Abstract

At the time of the HERA luminosity upgrade during the shutdown period 2000/2001, the tracking system of the ZEUS experiment will be upgraded with a silicon Micro Vertex Detector (MVD). The barrel part of this detector is 60 centimeter long with silicon sensors arranged around the beam pipe. The forward part consists of four circular shaped disks. In this note we discuss in some detail the support structure, the geometry of the silicon modules and the cooling of the front end electronics. In addition the assembly procedure and its accuracy will be discussed.
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1 Introduction

At the time of the upgrade of the HERA electron proton collider during the winter shutdown 2000/2001, a silicon vertex detector will be installed in the ZEUS experiment. With the increased HERA luminosity, the emphasis of the physics studies will shift to high $Q^2$ events. The vertex detector extends the coverage of the existing central tracking detector substantially in the forward direction. The momentum and position resolution will be improved to allow the reconstruction of secondary vertices. If any anomaly is observed in the high $Q^2$ events the identification of secondary vertices will provide crucial information.

Precision tracking near the vertex will allow the measurement of heavy quark production with minimal background. In combination with the observation of the scattered lepton will the identification of charm events allow an independent measurement of the gluon density in the proton. The observation of charm in photo-produced jets provides information on the parton content of the photon and allows direct tests of QCD models for the photon structure. Earlier studies [1] have shown that for the identification of charm in DIS events an impact parameter resolution of about $100 \mu m$ is required for efficient charm tagging.

In this note we concentrate on the design of the detector with emphasis on the mechanical support structures, cooling and alignment. A laser alignment system, to monitor the geometry of the structure is described elsewhere [2].

2 Design

2.1 Design Goals

For the simulations presented in the proposal [1] the following specifications were required:

1. polar angular coverage between $10^\circ - 170^\circ$

2. three spatial measurements per track, in two projections

3. $20 \mu m$ intrinsic hit resolution for normal incident tracks

4. impact parameter resolution of order $100 \mu m$ for polar angle of $90^\circ$, increasing gradually to $1 \, mm$ at $20^\circ$, for tracks with momentum greater than 2 GeV

5. noise occupancy $< 10^{-3}$

6. hit efficiency $> 97\%$

7. alignment accuracy $20\mu m$

8. two-track separation $200\mu m$. 

3
With the choice for analog readout for the silicon sensors, the expected intrinsic resolution is about $10 \mu m$.

The space available for the micro vertex detector is limited by the inner bore of the central tracking detector (diameter 324mm). Another consideration to be taken into account is the longitudinal size of the particle bunches; while the electron bunch is about 1 cm long, the proton bunch extends over about 20 cm, resulting in a spread of 20 cm for the position of the interaction point.

The short bunch crossing time at HERA of 100 ns requires fast electronics for handling the signals of the silicon sensors which has lead to the requirement that the readout electronics and therefore also cooling and cabling is located near the sensors.

Figure 1 shows the layout of the MVD parallel to the beamaxis. We distinguish a forward (proton direction), central (barrel) and rear (electron direction) section. The barrel section is about 65 cm long. Three layers of silicon strip sensors are arranged in concentric cylindrical planes surrounding the interaction point. As shown in figure 2 a small fraction (<25%) of the azimuth angle is covered by two cylinders due to limited space. The polar angular coverage for tracks with three hits ranges from 30° to 150°. The forward section is equipped with four planes of silicon strip sensors arranged around the beam pipe as shown in figure 3 extending the angular coverage down to 7° from the beam line; the rear section is kept free for cabling and cooling access. More details will be given in the following paragraphs.

2.2 Beampipe

The inner dimensions and shape of the beam pipe are determined by the required beam aperture during injection and the synchrotron radiation emitted by the electron beam. The design of the new interaction region for the HERA luminosity upgrade [3] leads to an increase of the synchrotron radiation power from 7 to 26 kW assuming electron beam currents
Figure 2: Cross section layout barrel MVD
Figure 3: Cross section layout wheels MVD; wheel 0 is nearest to the barrel. The shielding of the beampipe is also shown.
of $I_e = 58$ mA and a beam energy of $E_e = 30$ GeV. Upstream collimation of the synchrotron radiation is no longer possible. The complete synchrotron radiation fan has to pass through the interaction region without touching any part of the central beam pipe or collimators. The synchrotron radiation will be absorbed by several absorbers downstream of the interaction region. Collimators on the right side of the interaction point at a distance of 0.8, 1.4 and 1.65 m protect the beam pipe from back-scattered synchrotron radiation. The resulting horizontal inner dimension of the central beam pipe is 115 mm with a 23.5 mm offset towards the outside of the HERA ring.

