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BEAM BASED MEASUREMENTS OF TITANIUM COATED CERAMIC CHAMBERS AT NSLS-II

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Abstract

We summarize recent experimental studies of the impedance and beam-induced heating of titanium-coated ceramic vacuum chambers used in the NSLS-II injection kickers. Spare chambers SN003 and SN001 were installed in test section C01. Equipped with 12 temperature detectors, we measured temperatures and beam currents during operational fill patterns. The results, highlighting the heating of chamber, will be thoroughly presented.

INTRODUCTION

Several accelerator facilities, including NSLS-II, reported overheating of their Ti-coated ceramic chambers due to lack of coating uniformity with appropriate thickness and/or poor coating adhesion. At NSLS-II, concerns over excessive heating measured in the kicker chambers prompted an inspection of their interior. Once opened, it was discovered that the Ti coating was damaged, and there was a significant color change in the ceramics compared to a spare chamber. This issue was critical to address for achieving the 500 mA design current at NSLS-II. Cooling fans were installed for temporary mitigation of the overheating, and then, as a reliable long-term solution, a tool for in-house coating of ceramic chambers has been designed, built, and commissioned [1–3].

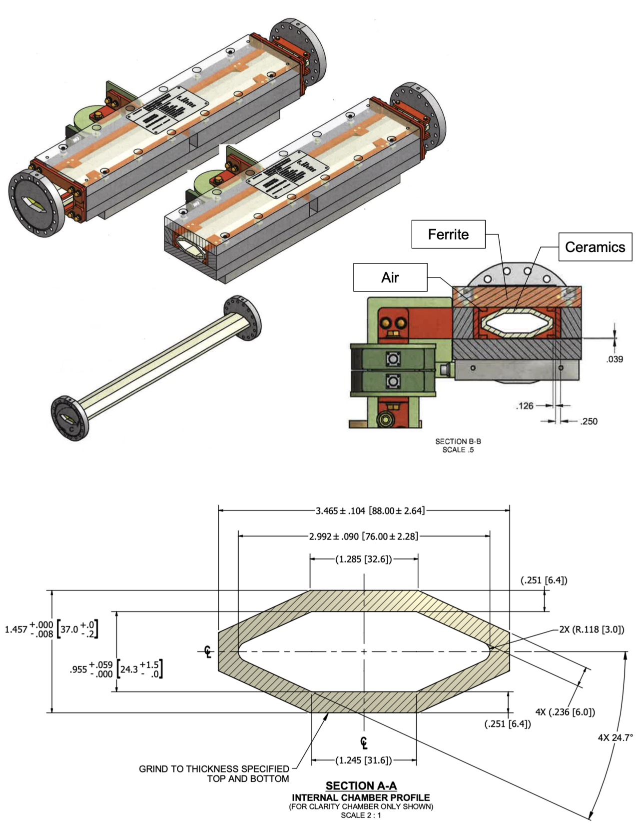

Figure 1: Schematic of the NSLS-II kicker chamber.

In this paper, we present a comprehensive experimental study of the beam-induced heating of Ti-coated ceramic vacuum chambers, recently completed at NSLS-II. The schematic of the ceramic chambers installed in NSLS-II injection kickers is shown in Fig. 1. The chambers have an octagonal profile measuring 76 mm (H) $\times$ 24.25 mm (V), the length of ceramics is 783 mm and the thickness is 6.4 mm. This profile matches the cross-section of the adjacent bellows and chambers. The original specification for the kicker ceramic chambers called for a 2 µm to 5 µm thick coating of Ti on the entire inner surface.

In the following sections, we will discuss the titanium coating process and measurements, beam-based measurements, followed by the conclusion.

TITANIUM COATING PROCESS AND MEASUREMENTS

To solve the problem of Ti coating quality, a new tool has been designed, built, and commissioned at NSLS-II as shown in Fig. 2. The ceramic beampipe undergoes a PVD (physical vapor deposition) coating process using magnetron sputtering to apply a titanium layer. A vertical set-up of titanium cathode wires is used within the ceramic chamber, where a plasma discharge is generated. This discharge is facilitated by a central anode rod, while an external solenoid applies a magnetic field to the ceramic chamber. This configuration facilitates the deposition of the titanium coating onto the ceramic surface.

