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

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Abstract

The laser alignment system ALMY was tested at the 15 m long 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 a distance of 15 m.

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1 Introduction

New alignment techniques have to be established for the construction of a future linear collider or light source. 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 focused 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 motion inside the undulator. This interaction can 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 alignment system uses reference marks on the undulator which have a known offset to the magnetic axis of the undulator. 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 like density fluctuations of the air can influence the straightness of the laser beam. Such effects 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 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.

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 has shown that it works within the background of radiation and electronic noise of the linac tunnel. It took data without any interruption during five days of linac operation with electron beam. Nine detectors were installed.The positions and movements of the sensors could be monitored all the time during this period.

A comparison between the measured positions and the design positions of the alignment marks can be seen in Fig. 4. The design position of the reference marks contains the offset of the reference mark to the magnetic axis of the undulator. The difference of measurement and design gives the displacement of the individual components to the magnetic axis of the undulator. It is shown in the lower part of Fig. 4. The measurement error is influenced mainly 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. 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. 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.

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. 5 and shows that the corrected measurements show a reduced dependence on the temperature variations.

During a period of about one hour we took data every second. These data are analysed in Fig. 7. First all measurements are shown corrected for the changes of the laser beam direction as explained before. The next plot of Fig. 7 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. The spatial resolution of the sensors is calculated out of the position noise and it varies between 0.7 μm near the tail of the laser beam and 2 μm at both ends of the alignment distance.

A comparision with other alignment methods is shown in Fig. 8. In between the expectable errors the measurements show good agreement. Only at both ends of the undulators some deviations are visible. Further investigations are needed to understand if there are systematic errors explaining this effect.

5 Conclusions

The laser alignment system ALMY was shown to work within the background of radiation and electronic noise inside the 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 if the number of sensors can be increased without reducing the accuracy of the measurement and to check the usable distance where the ALMY system works.

However it should be possible to use ALMY as a fast alignment system for complete beam line sections which could be up to 15 m long.

6 Acknowledgments

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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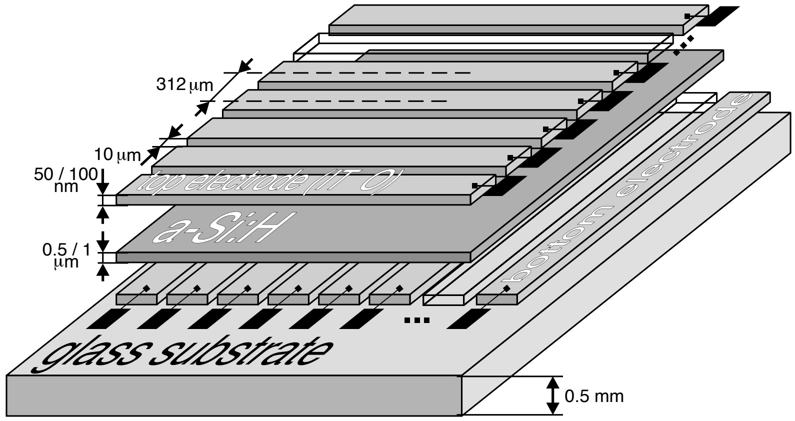

Fig. 1. Cross section of the photosensitive detector.

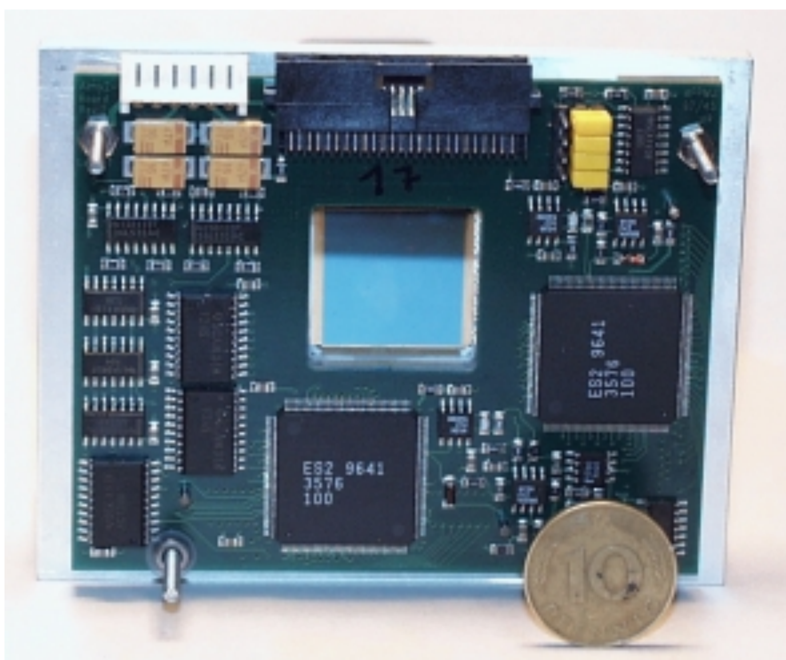

Fig. 2. Complete module including sensor and readout electronics is shown.

