DESIGN OF AN OGIVE-SHAPED BEAMSTOP

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Abstract

This paper addresses the evolution, design, and development of a novel approach for stopping cw (continuous-wave), non-rastered proton beams. Capturing the beam *in vacuo* within a long, axisymmetric surface of revolution has the advantages of spreading the deposited energy over a large area while minimizing prompt neutron backstreaming and reducing shield size and mass. Evolving from a cylinder/cone concept, the ogive shape avoids abrupt changes in geometry that produce sharp thermal transitions, allowing the beam energy to be deposited gracefully along its surface. Thermal management at modest temperature levels is provided with a simple, one-pass countercurrent forced-convection water passage outside the ogive. Hydrophone boiling sensors provide overtemperature protection. The concept has been demonstrated under beam conditions in the CRITS (Chalk River Injector Test Stand) facility at Los Alamos.

1 INTRODUCTION

The Accelerator Production of Tritium (APT) program [1] requires several commissioning beamstops [2]. This paper discusses the first of these, which will be used to commission the Radio Frequency Quadripole (RFQ) and the first Coupled-Cavity Drift Tube Linac (CCDTL sections in the Low Energy Demonstration Accelerator (LEDA) presently being built at LANL (Los Alamos National Laboratory) [3]. The first LEDA beamstop must accommodate a 0.1 A proton beam in cw operation at energy levels of up to 6.7 MeV. Early studies showed that conventional beamstop approaches (e.g., plate-type with beam rastering to distribute the heat) would result in a large, costly, immobile installation with significant radiation back-streaming issues—attributes which would severely complicate the job of developing and maintaining the Linac. These issues are addressable with an approach that minimizes the projected area (footprint) presented by the beamstop normal to the beam.

Eliminating rastering reduces this footprint to that of the beam spot size, but requires management of sharply higher energy fluxes imposed by the Gaussian beam. The circular spot shape of the beam suggests a conical impact surface for the beamstop, a concept which has been successfully used on other Linac applications.

Even smaller orthogonal footprints result when the conical geometry is combined with an upstream cylindrical scraper section that exploits the divergent qualities of the beam to spread the heat distribution. The conical end section then would capture the central portion of the beam while the wings of the Gaussian distribution are deposited in the cylindrical section. The cone/cylinder beamstop proportions are governed by the practical combination of radius and length that captures the beam within a minimum radius without spillage. This typically results in a long, thin structure, with a re-entrant configuration that inherently minimizes both the back-streaming potential and the radial shield thickness requirement. The circular cross-section also minimizes edge effects which could produce hot spots. However, the abrupt cone/cylinder intersection creates a sharp thermal gradient that needs to be smoothed out. The graceful, continuous inflection obtained by replacing the cone/cylinder with an ogive shape is a logical solution to this problem.

The ogive shape addressed here is generated by revolving a circular arc about a centerline to produce a surface of revolution, as shown in Figure 1. The ogive contour adjusts the angle of incidence as needed to accommodate the variable power density of the diverging beam: the greatest angles occur where the power density is lowest, and vice versa, resulting in a smooth, relatively mild heat flux profile on the beamstop surface.

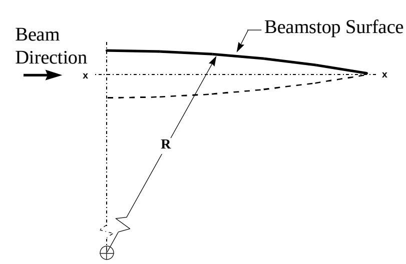

Figure 1: Ogive Shape

2 DESIGN CONSIDERATIONS

Table 1 summarizes the LEDA beamstop design, which is based on the ogive concept.

Table 1: LEDA Beamstop Design

BEAM CHARACTERISTICS	
Energy x Current	6.7 MeV x 0.1 A, Gaussian
Operation	1 Hz to cw (~ 6 mos. At cw)
PHYSICAL FEATURES	
Overall Dimensions	~ 109-in Height x 133-in Length
Beam Centerline Height	72-in
Target Geometry	Axisymmetric; Tangent Ogive
Target Dimensions	6-in ID x 92-in L x 0.1-in Thick
Target Material	Electroformed Nickel
Coolant	Water outside (vacuum inside)
Coolant Flow Arrangement	1-Pass Forced Convection, Counterflow to Beam Direction
Neutron Shield	Water
Neutron Shield Tank Material	Aluminum
Gamma Shield	1-in Lead Wall on Upstream Face
THERMAL MANAGEMENT	
Heat Removal	670 kW
Peak Heat Flux	212 W/cm^2 incident to surface
Peak Wall Temperatures	275 F water; 430 F beam
Water Conditions	305 gpm, 60 F/75psig in; 35 psid

The ogive beamstop is integrated into a simple, replaceable water-cooled cartridge that connects directly to the upstream beam pipe. In the arrangement shown in Figure 2, a flow shroud around the ogive creates an annular passage for once-through, forced-convection water cooling.

