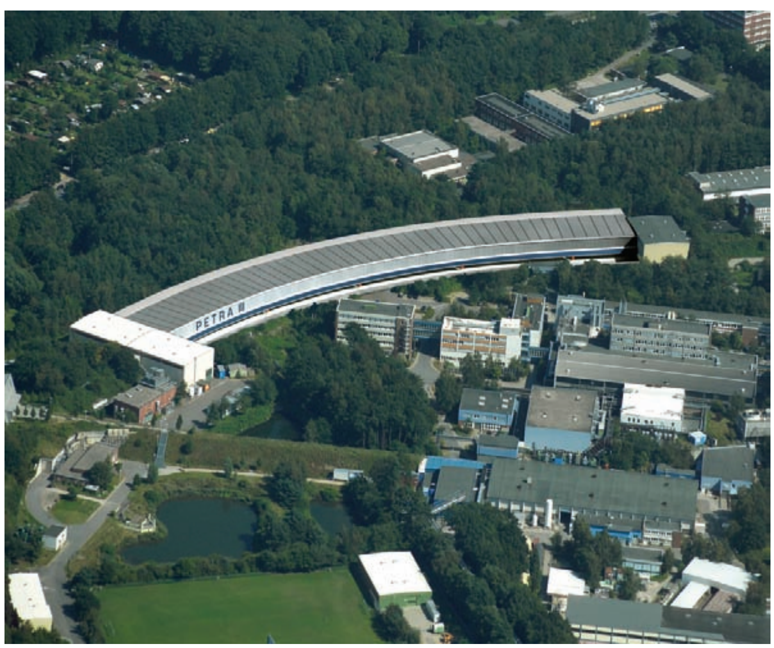

Figure 1: The new PETRA III hall (fotomontage)

As the new hall for PETRA III (see Figure 1) is located completely on the DESY grounds, there is no need for a formal public approval procedure ("Planfeststellungsverfahren"), as for example for XFEL. A building license ("Baugenehmigung"), which is much less complicated to obtain, is sufficient here. This building licence for the new PETRA III hall was granted by the building inspection department of the district authority of Altona on July 13, 2006.

2.1. Reference frame

Since PETRA had no reference points in the tunnel so far, the machine itself carried the reference information. From today's point of view this is not an optimum solution. So some efforts were made to install a new reference system in the tunnel.

About 1600 reference points were installed in the PETRA tunnel during the last shutdown. While a regular distribution all over the tunnel would have been desirable, compromises had to be made because of other installations in the tunnel. One side of the rectangular tunnel shape is completely blocked from access or even from view because of the machine and the power distribution system. The other side of the tunnel, the floor and the ceiling were suitable for mounting reference points. So a regular shape of 2 floor-, 3 wall, and 2 ceiling-points had been developed. This regular shape was installed every 10m throughout the whole tunnel (see Figure 2).

