MECHANICAL CONCERNS FOR LONG STRAW-TUBE ARRAYS

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Abstract

A calculation of the force required to buckle an array of straw tubes is presented together with a description of an experiment being carried out to test this. A way of safely handling long straws during the assembly process is discussed which incorporates quality control on the straw integrity. A new method is presented for fixing the wire in a straw in such a way that a specified tension of the wire is assured. Finally, a rapid method of measuring the tension of wires in long tubes is discussed.

Introduction

This study of techniques of constructing straw-tube-chamber arrays was carried out under the auspices of the Central and Forward Tracking Subsystems Group, and was motivated in part a the proposal to study B-decays at the SSC.[1] The latter consideration leads to design parameters that are somewhat different than those of our collaborators who were motivated by experiments such as the Solenoidal Detector (SDC):

- We are concerned with self-supporting arrays of glued straws. The strength of the walls of the array should be sufficient to resist buckling under the tension of the wires, rather than the necessary rigidity being provided by an exoskeleton.
- A B-physics experiment would need straw tubes of lengths up to only 2 m, compared to 4-6 m for the SDC, and these straws would be in a vertical, or near vertical orientation. Hence we are pursuing a straw-tube-chamber design with a 2-m-long unsupported wire.

To get some immediate experience of the constructional problems, an Ohio State U. design[2] has been used for the straw-tube end plugs. This has resulted in our working with straws of a larger diameter (7 mm) than might be optimal at the SSC, but has given us valuable experience that will be needed for work with smaller straws. Indeed, after assembling a hundred or so straws to that design, our technical staff found that there were improvements that could be made to facilitate the attainment of correct wire tension. Also, after working with the O.S.U. method of straw alignment, it was not found to be suitable for extension to longer straws, and a different method has been developed.

A proper wire tension is very important in minimizing the gravitational sag of the wire and determines the ultimate high voltage that can be applied to the straw. We anticipate having to measure and remeasure the wire tensions at several stages during the fabrication, and therefore need a fast efficient method for wire tension measurement. We have built two instruments using differing techniques, and from the experience gained with these we are able to identify a better technique.

This paper describes results from a buckling calculation and the work that is being done to check those results. It discusses improvements to the O.S.U. State method of straw assembly, and describes wire-tension measurement techniques suited to long wires.

Buckling of Straw-Tube Arrays

The buckling of single tubes is described by the Euler criterion

$$F = \frac{\pi^2 EI}{L^2}, \tag{1}$$

where F is the load, E is Young's modulus for the straw material, I is the bending moment, and L the length. This can be extended to $N \times N$ arrays of straws using the parallel-axis theorem giving

$$\frac{F}{N^2} = \pi^3(N^2+1)E\frac{R^3T}{2L^2}, \tag{2}$$

where R is the radius of the straw, and T is the wall thickness. For convenience, the force required to buckle an array has been divided by the total number of tubes in the array, N^2, giving a measure of the maximum wire tension that may safely be applied. A plot of F/N^2 is shown in Fig. 1as a function of the length of the straw. The buckling load has been calculated for two wall thicknesses: 50.8, and 25.4 μm. The plot is for a 7-mm straw radius and assumes free (unrestrained) ends.

If the only force on the straw-tube array is the compressive force due to the combined wire tensions, then it

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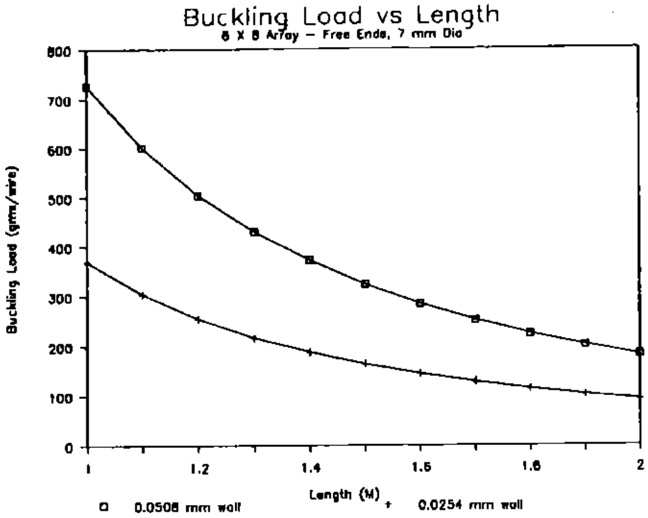

