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FURTHER EXPERIENCE OF SPARK CHAMBER OPERATION AT LOW PressURES

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1. INTRODUCTION

The cylindrical wire chambers in the proposed coherent-interaction experiment will be contained in a low-pressure gas mixture of He and C\textsubscript{2}H\textsubscript{5}OH. The density of this gas mixture must be as small as possible in order not to stop low-energy α's (1 - 2 MeV). Read-out by the charge-division method is desired because of its compatibility with axial wires, which are preferred.

In order to see more clearly how these requirements can be met, we have made further studies and tests. We describe the design of a cylindrical test chamber and some experience gained from the measurements on this chamber. The results from these tests led us to construct another chamber with a wider gap for which we give some performance figures. Finally we indicate the main features of the design of the two cylindrical spark chambers to be used in the experiment.

2. THE CYLINDRICAL CHAMBER

2.1 Mechanical design

A simplified view of the set-up is shown in Figure 1. The chamber itself was designed and built by the Muratori group. The two planes have diameters of 20 and 22 cm, the length is 20 cm and the gap width is 2 cm. The wires, made of
stainless steel, have a thickness of 50μ, which gives a good transparency and a high wire resistance. The wires are spaced 2 mm apart, which gives a transparency of 97.5% for each plane.

2.2 Gas mixture

We have tried mixtures of He, Ar and Ne and we have examined the influence of various quenching agents (C₂H₂, C₂H₄, C₃H₈, CH₄, C₂H₆O, NH₃, I₂). The smallest gas density at which defined sparks could be obtained was found for the combination of He and C₂H₆O.

2.3 Trigger system

An Am²⁴¹ source defining a 0.6 mm wide beam of 58-MeV α's and a solid state detector were placed on opposite sides of the two planes. In order not to get a too long delay between the triggering pulse and the particle traversal, a trigger coincidence system was used to pick up the timing information at the early rise of the solid state detector (SSD) pulse. The SSD pulse and the triggering pulse are shown in figure 2. The delay between particle traversal and HV pulse was estimated to be 200 ns.

2.4 HV pulsing system

The trigger pulse was fed to the EGG HV-100 pulser the output of which fired an EGG spark gap. A diagram of the electronics is shown in figure 3. As the charge-division read-out method is used, it is necessary to prevent fluctuations in the total charge Q dissipated in wire and spark. We therefore chose the condenser C made of mica, which has a smaller temperature coefficient than for instance a ceramic condenser. It is also important to empty C from all its charge before the spark gap ends conducting. This was secured by shunting the spark gap with a RC circuit, the time constant of which was much longer than the spark-chamber time constant.

2.5 The charge-division read-out system

The currents or charges that flow in the leads connected to each side of one of the planes, divide in proportion to the impedances measured up to the spark position. Signals which measure position, can thus be obtained from
toroid-ferrite cores wound around the leads. This read-out method has been invented and elaborated by Charpak. In our case we have chosen to get signals proportional to the charges flowing in the chambers. As was seen in figure 1 the spark gap is connected to the circumferential conductors in two points via copper bars. This was done in order to compensate for the variable impedance increment from the circumferential conductor due to different azimuthal spark positions.

2.6 Network analysis

As the planned cylindrical wire chambers will have bigger dimensions than any existing spark chamber employing the current read-out, the precision might be off-set. We attempt therefore to make an analysis in which the charges are functions of the desired position \( x \). A complete network of a chamber like the one in figure 1 (see figure 4) would be too difficult to solve analytically. However, a numerical solution by means of a computer could easily be done, as it is possible to get explicit expressions of the considered network.

In order to get an analytic expression, calculations will be done for an approximate network (figure 5) in which the circumferential impedance is regarded as small beside \( R \). The spark wire is shunted by the remaining \( n-1 \) wires and the components inside the dashed box of figure 5a change via a \( \Delta-Y \) transformation to the components in figure 5b.

The loop equations are:

\[
\frac{\Delta Q}{\Delta t} = V + R \left( i_1 + i_2 \right) \tag{1}
\]

\[
i_1 + i_2 = \frac{-\Delta Q}{\Delta t} - \frac{Q}{CR} \tag{2}
\]

\[
V = L \frac{d}{dt} \left( \frac{1}{n} \right) i_1 \tag{3}
\]

\[
V = L \frac{d}{dt} \left( \frac{1}{n} \right) \frac{r(1-x)}{n} i_2 \tag{4}
\]

An exact solution of this system will lead to a third order differential equation in for instance \( Q \).
As $R/mL \gg 1$ for spark frequencies of 50 - 100 MHz and as the wire number $n$ is large, we approximate eq. 1 by

$$\frac{Q}{C} = R_e (i_1 + i_2). \quad (1a)$$

Eqs. 1a and 2 give a solution for the sum current

$$i_1 + i_2 = \frac{Q_0}{R \frac{1}{e}} e^{-\left(\frac{1}{R_e} + \frac{1}{R}\right) t/C} \quad (5)$$

