CHARA TECHNICAL REPORT

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Vacuum Tube Support and Sealing Considerations

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1. INTRODUCTION TO THE CHARA ARRAY PROJECT

The Center for High Angular Resolution Astronomy (CHARA) of Georgia State University will build a facility for optical/infrared multi-telescope interferometry, called the CHARA Array. This array will consist of initially five (with a goal of seven) telescopes distributed over an area approximately 350 m across. The light beams from the individual telescopes will be transported through evacuated pipes to a central laboratory, which will contain optical delay lines, beam combination optics, and detection systems. The facility will consist of these components plus the associated buildings and support equipment, and will be located at the Mount Wilson Observatory in southern California. The CHARA Array is funded by Georgia State University and the National Science Foundation.

2. OVERVIEW

The CHARA optical train must transmit light to the central laboratories without significant degradation of wavefront quality. For this purpose, vacuum tubes will be provided for turbulence-free beam propagation.

Aluminum tubing in 8 inch outside diameter and 30 foot sections was selected for the cross-country transport of beams, as described in CHARA Technical Report No. 72. The mechanical supports and the vacuum joints for these tubes are the subject of this report.

3. GENERAL REQUIREMENTS

The longest beam tube strings are approximately 330 meters end to end. The minimum tube temperature will typically be in equilibrium with the air on cold nights. The lowest temperature is assumed to be 10F. The maximum temperature will occur with direct insolation on a hot day. An estimate of this temperature was obtained on tube stored on pallets in the sun prior to installation. A temperature of 100F was found when the air temperature was 85F. A tube temperature of 110F will be assumed.

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¿From tables in Eschbach (1974), the expansion of a 30 foot length of 6061 aluminum from 10 to 110F will be 0.45 inch. So clearly, accommodating this expansion is a critical concern, on a par with maintaining a vacuum seal.

The beam transport tubes will be exposed to a variety of conditions, including daily direct sun in some cases, freezing rain, and the possibility of impulsive forces due to falling tree limbs.

4. VACUUM SEALS

An obvious option was discarded at the start. Metal flange joints with O-ring seals and metal bellows, though a standard laboratory and industrial solution, would be far to expensive for CHARA. For example, a stainless steel bellows of 8 inch size, with an extension capability of 0.375", costs of order $470 each. Further, the survivability of the O-ring seals in the exposed environment (eg freezing rain within the joint) is in question.

Two classes of "rubber" seals were considered - expansion joints and tube bands.

The expansion joint problem is a standard one in plumbing, and supply companies list rubber joints fabricated from a variety of materials and with various configurations. These are generally available for standard tube sizes, and our 8 inch outside diameter is not a standard pipe size. These joints are also rather expensive, typically $250 each. They are designed for positive pressure in the pipe, rather than for a vacuum. And they are normally intended for underground use, where temperature fluctuations are smaller and UV exposure is not a problem.

Nevertheless, we did find a candidate - an expansion joint marketed under the name NoHub. It is intended for sewer lines, and by chance a standard sewer pipe matches the 8 inch CHARA tube size. The price is very attractive, about $9 each. The joint is very strong and rigid, and it is evident that it will not pull into the tube gap very far. However, the inner surface has several ridges, which are intended to form the water-tight seal. It's not clear that they will form a good vacuum seal. They are not UV stable, but a standard stainless steel band, with integral clamps, is available (at additional cost) for protection.

The second candidate was a duplicate of the band designed and fabricated for the similar NPOI requirement. These are extruded, 60 durometer neoprene bands, 0.25 inch thick, 6 inch long. They have a smooth internal surface. The rubber is UV stabilized, is rather pliable, and will be pulled into the tube gap to some extent. NPOI acquired bands of this description from several vendors with mixed results, finally obtaining a satisfactory product from United Seal and Rubber. In CHARA quantities, the bands cost $26.29 each.

5. VACUUM TESTS

A test fixture was set up, with two sections of 8" aluminum tubing, each welded closed on one end, and the two sections joined with a band. A vacuum pump and gauge were used to pump the bands down and to monitor the loss of vacuum.

Figure 1 shows the result. The leak rate of the NoHub band was 8 times larger than the rate for the neoprene band. Was the neoprene leak rate satisfactory? The goal is for the entire system to remain below 1 Torr without pumping for at least 24 hours. The measured pressurization rate during the test gives an upper limit to the band leak rate,

