4.2.6 Horn Alignment Cross-hair System

4.2.6.1 Alignment cross-hair function and specifications

The purpose of the NuMI horn alignment cross-hair system is to allow locations of the NuMI magnetic horns to be determined relative to the incident proton beam centerline. This is to be accomplished by scanning the incident beam, at low intensity (roughly 10^{12} protons per pulse), horizontally and vertically across the cross-hair locations. The locations of the cross hairs are determined by observing the changes in signal level in a beam loss monitor (BLM) located downstream of each horn. The BLMs are mounted well away from the beam axis and detect secondaries from beam proton interactions in the cross-hair material. The cross hairs consist of horizontal and vertical aluminum strips attached to the downstream end of Horn 1 and the upstream and downstream ends of Horn 2. While it is not possible to attach a cross-hair structure to the upstream end of Horn 1 due to the production target location, the narrow neck of the inner conductor of Horn 1 provides essentially the same alignment function as an upstream cross-hair structure when it is scanned by the incident beam.

Adam Para described the initial conceptual design of the cross-hair alignment system in NuMI-B-796. Byron Lundberg used MARS to perform a series of beam-heating calculations for different cross-hair materials (NuMI-NOTE-BEAM-882). It can be concluded from this study that aluminum will survive normal full-intensity operation of the NuMI beam if the cross hairs were centered 2.5 mm from the beam centerline and are not more than 1.0 mm wide.

The performance of the cross-hair system has been simulated and documented by Debbie Harris (NuMI-NOTE-BEAM-864). The simulation was performed only for the low-energy neutrino beam configuration. The conclusion of this study is that the transverse alignments of the upstream and downstream ends of each horn can be determined to a precision of ±0.5 mm. The study concluded that the aluminum cross-hair material of the cross hairs should be 6 mm deep along the beam line for the downstream cross hairs on both horns and 18 mm deep for the Horn 2 upstream cross hairs, in order to achieve an acceptable signal to noise ratio in the BLMs. It has been decided to double the thickness of the cross hair material (to 12 mm and 36 mm respectively) to allow for the possibility of worse signal to noise. The simulations indicate signal-to-noise ratios of 0.6 to 0.8 for the cross-hair scans (with the doubled thicknesses) and >10 for the Horn 1 neck scan. The simulations also indicate that the cross-hair material causes changes of less than 0.2% in the neutrino flux and the near/far detector event rates.

The cross hair system consists of the following components:

1. Three aluminum cross hair structures and hardware to mount them to the horns. The locations must not be permanently affected (±0.25 mm) by temperature changes, horn pulsing and other perturbations that occur during NuMI operation. **Figure 4.2-17** shows an end-on view of the Horn 1 cross-hair structure.
2. Two beam loss monitors (BLMs), one located downstream of each horn, and associated hardware and readout electronics, including gun-drilled holes for cable penetrations. BLMs will remain in position during high intensity running but they must be replaceable if they are damaged.
3. Vertical and horizontal trim magnets, located roughly 23 m upstream of the upstream face of Horn 1. These are used to perform scans of each set of cross hairs and of the neck of Horn 1.

The cross-hair system specifications include the following:

1. The system must determine the transverse location of Horn 1 to a precision of ±0.5 mm and of Horn 2 to ±1.0 mm, relative to the proton beam centerline. These requirements limit the distortion of the neutrino energy spectrum by horn misalignment to an acceptable level.
2. The proton beam location is assumed to be determined to a precision of ±0.1 mm and ±15 μrad by multiwire chambers upstream of the NuMI target.
3. The system requires the ability to perform horizontal and vertical scans of the proton beam position, at low intensity, over a range of ±3.5 mm at the locations of the cross hairs and ±12 mm at the location of the neck of Horn 1. Scans are performed with the target and baffle moved out of the beam.
4. BLM response should be stable and sensitive to rate changes of ~5% at intensities expected during scans (10^7 particles/cm^2/10^{12} protons/spill).
5. The proton beam is assumed to have an rms size of 1 mm and divergence of 0.9×10^{-4} in both horizontal and vertical at the NuMI target. Primary beam instrumentation that monitors proton beam intensity and location must perform according to the same specifications at low intensity (10^{12} protons per pulse) as at high intensity.
6. The signal-to-noise determined by the simulation will degrade if the material in the beam is increased beyond that assumed.
7. The cross hairs are mounted permanently to the horns at locations close enough to the beam centerline to provide adequate signals for the scans and far enough away to prevent damage to the cross hairs during full intensity running.
8. The cross hair material should have a negligible (<1%) effect on the neutrino flux.
9. The upstream and downstream cross hairs on Horn 2 should be located on opposite sides of the beam so that they can be scanned individually.

B. Alignment cross-hair system parameters

Table 4.2-9 summarizes the parameters used for the locations and dimensions of the aluminum cross hair material in the simulations study (NuMI-NOTE-BEAM-864). The

BLMs for Horns 1 and 2 are located at z = 4.01 m and 14.14 m respectively (in the Monte Carlo coordinate system, relative to z = 0 at MCZERO at the entrance to Horn 1). Note that the GEANT simulation used slightly different values for these locations, z = 4.099 m and z = 14.573 m respectively. The signal-to-background ratio was found to be independent of the distance between a BLM and the beam centerline for distances of 15 to 35 cm. Each BLM is located at beam elevation and displaced horizontally by 30 cm from the beam centerline. Each will collect a charge of roughly 33 nC during a beam spill of 10^{12} protons on target.

