ANALYSIS AND REDESIGN OF RF FILTER BAR TO RELIEVE THERMAL STRESSES

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I. ABSTRACT

During operation of the electron storage ring at the Center for Advanced Microstructures and Devices (CAMD), high thermal stresses were induced in RF filter bars, causing the bars to deflect into the path of the emitted beams. Finite-element models (FEMs) were developed to model both the original and alternate RF filter bar designs. An improved filter bar design was implemented.

II. INTRODUCTION

Filter Bar Description

The ring at CAMD consists of eight segments with eight dipole-magnet vacuum chambers. Each dipole chamber bends the electron beam 45 degrees. As the electrons are turned, radiation is emitted in the horizontal plane tangential to the path of the electrons. The resulting fan-shaped beam of radiation passes between two horizontal RF filter bars.

As originally designed, each RF filter bar (Figures 1 and 2) was approximately 1.18 inches wide, 0.54 inches high and 92 inches long. It was curved to form an arc of 45 degrees to conform with the shape of the chamber. Each bar was suspended or supported by five posts. Four of the posts were in slots elongated by one-eighth of one inch to allow for differing thermal expansion during the vacuum bake-out cycle, while the center post was not free to move.

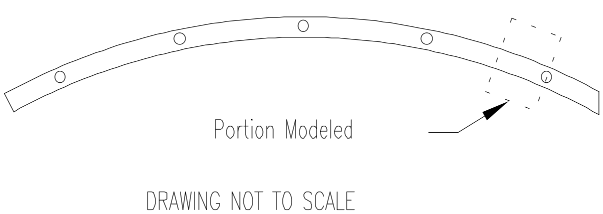

Figure 1: RF Filter Top View

Problem Description

When the electron storage ring is properly aligned, virtually no radiation is absorbed by the RF filter bars. As the alignment becomes worse, a greater percentage of the emitted radiation strikes the filter bars, and the temperature of the bars increases. At CAMD, minor misalignments, coupled with an RF filter bar design that did not accommodate significant thermal expansion, resulted in the bars heating and bowing vertically into the path of the radiation. To prevent reoccurrence of this event, an improved RF filter bar design was sought.

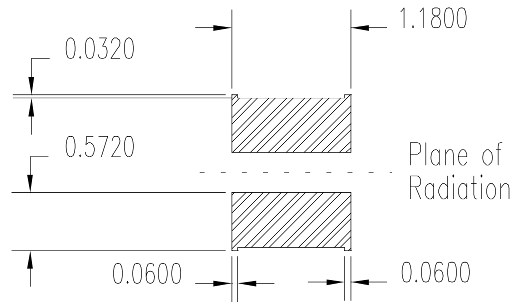

Figure 2: RF Filter Bars Side View

III. MODELING EFFORT

Model of Original RF Bar

A FEM of the original filter bar was developed using the commercial package ANSYS to predict the thermal stresses and deflections created when the bar absorbs a small percentage of the radiation emitted within one chamber. CAMD personnel provided the estimate that the original problem may have resulted from the bar absorbing as little as 200 watts of the 6000 watts generated in the chamber. The bar was modeled with three dimensional eight node elements. The assumptions used to model the problem are listed as follows:

- The synchrotron radiation striking the bar was completely absorbed.
- 200 watts of synchrotron radiation struck the bar at the bottom of the inside edge.
- The radiation was evenly distributed along the length of the bar.
- All surfaces of the bar had an emissivity of 0.5.
- The bars radiated to surroundings that were at a temperature of 535 deg. R (75 deg. F).
- There was no conduction heat transfer through the posts or through contact with the walls of the chamber.
- The bar had a rectangular cross section; the small ridges were ignored.
- Only elastic deformation was considered (even though stresses were above the elastic limit); plastic deformation and creep were ignored.

- The material properties of the bar were not affected by temperatures.
- All degrees of freedom are restrained at the posts.
- Because of symmetry, only one eighth of the bar needed to be modeled.

In the steady state case in which the bar absorbs 200 watts, thermal stresses in the bar were quite high, and the deformation in the vertical direction was significant.

Models of Alternate RF Bar Designs

A series of FEM models was built to predict the performance of different RF filter bar designs. The primary design criteria of the new designs are listed below:

1) The most important criteria of the new RF filter bars is that they be able to continuously absorb a small percentage of the emitted radiation (200 watts out of a possible 6000 watts) without deforming into the path of the radiation.