Figure 1: The buckling force per straw in an $N \times N$ array of straw tubes as a function of the length of the straws. The tubes are glued together to provide a large bending moment.

can be seen that, for a 2-m-long array constructed from straws with 25.4-μm wall thickness, the maximum load before buckling is 100 gms, only a factor of two larger than the force required to keep a 20-μm-diameter gold-plated-tungsten wire taut. The figures, that these buckling formulae predict, can vary by large factors from the figures obtained by experiment. This discrepancy is due partly to the theoretical model used: as there are many different modes of buckling and there are many different axes along which buckling can occur, and partly due to the non-symmetrical nature of the actual straws: they are after all not a true cykinder and the material properties may be non-uniform. Usually, all these effects combine to reduce the actual observed buckling force so that the factor of two is not a large enough safety factor.

The prediction (2) is being checked with an array of tubes fabricated at Princeton U. Once glued, the array will be fixed to a granite surface plate and restrained from buckling along the diagonal. A force meter is then used in conjunction with a screw, to apply and measure the longitudinal force.

An improvement in the strength of the structure, whilst still maintaining a minimum of material, can be obtained through the use of an epoxy glue filled with microspheres.[3] Because the glue has a very low density, all the interstitial gaps can be filled, resulting in a much stronger structure. Alternately, the number of straws in an array can be increased.

Improvements in Array Assembly

The Ohio State U. method of assembly of straw-tube arrays[2, 4] has been used to great effect for short (typically 50-cm-long) arrays. This method aligns the straws accurately by inserting a precision-ground, stainless-steel rod into each straw and then positioning the rod with dowel pins located in a precisely drilled end caps. This method becomes quite cumbersome when 2-m-long straws are anticipated. Instead of locating the straw by using its internal surface, it is more desirable to use the external surface. However, straws with thin walls are very fragile and deform easily under any force perpendicular to the axis of the straw.

One solution that we are pursuing is to pressurize the straw to 15 p.s.i. before placing it in a precisely machined positioning jig. This has the added advantage of performing a quality control on the straw, as punctured tubes are easily detected. Pressurization can be conveniently carried out by attaching bicycle-tire valves temporarily to the end plugs of the tubes After inflation, the straws can be left overnight and checked for leaks the following day. While still inflated, the straw can be handled safely with little danger of buckling. This speeds up the gluing and positioning process.

After gluing the assembly, the next step is the stringing of the anode wires. When using the Ohio State feedthrough, Fig. 2a, we encountered difficulty in attaining the correct wire tension. The problem is that the wire is secured by clamping it between a conical brass pin and the internal cylindrical surface of the plastic feedthrough. The pin is inserted in a direction towards the centre of the straw and opposite to the tensioning force. Any friction between the pin and the wire tends to push the wire back into the straw and reduces the wire tension.

FIG. 2A

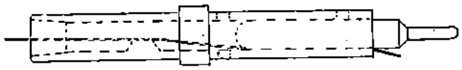

FIG. 2B

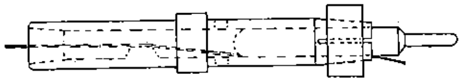

Figure 2: a): The Ohio State U. design of a plastic feedthrough for positioning and clamping the anode wire of a straw-tube chamber. b): A modified feedthrough with a slotted end and a clamping ring that squeezes the feedthrough to the brass taper pin without causing longitudinal forces that change the wire tension.