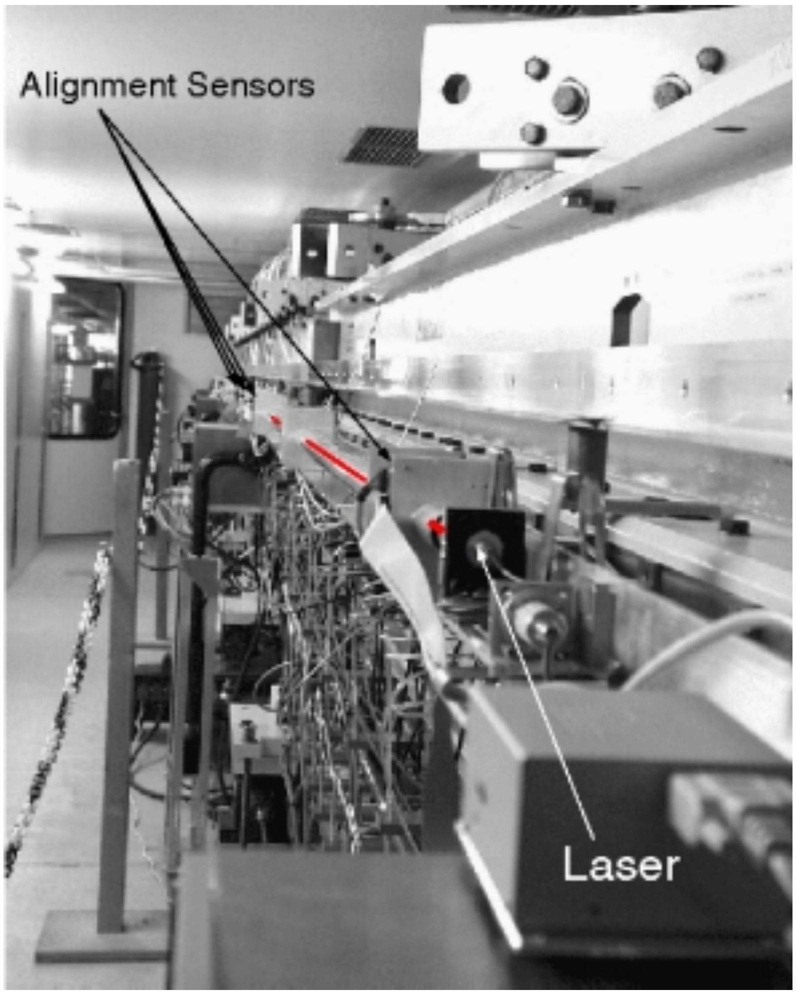

Fig. 3. Test setup of the laser alignment system at the TTF undulator

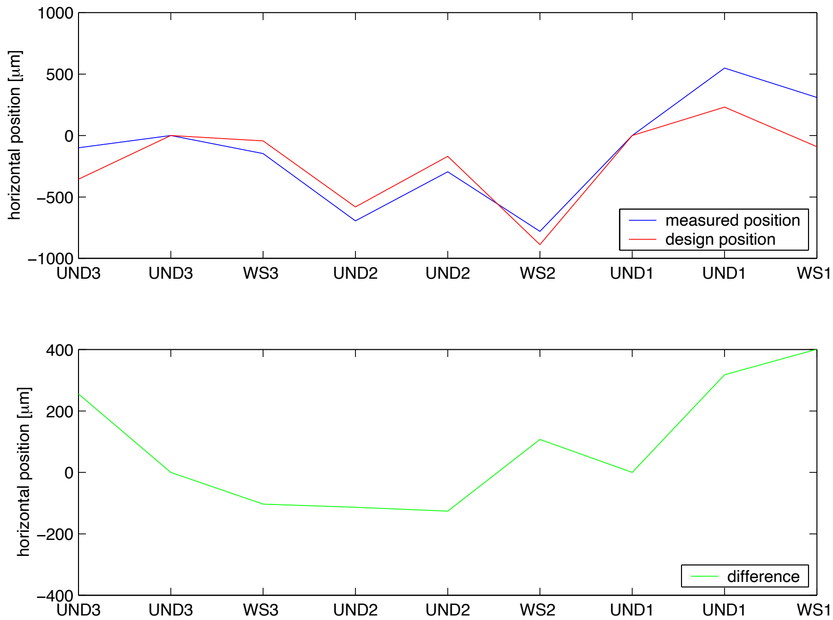

Fig. 4. Result of the alignment measurement. Shown are the positions of the three undulator modules (UND1, UND2, UND3) and of three of the four diagnostic monitors (WS1, WS2, WS3)

