BEAM STOP DESIGN METHODOLOGY AND DESCRIPTION OF A NEW SNS BEAM STOP

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Abstract

The design of accelerator components such as magnets, accelerator cavities and beam instruments tends to be a fairly standardized and collective effort within the particle accelerator community with well established performance, reliability and, in some cases, even budgetary criteria. Beam stop design, by contrast, has been comparatively subjective historically with much more general goals. This lack of rigor has lead to a variety of facility implementations with limited standardization and minimal consensus on approach to development within the particle accelerator community. At the Spallation Neutron Source (SNS), for example, there are four high power beam stops in use, three of which have significantly different design solutions. This paper describes the design of a new off-momentum beam stop for the SNS. The technical description of the system will be complemented by a discussion of design methodology.

INTRODUCTION

A new off-momentum beam stop has been designed for the SNS high energy beam transport (HEBT) line [1]. This assembly is a replacement for a previously installed water cooled version that is inoperable due to its inability to reject radiolysis formed gas products.

Beam stop technical development in general involves an iterative mechanical design process in combination with neutronics, thermal and stress analyses. It is fundamentally an exercise in material specification, geometric configuration and the selection between a passive or forced cooling system. The overall design process tends to require contributions from a variety of technical experts and numerous solutions may be developed to meet the basic physics requirements.

The technical design process must be balanced with other project considerations including personnel safety, ranging from component handling to health physics exposure during servicing, long term service and disposal requirements, and budget. This paper describes the details of the new SNS off-momentum beam stop design along with a recommended methodology for future beam stop design efforts.

PHYSICS SPECIFICATION

The new SNS off-momentum beam stop is intended for use at a nominal operating power level of 5 kW but has been designed to operate during off-normal conditions of 10kW. Two peak beam density cases were assumed as the basis for the design. These beam distributions were used as load cases for the neutronics and thermal analyses performed during the design process and are summarized below in table 1.

Table 1: Physics Specification for new Beam Stop

	Case 1	Case 2
Power Absorption	10 kW	10 kW
Energy [MeV]	800	1300
Linac power [kW]	1200	3000
dp/p	0.001	0.001
N (protons per macropulse)	1.55e14	2.39e14
σ_x [mm]	8.1	8.01
σ_y [mm]	5.3	5.3
For x> x_m [mm]	19.2	21.7
x' [mrad]	0.78	0.78
Peak density [p/mm^2] per macro pulse	3.32e10	2.26e10
Peak flux [p/mm^2] per sec	1.99e12	1.36e12
Peak flux [p/mm^2] per macropulse	3.3e13 in 0.001 sec	2.3e13 in 0.001 sec
Window Dia.	≤ 10 inches	≤ 10 inches

BEAM STOP DESIGN DETAILS

The system assembly consists of a forced-air cooled aluminium billet backed by a steel billet in a dual shell steel enclosure as shown below in figure 1. Forced air from a centrifugal blower enters the outer shell on the beam line side and is redirected to the inner shell behind the steel slug to remove beam-deposited energy. The primary aluminum beam stop has machined channels and a contoured nose to optimize flow around the convection boundary and direct flow against the outer face of an aluminum vacuum window (figure 2). The aluminum billet is also machined to incorporate a thermocouple array that monitors internal beam stop temperatures.

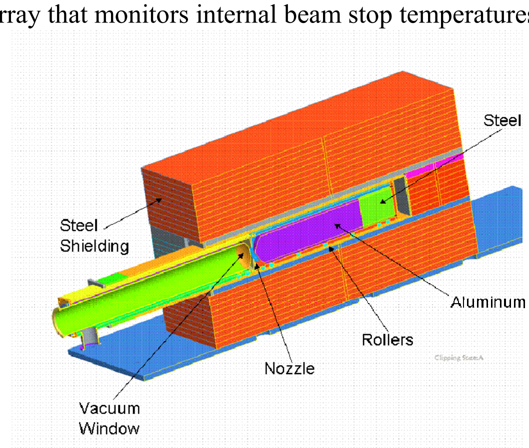

Figure 1: Cross sectional view of the new off-momentum beam stop and vacuum assembly.

