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Informal Report

Thermal Finite Element Analysis
X9 and X29
X-Ray Ring Crotch Radiation Absorbers

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ABSTRACT

This report details the efforts by engineers at the National Synchrotron Light Source (NSLS) of Brookhaven National Laboratory (BNL) to evaluate the reliability of water-cooled radiation absorbers used in the NSLS X-ray ring. The absorbers on this report are part of the X-9 and X-29 dipole vacuum chambers. The absorbers are located at the intersection (crotch) of the beamline exit ports with the electron beam chamber, and are generally referred to as "crotches". The purpose of this analysis was to demonstrate the thermal reliability of the crotches under operating conditions that will be present over the expected life of the ring. The efforts described include general engineering layouts, engineering calculations, finite element analysis (FEA), results and conclusions of the analysis, and future design recommendations.

Keywords: crotch, thermal analysis, maximum temperature, NSLS, X9, X29, X-ray ring

INTRODUCTION

At the NSLS, electrons are accelerated in a storage ring. When the light beam passes through bending magnets, photons are emitted tangent to the beamlines into beam ports where they are used for research experiments. The crotch assembly shown below is positioned at the entrance to these beam ports in order to absorb any runoff from the beam and consequently protect uncooled sections of the beam chamber. This particular design is to be used where 0°, 2.5°, and 10° ports will be present, namely X9 and X29.

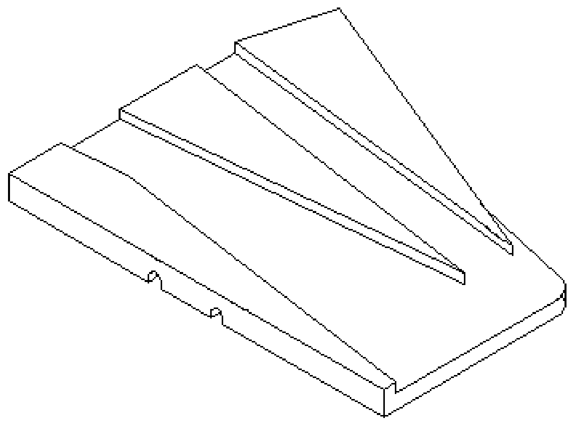

Figure 1: Cross-section of crotch used in FEA model.

As part of the design of these absorbers, Finite Element Analysis was conducted on a model of the part to determine the range of temperatures to be expected. The target maximum temperature at any point in the part is 450° F. The FEA is a first look at a design developed by the authors. The initial results show that the proposed design can achieve the desired temperature levels.

SCOPE

This report documents the tasks undertaken to demonstrate the thermal reliability of the NSLS x-ray ring exit chamber crotches, under operating conditions over the expected life of the ring. This analysis used results from other calculations, such as the convection-heat-transfer coefficient estimation for the cooling coils and ray tracing analysis to determine the location and intensity of radiation on the crotch surfaces. This report includes the following:

I. Mechanical analyses to characterize the thermal loading to which this crotch will be exposed. In all cases, the analyses attempt to use the worst case scenario.

II. A description of the pre-processing of the FEA model.

III. A description of two different iterations made, including the assumptions made for each model.

IV. Results of the FEA models.

V. Conclusions and recommendations based on the results.

These analyses should only be considered when studying the crotches installed in the X9 and X29 beam ports. No generalizations should be made regarding the results and conclusions of the efforts described in this report.

MECHANICAL ANALYSES

Description of crotch absorber:

The crotch assembly is positioned at the entrance to the beam ports in order to absorb any runoff radiation from the beam and consequently protect uncooled sections of the beam chamber. It is to be manufactured with Oxygen-Free High Conductivity (OFHC) copper. The material properties, as used in the FEA model, are listed below.

Material Property	**Value**
Mass density [lb/in^3]	0.3203
Thermal Conductivity [Btu/(s-in-°F)]	5.183e-3
Specific Heat [Btu/lb-°F]	0.092

Table 1: Material properties for FEA copper.

The outer sides of the crotch contain grooves where cooling coils will be installed and brazed. These coils intend to reach the areas of the crotch that will absorb more radiation and will consequently achieve a higher temperature.

Pre-processing:

The information provided by NSLS scientists, and organized by Donald Lynch, included position tolerances of the beam and maximum power densities expected on the surface of the crotch. The power density used in this analysis is the power density calculated for bending magnet radiation for beam conditions of 500 mA current at 2.584 GeV. The insertion device upstream of this crotch was assumed to have worst case opening angles equal to those of the IVUN magnet in the X-13 straight section. Under such an assumption the crotch surfaces would see no power loading from the insertion device under any mode of operation and under any feasible beam position and trajectory tolerances. The power density was calculated to be 40.02 W/mRad. The incidence vertical length is 0.008 in. With this information, we obtained the maximum incidence angles on the crotch surfaces. Knowing the power density, we calculated "pseudo" heat transfer coefficients to account for the radiation absorbed by the crotch A spreadsheet analysis of the cooling water flow characteristics was performed to obtain the information needed regarding the cooling coils. Four surfaces were identified as major heat transfer contributors. Table 1 below summarizes the parameters used in the FEA model.

