THERMAL MANAGEMENT OF MAGNETIC FOCUSSING HORNS USED IN THE NARROW AND BROAD BAND NEUTRINO BEAMS AT THE AGS*

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

Abstract

Operation of the AGS Neutrino Horns and their internal and external targets takes place in an environment of high voltage, severe shock and vibration, and high radiation. To insure reliable operation, energy from Joulean heating and the proton beam interaction must be dissipated to keep component temperatures at the lowest levels practical. This has been accomplished by carefully choosing component materials and providing dedicated air and water cooling systems to transfer the 6 kW of heat efficiently and safely to the environment. This paper describes how the rigid horn and target thermal design constraints were satisfied, and provides some record of the current operating experience.

Introduction

The fast extracted beam line at the Brookhaven AGS utilizes a train of focussing horns in the production of neutrino beams. The first horn in the train in both the Narrow Band and Broad Band operating modes and the production target require mechanically assisted means to safely dissipate the absorbed energy during normal operation. Since the overall design and operation of these horns is described in detail elsewhere (Ref. 1, 2), this paper will concentrate on the design areas of the horns and targets which are concerned with thermal management, and also describe the ancillary air and water systems which ultimately dissipate the absorbed energy to the environment.

Narrow Band Horn

The first horn in the Narrow Band train and its target are shown in Fig. 1. In narrow band running, essentially all the incident beam (28 GeV, 10^{13} protons/pulse) is intercepted by the target and the beam plug, the majority being in the plug. To satisfy physics constraints, the plug is tapered, having a small diameter at the upstream end which gradually increases. Since most of the beam would be absorbed at the upstream end of the plug and thus create an unacceptable volumetric heat generation rate, a low Z insert (graphite) was designed into the plug upstream end to allow the beam to distribute itself axially further along the plug and thus lower the volumetric heat generation rates.

The material for the plug was chosen to satisfy physics constraints (high Z) and to withstand the temperature and shock extremes encountered. Copper had been used in the past but the increased beam intensities, low melting point, and low strength at higher temperatures made copper marginal at best. Additionally, at higher temperatures, copper forms a surface scale which would be shaken off in operation. Incoloy 800 H, a stainless steel with a high nickel content, became the chosen material. Incoloy has a melting temperature of 1385°C, compared to copper's 1082°C, and retains much of its strength at elevated temperatures. Commercially, Incoloy is used for the sheath material on the heating elements of electric cooking ranges.

In the horn application, the plug must transfer all the energy absorbed to the inner conductor through the annular space between them. Natural convection and radiative transfer are the two heat transfer modes employed. To increase the rate of radiative transfer, both the outer surface of the beam plug and the inner surface of the inner conductor were treated (blackened) to increase their emissivity. Approximate increases in the plug were from 0.2 to 0.7, and in the inner conductor from 0.1 to 0.3, increasing in the radiative transfer rate by a factor of ten. Additionally, the annular space is filled with two atmospheres of helium since calculations showed that this increases the natural convection heat transfer over what could be realized with air by a factor of three. The helium is contained in the annular space by a thin titanium window.

The amount of heat to be dissipated in the inner conductor includes both the heat transferred from the beam plug and the Joulean heating from the current pulses passing through the inner conductor. Although the inner conductor has a wall thickness of 3.2 mm, the electrical current is transported through it only near the outer skin to a depth of about 1.4 mm. Since the outer dimensions of the inner conductor are 6.7 cm diameter at the upstream end, tapering out to 10.8 cm diameter and then back to 7.2 cm, a significant amount of heat is generated during each current pulse.

Both the Joulean heating and the beam heating energy are dissipated to a falling water film on the outside of the inner conductor. Prior experience with spraying water on the inner conductor showed that approach had shortcomings since a high-pressure system was subject to leaks and long hookup and disconnect times in the high radiation area. Utilizing a low pressure water film system, water is from a distribution manifold not connected to the horn. The water is passed through nozzles and allowed to free fall to funnels located on the upper surface of the outer conductor. The free fall also provides an electrical break. The funnels each have a 4.8 mm orifice through which the water passes and then falls onto the inner conductor providing a film over the surface. It was determined by experimentation that, for the size orifice chosen, the water film would extend axially on the inner conductor a distance approximately equal to the diameter of the inner conductor at that location. A knowledge of the Joulean heating and the beam energy deposition determined by a computer code called CASIM provided the heat sources. Then the heat transfer was modeled using another computer code called HEATING5 to optimize the location of the funnels. After falling as a film over the inner conductor, the water runs along the bottom surface of the outer conductor and then is directed through another free fall (electrical break) to the water return manifold.

