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A CONCEPTUAL DESIGN OF THE 2+ MW LBNE BEAM ABSORBER*

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Abstract

The Long Baseline Neutrino Experiment (LBNE) will utilize a neutrino beamline facility located at Fermilab. The facility will aim a beam of neutrinos, produced by 60-120 GeV protons from the Fermilab Main Injector, toward a detector placed at the Deep Underground Science and Engineering Laboratory (DUSEL) in South Dakota. Secondary particles that do not decay into muons and neutrinos as well as any residual proton beam must be stopped at the end of the decay region to reduce noise/damage in the downstream muon monitors and reduce activation in the surrounding rock. This goal is achieved by placing an absorber structure at the end of the decay region. The requirements and conceptual design of such an absorber, capable of operating at 2+ MW primary proton beam power, is described.

INTRODUCTION

The Long Baseline Neutrino Experiment, a new neutrino oscillation experiment, is planned to start at the end of this decade. This experiment will utilize a neutrino beam facility located at Fermilab site. At the site, the neutrinos will be produced by 60-120 GeV protons from the Main Injector synchrotron [1] toward a detector placed at the Deep Underground Science and Engineering Laboratory in the former Homestake gold mine, South Dakota.

As by-product of neutrino production, a flux of primary protons (~ 15% of protons) and non-decayed secondary hadrons (mostly π and K-mesons) and leptons must be absorbed to prevent them from entering the surrounding rock of the excavation and inducing radioactivity. This is accomplished with a specially absorber structure (for short Absorber in the text) which is located directly after the ~ 250 m long decay pipe (DP). It is a pile of aluminium (Al), steel and concrete blocks, some of them water-cooled, which must contain the energy of the particles after the DP. The vast majority of these secondary hadrons and primary protons are stopped in the Absorber. The fluxes of secondary particles (mainly neutrons) escaping the system, must be attenuated by the Absorber and shielding to the tolerable levels. According to the simulation, in total, 21% of the total beam power is deposited in the Absorber where the primary protons deposit approximately 80% of this energy.

ABSORBER REQUIREMENTS

For LBNE, we designed the Absorber to accept a beam with maximum power of 2+ MW at an energy of 120 GeV. The parameters of such a beam are summarized in Table 1. The beam is tilted down by 102 mrad to center neutrinos at DUSEL. The decision on 2+ MW is based on the plans for the future upgrade of the Fermilab accelerator complex when LBNE is going to get 2+ MW on target. If at the initial stage of the DUSEL experiment, the Absorber is not designed for the maximum beam power, at the time of upgrade, a possible underground retrofitting of the shielding and modifying the Absorber core will be not practical. Moreover, building a new Absorber and disposing of the highly-radioactive old one will be extremely expensive.

Table 1: Beam parameters for 2.3 MW Absorber operation. These parameters were used for the modeling of the energy deposition at the Absorber structure.

Beam Parameters	Values
Proton beam energy	120 GeV
Spill cycle time	1.33 s
Maximum intensity	1.6×10^{14} (protons/spill)
RMS beam size @ target	1.5 mm H x 1.5 mm V (σ)
Angular divergence @ target	17 μrad H x 17 μrad V (σ)
Total beam power	2.3 MW

The Absorber must be designed to sustain the beam energy deposition under expected normal operational conditions as well as under all accident situations that may occur with some reasonable probability. In the case of normal operation, the Absorber should dissipate 642 kJ energy per beam spill. Such power requires special attention to the cooling of the Absorber components, especially its core.

For the accident cases, two major conditions were modelled. The first one assumes that a mis-target primary proton pulse of 3.07-MJ energy, after interaction with air in the decay pipe, hits into the central part of the Absorber. In this case the full beam energy is deposited directly into the Absorber structure. Every beam spill will increase the temperature in the center of the core by approximately 27 C. The requirement is that the Absorber should sustain at least 15 accident pulses, for the total duration of 20 s. During this time, the thermo-protection embedded in the core blocks should generate a signal to inhibit the beam permit. The second accident case could occur due to a beam control failure when the beam is mis-steered relative to its original direction. This is a single 3.07-MJ pulse accident condition and we assume primary beam instrumentation will trip the beam permit before a 2nd or no more than 3rd pulse. Using a simple target/baffle model, where we assume one baffle and one

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Table 2: Absorber design parameters and calculated peak temperatures.

Absorber Parameters	Values
Impact energy at normal operation	642 kJ
Impact energy at accident condition	3.07 MJ
Accident condition – direct beam	15 pulses
Accident condition – mis-steered beam	2 pulses
Max. temperature in Al core - normal	187 C
Max. temperature in steel core – normal	247 C
Max. temperature in Al core – accident, 10 p	456 C
Max. temperature in steel core – accident, 10 p	340 C
Temperature rise per accident pulse Al (Steel), 10p	27 (9) C

passive aperture restrictor, 10 m apart, with 40 mm diameter upstream and 20 mm diameter in front of target we estimated that the maximum radius at Absorber that can be hit by beam is 900 mm. The primary concern for this case is hitting a water-cooling channel, with possible water hammer effect.

