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DESIGN STUDY OF A LARGE CYLINDRICAL DRIFT CHAMBER

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ABSTRACT

A design study of a large cylindrical drift chamber of 4.5 m length and 3.4 m diameter for an experiment at a large e^+e^- storage ring is presented. Measurements of the electrostatic stability of the wires and of the pulse propagation along the wires are reported. The mechanical design, minimizing the amount of material traversed by particles, is discussed.

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1. INTRODUCTION

In this paper we will discuss problems arising from scaling up a classical cylindrical drift chamber to a system with many long wires, and their possible solutions. Electrostatic wire stability, pulse propagation along the wires, and a mechanical structure minimizing the material traversed by particles will be treated.

The chamber under study is 4.5 m long and 3.4 m in diameter; it has a cylindrical hole in the middle, 80 cm in diameter, to provide space for a smaller cylindrical chamber around the beam pipe (see fig. 1). The chamber was designed to study e^+e^- collisions at energies around the Z^0 resonance [1].

1.1 Design aims

The chamber design was based on the following specifications:

- i) position measurements with an accuracy of $\approx 150 \mu\text{m}$;
- ii) good tracking efficiency;
- iii) minimal overlap problem of particles in jets, i.e. good two-track resolution;
- iv) minimum amount of material traversed by particles.

These specifications led to the choice of a cylindrical drift chamber with many azimuthally staggered small drift cells. A distance of 2 cm between sense wires on 40 cylindrical layers was chosen. These 40 layers include 31 axial ones and 9 at a stereo angle of approximately 3 degrees.

The aim of reaching a precision of $150 \mu\text{m}$ leads to the requirement that the error from the electronics be kept below $50 \mu\text{m}$. This error includes the combined effect of the digitization and the timing variations due to threshold fluctuations. It corresponds to a timing accuracy of approximately 1.5 ns. The voltage at which the drift cells must be operated lies within the range of 1500 to 2000 V, depending on the gas mixture chosen.

1.2 Mechanical structure

Each end-plate has 77,280 holes for the wire feedthroughs, 64,400 for field wires strung at 5.0 N and 12,880 for sense wires strung at 0.65 N. The total force applied to the end-plate is 33×10^4 N. To sustain this force with an acceptable deformation (3 mm), a 120 mm thick flat plate would be needed (fig. 2). Even a 30 mm conical end-plate would be required for an unconstrained dished end-plate. This sort of thickness would have greatly impaired the usefulness of the detectors behind the end-plates.

To solve this problem, each end-plate is made of a solid, 5 mm thick, aluminium alloy dish-plate (inclined at 15 degrees from the flat surface) rigidly fixed by its outer diameter on a cylindrical high-inertia beam. The aim of this cylindrical reinforcement beam is to fix (both in radial displacement and rotation) the outer rim of the dish-plate. If the beam is considered perfectly rigid, the maximum axial displacement of the 5 mm thick end-plate is 2.2 mm (fig. 2). With a reasonable beam (such as one with walls of rectangular section 100 mm $\times$ 200 mm and 25 mm thickness) this deformation will be no more than 3 mm. The outer shell consists of six panels of honeycomb structure designed to take the full load without buckling. The equivalent thickness is 2 mm of aluminium. The gas tightness can be assured by an external layer of mylar wrapped around the external shell. The inner tube has no mechanical role and is only there for gas tightness.

1.3 Drift cell geometry

A hexagonal geometry was investigated, with a maximum drift distance of 1 cm [2]. The cells are combined into layers as shown in fig. 3. The cell size and the azimuthal staggering ensure an adequate two-track resolution.

For the tests, 4.5 m long wires were used, 20 μ m thick gold-plated W (Re 3%) sense wires and 100 μ m thick Cu-Be field wires. In order to work safely below the elastic limit, the sense wires were strung at 0.65 N. The field wires were strung at $\approx$ 5.0 N, equalizing the gravitational sag of field and sense wires, keeping the symmetry of the cells all along their length.

