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THERMO-MECHANICAL RERPONSE OF THE HALO INTERCEPTS INTERACTING WITH THE SNS PROTON BEAM*

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Abstract

Integral part of the primary collimator of the SNS accumulator ring is a halo intercept assembly in the form of movable scraper blades that allow interception of the halo protons in four planes. In order to achieve large coulomb scattering of the halo protons and energy losses of less than 1%, platinum was chosen as the material of choice while its thickness was optimized to satisfy the energy loss requirements. This paper outlines the adopted design of the scraper assembly and presents the thermal response of the system that intercepts the beam halo as well as the subsequent thermal stress analysis and the issues associated with the performance of the scraper. Specifically, the current design incorporates a highly conducting material (copper) in the blade structure interfacing with the platinum scraper and is responsible for conducting the deposited energy away from the beam interception region. The mechanical performance and durability of such system, especially of the special bonding between the dissimilar materials, is the primary focus of this effort.

1. INTRODUCTION

In this paper we estimate the thermo-mechanical response of scrapers that have been placed in the beam halo. The perturbation introduced in the halo trajectory by the coulomb scattering in the scrapers is sufficient that it eventually impacts one of the absorbing structures placed in the collimation straight of the ring. It has been determined that 0.55 cm of platinum [2] results in the optimum amount of coulomb scattering, while simultaneously minimizing the energy loss per pass through the scraper. It is thus reasonable to expect that particles that do not immediately impact an absorber will impact one within the next few orbits around the ring. The absorbers are placed at 300π mm-mrad, while the scrapers are at 140π mm-mrad, and the vacuum chamber is at approximately 480mm-mrad. The scrapers are subjected to periodic thermal loads that increase as the ring accepts particles from the LINAC, and when the desired intensity has been reached (~ 1200 turns) it drops off precipitously as the particles are passed to the target. This pattern repeats itself sixty times per second. Thus, fatigue, and possibly thermo-mechanically enhanced stresses will be investigated as possible causes of failure. In addition, material damage due to exposure to the high-energy proton beam will be addressed. The following sections outline the scraper design, method of analysis, and the results.

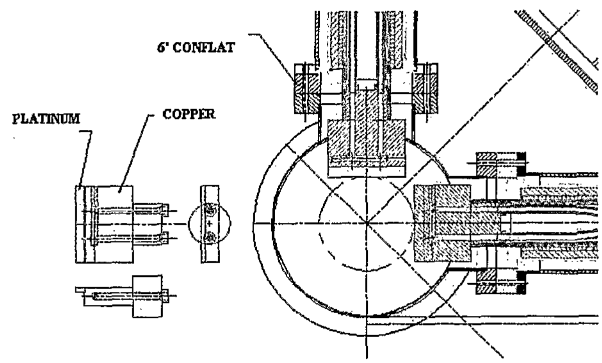

Figure 1. SNS halo intercept layout

2. DESIGN AND ANALYSIS

A scraper consists of a platinum piece (mentioned above), 0.55 cm thick, 5.0 cm long, and 1.0 cm wide. This piece is attached to a copper block of similar dimensions, except that its thickness is increased sufficiently to include a water-cooling loop. The copper block is attached to a hollow stainless steel arm, which is support on an appropriate linear bearing. A bellows separates the system vacuum from the environment, and a chain driven linear drive system moves the arm back and forth. The drive motor and its controls are placed far from the scraper to minimize damage to the electronic control mechanism. Additional shielding will be placed between the scraper and the drive motor in the actual installation. The mechanical arrangement of a scraper and its drive system is shown in Fig. 1. Figure 2 is a schematic of the copper/platinum arrangement that includes the cooling loop. The finite element analysis of the scrapper is based on the discretization of the shown volumes.

The method of analysis employed in this estimate starts by determining the energy deposited in the scraper as a function of position. This result is in the form of Joules/cm^3-p$^+$, and thus the time dependent heat source

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scales this value during the time dependent pulse. This pulse is in the shape of a tri-angle, building up for 0.0166 seconds and drops off in one micro-second. Figure 3 depicts the time structure of the micro-pulses in the accumulator ring.