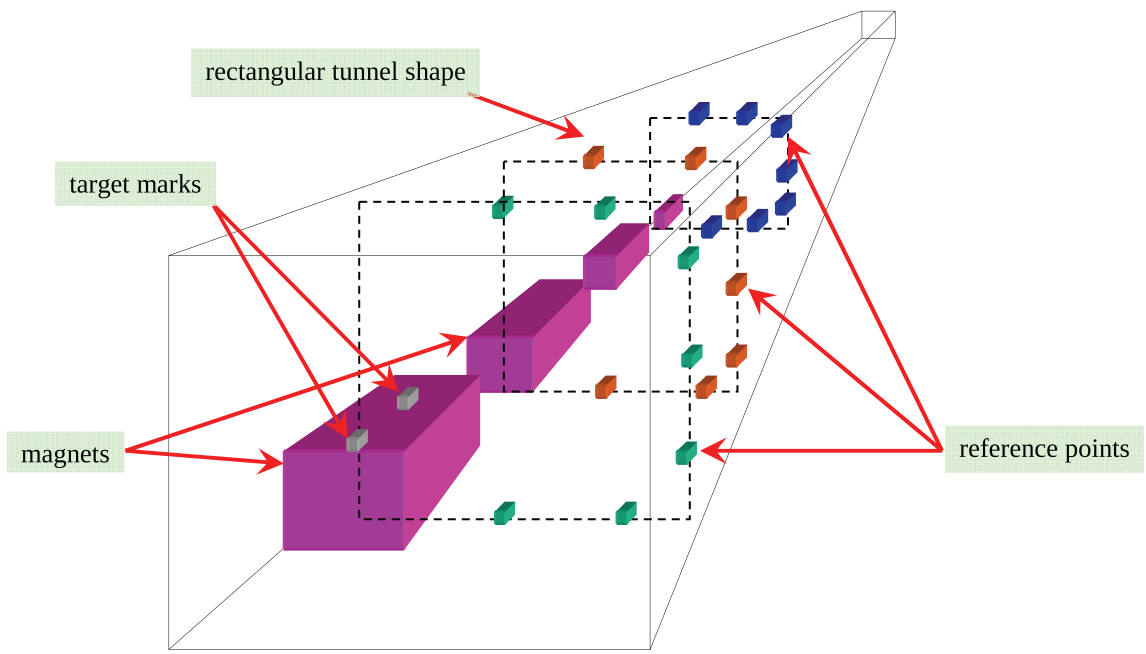

Figure 2: reference points in the PETRA tunnel

After installing the reference points, the existing reference information was transferred from the machine to the reference field, thus creating a new reference frame. This transfer measurement from the machine to the wall markers was done using two laser trackers, a relationship to the DESY reference frame has been established using GPS. The GPS-Points are situated on top of the PETRA wall. Plumbing tubes allow direct sight from these points into the tunnel. To transfer the GPS-Coordinates into the tunnel a KERN-E2 theodolite was placed in the tunnel below the tubes on a marked point with a centering bolt. The vertical angle to an above marker, representing the geometrical center of the

GPS-Antenna, has been measured in two perpendicular azimuths. The vertical distance has been measured with a tape, as this length is not critical for the calculation of the coordinates. The marked points in the tunnel are then bearing coordinate information from the outside network and are integrated into the tunnel network measurement.

The network adjustment software PANDA which has been used for all purposes of network adjustments and deformation analysis at DESY for long was not capable of handling laser tracker measurements, because the mathematical algorithm of PANDA is only correct, when the vertical axis of all the instruments is strictly vertical. While this is true for all sorts of tacheometers, it can not be guaranteed for laser trackers, because they neither have a precise bubble nor an internal compensator. PANDA is being redesigned to be able to incorporate process tracker measurements, but this procedure is still ongoing. In the meantime we use Spatial Analyzer (SA) to adjust the first part of the PETRA network, a graphical result is shown in Figure 3.

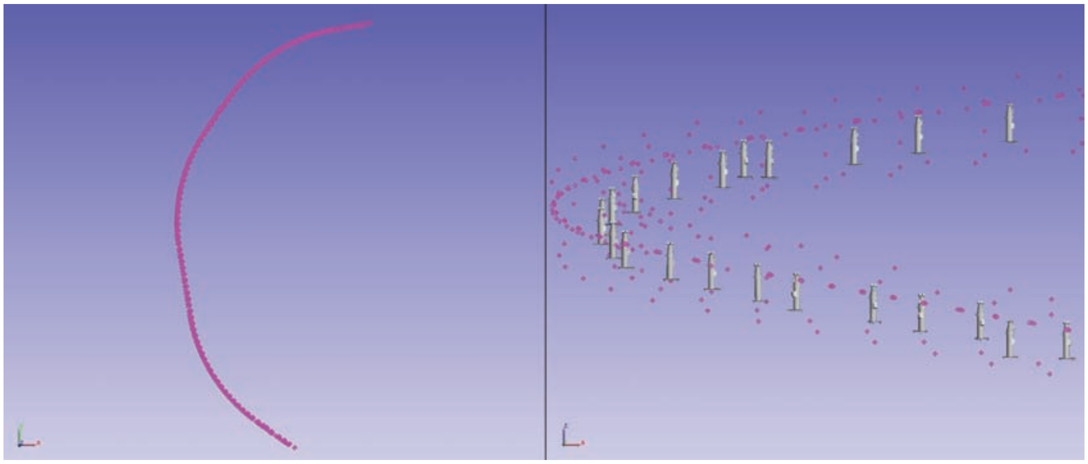

Figure 3: PETRA reference network (part), top view and 3D view

During the last shutdown the transfer from the machine to the reference points could be done for 3/8th of the ring, the remaining 5/8th have still to be finished in the upcoming long shutdown beginning July 2007.

2.2. Reconstruction of the machine

Some efforts have been made to prepare the reconstruction of the machine in 2007. All quadrupoles and dipoles will be removed from the tunnel during the reconstruction phase, all coils will be checked and, if necessary, replaced. During this procedure every magnet will get its own target marks and its individual transfer measurement to represent the magnetic axis by the target marks. Two target marks, accompanied by two reference spheres for the tilt measurement (roll) are sufficient to define the position of each component in six degrees of freedom.

2.3. Girder concept

For the new 1/8th of the machine, which will be situated in the new PETRA III hall (see Figure 1), a girder concept has been developed. The focus has been on a precise but nevertheless easy and fast alignment of the magnets on the girder and of the girders in the tunnel. This girder concept will be addressed in the separate talk “The PETRA III Girder-Concept”, also at IWAA 2006.

