TESLA 2000-09
May 2000

A Test of the Laser Alignment System ALMY at the TTF-FEL

S. Roth [a], S. Schael [b,1], G. Schmidt [a]

[a] *Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, D-22603 Hamburg, Germany*

[b] *Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 München, Germany*

Abstract

The laser alignment system ALMY was tested at the undulator section of the TESLA test facility. The positions of the undulator modules relative to each other have been determined with a precision of 0.1 mm, limited by the accuracy of the mechanical support of the sensors. Additionally, ALMY allows to measure movements or drifts over several days and we found that the undulator components are stable within 10 μm. The resolution of the sensors is better than 2 μm over the 15 m long alignment system.

1 Introduction

New alignment techniques have to be established for the construction of a future linear collider or light source. Especially the components of the final focus system have to be aligned with a precision in the micron range. Additionally, continuous monitoring of the positions is necessary to correct for possible movements of the individual components.

For the proposed TESLA collider [1] the integration of a X-ray free electron laser (FEL) is planned. It will use the effect of Self Amplified Spotanous Emission (SASE). In such SASE FEL a tightly focussed electron beam of high charge density is sent through a long undulator. The focussing is achieved by separated or integrated quadrupoles. The SASE effect results from the interaction of the electron bunch with its own radiation field created by the undulation motion. This interaction can

1 now at I. Phys. Inst., RWTH Aachen, D-52056 Aachen, Germany

only take place if the electron and the photon beams overlap. To keep the electron beam inside the undulator on a straight line the precise alignment of the individual undulator modules and the focusing elements with respect to each other is crucial.

A FEL working in the vacuum ultraviolett (VUV) has been constructed at the TESLA Test Facility (TTF). At the TTF-FEL [2] the electron beam position must be straight with transverse deviations of less than 10 μm rms over the entire 15 m long undulator. Therefore the magnetic axis of the undulator with a superimposed FODO structure must be aligned with about the same accuracy. For the alignment of the three individual undulator segments a commercially available interferometer system has been used which reaches a precision of the order of 5 μm. The magnetic axis of the whole undulator is estimated to be straight within 30 μm [3].

As the laser interferometer is a manual system it has the disadvantage that it cannot be used during operation of the machine. Therefore it cannot deliver a continous monitoring of the positions of the undulator components. As an alternative we tested the ALMY [5] system. It is a multi-point alignment system that has been developed for the muon spectrometer of the ATLAS detector at the Large Hadron Collider. It uses an infrared laser beam, acting as alignment reference, which transverses several transparent silicon sensors. The sensors measure the laser beam position in both transverse coordinates. Thermal effects onto the laser beam are shielded by means of an aluminium tube around the laser beam.

2 The Transparent Silicon Sensors and the ALMY System

The optical sensors have to combine high position resolution and high light transmission. To optimize the transmission thin films of amorphous silicon (a-Si) are used as photo-sensitive material. The amorphous silicon strip sensors were produced at Heimann Optoelectronics and provide high precision position measurement at relatively low cost. CVD techniques are used to deposit the 1 μm thick photo-sensitive layers onto a 0.5 mm thick glass substrate. High-quality polished parallel glass wafers

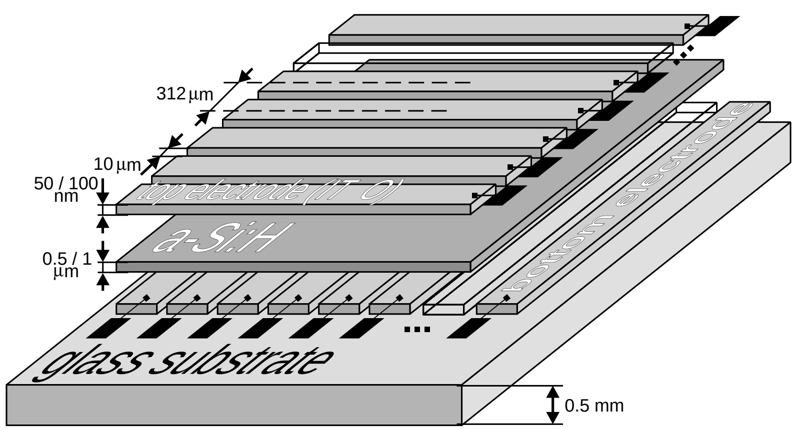

Fig. 1. Cross section of the photosensitive detector.