By using the relation above and by eliminating $V$ from eq. 3 and eq. 4 a solution for $i_1 - i_2$ will be obtained that reads:

$$i_1 - i_2 = \frac{Q_0 (1 - 2x)}{R_e [1 - 2nL eC(1/R_e + 1/R)]} \left[ e^{-\left(\frac{1}{R_e} + \frac{1}{R}\right) t/C} - e^{\frac{-rt}{2nL_e}} \right] \quad (6)$$

The summed charges $Q_{\text{sum}}$ and the difference in charges $Q_{\text{diff}}$ are obtained by straight integration.

$$Q_{\text{sum}} = \int_{0}^{\infty} (i_1 + i_2) \, dt = \frac{Q_0}{R \left(1 + \frac{e}{R}\right)} \quad (7)$$

$$Q_{\text{diff}} = \int_{0}^{\infty} (i_1 - i_2) \, dt = (1 - 2x) \frac{Q_0}{R \left(1 + \frac{e}{R}\right)} \quad (8)$$

$Q_0$ and $R$ are constants with high accuracy whilst $R_e$ is dependent on spark resistance, on position $x$ and on wire resistance $r$.

For inox wires with a diameter of 50μ this latter resistance is 45 Ω/cm at spark frequencies. The wire inductance is practically negligible. The feeding copper bars which have a cross-section of 15 x 0,5 mm have a negligible resistance and an inductance of 20 pH/cm at spark frequencies.

When only $Q_{\text{diff}}$ is recorded, due to the change in $R_e$, it is worth while to increase $R$ as much as possible (eq. 8) in order to improve precision and linearity.
The core signals $E$ are doubly integrated in an RC circuit (figure 6). In order to separate the position information from the instantaneous electromagnetic radiation, we used a delay line, which, at the same time, acts as a filter for the high frequencies present in the read-out signal. Following the delay cable the pulses are amplified and smoothed in the N4142 amplifier and fed into a pulse height analyzer. The capacitor $C_i$ has to be designed so that the steady state solution to equation 9 (we neglect $R_i$ in this context)

$$E = L \frac{di}{dt} + V_i$$

$$\int \frac{dV_i}{C_i \, dt} = \dot{E}(t) = L \frac{dV_i}{dt} + V_i$$

is negligible at the time when the amplitude has to be recorded. The condition therefore is that $L C_i \gg (R C_i)^2$.

The resistance $R_i$ should be small enough to avoid pile-up at high pulse rates and big enough not to discharge $C_i$ during the accumulation of charge.

2.8 Results of tests

The purpose of the tests was to get a good spatial resolution, small memory and dead-time and good inclined tracks at a smallest possible gas density.

A typical position spectrum is shown in figure 7. The half width including the 0.6 mm $\alpha$ beam width is seen to be 0.9 mm. When the resistance $R$ was reduced below 5 k$\Omega$, the resolution got worse in good agreement with equation 8.

In order to get a short memory time, it was necessary to increase alcohol pressure, clearing voltage and to reduce the resistance $R$ (see figures 8 and 9). These modifications reduce the precision and increase the density. Still the memory times are longer than normal. This, we believe, is due to the long life-time of the meta-stable states in low-pressure He that makes it very probable that an electron is present even if the high-voltage pulse is much delayed with respect to the ionization moment. In the presence of a track with a density of 1000 ion pairs/cm one electron elsewhere in the chamber is harmless, but one electron alone is sufficient to start the mechanism ending in a spark.
In order to check this we took a spectrum with an additional high-intensity α-source at a different position (1 α every 20 µs was entering the chamber). Using the same values as for the plot in figure 9 and with a clearing voltage of 150 V, we found that the position spectrum from the collimated source was unchanged. Thus we conclude that in our case the maximum flux of particles through the chamber may be higher than what is given by the memory time.

At a total gas pressure of 40 mm Hg it was not possible to get localized tracks with a partial alcohol pressure below 6 mm Hg. As the density of C₂H₆O is 12.5 times that of He we were thus not able to reach an equivalent of 76 mm Hg of pure He, which is our design goal. In order to reduce the pressure, we were therefore obliged to construct a new test chamber with a gap of 4 cm (next section).

3. THE 4-cm GAP CHAMBER

3.1 Design

The chamber was made of plexiglas (see figure 10). The size of the wire planes was 40 x 10 cm² and the plane was slightly curved in order to correspond to the radius of curvature of the smaller chamber to be used in the experiment. One plane was made of 50µ gold-plated molybdenum wires, short-circuited by copper bars in each end. This plane was used for normal read-out and the choice of wires was done in order to see if the sputtering of material from the molybdenum wires was less pronounced than the sputtering from the 100µ inox wires on the other plane. The wires in this latter plane were interconnected in each end by means of Konstantan wires. This was done in order to get a high resistance for reading, by means of charge division, the wire in which the spark current was propagating. The electrical and mechanical systems were similar to those described in the previous section.

3.2 Performance and results

With this new gap we can get defined tracks, for a total pressure of 40 mm Hg, down to partial alcohol pressures between 2 and 3 mm Hg. We have, however, examined the properties of this chamber at a partial pressure of 4 mm Hg.
The high-voltage pulse was of the order of 15 kV and the clearing voltage 150 V. Under these conditions we have had a resolution of \(~1\) mm for straight tracks with a resistance \(R = 22\) k\(\Omega\).