We have had some success with a modified design that takes the original plastic feedthrough and puts a longitudinal cut, Fig. 2b, into the end of it, allowing the ends to splay out. The pin is inserted without much force and the wire is clamped by pushing a ring over the splayed ends, forcing them together. In this design there are no extra longitudinal forces introduced on the wire during the clamping process.

Measurement of Wire Tension

Most wire-tension measurements make use of voltages induced by the movement of a current-carrying wire in a magnetic field. There are three general techniques for exploiting this effect:

1. The induced voltage can be amplified and measured. This is a maximum at resonance. A sweep of the frequencies around the suspected resonant frequency is made and terminated when the induced voltage is a maximum. A meter using this principle has been developed at Fermilab,[5] and has also been built at our lab.
2. The phase difference between the driving and driven voltages can be utilized.[6] Again a frequency sweep around the suspected resonant frequency is made, and the frequency at which the phase difference drops to zero, is recorded. An example of this type of device has been built at Princeton U. and is capable of very precise measurements to 0.25 Hz.A plot of the phase shifts measured on a 50cm long wire is shown in Fig. 3
3. The wire can be subjected to a short current pulse and the subsequent ringing-frequency recorded.[7]

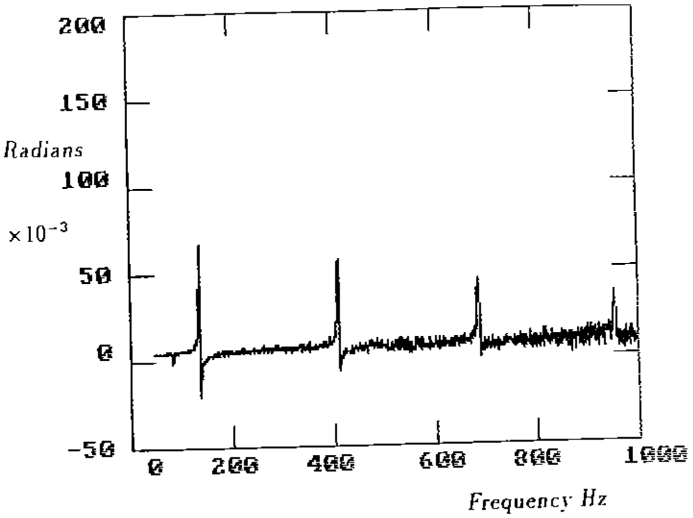

Figure 3: Phase shift versus Frequency showing four clear resonances

With 2-m-long straws the resonant frequency is very low (~ 60 Hz), though higher harmonics can be used to good effect. These mechanical systems have a fairly high Q so that the resonance curve is quite narrow, typically 2 to 3 Hz, at these frequencies. They also seem to have quite a lot of "inertia" in that changing from a driving frequency of say 60 Hz to 62 Hz, requires a wait of several seconds for the wire to stabilize its oscillations at the new frequency. A long time is required to achieve an accurate measure with the frequency-scanning techniques as the possible range of frequencies has to be spanned in a set of small increments with pauses at each step. We are now pursuing the third option, which offers the possibility of making an instantaneous measurement – crucial for large arrays of tubes.

Conclusion

The force required to buckle an array of straw tubes has been calculated. These calculations have a large uncertainty due to material imperfections and nonuniformities in assembly – for example, the nonuniform application of glue. They are to be compared with experimental results, and if they do indeed describe the buckling in a reasonable manner, they can be easily extended to describe straw arrays with different diameters, lengths, and numbers of straws.

Practical experience is being gained in the assembly of large straw-tube arrays, which has led to new methods of assembly that are better suited to long straws. Improvements have been made in the manner of clamping the wire so as to leave the wire tension unaffected.

Experience with two techniques for measuring wire tensions has shown that they are very time consuming when working with long wires. A third method that utilizes the ringing frequency is being exploited which has the potential for making rapid measurements. This is essential when large arrays of tens of thousands of straws are being contemplated.

References

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[3] H. Kagan, private communication.

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[7] Wire Tension Meter Model NE-660 A, manufactured by K.F.K.I. H-1525 Budapest, Hungary P.F.49.