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heating of the cryogenic BPM cables***

**P. Thieberger, C. Pai, K. Mernick, T. Miller, M. Minty,
K. Hamdi, A. Ghosh, J. A. D'Ambra**

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HIGH INTENSITY RHIC LIMITATIONS DUE TO SIGNAL HEATING OF THE CRYOGENIC BPM CABLES *

P. Thieberger, C. Pai, K. Mernick, T. Miller, M. Minty, K. Hamdi, A. Ghosh and J. A. D’Ambra
 CAD, Brookhaven National Laboratory, Upton NY 11973, USA

Abstract

The signal cables from the beam position monitors (BPMs) in the cryogenic sections of the Relativistic Heavy Ion Collider (RHIC) need to satisfy somewhat conflicting requirements. On the one hand, the cryogenic load due to heat conduction along the cable needs to be small, which led to the use of stainless steel jacketed cables with Tefzel insulation. On the other hand, radio frequency losses need to be reasonably small to reduce heating due to dissipated signal power. As the beam intensity in RHIC increased over the years, and the bunches are becoming shorter, a point is being rapidly approached where these cables will soon become a performance limiting factor. Here we describe an extensive study of this problem including cable loss measurements as a function of temperature and frequency, characterization of the copper center conductor, and simulations using Particle Studio (PS) and ANSYS.

INTRODUCTION

The signal heating limitations of the RHIC cryogenic BPM cables were recognized and analyzed in 1995 [1, 2]. In particular, the Tefzel insulator has an operational temperature limit of 150 °C. Continuing RHIC upgrades to higher luminosities will hopefully lead next year [3] to the new goal of 111 bunches of 3E11 protons each with an RMS bunch length of 20 cm (henceforth the “upgraded beam”). The cable limit is expected to be approached, and more detailed estimates have now been performed to ensure safe and reliable operation.

CABLE LOSS MEASUREMENTS

Cable losses as a function of frequency were measured with a signal analyzer at eleven temperatures ranging from 4 K to the maximum operating temperature of the cable which is 423 K (150 °C). To perform these measurements at the various temperatures two different cryostats, an ice bath and an oven were used. A spare RHIC 125 cm long BPM cable was formed into a 10 cm diameter spiral and connected to two lead-in cables of the same type.

To take into account the temperature dependent losses in these lead-in cables, a short (8 cm long) “dummy” connection was used as shown in the Fig.1 inset, and the results shown in figure 1 were obtained by subtracting at

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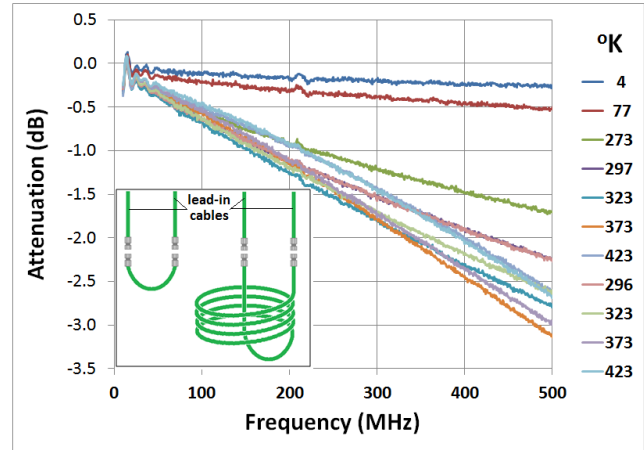


Fig.1: Cable attenuation as function of frequency measured at 11 temperatures ranging from 4 K to 423 K; the operating temperature limit for the cable.

each temperature the losses measured with the dummy from the ones measured with the sample under identical conditions. The frequency range up to 500 MHz contains over 95% of the signal power for 20 cm rms bunches.

From these curves, the loss per unit length is later calculated considering an effective cable length of 125 – 8 = 117 cm where 8 cm is the length of the “dummy” connection. The Fig. 1 data show that above ~180 MHz, some of the lower temperature losses are larger than losses at higher temperatures. This surprising behavior, which was confirmed by repeating the measurements with different signal analyzers, is probably due to peculiarities in the dielectric losses in the Tefzel insulator.