In the narrow band running, the target is located external to the horn, just upstream. The target design is patterned after that employed at CERN (Ref. 3) and essentially consists of target material 3 mm diameter by 100 mm long surrounded by a 28.6 mm diameter cylinder of ATJ graphite which, in turn, is encased in a finned aluminum can. Initially, the target material was 75% tungsten, 25% rhenium and, since contamination was a concern, this material was sealed in the aluminum container using titanium windows. A remotely located

*Work performed under the auspices of the U.S. Department of Energy.

centrifugal fan is employed to deliver 10 m/sec of cooling air to dissipate the heat absorbed in the target assembly.

Broad Band Horn

The first horn in the Broad Band train is shown in Fig. 2. It is very similar to the Narrow Band horn; however, there is no beam plug and the target is internal, being located at the extreme upstream end of the inner conductor. The water cooling is the same as the narrow band running; however, more funnels are located at the upstream end of the inner conductor since there is more Joulean heating from its smaller diameter and beam heating from the target.

The target material is titanium, 6 mm diameter by 500 mm long, and is sealed by aluminum windows to prevent contamination.

Water System

The primary design consideration for the water system was reliability with maintainability a close second. The reliability consideration was twofold: firstly, the horns are very costly to make and, after a very short running period, get extremely "hot" radioactively. Since the water system provides the horn cooling and the cooling is crucial to the horn survival, the reliability of this system is extremely important. Secondly, the water system itself gets "hot" and the minimizing of human interaction on the hot system is desirable.

The horn is located inside the Fast Extracted Beam tunnel at the Alternating Gradient Synchrotron (AGS). With the exception of connecting piping and the system reservoir, all other water system components are located external to the tunnel in a shielded pump house. This pump house is constructed so that any system spills or leaks will drain into an underground waste sump, sized to hold three times the system capacity.

The system reservoir was located in the tunnel so that short-lived decay particles could be reduced by seven half lives before returning to the pump house, thus keeping the house and component levels as low as practical. Individual components in the pump house requiring periodic attention, such as bag filters and deionizer cartridges, are separated by walls so that individuals working on one are not irradiated by the others. In addition, all major components have a redundant second, and sometimes third, unit which both increases the system reliability and allows each component radiation cool-down time before servicing.

Key elements of the water system are shown schematically in Fig. 3. The system is filled through the deionizer to bring it up to the required resistivity. Once filled, a small portion of the main flow is continuously circulated through the dionizer to retain the required 18 MΩ resistivity. The main flow then travels from the horn pump through a heat exchanger, bag filter, and then to the horn head tank. The fluid level in the head tank is closely monitored and compared to the flow rate, since this gives a positive indication, remote from the tunnel, of what the flow conditions are in the tunnel. With the exception of thermocouples, all instrumentation used in the water system would not survive the high radiation environment of the tunnel. Therefore, the water system was designed so that the necessary and important flow parameters could be measured in the pump house.

Water flowing from the horn head tank flows into the tunnel to the horn manifold. From this manifold, the water free falls through nozzles to individual funnels on the horn itself. This free fall provides electrical isolation of the horn, as well as isolating the water system from the mechanical shock the horn experiences each time it is pulsed. By free falling, the water cools the horn at atmospheric pressure, therefore eliminating the high-pressure leaks which plagued the older designs employing high-pressure spraying. Water returns from the horn again by free falling to a drain manifold and then to the system reservoir. The free falling of the water allows the horn to be removed and installed with a minimum of connections in the hot environment. The water then returns through the system reservoir to the horn pump.