2. ELECTROSTATIC STABILITY

The length of the wires puts certain constraints on the high voltage that can be applied before electrostatic instabilities take place. The relation between the critical voltage V_{crit} at which the cell becomes unstable, the wire length L , and the mechanical tension T applied on the sense wire, is written as

$$V_{\text{crit}} = K \frac{D\sqrt{T}}{L}, \quad (1)$$

where D is the distance of the sense wire to the field wires; K is a constant varying slowly with D and the wire diameters. Measurements were performed on a cell with slightly different parameters; these measurements can be applied to the standard cell by scaling with eq. (1). The parameters of the measured cell (type II) and the standard cell (type I) are given in table 1, together with the calculated critical voltages. The measured deflection as a function of the applied voltage is shown in fig. 4. For ease of interpretation a "scaled voltage" is also given, which provides the scaling of the results of a cell of type II to the standard parameters. Below 3000 V the deflection is smaller than 50 μm , corresponding to a safe voltage of 6000 V in the standard cell.

An approximate calculation indicates that for a multicell layer the critical voltage is lower by a factor of $\sqrt{3}$. This leads to a corresponding safe operating voltage of 3460 V for multicell layers. Measurements were performed on a layer of cells with standard parameters (table 1, cell I). As was expected, no visible deflection was observed up to 3000 V. Field wires showed 200 μm deflection at this voltage. In a cell with one broken field wire the cell symmetry is lost and deflections of the sense wire of ≈ 1 mm were observed.

In conclusion, it is shown that no problems are to be expected from electrostatic instabilities in the voltage range of 1500 to 2000 V for this type of cell. Special care has to be taken in the case that one of the field wires is broken.

3. RISE-TIME AND ATTENUATION OF PULSES

The use of thin wires of high resistivity in long drift cells can cause a variation of pulse height and shape depending on the position along the wire where the pulse was induced. In the following, L is the distance between the position where the pulse is measured and where it is induced.

One effect is the attenuation of the pulse height as a function of L . The measured pulse height I_{out} is attenuated compared to the induced pulse height I_{in} according to

$$I_{out} = I_{in} e^{-\alpha L},$$

where α is the attenuation constant.

Owing to the non-negligible resistivity of the sense wire, a difference is to be expected in the propagation time of waves of different frequency, thereby distorting the pulse shape. The difference in rise-time of a pulse near the end of the wire where the pulse is measured or far away from it, induces in the drift-time measurement a dependence on the longitudinal position of the hit along the wire, in addition to the propagation time of the pulse.

3.1 Calculations

The properties of the pulse propagation in the drift cell were calculated following ref. [3]. In this treatment the pulse shape is predicted with a high-frequency and low-frequency approximation, which can then be joined graphically. The predictions of the shapes of the leading edge of the pulses are shown in fig. 5 for two different sense wire diameters, and different distances from the measuring end L . As is shown, for a standard cell for $L = 4.5$ m the attenuation is roughly a factor of 6. For $L = 2$ a factor of ≈ 2.5 attenuation is expected. Approximate values for the predicted rise-times are: 0.7 ns ($L = 4.5$ m) and 0.4 ns ($L = 2$ m).

The attenuation can be calculated in a simple way by considering the drift cell as a lossy coaxial transmission line, as shown in fig. 6. The attenuation constant in the high-frequency approximation reads:

$$\alpha = \frac{R}{2Z_0}$$

with

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}.$$

In this case

$$R = 308 \, \Omega/\text{m}$$

$$L = 1.4 \times 10^{-6} \, \text{H/m}$$

$$C = 8.0 \times 10^{-12} \, \text{F/m}$$

$$G = 0.$$

These values give $|Z_0| = 414 \, \Omega$ ($\omega \rightarrow \infty$) and $\alpha = 0.372 \, \Omega/\text{m}$, corresponding to an attenuation of a factor 5.3, consistent with the calculations shown in fig. 5.