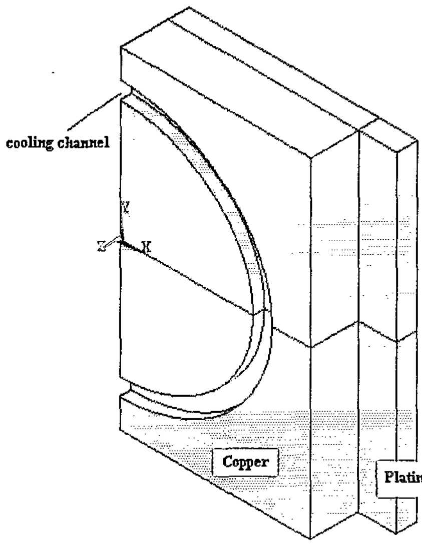

Figure 2. Schematic of the Platinum/Copper (half) arrangement showing the cooling channel within the copper block

During this build-up the number of particles increases from zero to 1.5×10^{14} (maximum followed number of particles per pulse), thus simulating the heat deposition rate. A thermal calculation is carried out to determine the temperature distribution. This step is followed by a stress analysis to determine the stresses due to thermal gradients and possible enhancement due to thermo-mechanical effects. The Monte Carlo code MCNPX [3] is used for the first step, and the thermal-stress analysis code system ANSYS [6] is used for the second step.

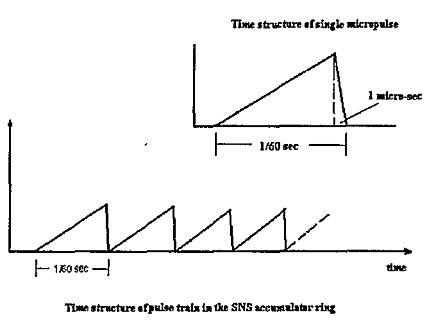

Figure 3. Pulse time structure

2.1 Thermal Analysis

The heat deposition rate is determined assuming a parallel beam of 1 GeV protons, with a hollow cylindrical shape. The actual beam is ignored in this calculation, since it is not affected by the scrapers, and only the halo portion is considered. Radially the halo is assumed to be 3 mm thick and it drops off in a step-wise fashion, with 75 % in the first millimeter, 20 % in the next millimeter, and 5 % in the last millimeter. The fraction of the primary beam assumed to be in the halo is 0.001, and thus the maximum number of protons in the halo per pulse is 1.5×10^{11}. However, given that beam may move closer to the scrapper due to instabilities a 1% of the total beam assumed to be intercepted by the scrapper. In the worst-case scenario, the beam may stray excessively toward the scrapper or the scrapper has moved into the beam by accident. In such case the platinum/copper mass will see the full beam with several micro-pulses before the beam is tripped. This accident scenario is currently under study.

From the neutronic calculations it is seen that the maximum heat deposited in the platinum scrapper is approximately 0.14 Joules/cc when assuming that only 0.1% of the beam is in the halo. The energy deposited with 1% beam in the halo is 1.4 Joules/cc.

There are two thermal conditions of interest in the interaction of protons with the platinum. First, is the temperature rise that is induced by each micro-pulse and its subsequent diffusion. If such rise is significant then fatigue issues in the material become important. Second, is the steady state that the system reaches after several micro-pulses. The operating temperature profile, given the energy deposited per unit time in the scrapper, will depend on the heat removal capacity that is provided by the coolant in the channel.