Prior operation of the horn showed that, since it was repeatedly subjected to very high impacts, there exits a potential for leaks to develop. Bearing this in mind, a drip pan was installed under the horn to catch any leaks. The water collected is returned to the pump house by gravity and then pumped back to the system reservoir. The drip rate can be measured so that one can decide whether or not a particular leak is serious enough to halt operation. As an added measure to assure adequate flow to the horn, an additional supply nozzle was allowed to discharge directly into the drip pan, thus showing that there was sufficient head to produce flow in other nozzles.

All of the water system material was either aluminum or stainless steel, since any copper or copper-bearing alloys would cause a significant amount of electrolytic corrosions, especially in the high radiation environment.

Operational Experience

Prior to construction of both the Broad Band and Narrow Band horns, extensive computer modeling was carried out to assure that safe temperature levels could be maintained with the proposed designs. The results of these analyses show that the maximum temperatures expected in the horns were 800-900°C in the beam plug of the Narrow Band Horn and 400°C in the target area of the Broad Band Horn. Since temperature measuring instrumentation would not survive the horn environment, the horns were run without beam and temperatures were measured immediately after turn-off to validate computer predictions. Additionally, the cooling of the Broad Band target region was checked with an electrical heater of the same dimensions.

Operation of the Narrow Band target as originally conceived presented a serious problem. The tungsten-rhenium material could not withstand the continued shock of the intense beam deposition and it broke down to a powder. Although this material was encased in aluminum, it breached the containment and was transported by the high velocity cooling air to a large area of the tunnel, generating a serious contamination problem. To avoid this in the future, the target material was changed to copper and sealed in the target container. A cover pressure of helium was then applied and the helium pressure was continuously monitored to detect any future contamination problem. The system then ran without problems as did the Broad Band train.

References

1. A. Carroll et al., "Overview of Recent Focussing Horns for the BNL Neutrino Program," presented at this conference.

2. A. Carroll, et al., "Large Acceptance Focussing Horns for Production of a High Intensity Narrow Band Neutrino Beam at the AGS", IEEE Trans. on Nucl. Sci. NS-32 (5), 3054 (1985).

3. R. Bellone, et al., "The Design and Prototype Tests of the CERN Antiproton Production Target", Proc. of the Workshop on High-Temp. and Energy Dens. in Target Materials, Fermilab, Batavia, IL (1980).