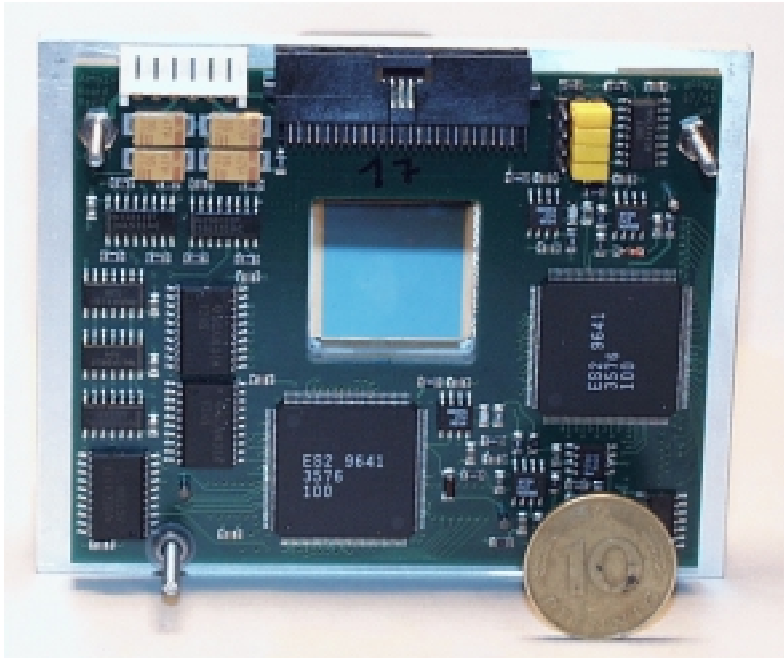

Fig. 2. Complete module including sensor and readout electronics is shown.

minimise uncertainties in the deflection of the transversing laser beam. The a-Si film is sandwiched by two 0.1 μm thick electrodes of indium-tin oxide (ITO) which are segmented into two orthogonal strip rows. The bottom electrode acts as ohmic contact while the top electrode forms a Shottky diode which is operated at about 3 V bias voltage. The strip pitch of about 300 μm has been optimized to the typical laser beam diameters of 3–5 mm. The structure of the sensors is shown in Fig. 1. Position resolutions of 1 μm over the whole sensor surface have been measured and transmission rates above 90% at $\lambda = 790$nm have been achieved [5].

The readout electronics is integrated inside the sensor module. In Fig. 2 a complete sensor module is shown. The photocurrents of all strips are multiplexed, amplified and digitized. These values are stored into a memory which can be readout by a VME bus system. The system can be read out with a rate which is limited to about one measurement per second at maximum.

3 The Test Setup

The undulator of the TTF-FEL consists of three undulator modules interspersed with four diagnostic modules containing wire scanners and beam position monitors [4]. The magnetic axis of the individual undulator modules itself has been measured using a 12 m long bench [3]. To build the undulator section inside the linac tunnel both ends of each undulator module and the diagnostic modules have to be lined up. As the alignment is done seperatly for the horizontal and the vertical coordinate this gives in total 20 reference marks.

