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SOLENOIDAL DETECTOR NOTES

WIRE STABILITY TESTS ON 4MM STRAW CHAMBERS

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1.) Calculation of Electrostatic forces

The electrostatic stability of a wire in a straw chamber is a function of the tension on the wire. The electrostatic limit can be estimated by using the linear term in the expression for the attractive force per unit length on a wire element displaced by δ from the center line of the cathode :

$$F=\frac{2\pi\varepsilon_0 V^2\delta}{[\ln(\frac{R}{r_0})]^2 R^2}, \qquad (1)$$

where V= voltage, R= cathode radius, r = wire radius, δ= displacement from center. In general this will be balanced by the tensional force of the wire. Therefore, assuming that the wire will have a sinusoidal shape about the central cathode axis, and imposing the boundary conditions that the wire is fixed at both ends , the condition on the wire tension for stability is: [1]

$$T > \frac{2\varepsilon_0 V^2 L^2}{\pi R^2 \ln(\frac{R}{r})^2}, \qquad (2)$$

where L is the wire length (meters).

For a 2 mm radius tube and a 12.5 μ radius wire this condition is

$$T > 5.6\times10^{-6} V^2 L^2 \text{ gm force} \qquad (3)$$

This is the minimum theoretical tension (in grams of force) required for stability for a given length of 4mm diameter straw at a specified voltage.

2.) Radial Displacements

We would now like to calculate the effect on the stability due to a net initial displacement of the entire wire from the tube axis. The effect of an initial wire displacement can be estimated in a manner similiar to the previous stability determination by assuming a shift of

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Δ from the symmetry axis. Assuming the wire distortion is sinusoidal, the total force on the wire can then be expressed as the integral :

$$F_{TOT} = \frac{2\pi\varepsilon_0 V^2}{\ln(R/r)^2 R^2}\int_0^L (A\sin(\pi x/L)+\Delta)dx \qquad (4)$$

The resulting tension in the wire is

$$T = \frac{LF_{TOT}}{2\pi A} = 5.6\times10^{-6}\, V^2L^2(1+\frac{\pi\Delta}{2A}). \qquad (5)$$

Notice that the tension now depends on the amplitude of the wire deflection unlike the first approximation for a well-centered wire. The deflection amplitude now can be solved for:

$$A = \frac{\pi\Delta}{2(\frac{T}{5.6\times10^{-6}\, V^2L^2}-1)} = \frac{\pi\Delta}{2(\frac{V_0^2}{V^2}-1)}, \qquad (6)$$

where V_0 is the stability limit for zero displacement from Eq. 3.

This amplitude function , A ,is shown in Fig.1 for a 1 meter long tube and a wire tension of 40 grams.

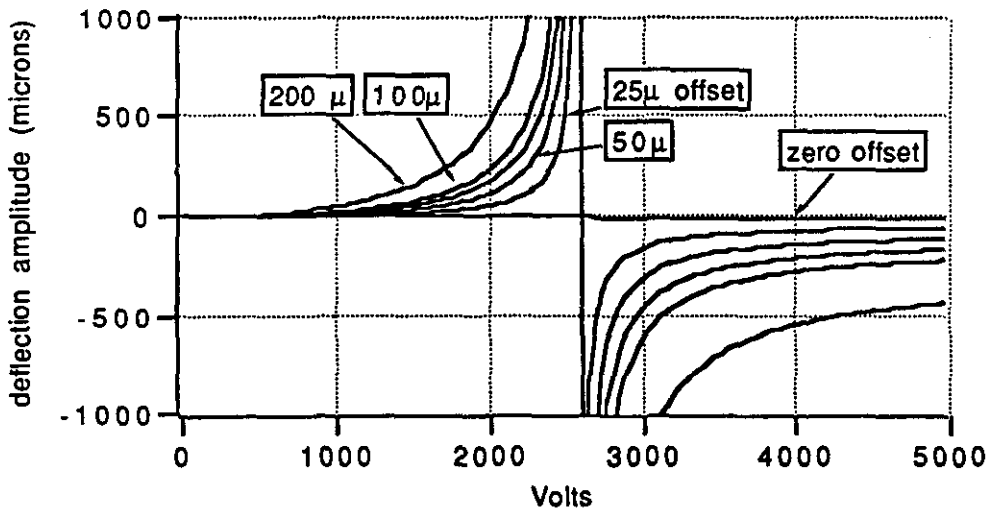

Fig. 1 wire deflection amplitude vs voltage
for several uniform radial offsets ,Δ.