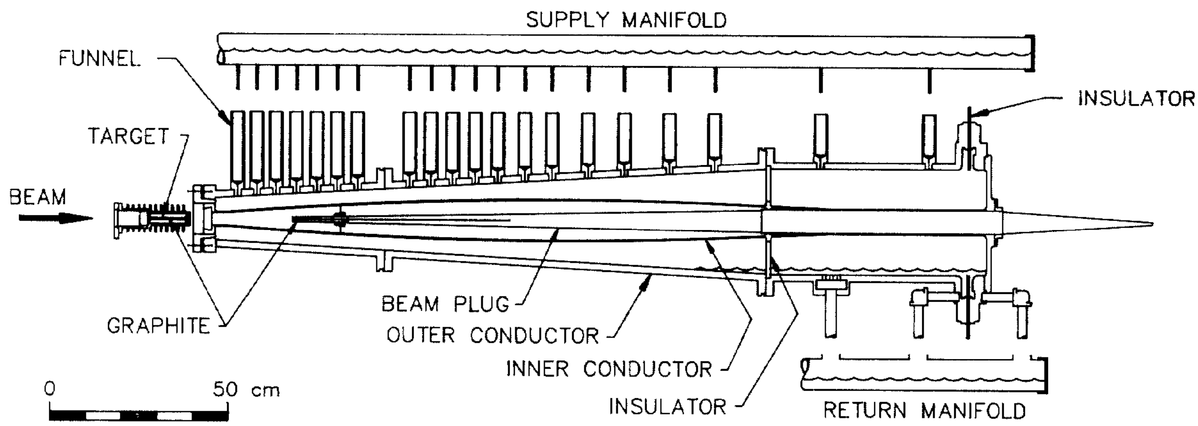

Fig. 1. NARROW BAND HORN #1

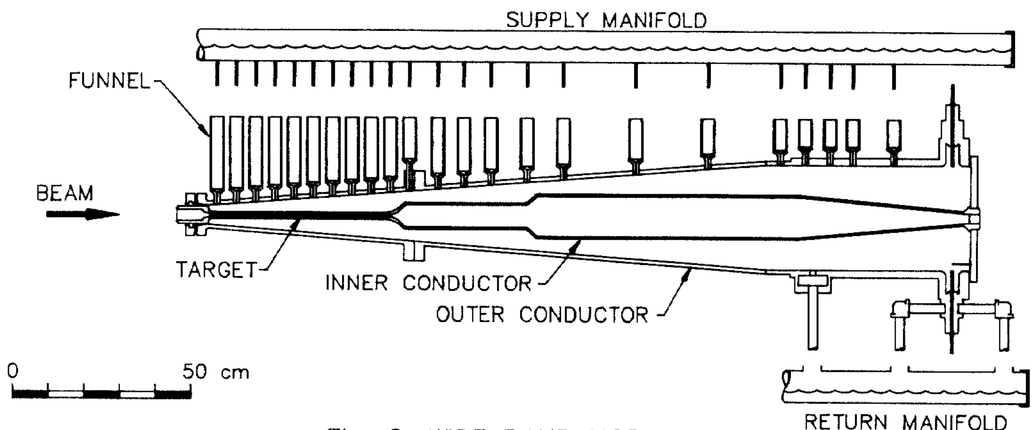

Fig. 2. WIDE BAND HORN #1

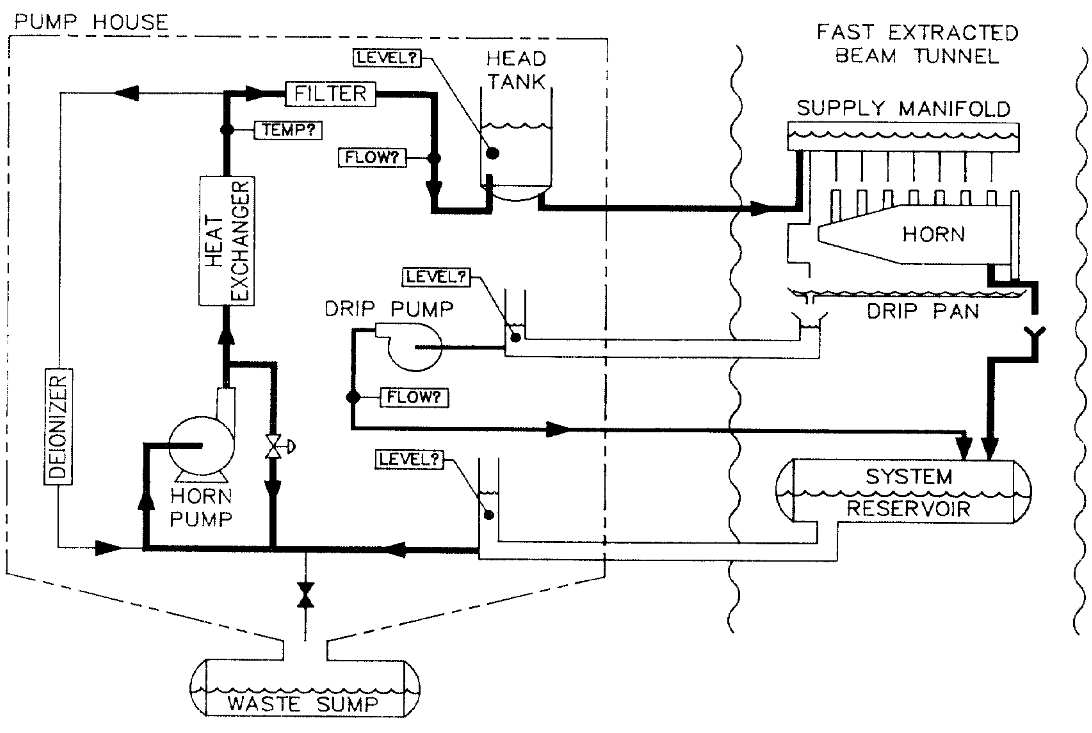

Fig. 3. WATER SYSTEM SCHEMATIC