After the coating process is completed, an annealing step is performed at a temperature of 400 °C. This annealing step serves multiple purposes. Firstly, it stabilizes the titanium film by allowing it to undergo an aging process, thereby reducing the occurrence of Eddy currents. Additionally, annealing helps to alleviate any stresses in the film that may have resulted from the deposition process. By dissolving surface oxides and nitrides into the bulk, annealing increases the resistivity of the coating. Furthermore, this annealing step acts as a final precautionary measure to prevent any blistering or flaking of the film due to thermal effects prior to installation.

A non-contact eddy-current probe was developed [4] to measure the relative coating thickness along the length of the

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Figure 2: Ti coating set-up.

ceramic chamber on both the top and bottom surfaces, ensuring the desired longitudinal uniformity is achieved. The film's uniformity is crucial to ensure consistent performance and reduce the likelihood of localized heating or impedance variations along the chamber. Calibration of the probe to

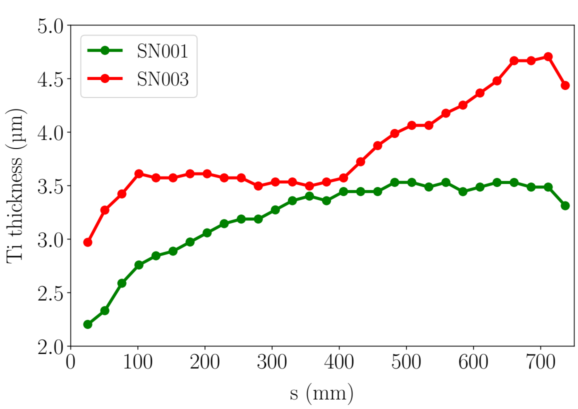

Figure 3: Ti film thickness profile along the chambers SN001 and SN003.

directly measure thickness proved unsuccessful due to the significant difference in the resistivity of the deposited Ti films compared to that of purchased titanium sheets. Because it is difficult to insert and calibrate the 4-point probe inside the chamber, we opted for a 2-point probe measurement. The flange-to-flange resistance of chambers SN001 and SN003, as measured by the 2-point method, is 5.6 Ω and 4.2 Ω, respectively. In this study, we have assumed a uniform transverse coating thickness, resulting in average thicknesses of 3.2 μm and 4.3 μm for chambers SN001 and SN003, respectively. We normalized the eddy-current values against the measured thickness to construct the longitudinal thickness profile, as illustrated in Fig. 3.

BEAM BASED MEASUREMENTS

The processed chamber SN003 was installed in the test straight section C01 at NSLS-II, as shown in Fig. 4. This chamber was equipped with 12 resistance temperature detectors (RTDs) that were strategically positioned to monitor temperature variations within the chamber. We conducted a series of measurements at NSLS-II using an operational fill pattern of 1200 bunches with a total beam current of 500 mA. The beam current and temperatures measured by 12 sensors were archived and post-processed. These measurements were done systematically over an extended period of time to ensure that the temperature reached equilibrium. To validate the results and ensure consistency, the same experiment was repeated for chamber SN001.

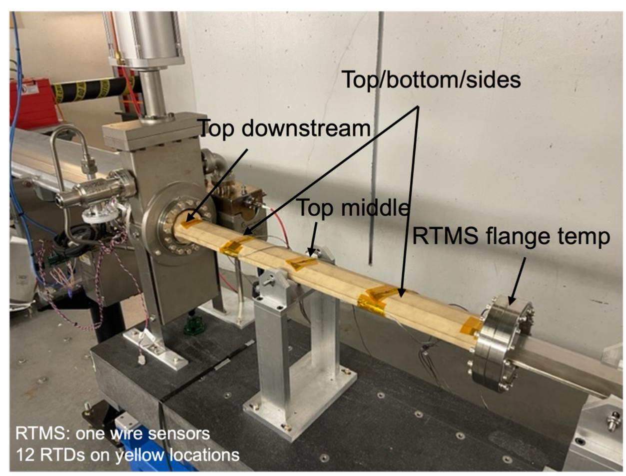

Figure 4: Chamber set-up with 12 RTDs placed in C01 at NSLS-II.

Figure 5(a and c) presents time-dependent temperature measurements of the SN003 and SN001 chambers with a beam current of 500 mA. The graph illustrates that the temperature reaches equilibrium over time. In Figure 5(b and d), measured temperatures at various RTD locations on the top, bottom, and sides of the chambers are presented. The temperature varies longitudinally along the chamber. As shown in the thickness profile in Fig. 3, where the thickness is greater, the temperature is lower, and vice versa.