Property	**Surface #1**	**Surface #2**	**Surface #3**	**Surface #4**
Location	Cooling coil	10° port	2.5° port	2.5° port
FEA assigned color	Red	Yellow	Blue	Brown
Beam angle intercepted [mRad]		89.1	21.43	21.48
Radiated area [in^2]		0.0412	0.0415	0.0412
Equivalent power on above area [W]		1782.5	428.9	429.9
Ambient temperature [°F]	81.9	1e10	1e10	1e10
Heat transfer coefficient [Btu/(hr-°F-in^2)]	11.3	1.475e-5	3.524-6	3.562-6

Table 2: Parameters used in Finite Element Analysis model.

Several assumptions were made in order to ease the construction of the FEA model. The most significant, if not obvious, is that the contact area of the cooling coils was made flat as opposed to circular. This simplified the meshing process while maintaining a good approximation, thermally. Also, the heat transfer solution was completed assuming steady-state characteristics. Two main iterations were made with the purpose of establishing a temperature range.

In terms of the actual modeling, only a half-model of the crotch was analyzed due to symmetry. The mesh is finer in places where the temperature was expected to be higher. Most of the elements are bricks, with a few exceptions in areas where the geometry did not allow for such elements, and where small temperature gradients were expected.

- 1st iteration: Forced convection cooling was placed all around the area where the coils would be brazed. The total area is 62.06 in^2.
- 2nd iteration: In this model, the cooling was placed on the vertical surface that would be in contact with the cooling coils. The total heat transfer cooling area is 16.03 in^2.

RESULTS

The figure below shows the results obtained for the first iteration. The highest temperatures can be observed at locations marked (1) and (2). Location (1) is the one farthest away from the cooling coils. Location (2) is a sharp corner and does not have as much material to dissipate the heat. Based on the two iterations, the temperature range was found to be 290-356 °F for the analyzed design. The “hot” spots are always the same. Thus, the proposed design is below the target temperature of 450 °F, demonstrating its thermal reliability.