2.4. Soil of the new PETRA3-Hall

During the examination of the ground it turned out, that there is an inhomogeneous clay layer below the ground (see Figure 4). The question came up, if impound water on the clay layer could cause deformations of the new hall. To answer this question a HLS was installed in the existing PETRA tunnel, which would give a good approximation of the ground movement of the new hall, because it is to be built in the same place. The distribution of the HLS sensors along the tunnel is shown in Figure 5.

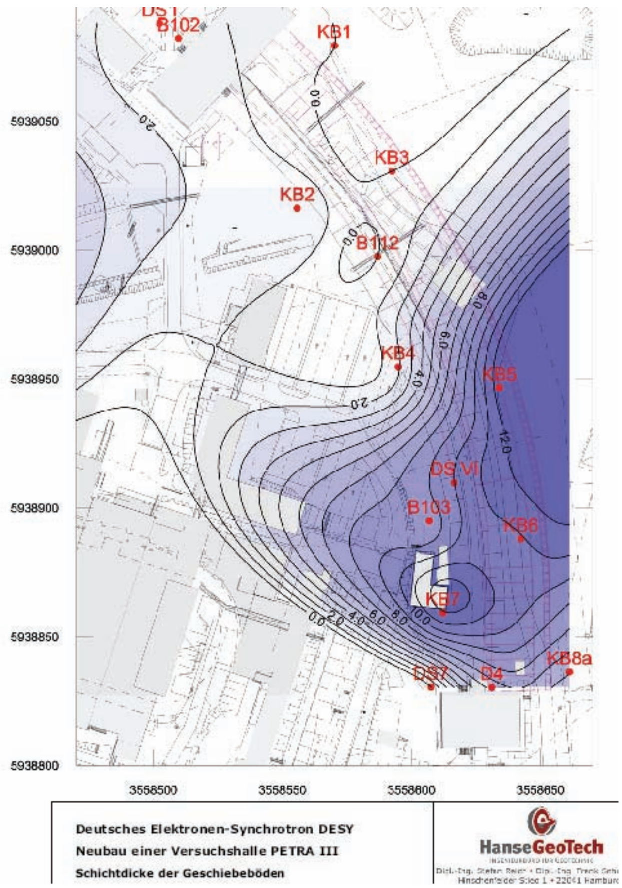

Figure 4: Underground clay layer at the position of the new PETRA3-Hall

The main goal was to detect the effects of ground motion over short distances, e.g. over a construction joint of the tunnel. Special interest was put on the construction joints between tunnel and old experimental halls, because the experimental halls will not be removed during the reconstruction process. So the new PETRA3 will fit between the old halls PETRA East and PETRA North-East.

It was shown that there was little movement of ~10µm between the tunnel and the halls, but about 100µm over a construction joint in the middle of the tunnel (Figure 5). This is not fully understood yet.

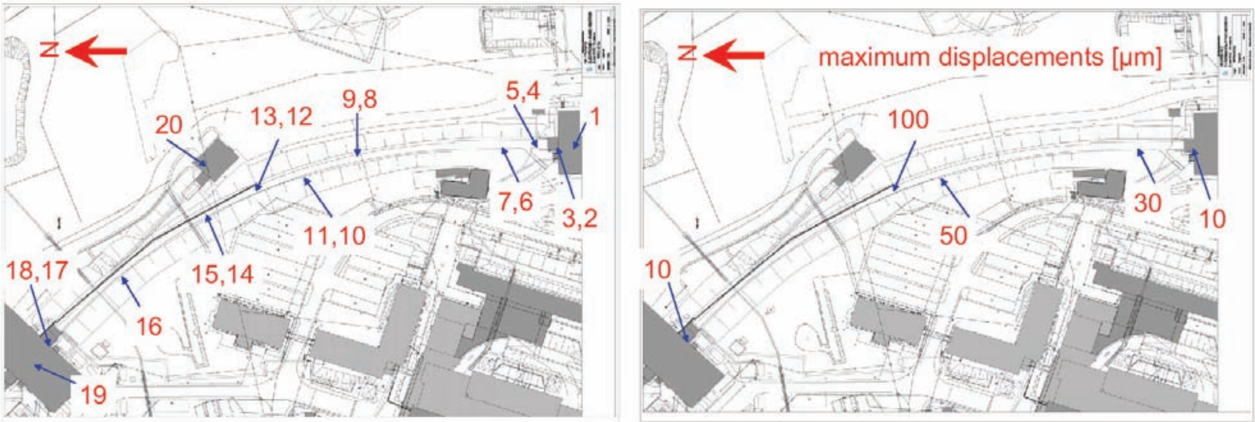

Figure 5: Position of sensors (left) and maximum displacements over construction joints (right)

Correlation with rainfall however revealed no coherence between impound water and tunnel movement. But when correlating the tunnel deformation with machine energy a strong relation was found with a lag of ~1h (see Figure 6). That means that the tunnel deformation follows the machine energy with a time constant of approximately one hour. While this can be expected to be a temperature effect, because tunnel temperature is strongly correlated with machine energy, the effect is still unclear. The thermal capacity of the concrete walls is much too big to explain deformations of the tunnel on such a short timescale.