The vertical dimensions of the beam pipe can be considerably smaller than the horizontal size, because the synchrotron radiation is mainly emitted in the horizontal plane. A height of 42 mm (inner dimension) provides sufficient aperture for the electron and proton beams, both at injection and luminosity operation. The forward part is of conical shape in order to avoid any back-scattered synchrotron radiation hitting the beam pipe. The advantage of an elliptical beam pipe is a reduced distance of the Micro Vertex Detector inner cylinder from the interaction point.

The aluminum-beryllium alloy AlBeMet AM162 [4] was chosen as the material for the central part of the beam pipe. AlBeMet (Be 68 %, Al 32 %) has excellent mechanical properties. The advantages compared to pure beryllium are its non-brittleness, weld-ability and somewhat reduced cost. The central beam pipe will be made out of two hot-formed half-ellipse sections (through the minor axis) welded at the longitudinal joint. A wall thickness of 2 mm results in a maximum stress of 130 N/mm$^2$, located at the major axis, corresponding to a safety factor of two w.r.t. to the 0.2 % offset yield strength. The radial deformation after evacuation was calculated to be 0.1 mm horizontally, and 0.45 mm vertically.

The rear and conical forward beam pipe sections will be made out of aluminum (AlMg4.5Mn), and will be electron beam welded to the central AlBeMet part.

The beam pipe is electrically shielded towards the outside world by a carbon fibre tube (0.5 mm thick) with a conductive layer at the inside.

### 2.3 Silicon strip sensors

#### 2.3.1 Barrel region

High resistivity n-type silicon is used to produce the single sided strip sensors, thickness $320 \mu m$. Details on these sensors, their characteristics and performance under test beam conditions are described elsewhere [5]. Table 1 summarizes the geometrical details.

Two sensors are glued together and one sensor is electrically connected to the other in a way as shown in figure 5, forming a half module.

For geometrical reasons we choose to orient the readoutstrips of the two sensors within one half module perpendicular to each other as shown in figure 5. Figure 6 shows an engineering drawing of the assembly. A Zirlex bar (5.8 x 65.44 mm, 0.4 mm thick) glued at the edge in between the sensors, forms the mechanical connection between the two. The use of this material assures a good isolation of the HV side of one sensor from the ground plane of
Figure 4: Details of the beampipe assembly.
Figure 5: Two silicon sensors are assembled into a half module; the two half modules are mounted on top of each other and form a full module.
the other one.

While the sensors overlap by 4.8 mm, the sensitive areas only overlap by 2 mm. Also indicated in the figure are small spacers, made of kapton and varying in thickness from 0.8 to 2.4 mm, which form the points where the connection to the support structure is made.

The electrical connection between the two sensors is made via a copper trace etched on a 50 µm thick kapton foil. The foil is precisely aligned, glued on the sensors and subsequently wire bonded to the strips. The connection of the sensor assembly with the front end readout is also made via a kapton foil, glued at one side on a sensor and at the other side on the hybrid as indicated in figure 5.

A surface of 123.68 x 64.24 mm² forms one readout cell of 512 channels and is called a "half module".

A 'mirror image' of this half module is also shown in figure 5; both are mounted on top of each other, separated by the spacers shown in figure 6 forming a "full module" with 1024 readout channels. Kapton spacers with a cross section of a few square mm and various thicknesses guarantee a parallel mounting of the two half modules. The two sensor planes are thus not back-to-back.

Two precision markers are glued to each half module to provide reference points for the alignment on the support structure (see also the paragraph on alignment).

### 2.3.2 Forward region

The Si-sensors covering the forward region are very similar, apart from their shape. Fourteen wedge shape sensors cover a circular plane around the beampipe. Figure 7 shows the geometry of one sensor together with the kapton foil guiding the signals to the hybrid. The strips run parallel to one tilted side; each sensor has a total of 480 readout strips with 120 µm readout pitch.