ABSORBER SIMULATION

The MARS15 Monte Carlo code [2] is used for energy deposition modelling. The results were fed to ANSYS [3] Fine Element Analysis (FEA) simulation to estimate the temperature distributions in different absorber blocks.

In the case of normal operation, the longitudinal energy deposition in the Al core is shown in Fig. 1. One can observe that the maximum energy is deposited in the 3rd and 4th blocks (blue zone on Fig. 1). This is the reason why in our design we placed the center of the 3rd block in the transverse center of the hadronic shower. For this block, the energy deposition was transferred to ANSYS FEA to simulate the temperature distribution and the necessary cooling conditions. Fig. 2 shows the final temperature distribution in the block over 10000 normal beam pulses. The temperature reaches a plateau at approximate 187.3 C. For this simulation, the cooling lines were placed around the perimeter of the block and water temperature was assumed constant at 25 C. This analysis shows that maximum operational temperature is below than any critical temperature of the Al material. For example, a point of concern was that exposure of Al material to high temperatures (~275 C) for long period of time could raise the issue of creep (time-dependent plastic deformation) and possible thermal distortion. The calculated peak temperatures are shown in Table 2.

The simulation showed that we could not keep the water cooling channels outside the 900 mm radius without overheating the Absorber core. To prevent direct beam hit on the core cooling channels placed inside the

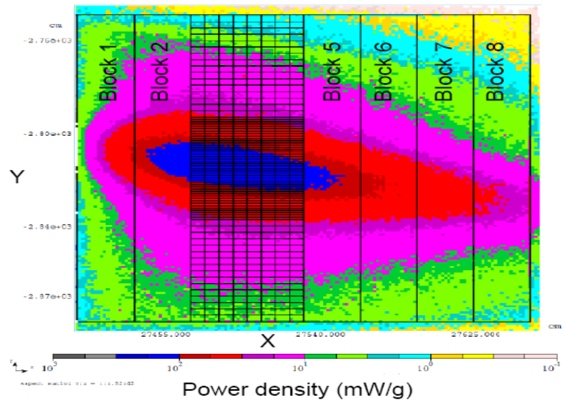

Figure 1: Result from MARS modelling showing the longitudinal energy deposition profile in the Al core of the Absorber for normal operation.

900 mm and to protect them from mis-steered beam, we introduced a pre-Absorber core mask (Fig.3).

Another point of concern is a possibility to melt a central part of the Al blocks in case of an accident condition. We performed an analysis to determine how maximum temperature in the core could reach over 600 C (the melting temperature for pure Al is 660 C). Fig. 2 shows the temperature distribution in the 3rd block after 10 direct beam pulses imposed over the operational regime with temperature of 187 C. The FEA shows increasing the temperature to 465 C. Extrapolating this dependence we found that after approximately 15 faulty pulses the maximum temperature in the center of the 3rd Al core block will reach ~600 C. To prevent such high temperature, we will instrument every core block with a number of thermocouples (8 by initial design) connected to a data acquisition system which should generate appropriate beam permit inhibits depending on the required temperature limits.

Similar simulation analyses were performed for other Absorber blocks and the results were taken into consideration in the overall design of the cooling scheme. It is worth to mention that the first steel block in the Absorber core (block number 9) will reach operational temperature of 247 C and 340 C after 10 faulty pulses.

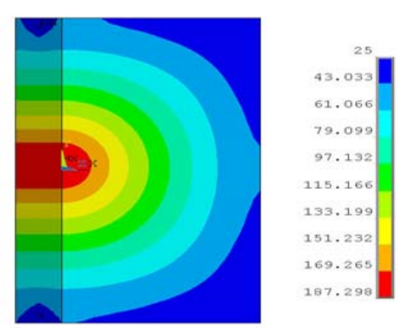

Figure 2: Result from ANSYS FEA simulation. The maximum temperature (in C) for the 3rd Al core block is shown after 10000 normal pulses.