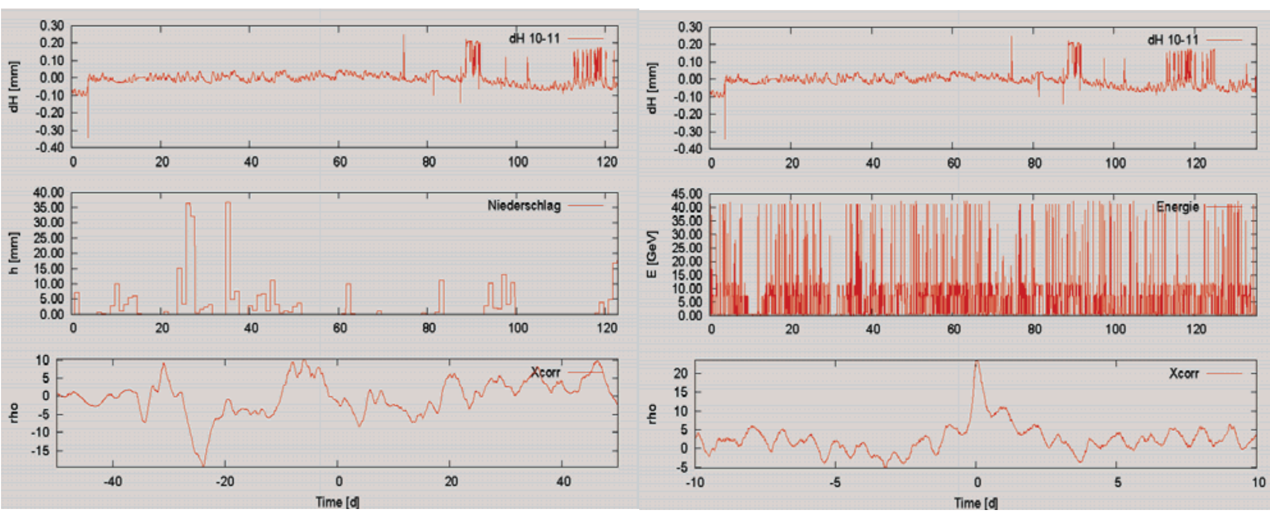

Figure 6: Cross correlation between tunnel deformation, rainfall (left) and machine energy (right)

3. XFEL

On April 27, 2005, the public approval procedure ("Planfeststellungsverfahren") for the construction and operation of the XFEL started. On August 9, 2006, the authority for Mining, Energy and Geology (“Landesamt für Bergbau, Energie und Geologie”) in Clausthal-Zellerfeld published the approval statement for the European X-ray laser project XFEL. This statement establishes the legal basis for the construction and operation of the XFEL.

On the technical side, the Technical Design Report (TDR) was published in July 2006 [1].

3.1. Public approval procedure

The survey and alignment group was involved mainly in cadastral work here, supplying base measurements and general planning information, as for example aerial views. Figure 7 shows a complete aerial view of the XFEL route (red) starting on the DESY grounds at the east, running north-west to the new experimental hall which is located outside Hamburg in the city of Schenefeld, Schleswig-Holstein. Only Just the five southern beam lines shown in this photo are to be built in phase one, the northern five beams are arranged for future extension. The HERA and PETRA rings with their halls are visible in blue. As it can be seen in Figure 7 the main linac is built nearly completely under an urban area, Bahrenfeld and Osdorf. This implies lots of land owners are involved in cadastral issues of this project, meaning a huge amount of work for the survey group.