### 2.3.3 Front end readout

The detector signals are readout by the HELIX 3.0 chip [6], a successor of an analog chip designed by the ASIC laboratorium at Heidelberg and adapted to the ZEUS application. The chip integrates 128 channels with a charge sensitive amplifier/shaper; the signals are then stored in an analog pipeline with a maximum latency of 128 clock intervals.
A half module is read out with four chips mounted on a hybrid. The dimensions of the hybrid are 56 x 35 mm and the components are mounted on a 300 $\mu$ thick aluminum oxide plate.

2.4 Layout of the MVD Barrel section

The area covered by the silicon in the barrel section is 622.4 mm long and is formed by two cylinders with radii of approximately 125 and 90 mm. A third layer close to the beampipe provides a coverage of about 75% in azimuth angle. Figure 2 shows a cross section of the layout of the silicon area in the barrel. The coverage is realized with segments of $\sim 64.2$ x $622$ mm$^2$ arranged like roof tiles, such that there are no gaps in azimuth angle between adjacent segments for the outer two cylinders.

Five full modules are fixed side by side, with 1mm gap in between, on a support frame and form a 'ladder' where the silicon covers an area of $64.2$ x $622$ mm$^2$. The modules are glued to the ladder via the earlier mentioned spacers. The ladder has also to provide the support for the hybrids, cabling and cooling for the front end electronics. Figures 8 and 9 show details of the layout; the flexible kapton connection between sensor and hybrid allows fixation of the hybrid on the side of the ladder on top of the cooling pipes. More details are given in par 3.2. Table 2 gives an overview of the parts forming the barrel detector.
Figure 8: *Top view and a cross sectional view of the ladder support*

<table>
<thead>
<tr>
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<th>inner cylinder</th>
<th>medium cylinder</th>
<th>outer cylinder</th>
<th>Totals</th>
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<td>90</td>
<td>125</td>
<td></td>
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<tr>
<td>number of ladders</td>
<td>4</td>
<td>10</td>
<td>16</td>
<td>30</td>
</tr>
<tr>
<td>number of silicon sensors</td>
<td>80</td>
<td>200</td>
<td>320</td>
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<td>40</td>
<td>100</td>
<td>160</td>
<td>300</td>
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<td>number of readout channels</td>
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<td>51200</td>
<td>81920</td>
<td>153600</td>
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<tr>
<td>number of readout chips (128 channels/chip)</td>
<td>160</td>
<td>400</td>
<td>640</td>
<td>1200</td>
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</tbody>
</table>

Table 2: *Statistics on the components for the barrel detector.*
Figure 9: *Details on the fixation of the hybrid on the ladder*
<table>
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<th>Value</th>
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</tr>
<tr>
<td>inner radius (mm)</td>
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</tr>
<tr>
<td>wedge angle</td>
<td>~13°</td>
</tr>
<tr>
<td>readout strip pitch</td>
<td>120 μm</td>
</tr>
<tr>
<td>number of channels/sensor</td>
<td>480</td>
</tr>
<tr>
<td>number of sensors/wheel</td>
<td>2 x 14</td>
</tr>
<tr>
<td>number of wheels</td>
<td>4</td>
</tr>
<tr>
<td>total number of sensors</td>
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</tr>
<tr>
<td>total number of readout channels</td>
<td>53760</td>
</tr>
<tr>
<td>number of readout chips (128 channels/chip)</td>
<td>448</td>
</tr>
</tbody>
</table>

Table 3: Statistics on the components for the forward detector.

2.5 Layout MVD Forward section

The forward MVD consists of four planes perpendicular to the beam axis; each plane has two sensor layers. Fourteen silicon sensors cover a circle; adjacent sensors are displaced in z (perpendicular to the beam line) by 3 mm and overlap in azimuth by 4 mm. Figure 3 shows the layout of the four planes at the different z-locations; the shape and positioning of the beampipe requires the use of shorter sensors (radial direction) in some locations. The two layers are mounted back to back on a support structure, separated by approx 8 mm in z-direction.

Table 3 summarizes the main parameters of the wheel geometry and the statistics on the individual parts. Details on the assembly are given in section 3.3.

3 Support structures

3.1 Overall support tube

The MVD has to fit inside the central tracking chamber, a cylinder with an inner diameter of 324 mm. The only available support points are located at the forward and the rear side of the CTD, a span of 2 meters. To make an efficient use of the available space it was decided to install the MVD + beampipe together; the support for the MVD has then to be made in two halves. The two half cylinders are joined together, providing a stiff support for the whole assembly. During and after installation the weight of the beampipe has to be taken by external supports.