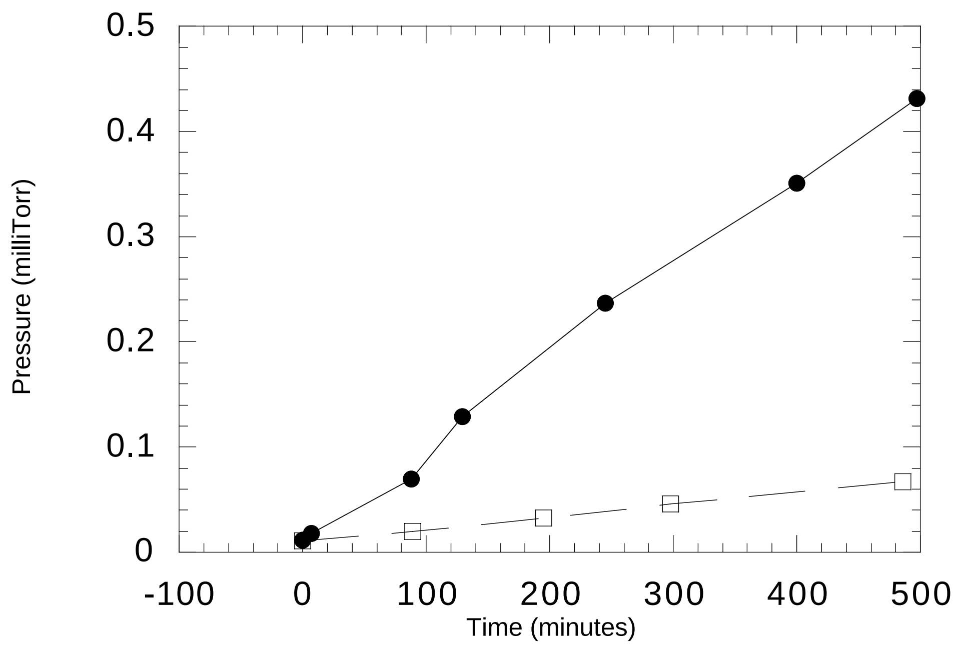

FIGURE 1. Vacuum test of two candidate tube bands. The upper curve (more rapid increase in pressure) corresponds to the NoHub commercial connector. The lower curve corresponds to the neoprene band, modeled after the NPOI concept.

since there could be small leaks in the welds, and some outgassing may be present. The rate was measured for one neoprene band and 2 feet of tube. For 30 foot tube sections, the pressurization due to band leak will be 15 times lower. Thus, in the absence of other factors, we can predict that if the system is initially pumped to 10 milliTorr, it will remain below 1 Torr for 3 months, and below 0.1 Torr for 9 days. If there is an outgassing contribution, it is not likely to be a problem. The aluminum tube is not exposed to any lubricant or solvent during or following extrusion, and the tubes were sealed with cardboard caps during transport and storage.

6. VACUUM BAND CLAMPS

Reports from NPOI on experience with rubber sleeved vacuum seals indicated initially that clamps were not mandatory on tube diameters less than 12 inches, though more recently it appears that clamps were added. A natural candidate for clamping rubber joints are hose clamps. For survivability, metal hose clamps should be stainless steel. For ease of installation (carried out under not-necessarily favorable conditions up to 30 feet above the ground) quick release clamps are very desirable. Further, to minimize damage to the rubber, a smooth inside clamp surface is required.

A minimum of 2 clamps per joint is needed, and 4 may be preferred.

In the size required, 8 inch inside diameter, the selection of metal clamps is somewhat limited. Not all of these features were found on a single metal clamp. Worm drive, smooth inside, stainless steel clamps are available, for example from McMaster-Carr, for $3.91 each in quantity.

Quick release, stainless steel clamps are available from MSC for $2.67 each in quantity, but these are not smooth inside.

An interesting alternative is plastic straping with clips, based on interlocking ridges on the strap and in the clip. The straping is available in bulk, which may be cut to any length, and the clips are sold by the hundred. A tensioning tool is available to tension to 150 pounds, which is typical of the tension achieved in worm-drive clamps. The straps are smooth on the inside. The clamps are reusable. In quantity, these clamps will cost CHARA approximately $0.42 each. They are also a cost-effective alternative for other clamping-tying applications, and for example are cheaper than nylon or steel cable ties of similar capacity, and are much easier to reuse.

The only question about the plastic strap is their survivability in UV. They are fabricated from polypropylene, which is one of the UV resistant plastics, and they are described as UV resistant. An inquiry to the manufacturer confirmed that they are intended for use in sun, and in fact they claim to have conducted 10 year life tests in direct sun. Finally, a test article was mounted in a sunny location on Mt. Wilson for a life test, which continues as of this writing. So far, so good.

7. TUBE WALK

During the diurnal and annual temperature cycles, the tubes will expand until the gap between them is fairly small, and contract until the gap is fairly large (0.5 inch, typically). When the gap is large, the bands will pull into the gap somewhat. When the temperature rises, the bands must be forced out by the expansion forces. If the tube string is not otherwise constrained, the tubes can walk, with one gap growing at the expense of other gaps shrinking. This is a tricky problem, as it arises due to imbalances in the large, imprecisely controlled stiction forces with which each band is mated to its tube ends.

In an attempt to minimize this effect, some effort will be made to equalize the stiction forces. All tube ends will be sanded with the same grit. All tube ends will be chamfered with the same radius. All will be similarly prepared with vacuum grease. All band straps will be tensioned similarly.