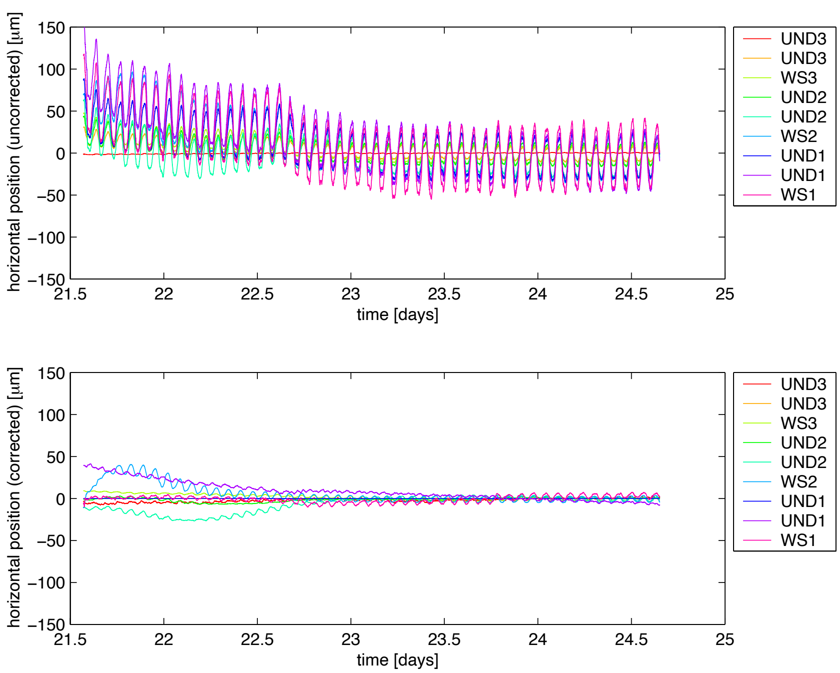

Fig. 5. Comparison between raw data and corrected data.

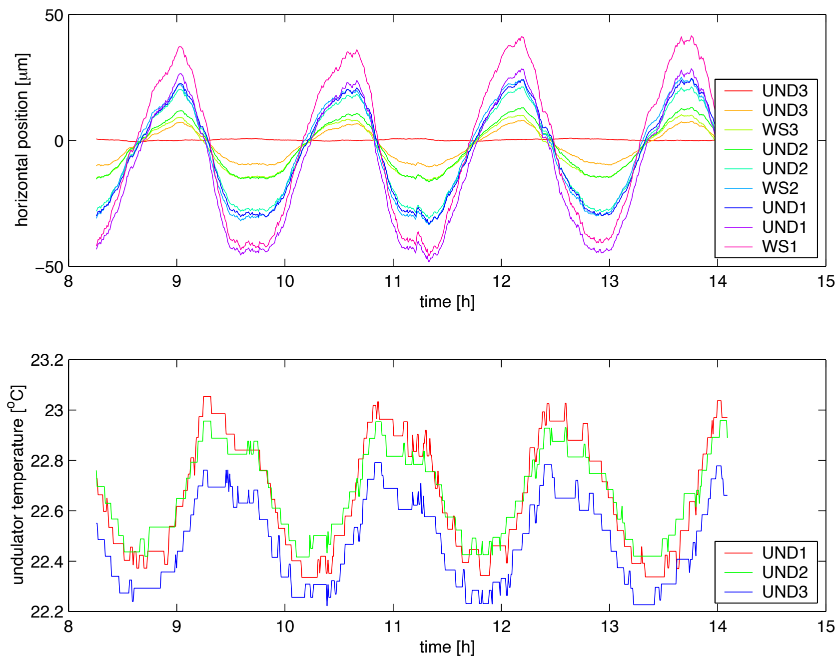

Fig. 6. Correlation between sensor alignment and temperature.