The support tube is an assembly of light weight cylinders connected to each other via flanges; a drawing of a half cylinder with flanges is shown in figure 10, while figure 11 shows a picture of the assembly of two halves, seen from the rear side.
Figure 10: Elements forming a half support tube.
Figure 11: Support tube seen from the rear side.
We distinguish the following elements

- **forward end flange**
  
  provides the support to the CTD at the forward end. The flange also incorporates a 'hard stop' for the beampipe to avoid that the beampipe comes too close to the silicon. Figure 12 shows the layout; the flange is made of aluminum.

![Figure 12: Perspective of the forward end flange with beampipeshielding and rear end-flange.](image)

- **forward barrel flange**
  
  this flange supports the forward end of the ladders. A 4mm thick honeycomb structure (nomex) is sandwiched between 0.5mm thick carbon fibre sheets (made of the material type B, described in 3.2), glued to a carbon fibre half ring which forms the connection between the honeycomb shells forming the half cylinder as shown in figure 13.
  
  The ring is made by winding carbonfibers, which are submerged in epoxy, onto a stainless steel mold \(^1\). The radial thickness of the ring is 4mm. After removing the

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\(^1\) Fa. Epicon Alkmaar BV
Figure 13: Technical drawing of the forward barrel flange.
carbon fiber ring from the mold, the shape remains. Since we need two halves for the assembly the ring is cut. It turned out that after cutting the shape of the two halves remains circular within 0.1mm, but the diameter reduced from 310.0 to 308.5 mm due to internal stresses. A second ring has been produced using a new mold with diameter of 312.0mm resulting in two halves with (inner)diameter of 310.9mm and a deviation from a circular shape of less then 50 $\mu$m.

At the location of the ladder support, ceramic inserts with a precise diameter (tolerance 0.2$\mu$m) are glued; these fit the precision support points (ceramic spheres, 5mm diameter and tolerance 0.1$\mu$m) which are mounted on the ladder.

At the rim of the flange several slots are foreseen for the passage of cables and cooling for the wheel detectors as well as for the light path of the laser alignment system.

- rear barrel flange

The rear barrel flange supports the rear side of the ladders. The cabling and cooling of the silicon detectors exits from this side. The rear flange is assembled from three parts: the outer, middle and inner ring. Once the ladders are mounted in the outer cylinder, the middle ring is assembled and subsequently the inner ring. At this side the ladder is supported at two points. The outer rim of this flange has the same slots as for the forward barrel flange for cable passage for the wheels. The flange is made of aluminum and a large effort is made to reduce the amount of material to a minimum; in most places the wall thickness is only 1 mm. Figure 14 shows an assembly drawing of the rear barrel flange.

- rear end flange

The rear end flange provides the connection of the MVD with the rear end of the CTD. Also provisions are made for the cabling and cooling connections. Similar to the forward flange, also here a 'hard stop' for the beampipe is foreseen. A technical drawing of this flange, which is made of aluminum, is given in figure 15.

- cylindric shells

The connection between the flanges is made by light weight half tubes. A 4mm thick honeycomb layer is sandwiched between two carbonfiber sheets. One carbonfiber sheet is assembled from seven layers of material 'type B' (described in 3.2) as follows:

1) XN50 UD Carbon fibre, 60$\mu$m thick, 0° orientation
2) XN50 UD Carbon fibre, 60$\mu$m thick, 90° orientation
3) XN50 UD Carbon fibre, 60$\mu$m thick, 0° orientation
4) T300 Carbon fabric, 110$\mu$m thick, 45°,-45° orientation
5) XN50 UD Carbon fibre, 60$\mu$m thick, 0° orientation
6) XN50 UD Carbon fibre, 60$\mu$m thick, 90° orientation
Figure 14: Assembly drawing of the rear barrel flange
Figure 15: Technical drawing of the rear end flange in perspective with beampipe shielding and forward end flange
7) XN50 UD Carbon fibre, 60\(\mu\)m thick, 0\(^0\) orientation

These sheets are preformed on a cylindrical stainless steel mold in an autoclave at 160\(^0\)C. Subsequently the same procedure is used to glue the carbonfiber sheets to the honeycomb layer for the production of the half tube. During this process the inside and outside of the tube is covered with a layer of 25 \(\mu\)m thick aluminum for electric shielding.