3.2 Measurements

The properties of the drift cell were measured with the set-up given in fig. 7. A current source was simulated at one end of the sense wire by a mercury pulser. The pulse shape was measured at both ends of the cell with a current probe (Tektronix P6022), which had a rise-time of 2.3 ns. The leading edge of the pulses on the input and output side of the cell are shown in fig. 8.

The results of these measurements can be summarized as follows:

- i) The attenuation is a factor of 6 over 4.5 m. This value is in agreement with the calculations.
- ii) The worsening of the rise-time is visible: t_{in} and t_{out} , the 10% to 90% rise-times of the input and output pulses are

$$t_{\text{in}} = (2.8 \pm 0.2) \, \text{ns} ,$$

$$t_{\text{out}} = (3.4 \pm 0.2) \, \text{ns} .$$

Correcting for the rise-time of the mercury pulser and of the current probe one obtains the rise-time Δ of a step pulse induced at 4.5 m distance from where it is measured:

$$\Delta(4.5 \text{ m}) = 0.8 \begin{matrix} + 0.8 \\ - 0.4 \end{matrix} \text{ ns} .$$

This result is not inconsistent with the predictions shown in fig. 5.

- iii) No cross-talk larger than 10% of the signal after 4.5 m attenuation (I_{out}) was observed. This is smaller than the amount which is expected from the primary ionization of a track passing through the neighbouring cell. It is therefore concluded that the cross-talk is essentially independent of the cell length.
- iv) The propagation velocity of the pulse step is 4 ns/m. If the position of the track along the wire is known to ± 10 cm accuracy, this effect can be corrected for with sufficient accuracy.

4. CONCLUSIONS

Considering the design aims (electronic resolution better than 1.5 ns) it is concluded that the attenuation factor and degradation of the leading edge are serious enough to consider one of the two following solutions:

- i) Install drift-time electronics on both ends of the wire. The maximum attenuation factor is then expected to be 2.5. This gives the possibility of a higher threshold, with a maximum time-slewing of 0.3 ns at 25% of the average non-attenuated pulse-height. This solution requires a doubling of the electronics (at least the preamplifiers), and is therefore expensive.
- ii) Use a thicker sense wire, e.g. 30 μm diameter. In this case, as can be seen from fig. 5, one obtains an attenuation factor of 2.5, as in the previous solution. The maximum time-slewing is, however, larger (again at 25%): 0.5 ns. In addition the gas amplification is smaller for the same high voltage.

An elegant solution was found by which the thickness of the end-plates can be reduced to 5 mm.

The drift cells are electrostatically stable up to voltages which enable safe operation in the proportional mode.

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REFERENCES

- [1] ELECTRA Collaboration, LEPC/I5 (1982).
- [2] We would like to thank K. Derikum (PLUTO Collaboration) for interesting discussions.
- [3] F. Schneider, The dynamical properties of charge-dividing proportional counters, CERN 82-06 (1982).

Table 1

Drift cell parameters

	Standard cell (type I)	Measured cell (type II)
Wire length L (m)	4.5	5.6
Sense wire to field wire distance D (cm)	1.00	1.15
Mechanical tension T (N)	0.65	0.20
Thickness of sense wire (μm)	20	20
Calculated critical voltage (V)	7670	3830
Measured critical voltage (V)	-	3850

Figure captions

- Fig. 1 : General view of the chamber.
- Fig. 2 : Maximum deformation of the end-plate as a function of plate thickness for different cone angles. The calculation assumes a rigidly fixed outer edge.
- Fig. 3 : Drift cell structure investigated.
- Fig. 4 : Measurements of the deflection of the sense wire as a function of the applied voltage in the horizontal and in the vertical projection. The voltage scaled to the standard cell parameters is shown below.
- Fig. 5 : Predictions for the leading edge of a step pulse measured at different distances L: a) standard cell (20 μm sense wire); b) same cell, but with 30 μm sense wire.
- Fig. 6 : Equivalent circuit of a lossy coaxial transmission line.
- Fig. 7 : Circuit used for measurements of the pulse shape.
- Fig. 8 : Pulse-shape measurements: a) of the input current; b) of the output current.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8