Optical alignment system for the ZEUS micro vertex detector

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Abstract

The electron–proton scattering experiment ZEUS will be equipped with a silicon vertex detector in preparation for the upgrade of the HERA collider. An optical alignment system for the vertex detector is being developed. The alignment system measures the position of the vertex detector with respect to the outer tracking detector as well as the shape of the vertex detector using semi-transparent amorphous-silicon sensors and diode lasers. A test of the alignment system was performed using the support structures of the vertex detector. The results are presented and discussed.

1. Introduction

The electron–proton collider HERA at DESY will be upgraded to increase luminosity during the shutdown period from September 2000. In parallel to the HERA upgrade the ZEUS detector will be equipped with a Micro Vertex Detector (MVD), which uses silicon strip sensors, to maximise the physics outputs after the HERA upgrade. The reconstruction of the displaced vertices with the MVD will allow the precise measurement of heavy quark production, which is sensitive to the gluon density of the proton. Also, the MVD will extend the polar angle coverage of the existing tracking detector, which is crucial for the study of high four-momentum transfer squared electron–proton deep inelastic scattering events.

In order to best utilise the MVD, it is important to know its shape and precise position with respect to the outer tracking detector. In the ZEUS experiment, an optical alignment system as well as conventional alignment method using tracks of charged particles will be used. The optical alignment system will perform measurements during the MVD assembly and data taking periods. The tests of the optical alignment system have been performed using the support structures of the MVD and the results are presented and discussed in this report.

The design of the MVD is described in Section 2, followed by the design of the optical alignment system in Section 3. The test results of the alignment system are presented in Section 4. Section 5 summarises this report.

2. Micro vertex detector

The following requirements were specified with the Monte Carlo simulation study presented in the MVD proposal [1]:

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• angular coverage of 10°–170°,
• three spatial measurements, in two projections each, per track,
• 20 μm intrinsic hit resolution,
• impact parameter resolution of order 100 μm at 90°, increasing gradually to 1 mm at 20°, for tracks with momentum greater than 2 GeV,
• alignment accuracy of 20 μm.

The available space for the MVD is limited by the existing tracking detector and the shape of the beam pipe. The space inside the tracking detector has length of about 2 m and diameter of 32 cm. In order to fulfill the requirements within the limited space, the layout of the MVD is determined as shown in Fig. 1. The MVD consists of two parts, barrel and wheels, which are supported by a tube made of two half cylinders. The barrel consists of concentric layers of silicon sensors. Four wheels cover only the downstream proton beam direction due to the asymmetric beam energies, 27.5 GeV electron and 920 GeV proton. Fig. 2 shows cross-sections of barrel and wheel.

High resistivity n-type silicon is used to produce the single sided strip wafers. The bulk thickness is 330 μm, and the p+ strip pitch is 20 μm with read-out strip pitch of 120 μm [2]. The sensors are read out by HELIX chips developed at the ASIC laboratory of Heidelberg University [3]. The intrinsic resolution of the sensor was measured as ~10 μm.

Two rectangular silicon strip wafers with orthogonal strip orientation are connected to form a half-module as shown in Fig. 3. Strips on both wafers are coupled with a triangular shaped Kapton foil, and 512 signal channels are read.

Fig. 1. Layout of the ZEUS MVD along the beam axis. The barrel part covers the interaction region. Four wheels cover the direction of the proton beam.

Fig. 2. Cross-sections of the MVD. Left and right are barrel and wheel, respectively.
out with four HELIX chips. The area of the half-module is 124 mm $\times$ 64 mm. Two half-modules with mirror image are placed on top of each other, forming a full-module with 1024 read-out channels. Fig. 3 shows five full-modules mounted side by side on support frame to make a 622 mm long ladder. The barrel part consists of 30 ladders surrounding the interaction region with three concentric layers of ladders. The innermost layer covers 75% of azimuth to accommodate the elliptic beam pipe.

A wheel consists of two layers of fourteen wedge shaped silicon wafers. The inner and the outer radii are 60 and 130 mm, respectively. Two sides of a wafer are parallel and the others tilted by $13^\circ$ in opposite directions. One wafer has 480 signal strips, which are parallel to one of the tilted sides, and signals are read out by four HELIX chips. Fig. 4 shows the wafer and wafers mounted on the support structure. A wheel provides radial and azimuthal coordinates per track, by using two overlapping planes with different strip orientations.

3. Optical alignment system

The optical alignment system comprises several collimated beams from diode lasers by Point Source and semi-transparent amorphous-silicon sensors, DPSD-516, by EG&G HEIMANN Optoelectronics. The sensors were first developed by Kroha et al. [4]. The beams provide alignment references and are detected by the sensors. These provide high-precision two-dimensional position information at each sensor location. Sensors are positioned at support structures of the MVD and the outer tracking detector as shown in Fig. 5. The positions of all the wheels and barrel are defined by these support structures, thus the alignment system measures the position of the MVD with respect to the outer tracking detector.