The flanges and the cylindric shells are glued together in a mold where the two halves are assembled.

### 3.2 Support structure barrel

The support structure for the silicon sensors in the barrel also incorporates the associated front end electronics, cabling and cooling. In order to conserve the high resolution properties of the silicon sensors we require a support structure which bends less than 25\(\mu\)m when all components are mounted.

The total weight to be carried by one ladder, silicon plus electronics, cooling and cabling is \(\sim\) 220 g. Early investigations of mounting the hybrids, carrying the front end electronics, directly above the silicon sensor, were abandoned because a proper cooling scheme could not be worked out in time. The hybrids have now a flexible connection to the silicon sensors via a kapton foil. The support structure is triangular to accommodate a support for the hybrids and cooling, providing at the same time the necessary stiffness. Carbonfiber material is used to realize a strong and lightweight construction. Two types of carbonfiber have been investigated for the support:

**Type A:** Standard carbonfiber, which is delivered in woven sheets. Two sheets are glued together by pressing them (1 atm) in between glass plates. This results in a sheet of 0.5mm thickness.

**Type B:** Unidirectional prepreg, made from pitch based carbonfiber (XN50A) and polycarbonate resin (RS-3) \(^2\). The fibers are only 60\(\mu\) in diameter. The carbonfiber sheets are made of five layers which are glued together in a autoclave at a temperature of 160\(^0\)C. The fiber orientation is 0/0/+/-45/0/0, resulting in a total thickness of 0.4mm. The zero degree orientation of the fiber corresponds to the length axis of the ladder; in this way the bending is minimized.

No deformation has been observed in function of humidity changes (test was performed in an environment where the humidity varied from 80 down to 5\%).

Strips of carbonfiber material with variable width and approximately 65 cm length are cut from the sheets and glued \(^3\) together with the help of a mold to form a ladder. During the development of the support structure the cross section and shape have slightly evolved to

\(^2\)produced by YLA inc, California
\(^3\)Araldite 106
accommodate cooling and hybrid fixation on one hand, and to increase the stiffness on the other.

### 3.2.1 Overview of ladder prototypes.

Table 4 gives an overview of the most successful shapes; it indicates the weight and type of material used. Ladder nr 1 and 2 had only a triangular cross section, while the trapezoidal cross section of nr 3 and 4 anticipated on the fixation of the hybrid on the side of the ladder. The ladders 5, 6 and 7 have the space for the cooling pipes incorporated in the shape of the carbonfiber material; with a special mold this part is made of one piece of carbonfiber. Ladder 5 and 6 are identical. For the bending test, the ladder is clamped at one side and supported on a single point at the other, which mimics the way the ladder is fixed in the barrel. The clamping is however realized only by means of a weight and not by screw fixation. Weights are not equally distributed, but put in the middle of the ladder. Figure 16 shows the bending of the ladder as a function of the applied weight. A clear linear behaviour is observed; material B is superior to the ‘ordinary’ carbonfiber material A and finally the introduction of a vertical support inside the ladder reduces the bending to the required values. Ladder nr 2 has a very good performance due to the fact that the ‘legs’ of the triangle are not glued together at the top (like for all the others), but bend in a mold from one sheet of carbonfiber material. This production method became too complicated when the trapezoidal cross section was required.

Ladder 4 has been put in an oven for 2 hours at a temperature of 40 °C; immediately after removal from the oven the bending profile was remeasured and did not show any difference from before.

The series production of the ladders are from the type 6, 7.

### 3.2.2 Measurement of ladder flatness

For the first four ladders from the series production the flatness of the plane to which the silicon modules are glued has been measured. The ladder is supported by the three support points and positioned on the marble table of a 3D measuring machine. The height of the plane is measured along three parallel lines over the length of the ladder. Along each line 35 measurement points are equally distributed. Figure 17 shows the distribution of the distance from the measurement points to the median plane for one ladder, a distribution which is typical for all four. Lines 1 and 3 are about 50 mm apart, at the location where the spacers are glued to support the modules; line 2 runs along the middle in between line 1 and 3, where the vertical support inside the ladder is located. The surface is flat within ±35 μ over the full length of the ladder.