THERMAL CONDUCTIVITY

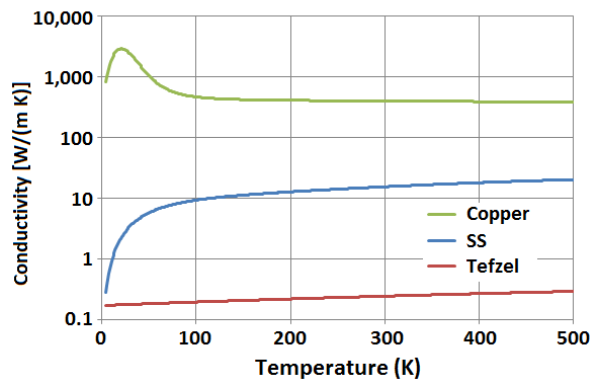


Fig. 2: Thermal conductivities used for the simulations

The thermal conductivity of copper is a sensitive function of the impurity content and was determined by measuring a Residual Resistivity Ratio value of 131. Values of the thermal conductivity parameterized for various RRR values given by NIST [4] were used to calculate the thermal conductivity curve for copper through interpolation. The curve for Tefzel was generated from the room temperature value [7] adopting a slope similar to the one for Teflon. This conductivity is so small that it isn't very significant.

SIGNAL AMPLITUDE AND FREQUENCY SPECTRA

The current pulse into 50Ω generated by a BPM stripline is due to a superposition of charges induced directly by the beam and the ones reflected by the delay-line structure formed by the stripline and the rest of the BPM. In addition, that charge of course depends on the beam position. An extensive series of Particle Studio (PS) [5] simulations was performed to characterize these signals as a function of position for the three types of cryogenic BPMs present in RHIC (see Table 1).

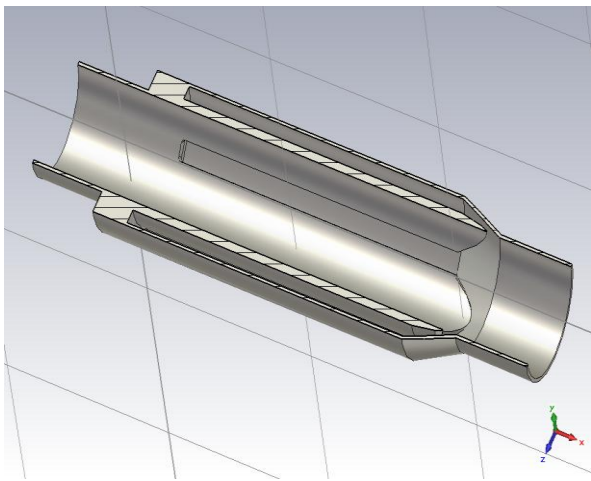


Fig. 3: Cutaway view of the Type 2 BPM model used for the Particle Studio simulations.

Figure 3 is a cutaway view of one of the BPM PS models used for the simulations. The number of mesh-cells used was about 195,000. At the ends of the striplines, where in reality 50Ω feedthroughs are located, these feedthrough were simulated by 50Ω resistors connected between the tip of the stripline and the vacuum housing. Figs. 4 and 5 show some of the results for a Type 2 BPM (see Table 1)

HEAT TRANSPORT SIMULATIONS

Power density inputs for the ANSYS heat transport simulations (Fig. 6) are calculated as if all the losses were dielectric. In reality resistive losses contribute too. The other extreme case of resistive losses only was also

simulated with nearly identical results. The cable diameter is small enough to make it practically irrelevant where along the radius the energy is deposited.

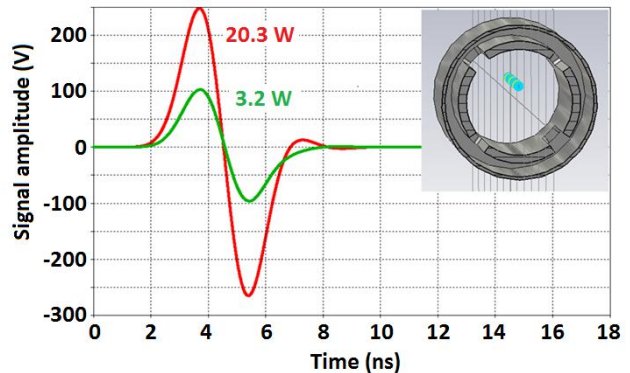


Fig.4: PS simulated signal amplitudes and powers from two opposite striplines induced by an upgraded beam displaced by 10 mm from the center line

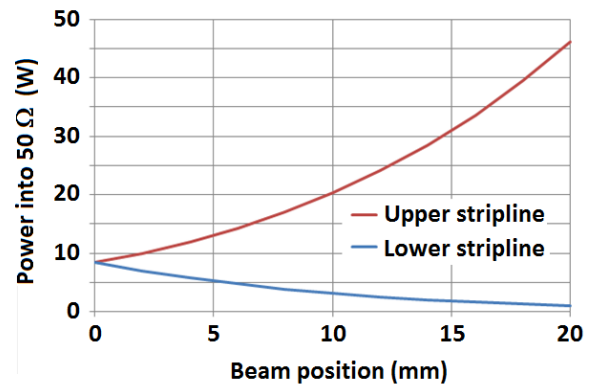


Fig. 5: PS simulated signal power as function of beam position from two opposite Type 2 BPM striplines.