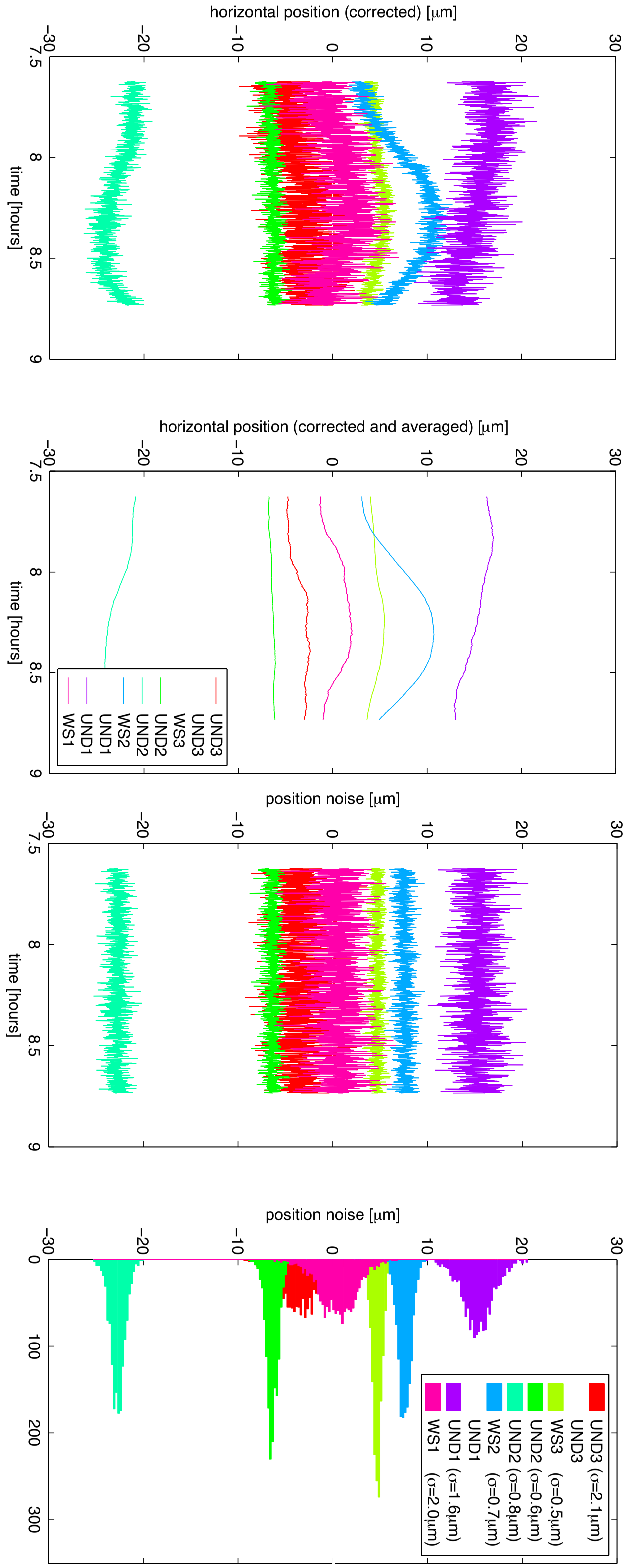

Fig. 7. Sensitivity and spatial resolution of the sensors in the current alignment setup.

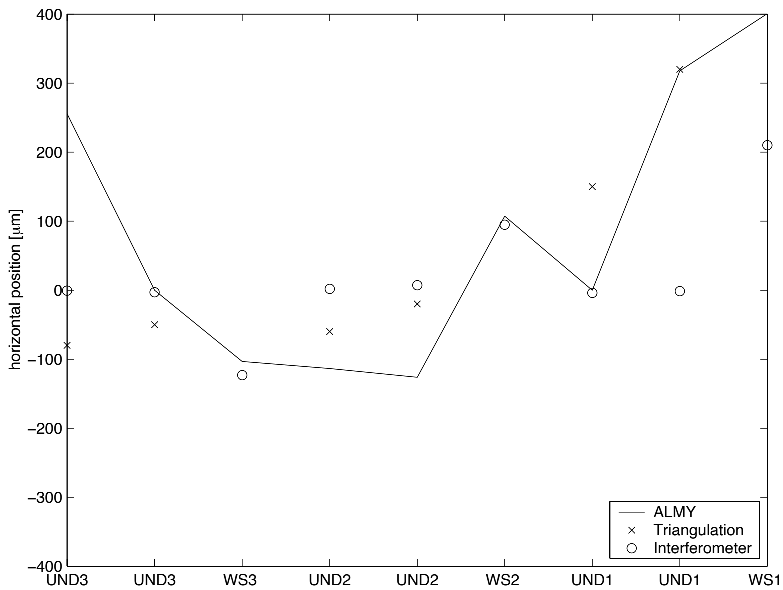

Fig. 8. Comparison of three different alignment measurements