### 3.3 Support structure of the forward MVD section

The forward MVD section consists of four planes called wheels. Each wheel is separated in two halves, similar to the barrel. Figure 7 shows the dimensions of the wheel sensors; these...
<table>
<thead>
<tr>
<th>ladder nr.</th>
<th>cross- sectional shape</th>
<th>weight (gram)</th>
<th>material type</th>
</tr>
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<td>4</td>
<td><img src="image4.png" alt="Diagram" /></td>
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<td>B</td>
</tr>
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<td><img src="image5.png" alt="Diagram" /></td>
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<td>6,7</td>
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<td>71</td>
<td>B</td>
</tr>
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</table>

Table 4: Overview of the various laddershapes. The width and height is the same for all: 66mm x 19 mm. The series production of the ladders are identical to nrs 6,7.
Figure 16: Deflection of a ladder as function of the applied weight.
Figure 17: The flatness along the ladder as measured for the first of the production series.
are glued to a 1 mm thick strip (made of G10) which has two fixation holes. The sensors are mounted on a L-shaped carbonfiber half ring, with seven straight sections, as shown in figure 18. Aluminum inserts in the short 'leg' of the ring guarantee precision holes for the positioning of the sensors. These are put back to back, such that the angle between the strips is $2 \times 13^0$. The sensors mounted side by side are staggered in z by 3 mm and overlap by 4 mm (2 mm in sensitive area). The 'long' side from the L-shaped support provides housing for the cooling pipe and supports the hybrid. The half wheels are supported at three points inside the main support tube (figure 10). Figure 19 shows a picture of the wheelsupport; the white balls are support points.

4 Material distribution

The material distribution for the module and ladder is summarized in figures 20 and 21. With all the readout electronics and cabling available we have calculated the contribution of all the individual parts to the total material budget. If all the material which makes up a module is equally distributed over its surface, the total thickness represents 1.5\% of a radiation length; for a ladder this amounts to 2.7\% (including the modules).

5 Cooling

The heat dissipation of the HELIX chips is about 2 mW/channel; with 512 channels per chip and 4 chips per hybrid this amounts approximately to 1 W per hybrid or 10 W per ladder. A total heat dissipation of 300 W in the barrel and 120 W for the wheels is therefore expected. A water cooling system with slight overpressure will be used. A description of the system is given in appendix A.

The water is distributed from a manifold inside the support tube to the ladders and the wheels. Stainless steel tubes, inner diameter 2.5 mm and wall thickness 0.1 mm, run underneath the hybrids and are integrated with the support structure. Thermal contact between hybrid and tube is established with heat paste. The connection between the manifold and cooling tube is made via a polyurethane tube (outer diameter 4 mm, inner 2.5 mm), which is clamped with a spring onto the stainless steel tube.

The cooling performance of this system has been measured for one ladder in a sealed box for different water flows and for three values for the power dissipation 1.1, 1.4 and 1.9 W per hybrid. Using water of approximately 15$^0$ C a typical water temperature increase of 1-2$^0$ C has been measured while the temperature on the hybrid rises to 20-23$^0$ C. The application of heat paste is crucial. Details of the measurements are described in appendix B.

$^4$Dow Corning 340 Heat Sink compound
Figure 18: Technical drawing wheel support
Figure 19: Picture of the support for the wheelsensors, with cooling pipes and fixation points.
Figure 20: Material distribution within a module
Figure 21: *Material distribution within a ladder*
6  Geometry and survey

6.1  Introduction

The precision requirements are defined in three levels.

1. **Mounting.** After a part is mounted to its support structure the inaccuracy is specified as the maximum deviation of the position with respect to the designed position.

2. **Stability.** Deformations of an object (i.e. module, ladder, wheel) defined as the maximal deviation due to changes in temperature, temperature gradients or mechanical stress.

3. **Survey.** After assembly parts of the detector are measured with either optical (mainly 2D) or mechanical (3D) survey machines. This survey defines the uncertainty in the measured position of the space point with respect to another well defined point on the detector. At this point we assume that a 2 dimensional object can be measured with a precision of $5\mu m$ and a 3 dimensional object with a precision of $10\mu m$. This is under the assumption that the survey is performed at NIKHEF with 2D and 3D machines.

A schematic overview of the detector components is given in figure 22 and 23.