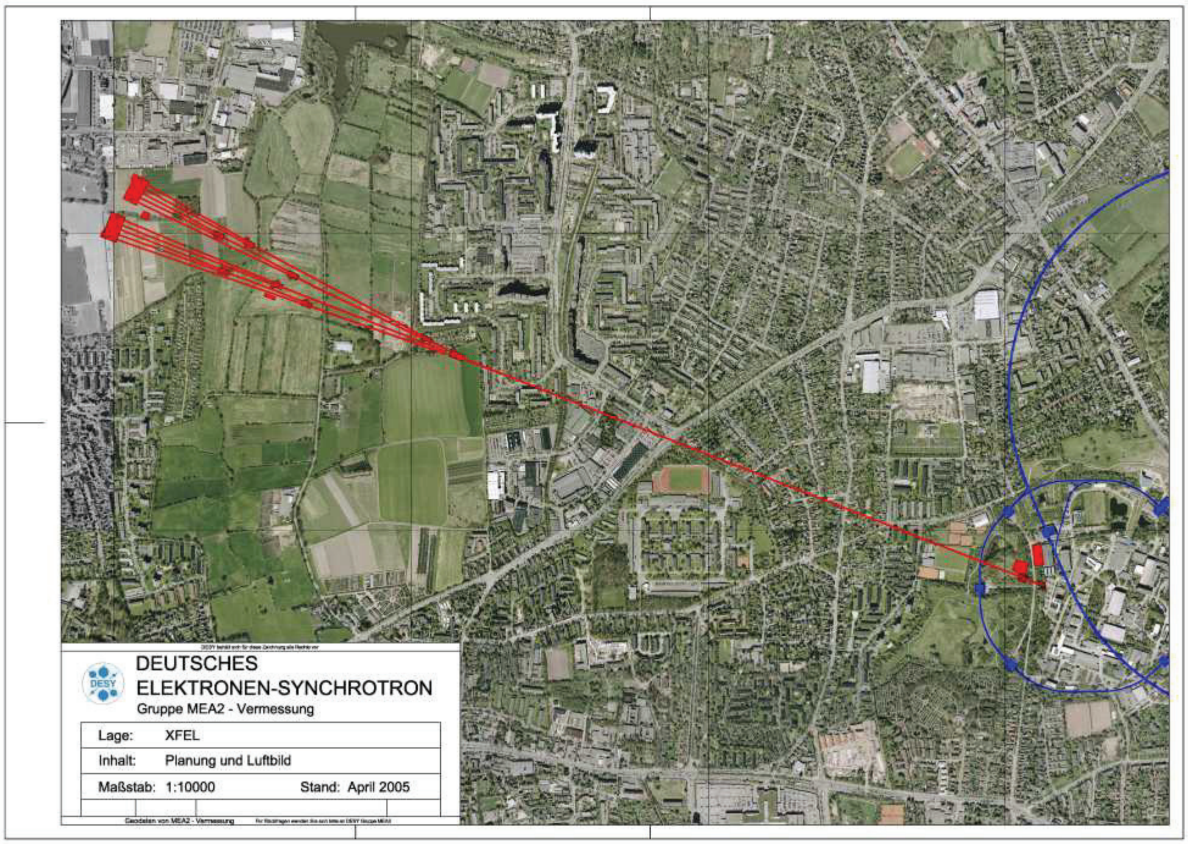

Figure 7: Aerial view with the route of the XFEL

3.2. Technical planning

Besides that technical planning was going on, starting with the design of the machine and the question whether the machine should follow the curvature of the earth or a straight line. Some calculations about the necessary bending angles have been carried out together with supplying information about a height profile for the planned route. Finally the decision was made to build the machine on two straight lines (see Figure 8), one for the main linac, starting on a tangential plane to an equipotential expanse at the DESY site, the other for the photon beams, tangential on another equipotential expanse in the middle of the photon beam. This results in a bend of 0.36 mrad between linac and the rest of the XFEL [5].

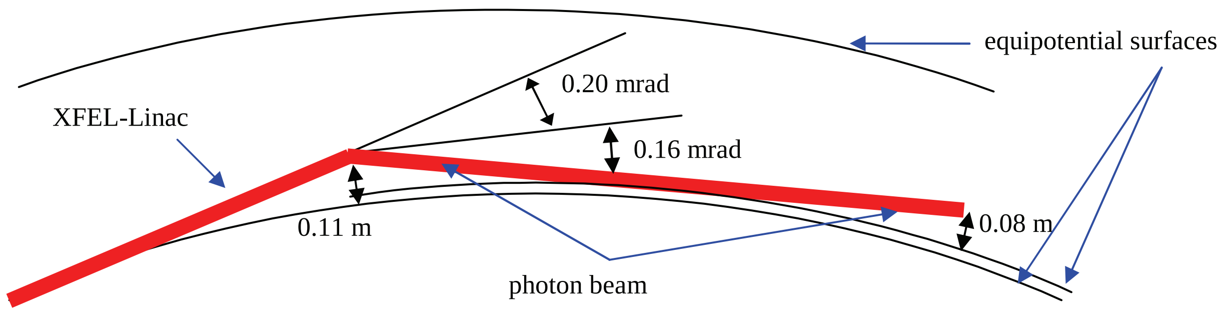

Figure 8: vertical design of the XFEL tunnel

3.3. Alignment concept

Accuracy requirements for aligning components of the main linac are on a moderate level of 0.3mm per 150m, this will be done with a classic survey and reference points in the tunnel. The connection of the monochromators with the undulators is far more challenging with an alignment accuracy in horizontal and height of 0.5mm per 1000m [1]. As this can not be done with today's free-air optical methods because of refraction, a new Straight Line Reference System (SLRS) is being developed at DESY. The principle is based on a laser line in an evacuated system. Two principles are currently investigated: a system which detects poissons spot on a CCD and a second one which uses fiber optics as direct light source target marks. The development of the SLRS is shown in a separate talk "Straight Line Reference System (SLRS) for the Adjustment of the X-ray Free-electron Laser (XFEL) at DESY" also held at IWAA 2006 [4].