Horn Alignment Cross-hair Parameters in GEANT Simulation						
Parameter	**Horn 1**		**Horn 2 Upstream**		**Horn 2 Downstream**	
Center in x (cm)	-0.250	0.000	0.250	0.000	-0.250	0.000
Center in y (cm)	0.000	-0.250	0.000	0.250	0.000	-0.250
Upstream edge z (m)	3.434	3.440	9.922	9.940	13.624	13.630
Length (cm)	0.600	0.600	1.800	1.800	0.600	0.600
Thickness in x (cm)	0.100	34.000	0.100	34.000	0.100	34.000
Thickness in y (cm)	34.000	0.100	34.000	0.100	34.000	0.100

Table 4.2-9. Characteristics of the three sets of cross hairs according to GEANT

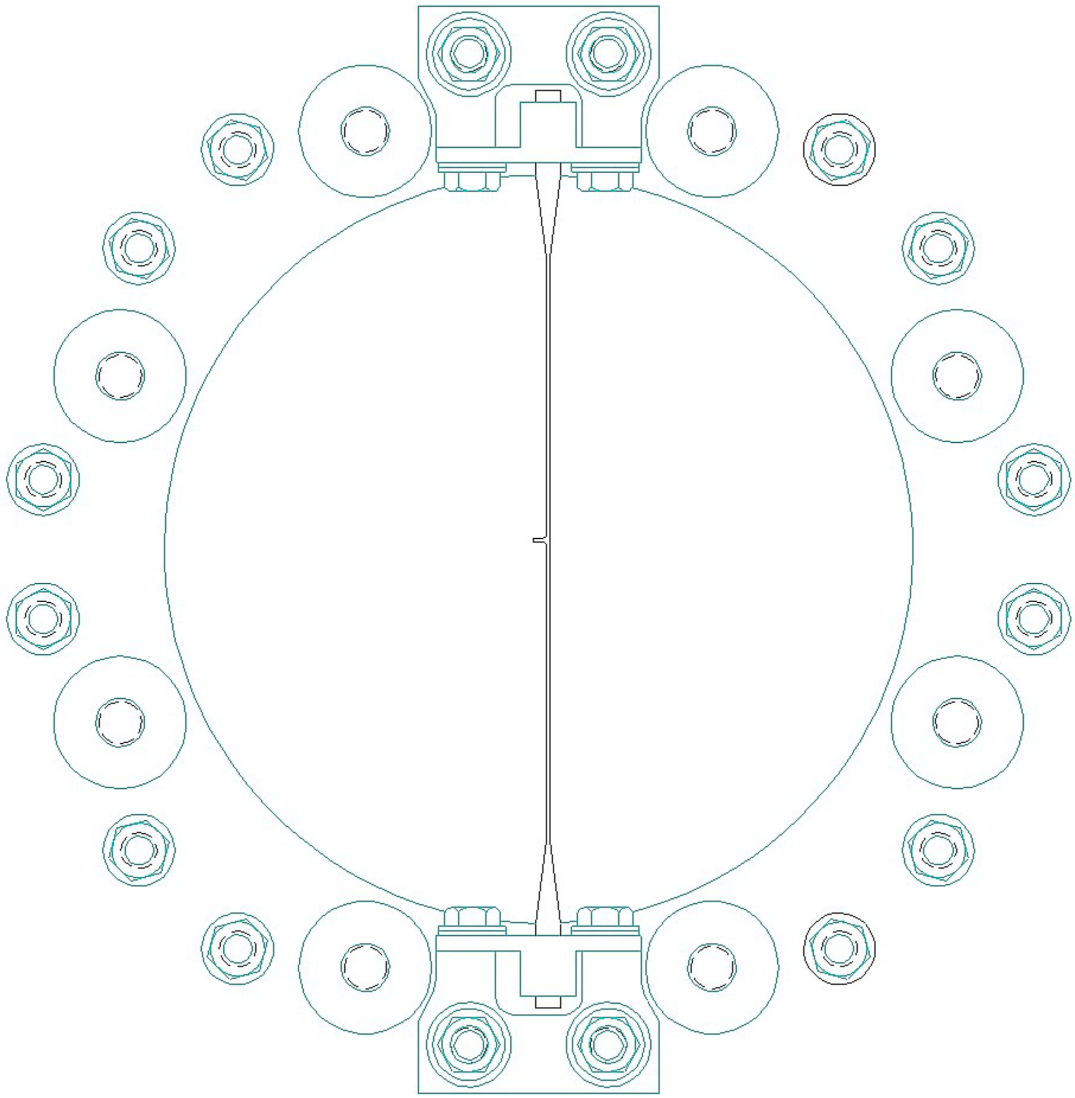

Figure 4.2-17. Drawing of the Horn 1 cross-hair structure.

This is an end-on view, looking into the proton beam, showing how the cross hair is mounted on bolts that are also used to tie the inner and outer conductors together. The aluminum cross hair material is 12-mm thick (along the beam direction) and 1-mm wide. The horizontal member is made only long enough (4-mm long, measured from the center of the vertical member) for incident beam scans, in order to reduce the amount of material in the beam and to simplify the support structure. Belleville washers provide a tension of about 80 pounds (at room temperature) on the vertical member, which is adequate to maintain positive tension at 100 C above room temperature (e.g., from beam heating). The cross-hair material is nickel plated to protect against corrosion.