3.1. Position sensor

The active material of the DPSD sensors is amorphous-silicon, which has a thickness of $\sim 1 \mu m$ and an area of $5 \text{mm} \times 5 \text{mm}$. Signals are
read out by strips made of ~100 nm thick indium-tin-oxide. The number of strips is 16 for each side of amorphous-silicon and strips on each side are perpendicular to each other, with the strip pitch 312 \( \mu \text{m} \) and the strip gap 10 \( \mu \text{m} \). The whole structure is deposited on a 0.5 mm thick glass substrate as shown in Fig. 6. The sensor is transparent for light with wavelength greater than ~600 nm as shown in Fig. 6. The transmission reaches a plateau of ~75% at wavelength around 700 nm. Although the transmission increases with longer wavelength, the sensitivity of the sensor drops rapidly, from 0.1 A/W at 690 nm to 0.01 A/W at 790 nm.

The signals from sensors are guided by 200 \( \mu \text{m} \) thick flexible cables developed at University of Oxford. The cable is made of copper, polyamide and glue. It is very flexible and lengths can be up to 20 m. The signals are read out by a EB168-DPSD microcontroller board from EG&G and processed on a computer via a RS232 interface.

### 3.2. Laser

The wavelength of the laser should be long enough to give good sensor transmission, however, short enough to have adequate sensor sensitivity. The available aperture for reference beam is 5 mm \( \times \) 5 mm and the beam should be contained in the aperture over 2 m. Taking all these into consideration, the wavelength of the laser was chosen to be 780 nm with variable output power of up to 4 mW. The beam shape is gaussian and the beam diameter was chosen as 1.5 mm at beam waist. Fig. 7 shows shape and divergence of the selected diode laser beam. The beam fulfil the requirements.

### 3.3. Sensor resolution

The DPSD sensors were characterised using a test set-up consisting of a computer controlled two-dimensional translation stage mounted on an optical rail system. A DPSD sensor was mounted on the translation stage and illuminated by the laser beam. Fig. 8 shows a signal distribution from a DPSD sensor. The surface of the sensor was divided into a grid and scanned. Then residuals were calculated as the difference between the position of the stage and the sensor. Fig. 8 shows the residual distribution. The distribution is broad since sensor strips were not aligned with respect to scanning axes. Also, the mean is shifted from zero, because the centre of the sensor was shifted from that of the stage. After removing the effects of...
misalignment of the sensor and the stage, the residual distribution becomes narrower but a systematic pattern of the residual still remains due to differences in the thickness of the amorphous silicon layer [5]. Fig. 9 shows the systematic pattern of the residuals over the sensor surface and the residual distribution after applying a correction matrix defined with a 250\( \mu \)m grid to the positions from the sensor with 100\( \mu \)m grid scan. The resolution is less than 2\( \mu \)m after all corrections.

4. Test of the alignment system

For the alignment system test, two lasers and twelve position sensors were installed on the support structures of the MVD which consists of four flanges inside a carbon fibre tube of diameter 32 cm and length 211 cm. The MVD support structure was placed in a support frame. For each beam, sensors were positioned at the four flanges and at two rings attached to the support frame as shown in Fig. 10. The outer two sensors mounted on the rings provide reference positions, like the ones in the final system on the outer tracking detector. The MVD support structures were deformed by applying load and torsion to test the alignment system.

Sand bags of 500 g were evenly distributed on top of the tube to measure the sag of the support structure. The results are shown in Fig. 11. Although sensors on each beam have different coordinate system, total displacement points to the
Fig. 9. The left plot shows the size of residuals at each grid point in grey scale. The right plot shows the residual distribution after all corrections.

Fig. 10. Schematic view of the alignment system test set-up. The left figure shows the cross-section of the set-up and the positions of the reference beams together with local sensor coordinate systems. The right figure shows the side view of the set-up. The path of the laser beam is indicated with arrow, and squares along the beam shows the position sensors. Inner four sensors were mounted on the flanges and outer two sensors are attached to rings. Each sensor location is labelled for later use.

Fig. 11. Results of the sag and torsion measurements. The left four plots show the measured sag. Top and bottom left plots show local $x$ and $y$ displacement with respect to beam 0. The next two plots are for the reference beam 1. Squares and pluses show the displacement for loads of 6 and 21 kg, respectively. The rightmost two plots show the results of the torsion test. The displacement of the sensor with respect to beam 0 and 1 are shown as a function of load. Each marker corresponds to a different sensor location as labelled.
negative $Y$-directions, which points to the centre of the earth.

For the purpose of measuring torsion of the support structure, a bar was attached to the FMVD end of the tube and load was applied on the bar. Fig. 11 shows the results of the torsion measurement. Displacements of the sensors linearly increase with the applied torsion and are larger for the sensors closer to the FMVD end, where the torsion was applied.

5. Summary

The ZEUS micro vertex detector will be installed during the shutdown period of the HERA upgrade program starting September 2000. The optical alignment system for the vertex detector is being developed. The system employs semi-transparent amorphous-silicon position sensitive sensors and diode lasers. The system was tested with the support structure of the vertex detector by applying load and torsion. The optical alignment system worked successfully and detected corresponding deformation. The system works well for the short term alignment procedure. The long term stability of the system is being studied.

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References