This new SLRS will be used for crossing the shafts, too. Because it is impossible to connect all outgoing tunnels with the incoming tunnel with a sufficient long straight line, there will be cross cuts between the outgoing tunnels and in the experimental hall to connect the reference systems, as shown in Figure 9.

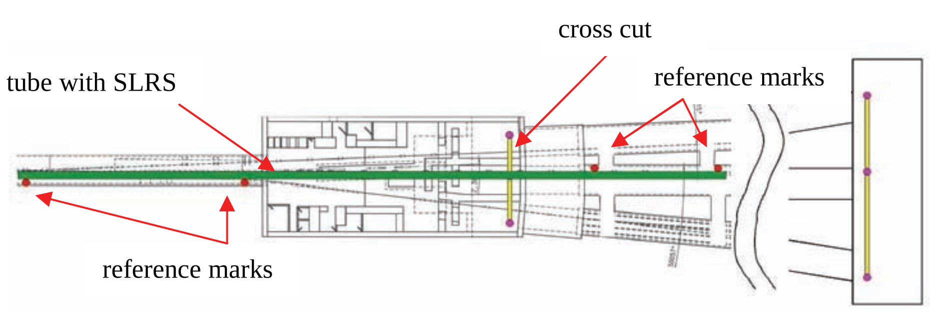

Figure 9: supplying the outgoing tunnels with the reference system

4. FLASH

On April 6, 2006 the DESY directorate decided for the new name FLASH instead of VUV-FEL (former TTF).

A new wire scanner system was installed at FLASH in 2005 to monitor the focusing quadrupoles between the undulators (see Figure 10). The coordinates from the tunnel reference network have been transferred from SMR target marks on the granite plates to the wire with a device called wire finder [7]. This has the advantage, that the wire scanner is not only executing relative measurements, but is completely integrated into the tunnel network. Results from the wire scanner can therefore be directly compared with other measurements, e.g. from laser trackers. With three wire scanner sensors measuring in lateral and height on each plate three rotations (nick, roll and gear) can be detected, as well as the two shifts in lateral and height. Shifts in longitudinal direction can of course not be detected. Figure 11 shows an example of the measurement data.