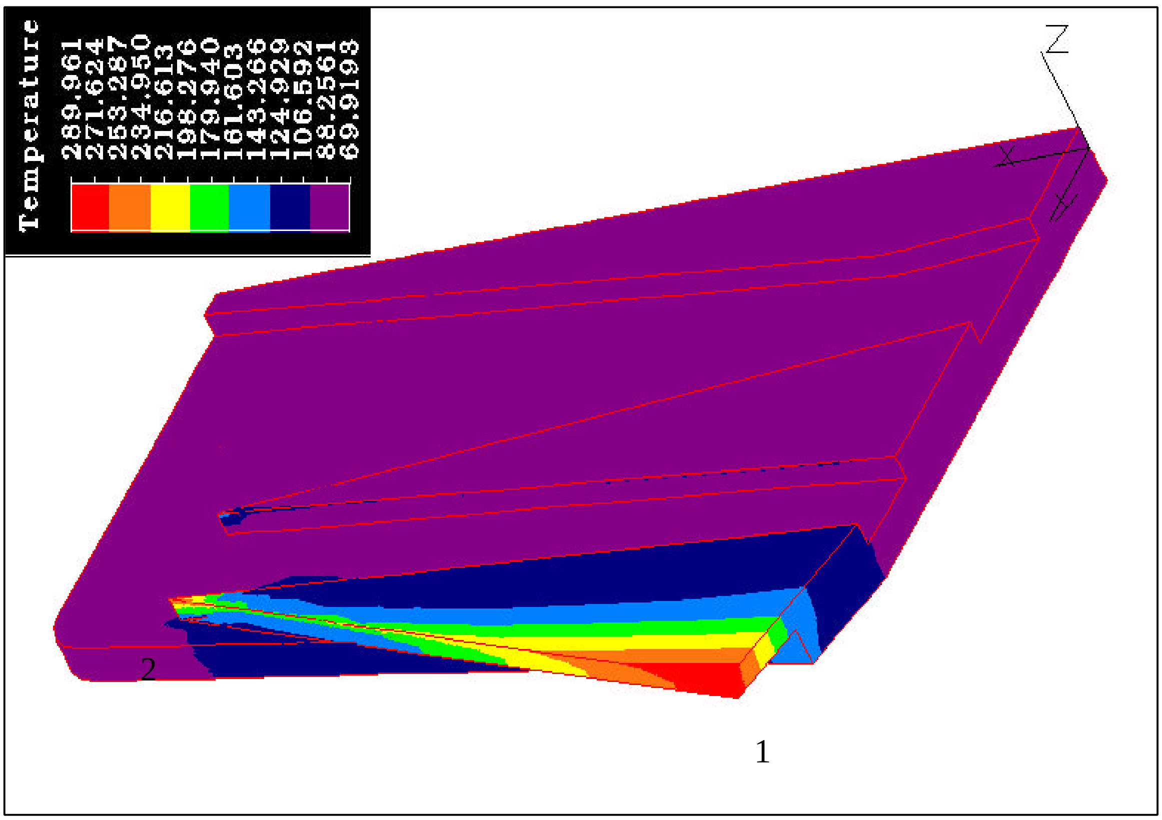

Figure 2: Resulting temperatures for iteration #1.

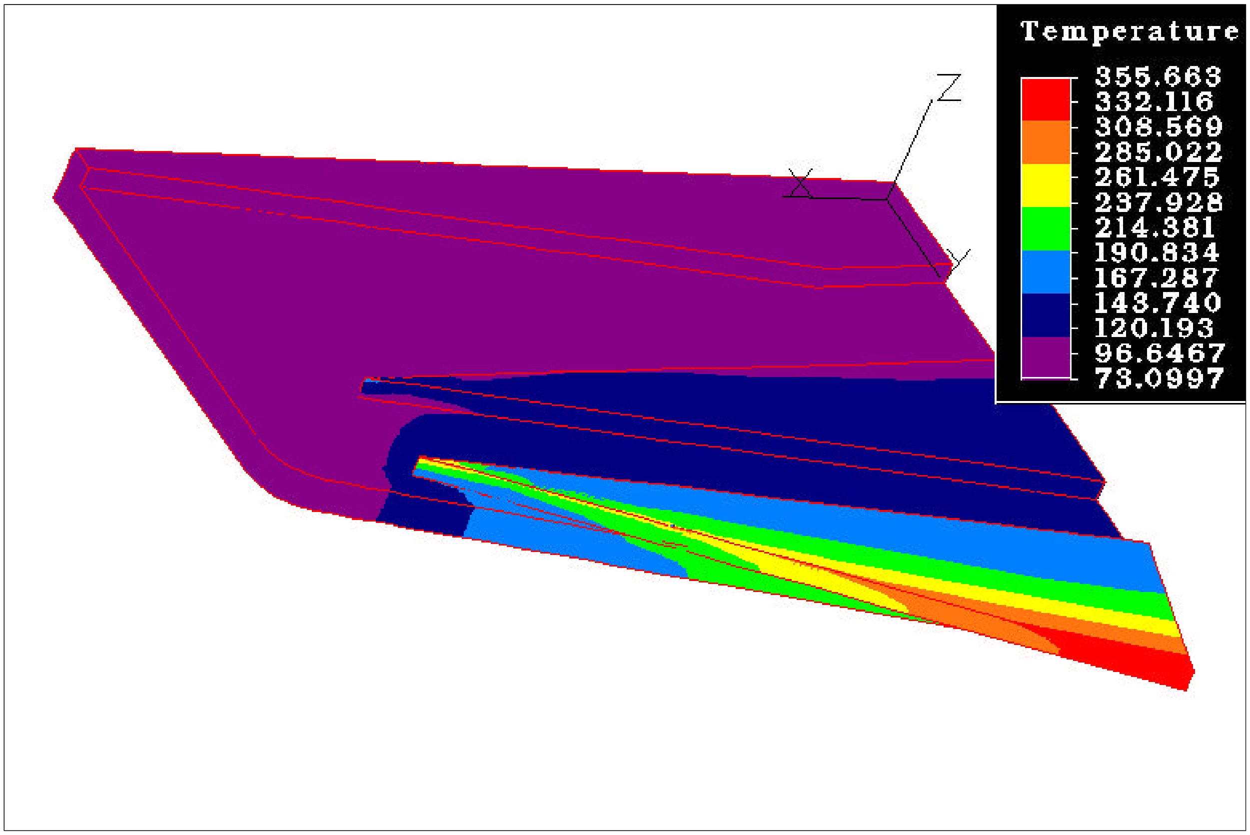

Figure 3: Resulting temperatures for iteration #2.

CONCLUSION AND RECOMMENDATIONS

The target maximum temperature of 450° F is comfortably achievable by the design analyzed in the two iterations. Secondary effects such as radiation and reflection off the crotch surface and natural convection were not considered in the analysis. These factors might reduce or increase the actual maximum temperature by some small percentage, which would not significantly impact the results. Given the large margin for error provided by the present calculations, we conclude that the subject crotch is adequately reliable for its intended service. Should the specified design conditions change significantly in the future, however, these calculations must be revisited.