In the case of \(20^\circ\) inclined tracks, it has been very difficult to get the sparks to follow the track without any distortion. By reducing \(R\) to \(~100\) \(\Omega\) which cuts down the RC-time constant to 50 ns, the inclined sparks look better. The precision when using \(Q_{\text{diff}}\) for the position determination was very bad, but when \(Q_{\text{diff}}/Q_{\text{sum}}\) was used, the precision came back to the order of 1 mm for straight, and close to 2 mm for inclined tracks. However, with inclined tracks we get more breakdowns in the frames. We think it therefore useful to make the isolation as good as possible which improves the conditions for inclined tracks.

The azimuthal read-out system worked satisfactorily. Each of the wires spaced by 2 mm were readily resolved.

As far as sputtering of material from the wires is concerned, we found the molybdenum wires somewhat better than the inox wires. We prefer, however, the inox wires, because of their higher resistance.

4. DESIGN OF THE CYLINDRICAL CHAMBERS

The mechanical design is presently being worked on. The chambers will have a 45°-opening in the bottom for support and feed-through of the conductors. The smaller chamber is slightly shorter than the bigger chamber in order to give a bigger opening angle. The wires are all of 70 \(\mu\)-inox except for the inside plane of the big chamber which should have gold-plated 50-70 \(\mu\) molybdenum wires interconnected at the ends by Konstantan wires. The wire pitch will be 2 mm. The suspending circular rings will be designed in order not to give electric field concentrations and will preferably be made of a material with low dielectricity constant.

The inside plane of the small chamber and the outside plane of the big chamber are ground planes.

The HV trigger systems will be identical to the systems in figure 2. The read-out system will be slightly different from now (see figure 12). In
order to balance hum and r.f. on the ground, we shall try to use the
differential input of the N4147 amplifier. To reduce pick-up further the
cores and associated components will be built as compact as possible and
adequately shielded.

   The purpose of the two-fold R.C. circuit shunting the cores is to
bring in a ground between the two cores without the risk of loosing ground
currents.
a = Trigger pulse
b = Solid state detector pulse

FIG.2
Circuit diagram for cylindrical spark chamber

\[ Q = Q_0 \]
\[ t = 0 \]

**Q\(_0\)** = Charge stored in C

**C** = Storage capacitor

**R** = Damping resistor

**L** = Inductance of feeding conductors

**I\(_1\), I\(_2\), I\(_3\), I\(_4\)** = Current picked up in the Ferrite cores

**\( \Delta l \)** = Inductance between feeding points on the circumference

**\( \Delta l \)** = Inductance of the circumference for a length corresponding to the wire pitch

\[ r = \text{Resistance of a wire} \]

\[ n = \text{Number of wires} \]

\[ x = \text{Spark position} \]

\[ L_s = \text{Spark inductance} \]

\[ R_s = \text{Spark resistance} \]

\[ 0 < y < 1 = \text{Relative azimuthal position on the circumference in which the active wire is positioned} \]

**Upper Network contains**

\[ \frac{1}{\frac{\Delta l}{y}} \text{ Elements} \]

**Lower Network contains**

\[ \frac{1}{\frac{\Delta l}{(1-y)}} \text{ Elements} \]

FIG. 4
Approximate network for cylindrical wire chambers
Circuit diagram of readout electronics, and pulse shapes of the primary spark current (i) and the induced voltage (E)

FIG. 6
\[ C = 500 \text{ pF} \]
\[ R = 10 \text{ K}\Omega \]
\[ V = 10 \text{ KV} \]
\[ P_{\text{tot}} = 40 \text{ mmHg} \]
\[ P_{\text{Alc}} = 6 \text{ mm Hg} \]
\[ P_{\text{Ar}} = 1.5 \text{ mm Hg} \]

Resolution = 0.9 mm at 0°

Cylindrical chamber. Tracks 1 cm apart

FIG. 7
$C = 500 \text{ pF}$
$R = 4 \text{ K\Omega}$
$V = 10 \text{ KV}$
$P_{\text{tot}} = 40 \text{ mm Hg}$
$P_{\text{Alc}} = 12 \text{ mm Hg}$

**FIG. 9**

Efficiency delay time plots

- C.L. = 150 Volt
- C.L. = 300 Volt
- C.L. = 450 Volt
Mechanical view of the 4 cm gap chamber

HV Plane. Azimuthal position for read out

Ground plane - Horizontal position for read out

r=15 cm

FIG.10
C = 500 pF
R = 350 Ω
V = 11 KV
$P_{\text{tot}}$ = 40 mmHg
$P_{\text{Alc}}$ = 4 mmHg

Resolution = 2 mm at 20°

The 4 cm gap chamber. Tracks 2 cm apart
FIG. 12

Block diagram of read out system

Gate Input

ADC

Shaping Ampl. Type N4142

Delay

50 Ω

C_i

R_i

E_i

C_i

R_i

E_i

50 Ω

Delay

Delay

50 Ω

C_i

R_i

E_i

C_i

R_i

E_i

50 Ω