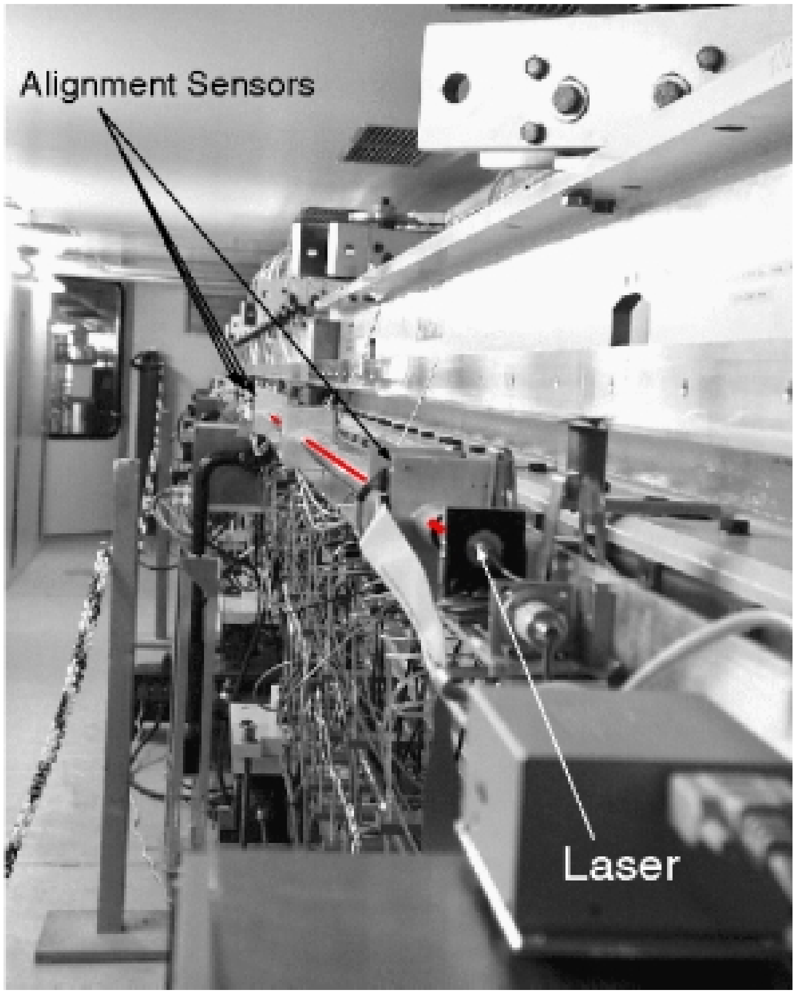

Fig. 3. Test setup of the laser alignment system at the TTF undulator

In Fig. 3 a view along the TTF undulator section is shown. For a first test of the ALMY system the sensors were placed at the alignment marks which determine the horizontal positions. Because of lack of space the last alignment mark has been used for installation of the laser optics. The laser sends a collimated laser beam with a diameter of 3–5 mm through all nine sensors. The laser beam is shielded against temperature gradients and fluctuations using aluminium tubes.

The readout of the silicon strip detectors is done by each sensor module individually and the digitized signal height of each strip is sent via RS232 connection to a data aquisition program running on a PC. Here a Gauss fit is performed to the shape of the measured beam profiles. The mean value from this fit is taken as the position measurement.

4 Measurement Results

The laser alignment system ALMY was shown to work within the background of radiation and electronic noise of a linac tunnel. It took data without any interruption during five days of linac operation with electron beam. The positions and movements of the sensors could be monitored all the time during this period.

After the sensor positions had been stabilized the horizontal position of the reference laser beam was measured. Two of the reference marks define a straight line and the positions of the alignment marks relative to this line can be determined from the data. The design position of the alignment marks is defined by the fact that the magnetic axes of the undulator modules and the centers of the diagnostic modules exactly line up. A comparison between the measured positions and the design positions of the alignment marks can be seen in Fig. 4. The difference of measurement and design gives the displacement of the individual components. It is shown in the lower part of Fig. 4. The measurement error is defined by the mechanical assembly of the sensors onto the alignment marks which has a precision in the range of 0.1 mm. Within this error one would conclude from this measurement that the undulator forms a straight line with exception of the components at both ends of the undulator section.

The setup has been operated in the linac for 4 days (21^{st} – 24^{th} of February 2000). Every 30 seconds a measurement was performed and the result written to disk. This allowed us to monitor the sensor positions continously and to look for movements of the individual components, either in form of oscillations or in form of drifts.