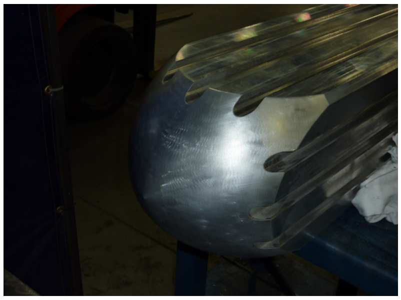

Figure 2: Aluminum beam stop contoured nose and channels

Selection criteria for beam stop material included heat transfer characteristics, structural integrity, long-term reliability, activation characteristics, contamination potential, ease of manufacturing and ease of handling. Aluminum and graphite were the primary material candidates due to their low activation potential and good thermal properties. Neutronics analysis was first performed to define the loads used in subsequent thermal and flow analysis of a baseline design for each material type. Mechanical design, system design and supporting analyses were then iterated to develop optimal design configurations for each material type. Computational fluid dynamics simulations, as shown in figure 3 below, were performed to refine the mechanical design and specify flow requirements. The flow requirements formed the foundation of a cooling system specification.

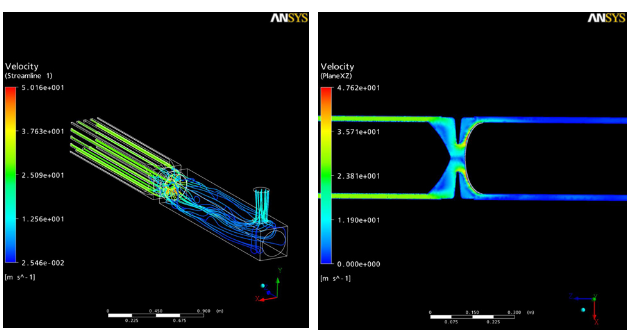

Figure 3: CFD simulation results for beam stop assembly

Candidate designs were then subjected to a second set of neutronics analyses for which radiation dose rates were calculated for different operating and cool down time scenarios (figure 4). Worst cases scenarios assumed beam stop irradiation to saturation levels. A set of spatial points was selected for comparison purposes based on the assumption that they would represent reasonable personnel locations during maintenance operations. Dose rates were higher for aluminum at some points and graphite for others but were roughly equivalent.

Aluminum was ultimately selected because it met thermal performance criteria and mitigated the risk of contamination production due to material ablation and erosion. A design configuration in which graphite was enclosed in a thin aluminium skin was considered but was abandoned due to perceived complexity and the potential for thermal contact issues at the aluminum graphite boundary.

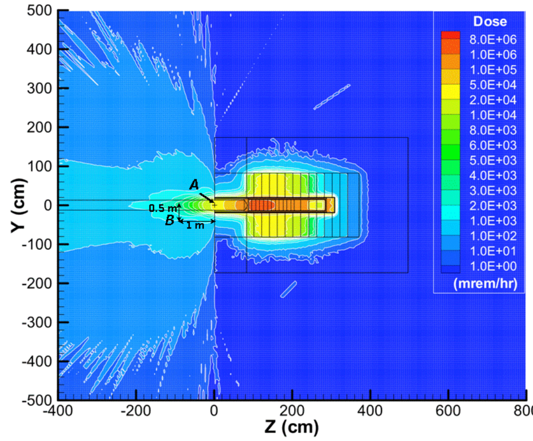

Figure 4: Aluminum beam stop activation at Na-22 saturation levels (16 years of operation at 10 kW) followed by 1 month decay

The cooling system developed to remove heat from the beam stop is closed loop air with a HEPA filter to remove airborne contaminants. Two water fed heat exchangers are used to remove heat from the air supply. One is located after the centrifugal blower to remove the heat of compression. A second is located after the beam stop to remove beam-deposited energy. An instrument suite including a flow meter, pressure transducers and temperature transducers is incorporated into the accelerator control system to monitor system operation.

The new beam stop assembly is currently installed and will be commissioned in the summer of 2010.

METHODOLOGY

An overview of the methodology for beam stop design is depicted in the figure 5 flow chart below. This flow chart captures the general elements of the process. Elaboration of the technical methodology will be minimal in this document due to space limitations. From the design perspective, the solution space for a viable beam stop design is large. A number of material choices are available along with a substantial number of variations on the four most common cooling schemes (conduction to surroundings, natural convection, forced-gas cooling and water cooling). This large design space affords considerable latitude with respect to individual preferences.