2) The decision was made by CAMD personnel to embed thermocouples in the new RF filter bars. The second design goal is that in the event all of the chamber radiation is absorbed by a bar, the embedded thermocouples should detect a rise in temperature of the front edge of the RF bar before the RF bar is damaged.

3) The capability of the bars to filter RF radiation should not be reduced.

Steady-State Solutions

Modeling results for a number of filter bar designs were obtained for the steady state case in which the bar absorbs 200 watts. In all cases, a primary design concept was that although bending in the vertical direction could not be allowed, some bending in the horizontal direction was considered acceptable. In the original design, the area moment of inertia resisting bending horizontally was about 4.8 times the value in the vertical direction, so the bar relieved compressive stresses by bending vertically into the radiation. In the first attempt to make the modeled bar bow horizontally, vertical notches were cut into the bar from the outside edge. A model was developed which predicted that the bar with notches would deflect significantly in the horizontal direction, but not in the vertical direction. The predicted horizontal deflection for the case in which the bar absorbs 200 watts is shown in Figure 3.

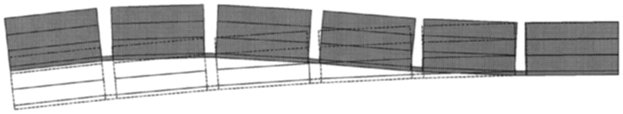

Figure 3: Bar Notched on One Side

A second proposed design involved cutting vertical notches into the bar from both the inside and outside edges. It was hoped that this design would relieve stresses by allowing compression, somewhat like an accordion, without suffering a large change to its overall shape. The model confirmed this hypothesis. If 200 watts of energy were absorbed by the bar, the maximum remaining tensile stresses were predicted to be 57 kpsi when notches were cut on both sides as compared to 140 kpsi with notches only on the outside edge of the bar. The predicted deflections (Figure 4) are also much smaller.

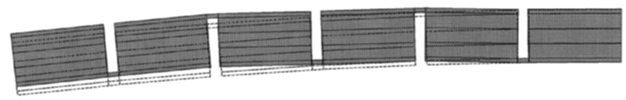

Figure 4: Bar Notched on Both Sides

Yet another alternative involved building the RF filter bar out of four separate sections, each approximately one-fourth of the total length and held in place by a single pin. A gap would be left between the sections for purposes of thermal expansion. The finite element model was used to study how much the radius of curvature would change if the bar was struck by radiation. This alternative offers the advantage of almost guaranteeing no build-up of thermal stresses, but the installation procedure was thought to be too complex so this last option was not seriously considered.

Transient Thermal Models

To satisfy the second design criteria in which the bar is subjected to a sudden heat input equal to the output from one chamber (6000 watts), a second set of models was used. In these cases, only a two dimensional transient thermal analysis was required.

Transient thermal models were used to determine where thermocouples should be placed in the bar. The installation of the filter bars would be easiest if the thermocouples were centered in the posts used to suspend the bars, but there was a concern that if radiation suddenly struck the bar, substantial damage to the bar could occur before the thermocouples measured a rise in temperature. The transient thermal models allowed the prediction of the temperature profile across the cross section of the bar as a function of time.

Modeling results showed that if the bar was made of stainless steel, the temperature of the lower corner would rise over 500 °R, where the radiative heat flux is applied, before the temperature in the middle of the bar changed. If the bar was made of copper, the temperature variation across the bar was decreased, due to the greater thermal conductivity of the bar. Figures 5 and 6 show the transient thermal response (for stainless steel and copper, respectively) when radiation striking the bar suddenly increases from 200 watts to 6000 watts. The conclusion of this modeling effort was that if the bar is made of copper, then the placement of the thermocouple is not crucial. However, if the bar is made of stainless steel, then the thermocouple should be placed as close as possible to the suspected region where the radiation is absorbed.