In addition, the tube support mechanism has the characteristic that it offers a restoring force on the tube, which will tolerate small displacements, but progressively oppose increasing displacements. The support geometry is shown in Figure 2. The vertical members are 3/4 inch diameter threaded steel rod. The effective vertical length is about 12 inches. The tube acts with a lever arm of about 12 inches also. Modeling this as a cantilevered beam, it is found that when the tube expands or contracts by 0.25 inch, the threaded rod will exert a restoring force of about 400 pounds. In order to ensure that the tube will not push an excessive distance, the frictional force holding the bands on the tube ends should not exceed 400 pounds by more than about 50%, or say 600 pounds. (It is assumed that the tubes do not slip with respect to the straps which attach them to the pole headpieces, for reasonable applied forces. This is a point which needs to be assured.)

For the following, we need a coefficient of friction for the seal bands on the pipe, preferably with and without vacuum grease, which may be applied but may be ejected by cyclic motions

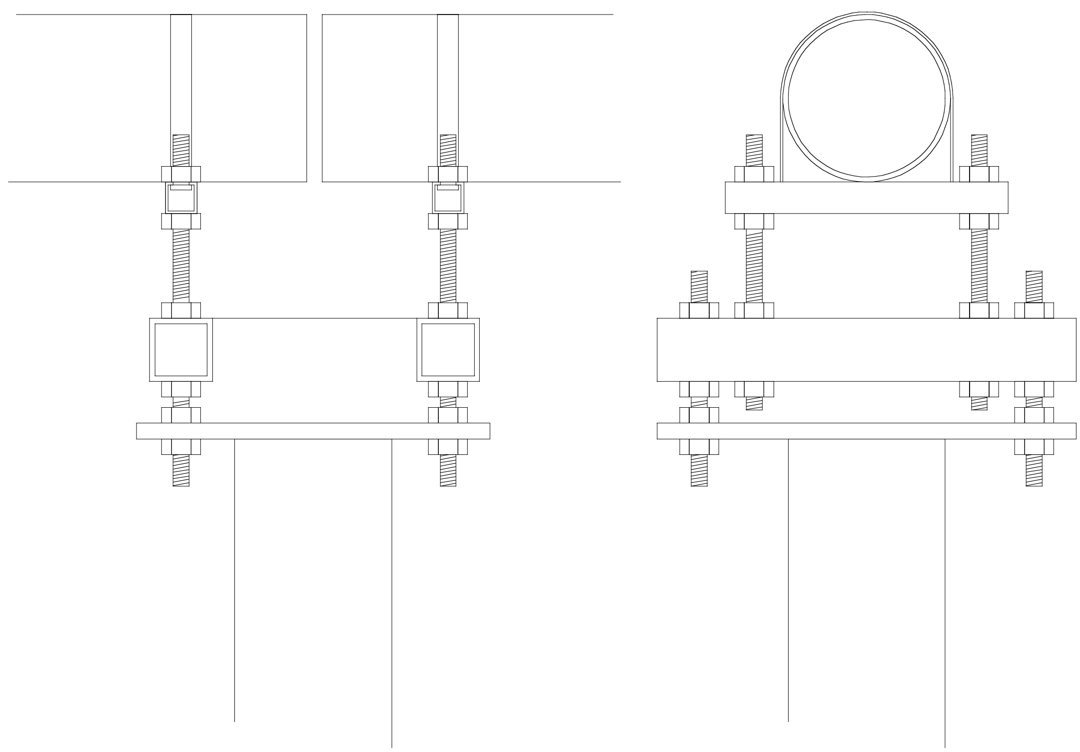

FIGURE 2. Support structure for the beam tubes. On top of a steel pole (diameter depends on height) a flat plate supports on threaded rod a 3 inch steel tube, which in turn supports a 1.5 inch section of U-channel. The channel anchors steel bands which hold the tube against the channel. This structure was designed for CHARA by Sea West Enterprises and Patrell Engineering Group.

of the seal. For the moment, we will adopt a coefficient of 0.5, since the grease has both lubricating and tacky properties. Some measurements would be a helpful guide.

Air pressure on the unsupported part of the seal band will generate a frictional force. For a gap in the range 0.125 to 0.5 inch, the force will range from 140 to 750 pounds, half of which will be effective on each half of a band. With the assumed coefficient of friction, this alone will produce a resisting force of up to 140 pounds, leaving about 450 pounds for the straps.

Assuming an effective strap area of 12 square inch for each of two straps, on each half of a band seal, and a coefficient of friction of 0.5, the maximum normal force exerted by each strap should be no greater than 36 pounds per square inch. From a balance of forces calculation, this gives a maxiumum strap tension of 128 pounds. This is close enough to the tension of the available strap tensioner (150 pounds) that the latter is acceptable.

8. REFERENCES

Eschbach, O.W., 1974, *Handbook of Engineering Fundamentals*, Wiley and Sons.

McMaster-Carr Supply Company Catalog, P.O. Box 54960, Los Angeles, CA 90054-0960, 562-692-5911.

MSC Industrial Supply Co. catalog, 151 Sunnyside Blvd, Plainview, N.Y. 11803-1592, 800-645-7270.