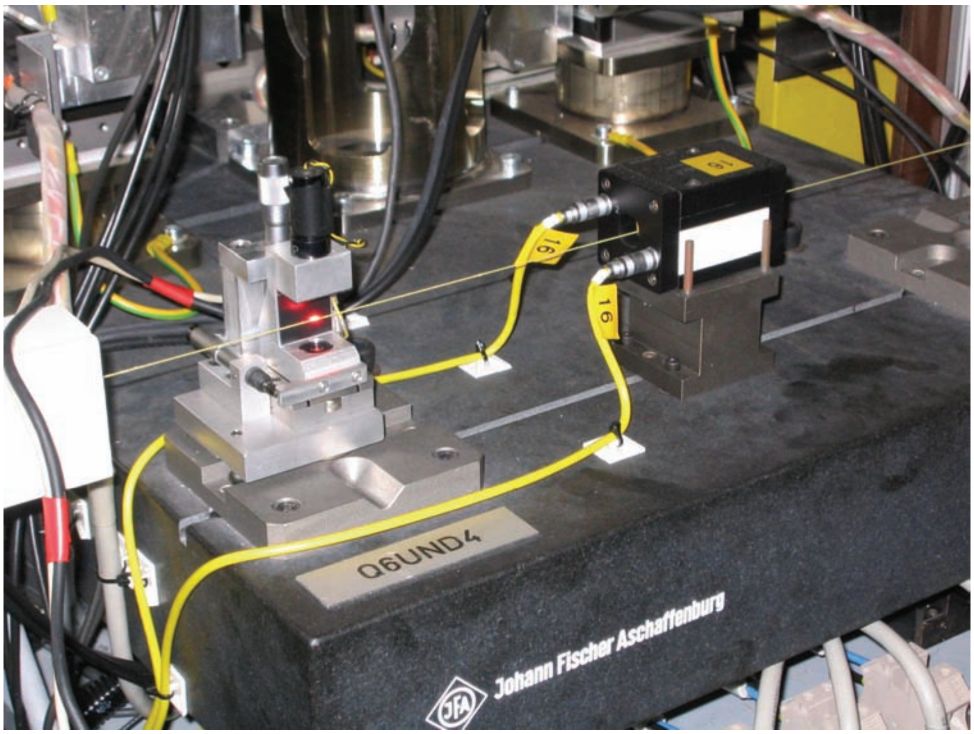

Figure 10: granite plate with wire positioning sensor and wire scanner

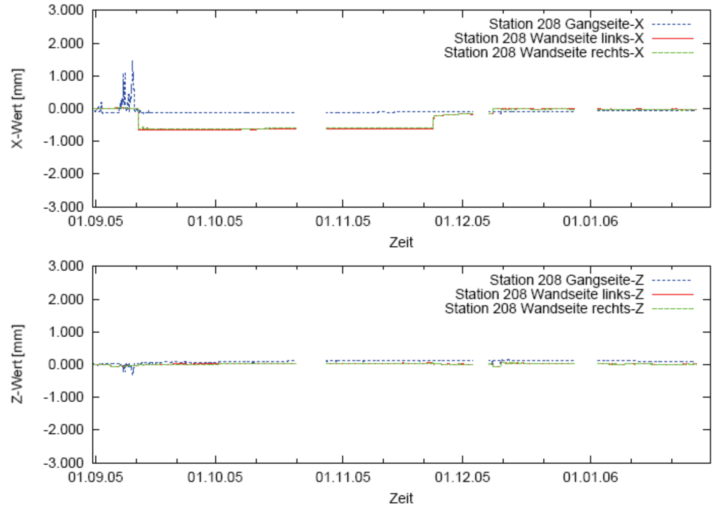

Figure 11: example results of wire positioning sensors on one plate

5. DESY, DORIS AND HERA

On, DESY, DORIS and HERA normal maintenance surveys were going on. HERA changed its run mode from electrons (e^-) to positrons (e^+), so some magnets close to the experiments ZEUS and H1 had to be shifted in radial direction about 2 to 7 mm. DESY II was remeasured completely together with the "e-Weg", which is the connection between DESY and PETRA (see Figure 12)

Figure 12: DESY III (left) and DESY II (right)

6. ILC

The survey and alignment department is participating in the development of a new measurement device, called the Rapid Tunnel Reference Surveyor (RTRS) for ILC together with the University of Oxford (UK). The air conditioned test tunnel as well as the mechanical measurement frames have already been prepared at DESY (see Figure 13). First tests of the measurement equipment inside the laboratory tunnel will start by the end of this year.