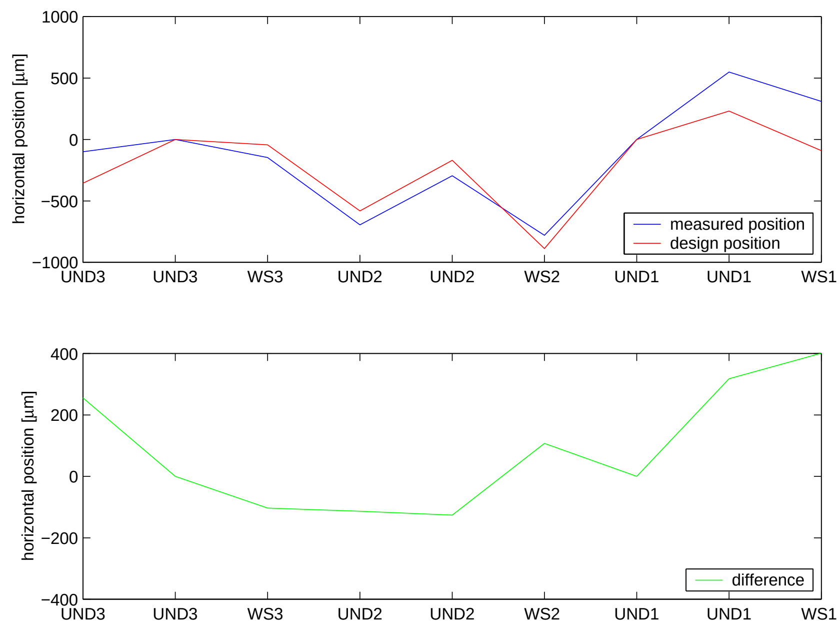

Fig. 4. Result of the alignment measurement. Shown are the positions of the three undulator modules (UND1, UND2, UND3) and of three of the four diagnostic monitors (WS1, WS2, WS3)

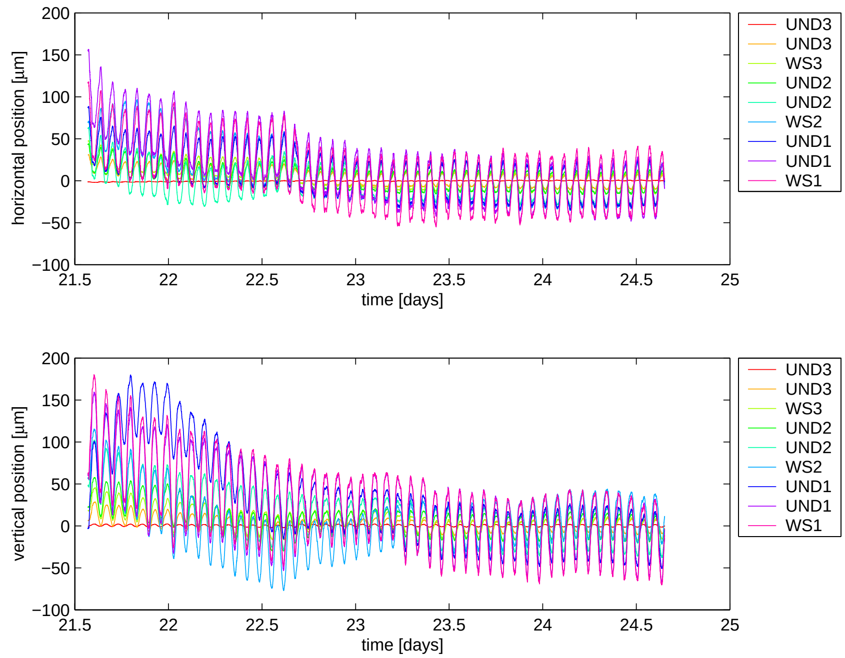

Fig. 5. Monitoring of the sensor alignment. Data of the whole measurement period (4 days) are shown.

