ASSEMBLY TECHNIQUES USED IN CONSTRUCTION OF NEUTRINO HORNS AT BNL*

W.P. Sims, A. Carroll, W. Leonhardt, R. Monaghan, C. Pearson, A. Pendzick, G. Ryan, J. Sandberg, G. Smith, P. Stillman, J. Walker
AGS Department
Brookhaven National Laboratory
Upton, New York 11973

Abstract

This paper will describe the techniques used in the assembly of the neutrino focusing horns which were installed in the fast extracted beam at the Alternating Gradient Synchrotron. The horns are coaxial magnetic lenses that are pulsed to a maximum of 14 kV and 300 kA. The materials and techniques used are further complicated by the fact that the horn must survive in a high radiation environment. We will describe both the techniques and materials that were used in making the high current electrical connections. This will include the silver plating of aluminum, methods for handling thermal expansion and large magnetic forces, and the fabrication of rigid coaxial conductors. The techniques described in this paper can be used in the assembly of any pulsed high current device.

Introduction

At Brookhaven National Laboratory we have designed and constructed 2 neutrino horn systems, one narrow band [1] and one wide band [2]. Horn #1 and horn #2 are both coaxial lenses as shown in Fig. 1. The narrow band system consists of a horn #1 with a plug collimator inside the inner conductor, horn #2 with a plug collimator and a large collimator between the two horns. In the wide band system the horns are built without collimator, but with the target installed in the upstream end of the inner conductor of horn #1. Both systems are electrically similar but have a small difference in inductance due to the larger physical size of horn #2 in the narrow band system. The outer conductors of horn #1 are identical, but the inner, water cooled conductors are geometrically different.

The construction of these new horn systems presented the opportunity to improve the horn design and fabrication techniques to increase the reliability and reduce the radiation burden for repair and maintenance. We will concentrate on the do's and don'ts of the assembly of the horns and power feeds.

General Rules of Assembly

The horns are operated as high current pulsed devices (max 300 kA and 14 kV). At this current any voids or poor contact will arc with enough energy to remove or weld metal, both of which can be disastrous. All current carrying connecting surfaces must be silver plated and coated with an insulating grease such as Dow Corning DC4 [9] when they are assembled. After running the horn system at about 100 kA for one hour all connections and the insulating cups must be retorqued. This retorquing must be redone after running at one-half power and full power for about two hours. One final recheck of all torque values must be done after the final test run of approximately 500 k pulses [5] at full power before beam is put on to the horns. During testing the system should be visually checked and temperature measurements should be taken on the rigid coax and near every joint as this is a good indication of a poor connection. With pulse power used in this device you must remember that all current carrying parts will move with each pulse.

Since the entire horn system is coaxial and with the pulse duration of 58 μs rise and width of 100 μs the current only penetrates 40 mils into the surface of the conductors. Care should be taken to insure there are no conducting paths that are thinner than 0.050 in., as this will cause heating. All welds must be full penetration as small gaps will cause arcs which will eventually cause catastrophic failure.

The insulating materials used in this device must be radiation hardened [8] and machineable. Four materials were used, Kapton, G10, G30, and Polypenpco. The Kapton is a polyimide film. We used 0.005 in. thick film and 0.005 in thick tape. G10 is epoxy resin filled glass laminate. It was used to center the inner conductor of the air coax. G30 is also a polyimide filled glass laminate having better resistance to water absorption than G10. It was used to insulate the horns from the support structure [3], as horn #1 is water-cooled and there is a possibility of water splashing on the G30. Polypenco is a polystyrene and used for the insulating cups and gas line isolators.

The water cooling system must have a full flow deionizer and be recirculating, as the water becomes radioactive from the beam. The system must be fabricated using only aluminum and stainless steel. Copper should not be used in this system not even a very small amount. Make sure the pumps have no copper in them (watch out for copper or brass impellers). In the past we had inner conductors totally destroyed by electrolysis in a few hours of running with only one copper fitting in the system.

Silver Plating of the Aluminum Contact Surfaces

The plating of the aluminum was handled in two ways. If the parts were small they were sent out to a commercial plater and the entire piece was plated. The larger pieces were plated by our technicians using a commercial process, developed by Rapid Electroplating Process Inc. [7], which was fast and worked well. The process is: 1) clean and degrease the surfaces, 2) apply an activator, rinse and wipe off, 3) apply a thin layer of copper plate, rinse and wipe, 4) clean copper with activator, rinse and wipe, 5) plate with silver and rinse. You need plenty of running water and purchase enough probes so you never use the same probe in different solution.