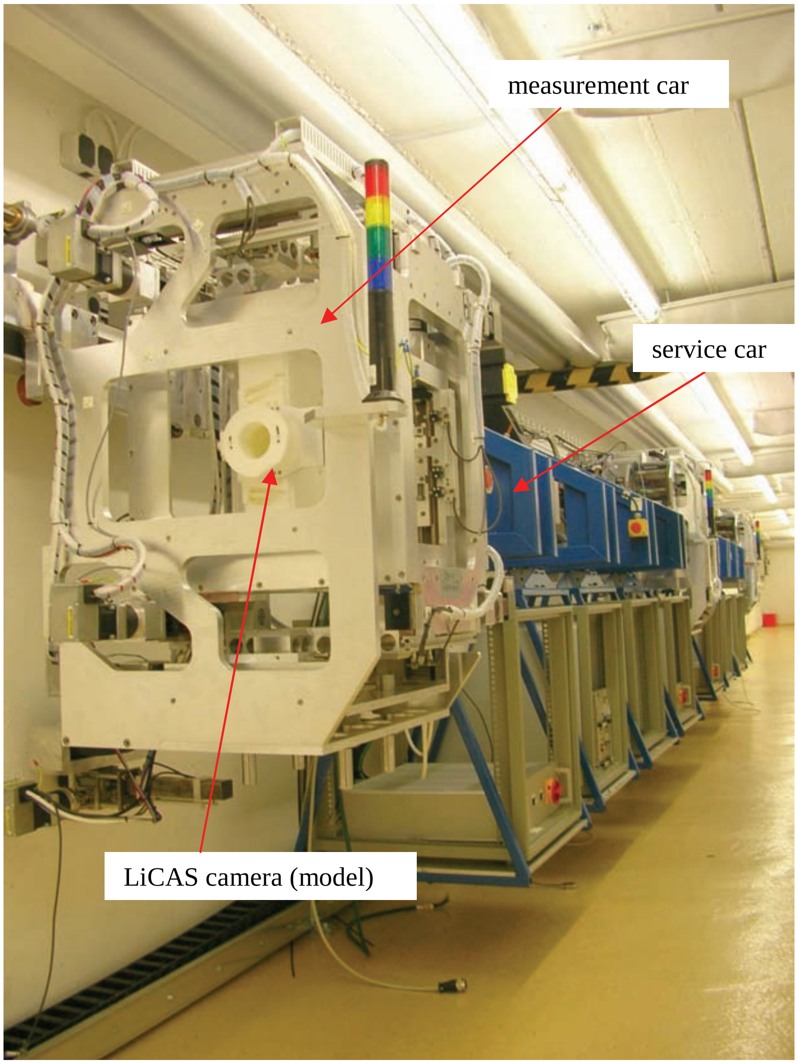

Figure 13: LiCAS train in the SLRS laboratory tunnel at DESY

There are two additional talks and one poster about the RTRS technology here at IWAA 2006, namely “The LiCAS-RTRS -- A Rapid and Cost Efficient Survey System for the ILC” [6], “Simulation of the LiCAS Survey System for the ILC” [2] and “Frequency Scanning Fibre Interferometer for Absolute Distance Measurements Over a Large Target Area” [3].

7. GEODETIC INSTRUMENTS

One issue is important enough to be mentioned here. The survey and alignment group at DESY amongst others uses two Laser Trackers from FARO, one SI tracker, purchased in 2002, upgraded to SI2 in 2004, and a second SI2 tracker, purchased in 2004. They are operated in interferometer mode only; ADM is not used since the detection of the “famous” 52mm-fault in 2002. After the upgrade to SI2 the ADM now seems to work properly (this has not been tested thoroughly by DESY), but when operated in interferometer mode, now both trackers show errors in distance measurement even immediately after the recalibration and certification by FARO. The error can be shown clearly by observing one single point twice with performing a beam break and homing in between the two measurements. The distance errors range from some 1/10 mm up to 433 mm, while the angular measurements produce results inside the specification (see Figure 14). Unfortunately it is still unclear by which circumstances the error can be provoked, but it continues happening on a timescale from once a week to several times a day. Of course the surroundings are quite normal: no extra magnetic fields, no synchrotron radiation (we were asked this by FARO for several times), no special lights, even a brand-new SMR from FARO could not eliminate the error. Neither FARO Europe nor FARO US were able to track the error down and correct it. After having Tracker 2 back from US-service the error seems to happen less frequently, but the beam loss rate has increased dramatically. A test setup in our laboratory can reproduce spontaneous beam losses within two minutes, when the tracker is following a very slowly moving SMR (about 10cm/30sec).

After not being interested in investigating the error any further during the last half year, FARO has finally moved a little bit and now wants to run a diagnosis on our trackers.

At the moment (and actually right from the beginning of the FARO story) we have the very unpleasant situation that we can not trust the results of our FARO trackers. The workaround is to measure every single point twice, with a beam break between the measurements. If the results differ more than 0.1mm, it is re-measured twice until a minimum of three results match together. Besides from being very time consuming this procedure is unusable when scanning surfaces or lines, which makes our trackers useless for this application.

Target	Time	Azimut [gon]	Vertical [gon]	Distance [m]	dA [mgon]	dV [mgon]	dD [mm]
6-B4	18:34:05	-35.5287	102.2880	7.485031			
6-B4	18:57:48	-35.5294	102.2872	7.051910	0.1	0.0	**-433.1**
6-B4	18:59:02	-35.5295	102.2871	7.051918	-0.1	-0.2	**-433.1**
6-B4	19:02:21	-35.5295	102.2873	7.485069			

Figure 14: Measurement protocol of IFM-error during a measurement at DESY Zeuthen, Germany (red line means, that the beam has been broken in between)

References

[1] DESY XFEL Project Group, European XFEL Project Team, Deutsches Elektronen-Synchrotron, “XFEL Technical Design Report”, ISBN 3-935702-17-5, DESY, Germany, July 2006

[2] Grzelak, G., et.al., “Simulation of the LiCAS Survey System for the ILC”, Stanford Linear Accelerator Center, Stanford, USA, September 2006

[3] Han, Y., Reichold, A., Perry, C., Bingham, R., “Frequency Scanning Fibre Interferometer for Absolute Distance Measurements Over a Large Target Area”, Stanford Linear Accelerator Center, Stanford, USA, September 2006

[4] Kaemtner, D., “Straight Line Reference System (SLRS) for the Adjustment of the X-ray Free-electron Laser (XFEL) at DESY” , Stanford Linear Accelerator Center, Stanford, USA, September 2006

[5] Prenting, J., Neubauer, G., “Status Report on Survey and Alignment Efforts at DESY”, Proceedings of the Eigth International Workshop on Accelerator Alignement, CERN, Switzerland, 2004

[6] Reichold, A., et.al., “The LiCAS-RTRS -- A Rapid and Cost Efficient Survey System for the ILC”, Stanford Linear Accelerator Center, Stanford, USA, September 2006

[7] Wolf, Z., Ruland, R., Dix, B., Arnett, D.,”Alignment Tools Used To Locate A Wire And A Laser Beam In The VISA Undulator Project”, Stanford Linear Accelerator Center, Stanford, USA, October 1999