The development of input parameters and design specifications is one of the most important components of the design process. The creation of a comprehensive physics specification in particular, with detailed beam parameters, can have a significant impact on material selection and cooling method. Beam characteristics and consequent localized heat effects tend to determine the level of mechanical complexity of the beam stop itself. For example, a highly concentrated energy deposition may require either a segmented or modular beam stop

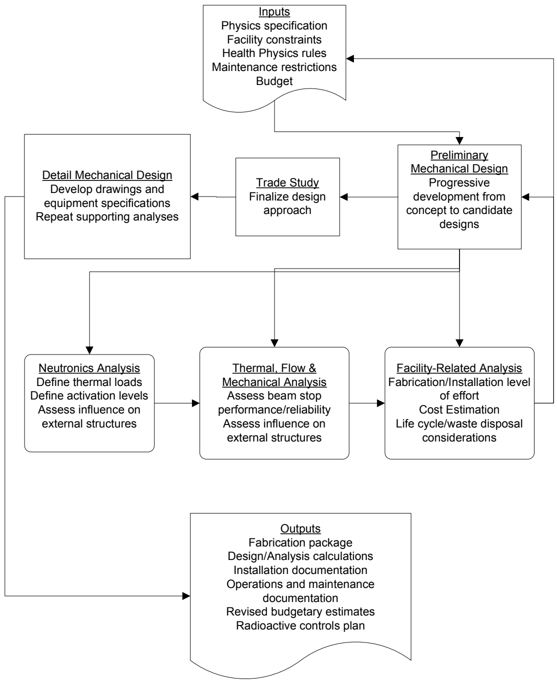

Figure 5: Design methodology flow chart.

with distributed cooling capabilities. A more diffuse energy distribution by contrast may permit the use of a monolithic beam stop with a simplified flow scheme.

In the case of the beam stop described in this paper, internal temperatures during irradiation were sufficiently low to allow the use of a monolithic design. For reference, segmented or modular designs may include stacked plate arrangements with flow channels perpendicular to beam direction or particle bed arrangements. They tend to be more complicated and expensive to fabricate.

It is also important to define facility, health physics and budgetary requirements in addition to physics requirements. The influences of many of these constraints tend to be coupled where a change in the design to meet one requirement impacts its ability to meet another. A thorough understanding of all requirements for the installation at the outset of the design process facilitates efficient development of a robust design. An incomplete or inaccurate set of specifications can result in a protracted design process or costly rework operations following initial installation.

An evaluation of all inputs is followed by the concept design phase. Design concepts are first developed for prospective configurations and subjected to neutronics and engineering analyses to evaluate thermo-mechanical performance and material activation levels. Thermal analysis and mechanical design are in turn used to help develop cooling schemes. If conduction to surroundings is not a viable option, then flow analysis may be required to determine if natural or forced convective cooling is necessary. The collective analyses in combination with mechanical design are used to develop a system concept.

The beam stop in our case was designed to fit within the shield enclosure of the previously installed assembly. This spatial limitation established additional constraints and analytical considerations as thermal loading and activation of the surrounding steel and concrete shielding also had to be considered. Development and analysis of system concepts therefore had to balance beam stop geometry definition and cooling solutions with the minimization of energy scatter to the surroundings.

Concept systems are then assessed with respect to manufacturability, operability, safety and cost. It is critical that prospective approaches be evaluated against initial inputs to ensure that they meet requirements. Candidate designs should be iterated to the point where all major technical and safety concerns are addressed.

A down selection process must occur once complete design concepts are developed. Some selection criteria, such as estimated construction cost, expected material activation levels and required service and maintenance operations, will be relatively objective and facilitate direct comparison. Others, such as system complexity, perceived risks and some elements of health safety exposure may be more subjective by nature. A more formal development of selection criteria will be more likely to produce a robust and reliable design. Completion of the mechanical design follows selection of the final design approach. It is recommended that critical supporting analysis be redone following completion of the detail design as details do tend to change during the final design process.

Outputs of the system design process should include all forms of supporting documentation. Fabrication and installation details tend to be a subset of the documentation required for highly activated installations. Because the personnel exposure and monetary costs of replacing highly activated installations are considerably greater than that of the initial installation, it is generally prudent to have life cycle plans for such installations. These can include both replacement and disposal plans.

SUMMARY

This paper presented an overview of the new SNS HEBT off-momentum beam stop and outlined a methodology for beam stop system design. The new beam stop consists of aluminium and steel blocks cooled by a closed-loop forced-air system and is expected to be commissioned this summer. The design methodology outlined in the paper represents a basic description of the process, data, analyses and critical decisions involved in the development of a beam stop system.

REFERENCES

[1] M.A. Plum et al, PAC09, WE6RFP027, T19 – Collimation and Targetry, pp. 1-3.