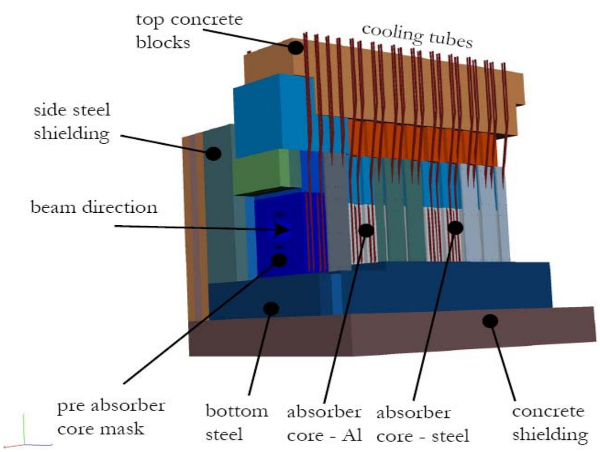

Figure 3: A 3D model of the LBNE Absorber. The front and the side steel and concrete shielding is removed to show the core structure and cooling lines.

ABSORBER REFERENCE DESIGN

Fig. 3 shows the 3D view of the Absorber. The light and dark brown colors represent the walls of the Absorber hall and the concrete shielding. The pre-mask of the core is shown in dark blue, while the Al and the steel core blocks are represented with gray colour.

The Al core consists of eight one foot-long Al blocks (60’’x60’’x12’’). The design of the block is shown in Fig. 4. Two continuous Al water-cooling lines are welded to the block. In case of an emergency water leak from one of them, the second cooling line will have enough flow to support the Absorber operation.

The core blocks are designed together with the upper part of the steel shielding (green box, Fig.4 left). This feature will allow us to change a core block in case of a total failure of both cooling channels. To perform this operation, a remote handling system is under design.

The Absorber core steel blocks are placed directly behind the Al ones (Fig. 3). By design, they are identical to the Al blocks except that their aluminum cooling tubes are clamped to the edges of the block. The number of the core steel blocks is determined by limiting the residual radiation in the Absorber hall, to allow performing of service work behind the Absorber pile.

The accident beam can be very harmful to the Absorber core cooling lines if it hits any of them directly due to a possible water hammer effect. Placing the cooling lines outside mis-steered beam area turned out to be impractical for adequate cooling of the Absorber core. To protect the cooling lines, we introduced an Al pre-core mask. Four of these pre-core blocks will be installed in the front of the Al core blocks. They are similar in design to the Absorber core blocks, with larger cross-section, having a through hole of 35” in the beam centerline location. The cooling tubes of the pre-core mask blocks are outside of the possible accidental beam area.

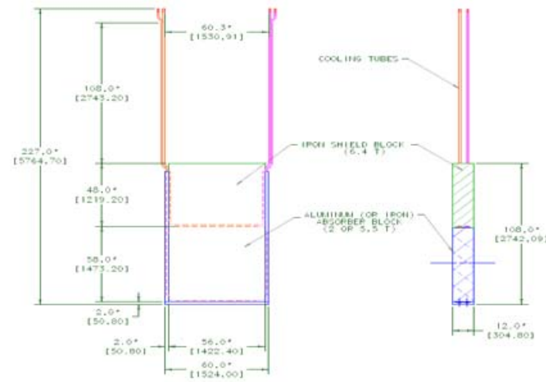

Figure 4: Design of the Absorber core blocks.

The steel shielding blocks are constructed in two independent layers. The first layer (closest to the Absorber core) is constructed of 48” thick steel blocks and lined up with the core blocks. The Absorber core and these blocks are staggered horizontally by +/- 1” to exclude the possibility of creating a longitudinal air gap where the hadron shower could propagate. There is no staggering in the vertical direction because the beam is tilted vertically. Some of the front blocks of this layer should be water-cooled; the power dissipation in them is large enough to rely only on the air convection

The second layer of 36’’ thick steel blocks provides additional shielding to the core. The gaps, created between the layers due to the staggering of the first layer, are filled with concrete. No water-cooling is anticipated for these blocks. In total, there is 7 feet thick steel shielding around the Absorber core.

For LBNE we plan to cast in place a concrete bed for the Absorber. The only removable concrete blocks will be the area above the Absorber core. This area (Fig. 3, top brown block) is covered with two overlapping layers of standard concrete blocks (3’x3’x6’). This will preserve the ability to open the upper part of the Absorber and replace the any core blocks in case of cooling accident.

SUMMARY

We presented a short description of the conceptual design of a beam absorber for LBNE. Our calculations, beam and thermo modelling, and engineering design are aiming for 20+ years of continuous LBNE operation at 2+ MW beam power.

REFERENCES

[1] The Fermilab Main Injector, Particle Accelerators, Vol. 26 (1990), p. 193.

[2] N.V. Mokhov, “The Mars Code System User's Guide”, Fermilab-FN-628 (1995); N.V. Mokhov, S.I. Striganov, “MARS15 Overview”, in Proc. of Hadronic Shower Simulation Workshop, Fermilab, September 2006, AIP Conf. Proc. **896**, pp. 50-60 (2007); http://www-ap.fnal.gov/MARS/.

[3] ANSYS Engineering Simulation, www.ansys.com.