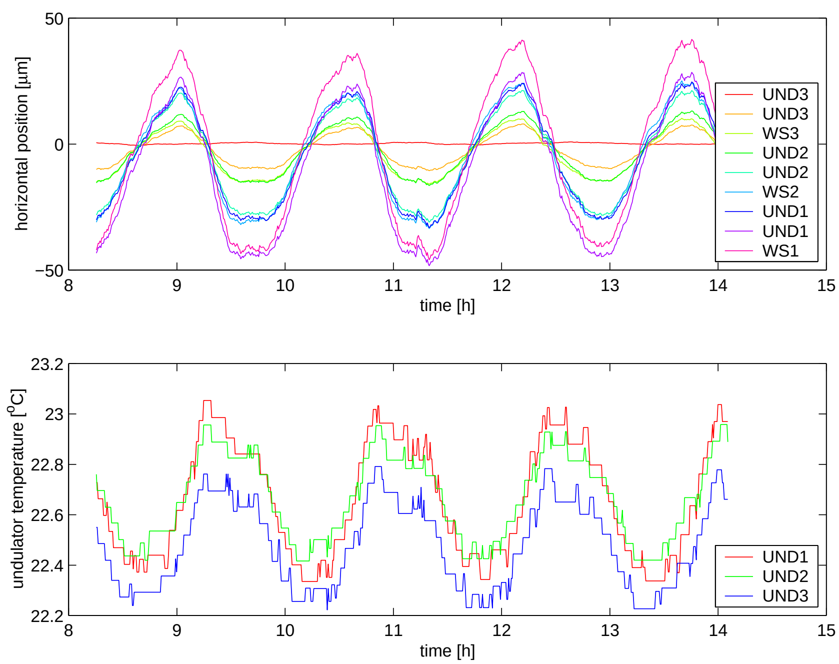

Fig. 6. Correlation between sensor alignment and temperature.

The result is shown in Fig. 5. One observes oscillations of the measured result with amplitudes of up to 50 μm and periods of about 40 minutes. As can be seen in Fig. 6 these oscillations are correlated with the temperature variations in the climatized hut, where the undulator is placed. The amplitude is proportional to the distance of the sensor from the laser.

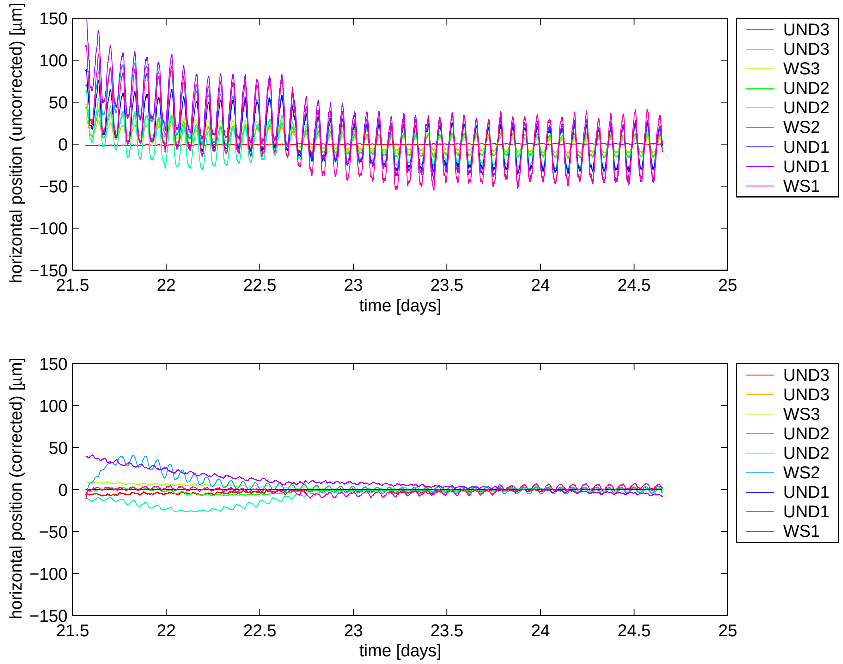

Fig. 7. Comparison between raw data and corrected data.