Notice that if we set a limit of 100 μ maximum amplitude , A, then we can find the relationship between the offset error and voltage limit. For instance, suppose we could construct the tube assembly with a maximum offset of 50 μ. This formula then limits the allowable voltage to V/V_0 = sqrt(1/ (50/70+1)=0.7. Since we plan to use a drift gas that requires 2000 Volts for good efficiency, the implies a V_0=3000 V. Then, using Eq. 3, for a maximum free span of 1 meter, we find the required tension = 50 grams.

3.) Measurements of stability

We have attempted to verify these expressions by performing a number of optical and electrical tests. The first test was with a 2.1 m length straw that was tensioned and positioned vertically with a central wire 25 μ in diameter.The tension of the wire was varied and the voltage recorded at the onset of instability, (when the supply tripped!).Oscillations of the straw were observed at instability when the tube was unsupported. Four support points were added to stop the oscillations , but as can be seen from Fig. 2 we were far from the theoretical limit. of 26 grams force at 1000 Volts.

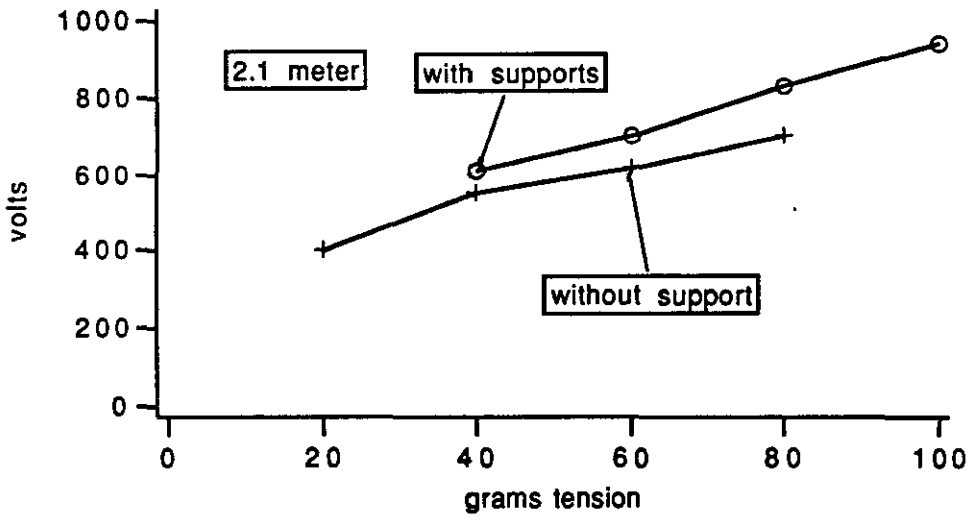

Fig. 2 Stability measurement

We know from further measurements that the problem was in the method of positioning the straw. In our initial tests we had tensioned the straw on a vertical jig and then added up to four glue joint contact points for transverse stability along its length. We now know that a much more accurate method must be used for positioning and holding the straw. Also the instability point was determined by the HV trip point, when the wire actually snapped over to the tube. In visual tests on such a system we have observed the wire to move about 300 μ and then suddenly snap over to the cathode. These measurements are shown in Fig. 3. for a two meter straw with 100 grams of tension. The measurements were made by melting a small hole in a straw and using an optical level to measure the wire position.

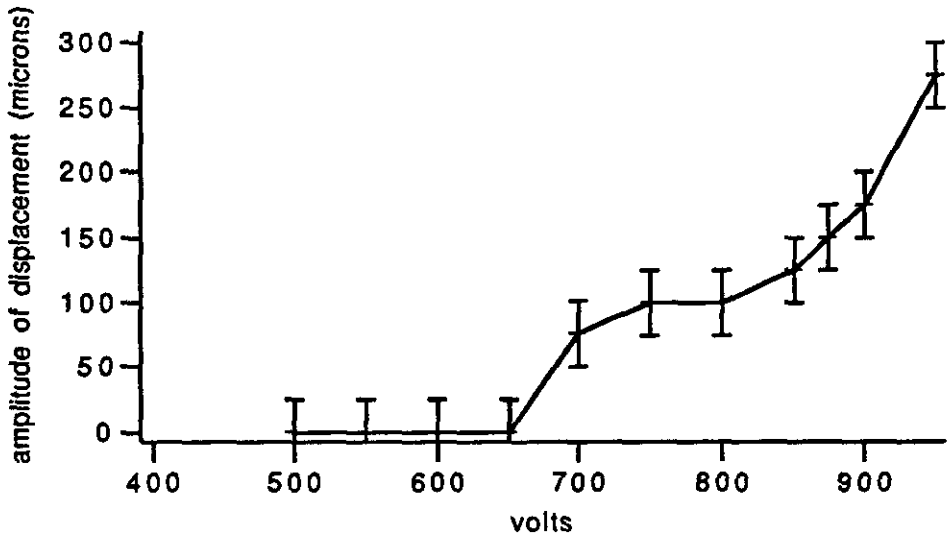

Fig. 3 Measured wire displacement from center vs voltage
for a 2 meter straw with unsupported wire at 100 grams tension.