Power Feeds

The power is fed from the power supply [6] via 32 coaxial cables to a transition header that connects to 4 rigid coaxial conductors then to a 4 to 2 reducer that feeds the horn with 2 rigid coaxial conductors. The rigid coax conductors are made up using 4.0 inch o.d. (0.1875 in. wall) aluminum pipe as the inner conductor with 12 wraps of 0.005 in. Kapton film, a 4.5 inch thin wall tube (0.065 in. wall) split lengthwise and slid over the Kapton wraps. Both the inner and outer tube are silver plated on the ends for about 8 inches in order to make the coupling connections. This rigid coax was made up in up to 21 foot lengths. The Kapton film was purchased in 60 inch and 48 inch wide rolls, cut to 21 foot length, and taped together with 0.005 in. Kapton tape along the 21 foot length to form a sheet 14 feet by 21 feet. The sheet was then very carefully cleaned with alcohol to remove all lint and dust particles. The static charge must be removed to keep dust particles off the sheet during the wrapping operation. The wrapping was done on a specially built winding fixture. The winding operation took 4 technicians to keep the film smooth and wrinkle-free. The film was taped down on the last turn in order to hold the film in place. The split outer tube was slipped over the film. After the outer tube was in place stainless steel hose clamps (worm gear type) were installed along the tube every 2.5 inches on center and are positioned 120 degrees offset from the slot in the outer conductor (Fig. 2). The clamps are

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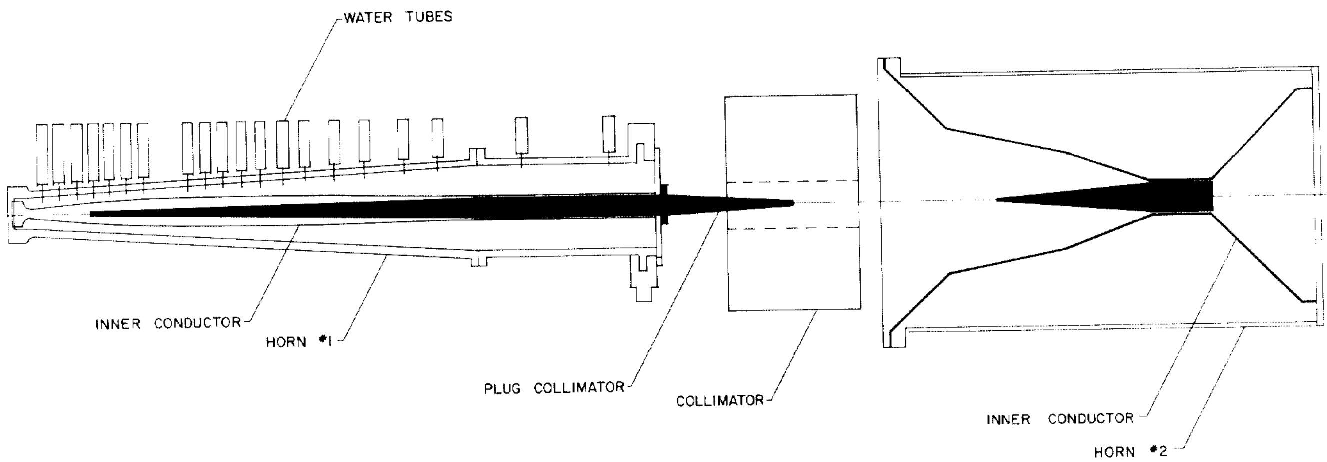

Fig. 1. Horn System Layout

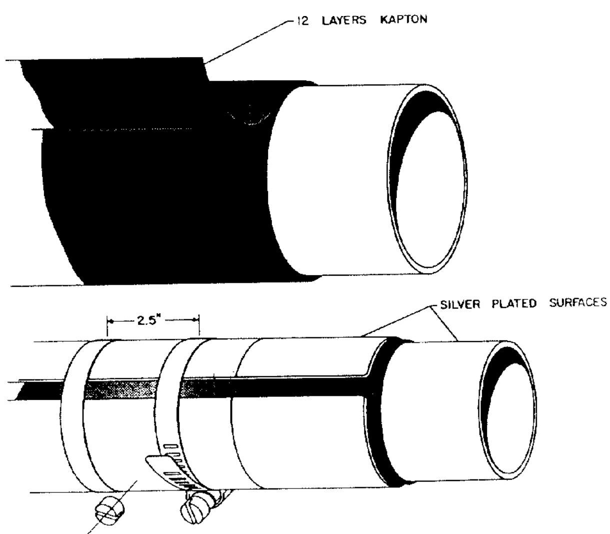

Fig. 2. Rigid Coaxial Assembly

torqued to 60 inch/pounds. These clamps must be retorqued due to the flexing during pulsing.

The coupling connections are made with what we call flexures. These are built to flex in the longitudinal direction to take up some of the growth due to heating during operation (the delta T is about 20 degrees C). The couplings are connected by using T-bolt clamps torqued to 130 in. lbs. The clamps must be retightened after a few hours of operation. Before installing the flexures the surfaces of both the coupling and the coax must be coated with insulating grease.

The transition header is made movable in the longitudinal direction and is preloaded with a heavy spring arrangement. This is done to take up the thermal growth of the four rigid coax conductors. We found during a high current run the growth was >1 in. The coax conductors are supported on stands down the 90 foot section to the four to two connector, they are insulated from the stands with G10 in a manner that allows the coax to slide longitudinally, while keeping them level and straight. It is important to keep the coax straight, when pulsing the coax will try to straighten out. This flexing can cause the Kapton to crack and will eventually cause a catastrophic failure.