The observed oscillations are caused by changes of the laser beam direction by 3 nrad due to the temperature change of 0.3 °C. As we are not interested in movements of the reference laser beam but in potential movements of the undulator components with respect to each other we put again a straight line through two of the components. The difference of the measured position from the straight line is then independent of changes in the laser beam direction. The result is shown in the bottom part of Fig. 7 and shows that the corrected measurements show only little dependence of the temperature variations.

During a period of about one hour we took data every second. These data are analysed in Fig. 8. First all measurements are shown corrected for the changes of the laser beam direction as explained before. The next plot of Fig. 8 gives the mean value of these single measurements averaged over five minutes. The resulting curve is much smoother than before and movements in the micron range are easily detectable. The resulting curves are showing the movement of the individual sensors to the reference axis. Correcting the single measurements for the movement of the sensors leads to the third plot (plot1 – plot2 + average value from plot1 = plot3). Its projection gives the spatial resolution of the sensors. The resolution varies between 0.7 μm near the tail of the laser beam and 2 μm at both ends of the alignment distance.

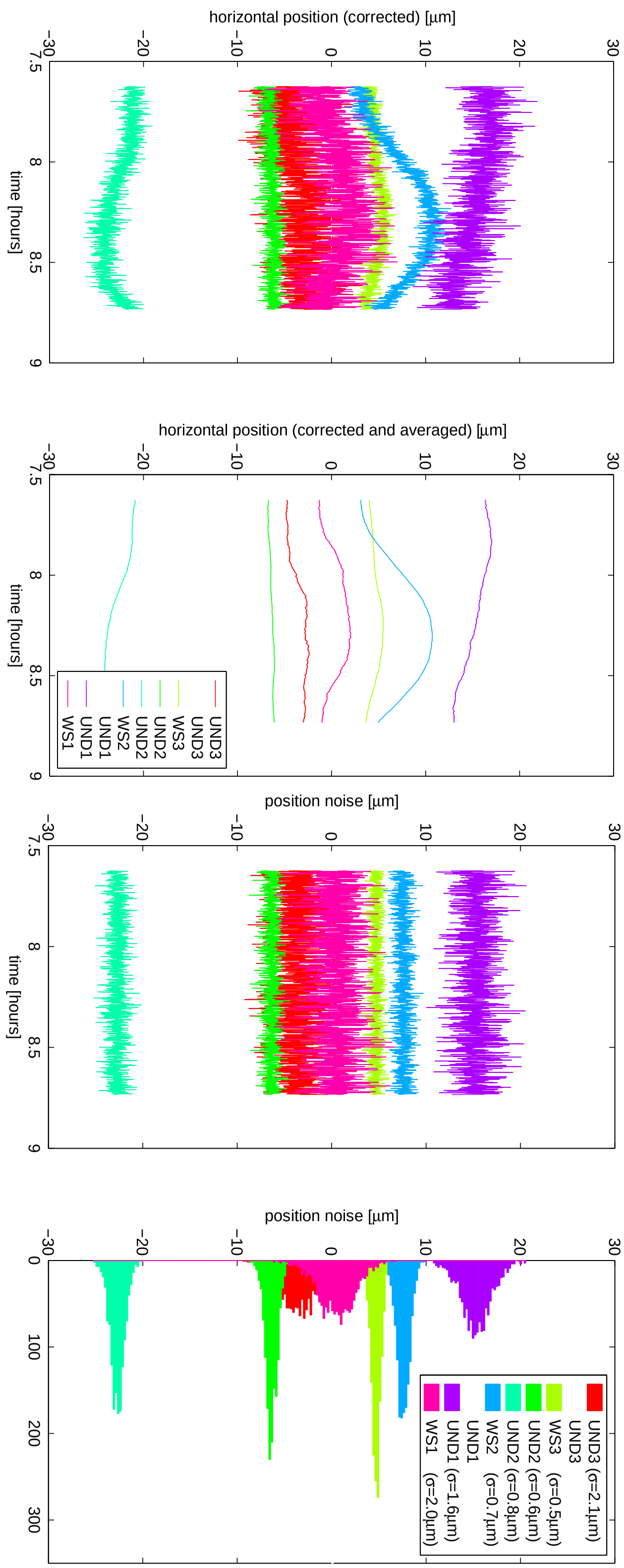

Fig. 8. Sensitivity and spatial resolution of the sensors in the current alignment setup.