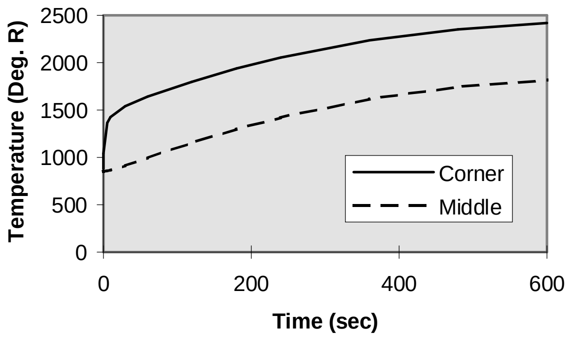

Figure 5: Thermal Response of a Steel Bar

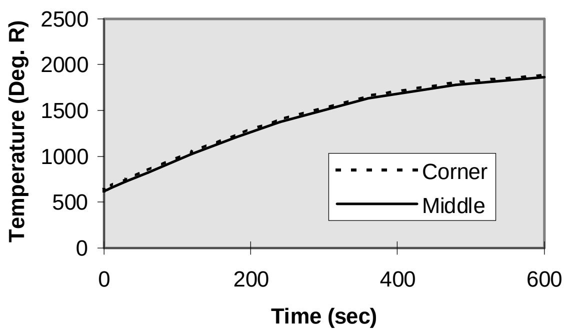

Figure 6: Thermal Response of a Copper Bar

IV. INSTALLATION

The dipole chamber with the most damaged RF filter bar was refitted with redesigned filter bars. The filter bars were removed and replaced by sliding them in and out of the ends of the chamber, instead of fully opening the chamber. This method minimized the required work on the chamber itself, but did not allow visual inspection of the filter bars before removal. It was noted however, that one of the posts supporting the upper bar had been deformed, indicating that it had been under severe shear stress while installed.

The new RF filter bars incorporated some of the ideas that had been tested using the finite element models (Figure 7). The new bars were made of four separate segments, each held by two pins in elongated slots. The slots are elongated to allow the pins to slide if necessary due to thermal expansion. Small gaps were left between the segments to prevent contact during any expansion. When the idea of subdividing the bar was originally modeled, each segment had been supported by only one pin, but two pins were used in the actual redesign to make installation easier. The additional pins were installed by drilling holes in the chamber, then welding the pins in place.

There was some concern that the pins would not slide in their slots due to cold welding, so notches were cut in the inside and outside edges of the bars similar to the notches that had been tested using the finite element program. It is hoped that these notches will allow thermal stresses to be relieved, if the posts fail to slide, without the bar deflecting into the path of the light beams.

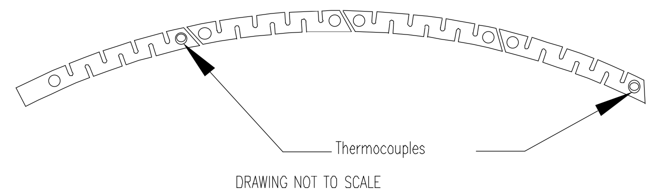

Figure 7: Redesigned RF Filter Bar

Thermocouples were installed in two of the posts holding the bar in place. It is hoped that high temperature readings from the thermocouples, as well as a decrease of vacuum in the chamber, will provide adequate warning if the bar is struck by excessive radiation.

The bars were made of stainless steel instead of copper because of the superior strength of the stainless steel. Since the chamber is also made of steel, the problem of welding two dissimilar metals was also avoided.

V. TESTING

The retrofitted chamber was installed on April 3, 1995. To date, the chamber is suffering from excessive photo-induced off-gassing, and no conclusive testing of the new design has been completed. The synchrotron radiation was directed onto a new RF filter bar once, and no symptoms of significant deflection of the bar were noted.

VI. CONCLUSIONS

The possibly that synchrotron radiation may accidentally strike the RF filter bars should be considered during the design of the equipment. Otherwise the bars may deflect into the normal path of the radiation due to thermal stresses caused by the radiation.

A finite element software package can be a useful tool while studying the alternate designs of the RF filter bars, and to predict what will happen when radiation strikes the bar.

An alternative filter bar design has been implemented in a dipole chamber at CAMD. Further testing is required to determine if the new bars can absorb radiation and heat up without affecting storage ring operability.

VII. REFERENCES

[1] Pearce, Jorge and Sah, Richard "Analysis of Dipole-Chamber Problems", Maxwell Laboratories, Inc., Brobeck Division, 4905 Central Avenue, Richmond, CA 94804-5803, USA, December 3, 1993.