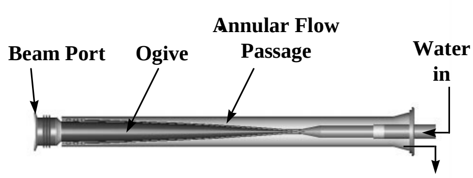

Figure 2: Ogive Beamstop Cartridge

The shielding advantages of the ogive approach are evident in Figure 3, which presents a cutaway view of

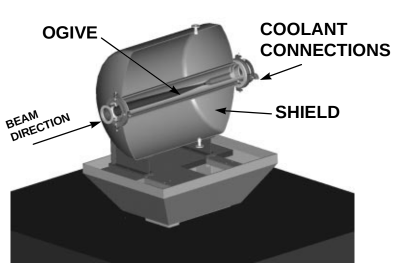

Figure 3: Integrated Beamstop Arrangement

the integrated beamstop assembly. The deposition of the beam energy deep within the small-diameter ogive makes it possible to have a near-4-pi, minimum-size neutron shield. The gamma shield wall is not shown.

2.1 Thermal Management

The thermal design is based on the quasi-Gaussian beam characteristics predicted for the LEDA linac, including the location and severity of hot spots produced by beam focus and steering errors. Figure 4 shows the mild axial heat flux and waterside temperature profiles predicted for the 6.7 MeV LEDA ogive at the nominal operating condition. The beam direction is from left to right.

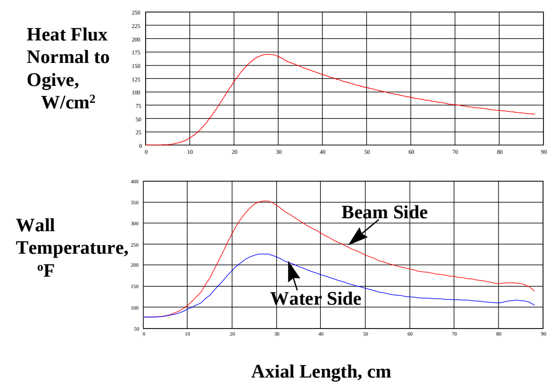

Figure 4: The heat flux normal to the ogive surface is about 1/30th of that normal to the beam cross-section, resulting in modest temperatures.

The thermal design is based on cooling with high-velocity water flow under sufficient static pressure to suppress boiling. Since the flow passage near the tip of the ogive is a venturi, care must be taken to ensure that the static pressure in this region will remain above the boiling limit.

2.2 Structural Design

The ogive structural analysis considered buckling, flow-induced vibration, thermal stress due to heat flux, thermal bowing due to misaligned beam, and the potential for thermal/flow feedback instability. Figure 5 is an example of the analytical sophistication needed to confirm structural adequacy.

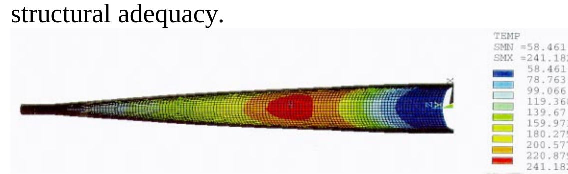

Figure 5 : Temperature Distribution of Ogive Coolant for One Case of Beam Misalignment

3 DEVELOPMENT

Although the LEDA beamstop has not yet gone into service, valuable experience has already been obtained on the fabricability and performance of the ogive concept.

3.1 CRITS BeamstopTesting

By happy coincidence, an adjunct proton Linac program at LANL urgently needed a new beamstop just as the LEDA design was being finalized, affording the opportunity to test out the ogive concept under actual cw, beam-on conditions similar to those of LEDA, but at reduced power levels. The water-cooled copper 6.5-in ID x 42-in long ogive, shown in Figure 6, was designed to accommodate a 1.25 MeV proton beam at 75 mA. With a proton energy well below the 2.2 MeV neutron activation threshold for copper, neutron shielding was not required. The ogive easily met design performance, permitting the CRITS linac to reach the highest cw 1.25 MeV beam power ever demonstrated [4]. During this testing, calorimetry performed on the ogive cooling water circuit helped verify the beam power measurements. The excess cooling capacity in the beamstop design defeated attempts to confirm the functionality of the hydrophone boiling sensors installed on the ogive flow shroud.

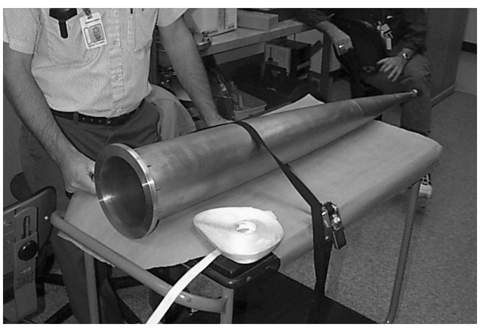

Figure 6: CRITS Ogive

3.2 *LEDA Beamstop Fabrication*

Unlike its CRITS predecessor, which was spun from a copper cylinder, the nickel ogive for LEDA was produced by electroforming. This plating method produced a robust, one-piece, seamless, near-net shape ogive section to which a machined nose was added, using an electroformed cold-weld process. Figure 7 shows the completed LEDA ogive beamstop before it was inserted into its cartridge (see Figure 2).

Figure 7: Electroformed Ogive for LEDA

The 6.7 MeV LEDA beamstop has been installed at LANL and is now undergoing precommissioning checkouts. Testing should begin later this year.

4 CONCLUSIONS

The CRITS and LEDA experience gained to date have validated the ogive approach, which is now being applied to the design of the beamstops needed to commission the low to intermediate energy sections of the APT.

5 ACKNOWLEDGMENTS

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6 REFERENCES

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