![Figure 22: The names and labels of the detector parts as they are used in the text.](image)

6.2  Assembly of the barrel section

Using the naming conventions as given in figures 22 and 23, the assembly of the barrel section proceeds as follows.
Figure 23: The coordinate systems and placement of the modules on a ladder. Dimensions are given in figure 8

- **Sensors:** The intrinsic precision of the sensors is in the order of a few micron, assuming the mask to mask alignment is 2 to 3 $\mu$m. The same holds for the uncertainty in the position of the alignment marks on the edge of the sensor with respect to the underlying strip pattern. The cutting edge is assumed to be 20 $\mu$m (specified by Hamamatsu).

- **Modules:** The module is produced in two half-modules. Using precision rotational and translation tools the sensors are glued together with a precision of 10 $\mu$m. This precision is defined as the maximum uncertainty in the distance of one survey mark to another (on another sensor). After assembly and complete curing of the glue the precision is confirmed with a microscopic measurement [7]. Figure 24 shows a picture of a half module in its transport box.

- **Ladders:** The ladder assembly goes in two steps, first the outer layer followed by the assembly of the inner layer. Five half modules are aligned. These are held in place with vacuum tools. The alignment of the half modules with respect to each other relies on survey marks on glass ears. The ladder is glued onto the modules via the spacers. In this step three alignment marks on the ladder (M1-3, ceramic spheres) are in a well defined position with respect to the module position. The position of the precision markers on the half modules are measured wrt the alignment marks on the ladder. The flatness of the assembly is given by mechanical boundary conditions of the half modules and the ladder. Figure 25 shows the ladder assembly jig; one distinguishes the five adjustable small tables which each support a half module and above that the rail with microscope support for the alignment of the half modules wrt each other. Figure 26 shows a picture of an assembled ladder mounted in a storage frame; the half modules are visible, while
Figure 24: *Half module in transportbox*
the hybrids, connected via the flexible kapton foil, are fixed on the backside of the ladder as shown in figure 27. Note also the cooling pipe which runs underneath the hybrids.

- Barrel: The ladders are mounted in a half cylinder. With the ball-like marker (see figure 23) on the front side, the ladder is mounted to the forward barrel flange. This fixes the position in the plane of the disk but allows the ladder to expand in the direction of the beam line. The holes in this disk have a position precision of 25 $\mu m$ with respect to their design value, however the positions are measured with a 3D survey machine (i.e. a precision of 10 $\mu m$). On the rear side of the barrel section, the ladders are screwed onto the (aluminum) rear barrel flange. The precision wrt to the design is expected to be in the order of 50 $\mu m$. After assembly of one half layer (respectively 8, 5 and 2 ladders) a 3D survey is performed. The overall uncertainty in the position of the ladders with respect to the centre of the cylinder is then 10 $\mu m$. Be aware that part of the space points are obtained through a software fit of the actually measured points. The relative position of the forward and the rear ladder markers cannot be measured directly. It is however constrained by the positions of the holes in the forward disk and the
Figure 26: Completely assembled ladder in storage frame
Figure 27: Hybrids mounted on ladder
measured position of markers M1 and M2 on the ladder (see figure 13).

6.3 Wheel Assembly

Figure 28 shows a picture of the assembly of prototype modules for the wheels.
A Description Cooling system

General Features

Enclosure:
The cooling system is housed in an 19 inch rack.
Outside dimensions:

- Height: 2310 mm
- Width: 600 mm
- Depth 670 mm

The water connections are placed in the left side wall. On 1120 mm from the floor. A kamloc 3/4” connector is used.
To allow air circulation through the condenser, at least 200 mm of free space is needed at the front and the back side of the casing.

Main parts fluorocarbon system:

- Aggregate:
- l’Unite Hermetique CAE 94602MHR R404A
- Heat exchanger Alfa Laval (1m2)
- Expansion valve Danfoss size 5
- Evaporator pressure regulator Danfoss

Temperature control:
The evaporator pressure regulator is set for an evaporation temperature of around 10 Celsius. The expansion valve is set for 5 Celsius super heating. Thus the water temperature will be around 15 Celsius.
The maximum cooling power of the system is 1.5 KW. The water pump puts .33 KW in the system. Net capacity 1.2 KW. To avoid ice forming the minimum evaporating temperature is set at 5 Celsius. When this is reached the compressor is switched off. A time relay sets the minimal off time (30 sec).