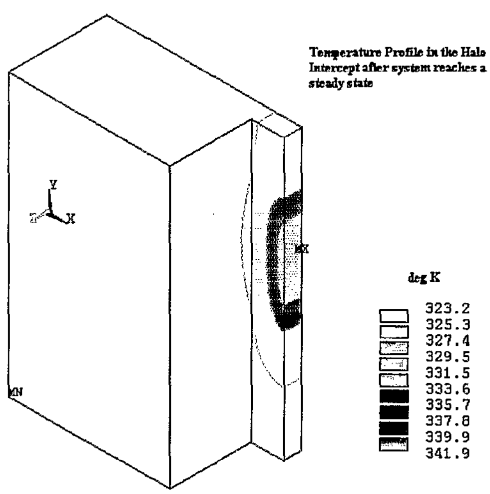

Figure 4. Temperature profile during steady state

By performing a thermal shock analysis on the model it is seen that the temperature rise per micro-pulse is negligible (less than 1 degree C) indicating that thermal fatigue under normal operating conditions is not an issue. In analyzing the steady state thermal condition that the system can reach with a reasonable choice of heat removal capacity, a peak temperature rise of approximately 42 deg. C was calculated. Shown in Figure 4 is the temperature profile in the platinum-copper arrangement.

2.2 Thermal Stress Shock and Fatigue

Following the thermal analyses of the previous section, the temperature profiles for both the steady state and the single micro-pulse interaction were introduced into a steady state and transient stress analyses respectively. As mention earlier, the shock generated by each micro-pulse and its connection to thermal fatigue is not an issue. The steady state thermal stress, on the other hand, is more serious. Shown in Figures 5 & 6 are the von Mises and axial stress profiles in the scrapper. As anticipated, the critical area is the interface between the two dissimilar materials. From Fig. 5 one deduces a von Mises stress of approximately 30 MPa shared by both materials at the interface. While the stress level may appear to be safe based on the strength of both materials, the way the two are bonded may be an issue. The stress level, however, may be reduced by an increase in the flow rate of the coolant in the channel. This iterative process will guide the final design of the scrapper assembly.

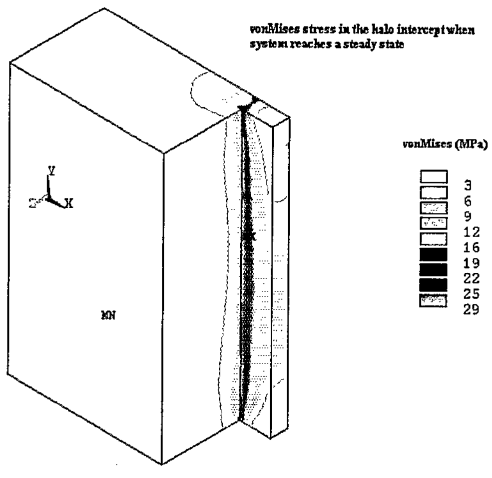

Figure 5. von Mises thermal stress profile under steady state conditions

3. CONCLUSIVE REMARKS

The neutronic, thermal and stress analyses of the SNS halo scrapper concept have shown that the adopted arrangement can satisfy both the beam dynamic requirements and also be able to withstand the thermal stress conditions in the long term.

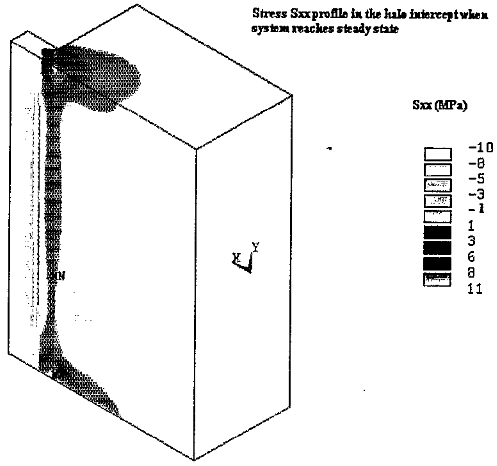

Figure 6. Axial stress profile in the platinum-copper arrangement under steady state thermal conditions

In order to complete the supporting analyses that guide the final design, the accident scenario of full beam intercept need to be evaluated. Further, estimates of radiation damage from experience data need to be incorporated into the overall picture.

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