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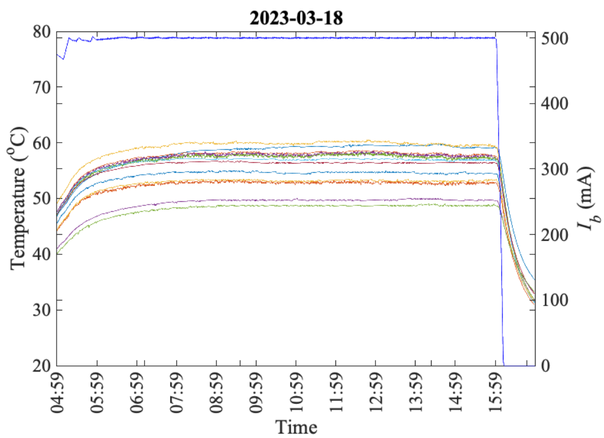
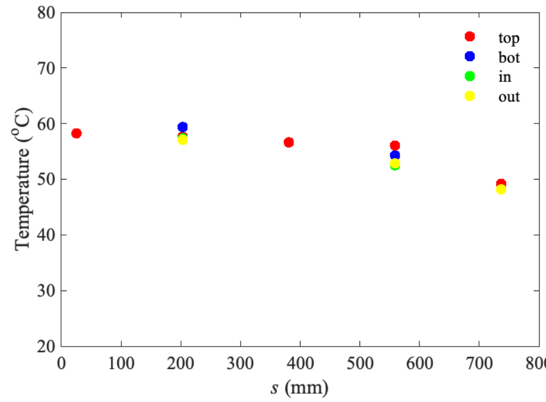
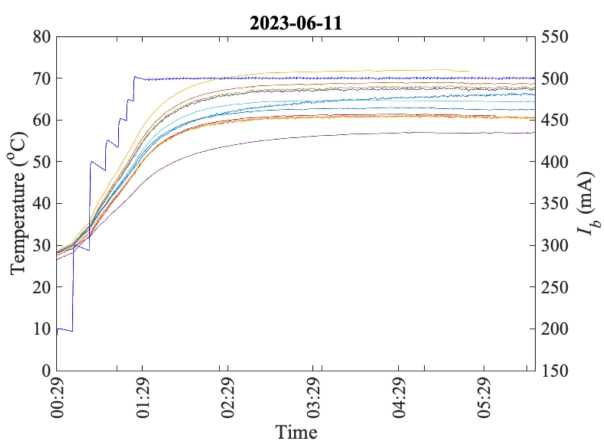


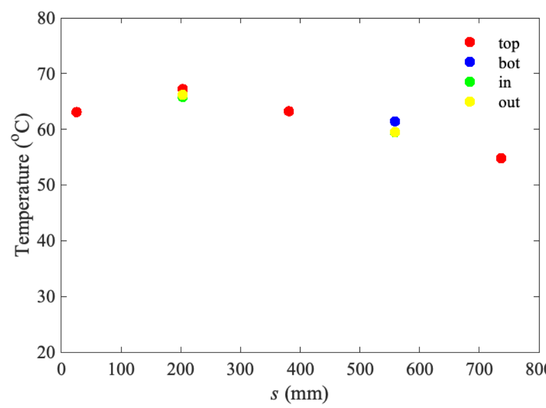
(a) Temperature rise monitoring for chamber SN003.



(b) Temperature at various RTD locations for chamber SN003.



(c) Temperature rise monitoring for chamber SN001.



(d) Temperature at various RTD locations for chamber SN001.

Figure 5: Monitoring of temperature rise over time at NSLS-II for a current of 500 mA, along with measured temperatures at various RTD locations on the top, bottom, and sides (inside and outside) of the chamber.

CONCLUSION

We summarized our studies of the beam-induced heating issues of titanium-coated ceramic vacuum chambers in the NSLS-II storage ring. Our measurements of the titanium coating thickness and its correlation with beam-based temperature data are crucial for benchmarking simulations of beam-induced heating, aiming to gain a deeper understanding of the impedance characteristics and heat distribution within the ceramic chambers [5].

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