Main parts water system:

- Pump Calpeda type B NTM G1E (.33 Kw)
- Expansion vessel Stainless steel 20 liters membrane type pre-pressure 1 bar absolute
- Electric valves Asco type SCE210D95, 24/50
- Strainer 1” bronze 100µ mesh.
- Flowswitch Turck
- Pressure valve 3/4” spring loaded set at 3 bar
- Pressure transmitter range 1-5 bar and 1-3 bar
- Temperature transm
- Pressure gauge 0-5 bar
- Air vent Automatic flexon
- Manometers pump pressure and expansion vessel pressure

**Description water system**

The water system has to be filled with water before the system can be put in operation. It is necessary to take the air vent plug out of the pump and to put it back again after the pump housing is filled. The water pressure in the expansion vessel should be around 0.5 bar.

With the electric valves still closed the system can be switched on. The water pump and the compressor start running. As the electric valves are still closed, the water circulates over the pressure valve and the manometer will read around 3 bar. The flow switch indicates the nominal flow in the system (green leds on). In case the flow switch senses insufficient flow (red led on) there is not enough water in the pump. Vent the pump though the special vent plug. After a short time (ca. 5 to 10 minutes) the water temperature will reach 15 Celsius. The compressor switches on and off to keep the water temperature around 15 degrees. If the external system is ready, the electric valves can be opened. The system is now in operation. During the first hours of operation the air will be removed through the automatic vents. Some water should be filled to keep the 0.5 pre-pressure in the expansion vessel. If all the air is removed the pre-pressure should be stable. Any drop in pre-pressure is then the result of a water leak. The PLC will switch off the system in case of an unacceptable large leak. Small leaks are unavoidable, we expect a leak rate of around one liter a month. As the content of the expansion vessel at 0.5 bar is 7 liter, the pre-pressure should be checked and eventually corrected every three months.

The scheme for the control of the coolingsystem is shown in figure 29
Figure 29: Layout of control system for the cooling
B  Ladder Cooling studies

Figure 30 shows a picture of the experimental setup. A ladder with cooling is situated in a box, inner dimensions 60 x 100 x 750 [mm$^3$]. Ten dummy hybrids (0.3 mm thick Al$_2$O$_3$) are fixed on the ladder on top of the cooling tubes, where heat paste $^5$ makes a thermal contact between tubes and hybrids. On each hybrid four resistors (22Ω) are glued to simulate the power dissipation of the chips. A total of sixteen temperature sensors measure the temperature at various locations, on the hybrids, in- and outgoing water and inside and outside the box. The PT100 is used to measure the temperature; the current through a tiny platina wire (encapsulated in a ceramic housing) is monitored$^6$, the resistance of the wire is a linear function of the temperature. The cooling and circulation of the water is provided by a NESLAB RTE-140 system.

Figure 31 shows an example of a measurement cycle. The monitoring of the temperatures starts at time=0. The temperature of the water entering the box is about 17°C. This temperature is measured indirectly via a sensor glued on the outside of the cooling pipe; this method might introduce some uncertainty, but if anything it will measure a value which is slightly higher than the real value. At time $\sim$2500 sec the power is switched on. One notices an almost instantaneous increase of temperature on the hybrids which reaches an equilibrium after about 500 sec, while the temperature inside the box slowly increases during 2000 sec.

The average temperature increase as a function of the dissipated power is shown on figure 32 and as a function of the water flow in figure 33.

$^5$Dow Corning heat sink compound
$^6$Tech Tempscan/1100 High speed temperature measurement system
Figure 30: Experimental setup for cooling tests
Figure 31: Temperature variation as a function time after power switched on
Figure 32: Temperature versus dissipated power

Figure 33: Temperature versus water flow
References


[2] ’Optical Alignment System for the ZEUS MicroVertexDetector’
Takashi Matsushita, Stewart Boogert, Robin Devenish and Roman Walczak
submitted to NIM, copy can be found in ”http://www-pnp.physics.ox.ac.uk/takashi/std4/std4.pre.ps.gz”


[4] AlBeMet AM162 is manufactured by Brush Wellman Inc., Electrofusion Products, Fremont, CA, USA.


K. Riechmann, Overview of the HERA-B vertex detector system and first results from prototype runs, Nucl. Instr. Meth. A 408 (1998),221-228.