In order to improve our measurements we built a new test system. A 4 mm square groove was machined in an aluminum channel with a linear runout of less than 50 μ. The wire was positioned at each end with x-y translators capable of 25 μ accuracy. The total length of the wire was 1.07 m. The wire tension was set at 40 gm for all the measurements we report here. This results in a catenary sag of 20 μ which we ignore. C02 gas was flushed through the straw to suppress HV discharge.

We first experimentally determined the position of maximum stability. This was done by translating the wire and testing the high voltage limit of stability. This corresponded to a maximum of 2500 volts and was taken to be the central axis of the straw. This is 8% lower that the theoretical limit, but a considerable improvement from the unsupported measurements. It probably reflects the residual misalignments in the straw positioning. Then the wire was translated horizontally in a series of steps to investigate the change in stability. Again the stability point was determined by the wire snapping over to short to the cathode.We found that the maximum voltage point dropped by about 100 volts for every 50 μ of horizontal displacement. of the wire. This is shown in fig. 4.

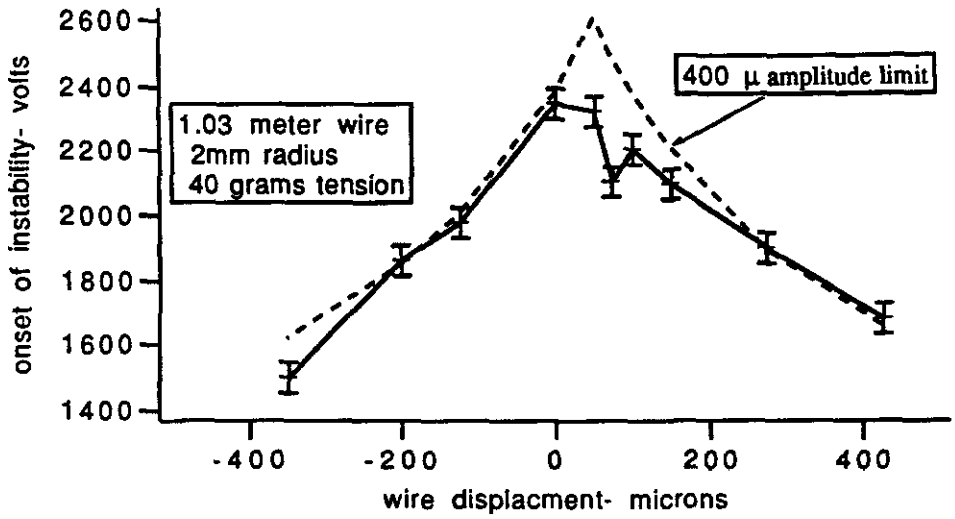

Figure. 4 Electrostatic stability limit vs. radial wire displacement.

We can compare this to the model for instability in Eq. 6 by assuming a maximum amplitude, A= 400 μ, before the sudden nonlinear onset of instability. This plot of the voltage limit vs wire displacement is shown in Fig. 4. The match to the data is reasonable. Thus the model expressed in Eq. 6 can be assumed to be correct up to maximum amplitudes of about 400 μ . After this point the forces are no longer linear and the wire rapidly goes unstable.

4.) Conclusions

One of the conclusions of this study is that for straw tube construction we must align the cathode structures to a precision better than 100 μ if we attempt stable, unsupported wires spans of 1 meter. Thus the requirements on the straw alignment is comparable to the precision required for wire placement.

We should mention that we have developed [2] a wire support mechanism that is simple and easy to implement. It may be that using wire supports every 50 cm would lead to a more conservative design and less restriction on tension and voltage. However we have yet to establish the requirements for gain stability, d vs t, variations. and attenuation.

References:

1 J. Carr and H. Kagen Proceedings of the 1986 Summer study on SSC (SNOWMASS) p 396
2.. R. Foster, IUHEE 90-3