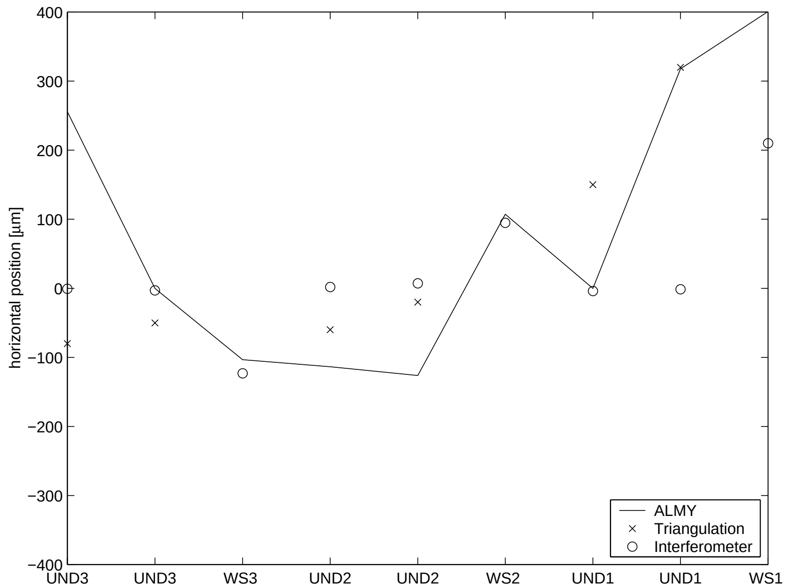

Fig. 9. Comparison of three different alignment measurements

5 Comparison with other Alignment Systems

In Fig. 9 we present the results of all 3 methods which have been used to align or survey the undulator positions.

Methode 1: Interferometer (5^{th} of November 1999) [6]
Commercially available laser interferometer with prisms to measure the transverse offset of a component to the straight line defined by a laser. This method was used by J. Pflüger to align the undulator. Unfortunatly it allows no thermal shielding of the laser path.

Methode2: Triangulation (15^{th} of November 1999) [7]
Alignment method based on triangulation and trilateration. Starting from two points the angles and distances to the undulator components are measured. Based on the net of angles and distances the position compared to the starting axis can be calculated. Refraction caused by temperature gradient disturbs the measurement. The effects of temperature gradient can be reduced by means of ventilation.

Methode3: ALMY (24^{th} of February 2000)
As described. A shielding against thermal effects was used.

The agreement in the center of the undulator area is good. Especially at the entrance of UND1 we find a discrepancy between the interferometer, the triangulation and ALMY. An explanation is not easy. The interferometer is not shielded against temperature gradients and has the largest errors in the UND1 area but they are still expected to be smaller than 0.1 mm. To gain further experience the undulator area should be remeasured to see if there is a systematic deviation between the three methods. A test bench could also help to compare the three methods.

6 Conclusions

The laser alignment system ALMY was shown to work within the background of radiation and electronic noise inside a linac tunnel. With an improved fixation of the sensors to the undulator and individually calibrated sensors the ALMY system it will be possible to measure online the position of the undulator components with an accuracy of better than 0.03 mm. Nevertheless further test should be done here at DESY to investigate the influence of the number of sensors onto the accuracy of the measurement and the usable length of the ALMY system.

Additionally it should be possible to use ALMY as a fast alignment system for complete beam line sections. Only the start and end point must be defined. The components in between can be aligned with online survey of their position to an accuracy of better than 0.1 mm. Therefore the system would also be interesting for other machines like HERA or PETRA or DORIS.

The purchase of several detectors for the alignment of new sections and the survey of the undulator is strongly recommended.

Acknowledgements

We would like to thank J. Brehling and the HASYLAB workshop for the construction of the detector mounting and T. Vielitz for his help during the installation of the test setup at the TTF undulator section.

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