The rigid coax conductor from the four to two connector and along the two horns are coupled between the two horns with four flexures that are made with a spider of soft spring material (beryllium copper) to take up thermal growth in the coax. The spring material thickness of 0.050 in. was a compromise to get as soft a spring as possible without excessive resistance. A special clamp was designed for the the flexures used on the two coax power feeds on the horns. Commercial clamps were not available that could withstand the forces on the two coax systems.

Inner Conductors Horn #2

The inner conductor in both the narrow band and wide band number 2 horns are basically the same geometry and both were designed to be preloaded by stretching the inner conductor lengthwise during assembly to make up for the thermal elongation of the conductor during operation. This was necessary because horn #2 is air-cooled and the inner conductor grows at a faster rate than the outer, because of the coaxial design. The narrow band horn has the added complication of a large collimator inserted into the center of the inner conductor.

Inner Conductors Horn #1

Since the inner conductor of the narrow and wide band horn #1 are water cooled [4], preloading is not necessary. Both inner conductors are made of very thin aluminum, so there is a minimum of material for the particles to pass through. There must not be any welds at points of changes in radii, as the force concentrations at these points will fracture the conductor. All the welds must be x-rayed for cracks or voids. The inner conductors must be held as straight as possible during welding, but may still require straightening afterward.

The narrow band inner conductor has a plug inserted, the plug is made of incoloy. A 0.25 in. hole is bored in the center and loaded with carbon to distribute the beam heating along the upstream (small diameter end). The plug is centered in the upstream end using ceramic balls, this is necessary as the plug due to beam heating, expands both in length and in diam. The balls have a very high crush strength.

The wide band horn inner conductor has the target inserted in the upstream end. The target is 20 in. long, 0.25 in. diam, made of pure titanium sealed in helium by welding. This insures that if the target disintegrates the material will be contained.

Flange Insulation

The flanges are insulated using 42 layers of 0.005 in. Kapton sheet. Each layer must be thoroughly cleaned and made dust free. The layers are put together as a blanket and held together with bolts on the outer edges. The blanket is then taped along the edges for easy handling.After the flanges are assembled the bolts and tape are removed to allow the layers to open out like the pages in a book, this increases the creep path.

Insulating Cups

The flange and connecting key bolts are insulated with cups and ferules machined from Polypenco rods (Fig. 3). The through bolts are wrapped with 0.005 in. Kapton tape a minimum of 2 layers to insulate the bolt at the joints on ferules. The cups are designed to have a high voltage creep path of a minimum of 4 in. along the surface. The flange and key assembly are designed so the cup insulators are under compression only with no shear forces. Each part in the cup assembly must be carefully examined before assembly to make sure there are no scratches or tool marks. If they are dropped or cracked they should not be used. Polypenco gets brittle when exposed to high radiation and may shatter under the continuous pulsing of the horn. The Polypemco turns dark brown after long exposure, but our experience has shown the loss of only one cup in tens of millions of pulses with the full intensity of the AGS on the horns. We believe that the one cup was cracked before or during installation.

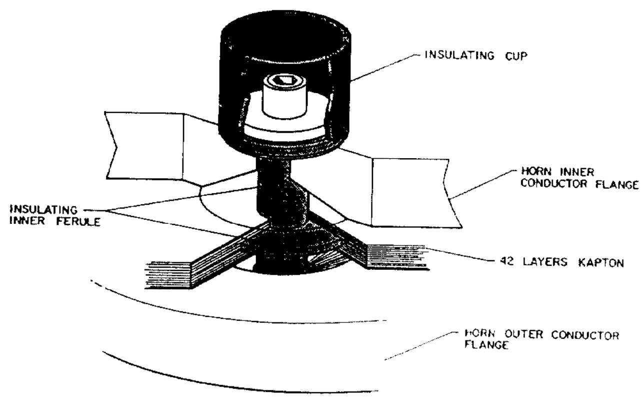

Fig.3. Insulating Cup Cross Section.

Conclusion

Magnetic focusing lenses for producing intense neutrino beams, at the AGS, have operated for the past 20 years at BNL. During its tens of millions of pulses in a high radiation environment, we have learned that there is an enormous premium to be placed on the high reliability of operation achieved by a careful selection of materials and close attention to detail during construction. In the past few years we have managed to achieve the reliability necessary to operate the horns with very little downtime. We have presented specific techniques and materials required to assemble horns which have the electrical integrity, and the thermal strength for long-term service.

Acknowledgements

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[7] Rapid Electroplating Process Inc. 14145 Wabash Ave., Chicago, IL.

[8] The radiation dose in the horn #1 area is about $5x10^9$ rads.

[9] A Silicone Dielectric Compound by Dow Corning Corp. Midland, MI.