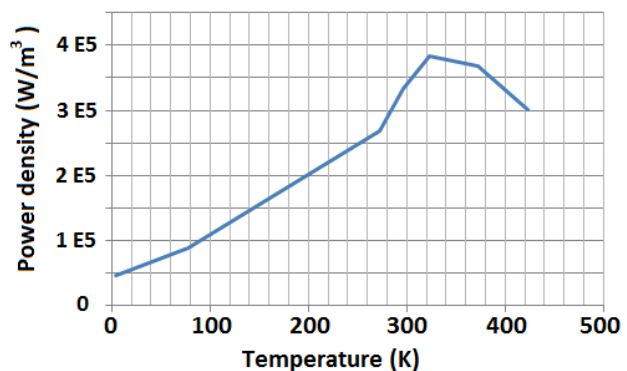


Fig.6: Power density in Tefzel as a function of temperature calculated by convolving the cable frequency response with the signal frequency spectrum.

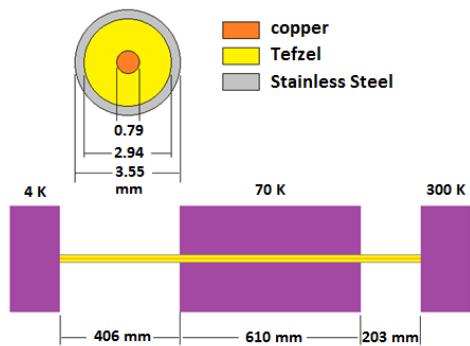


Fig. 7 Schematic representation of the geometry used for the ANSYS heat transport simulations

The curve labeled 1.00 in Fig. 8 shows the ANSYS simulated temperature profile along the cable for a type 2 BPM with a centered upgraded beam. The power or load factors labeling the other curves correspond to powers larger by the indicated factors.

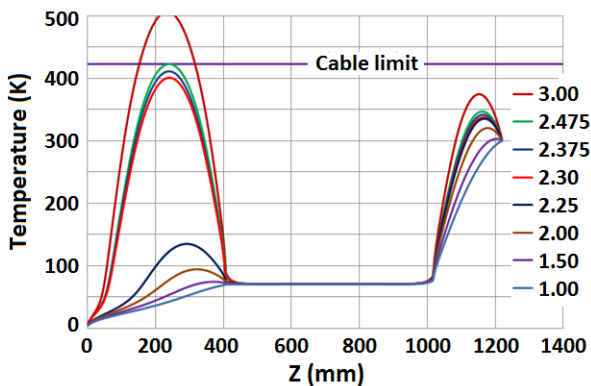


Fig.8. Cryogenic cable temperature profiles obtained from the ANSYS simulations. The curve labeled 1.00 corresponds to the upgraded beam centered in a type 2 BPM. The other labels indicate correspondingly higher power factors.

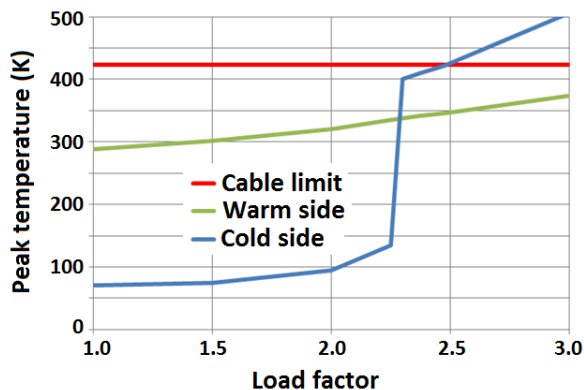


Fig. 9 Peak temperatures as function of the load factor where 1.0 corresponds to the upgraded beam centered in a Type 2 BPM. The jump at the “cold” or BPM side of the cable indicates an incipient temperature runaway situation that must be avoided.

RESULTS AND CONCLUSIONS

The maximum allowable beam displacements to just avoid the incipient temperature runaway situation shown in Fig. 9 are shown in Fig.10 and Table 1.

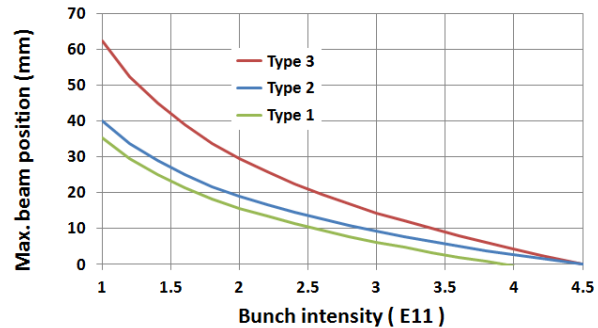


Fig.10 Maximum allowed beam displacements as function of bunch intensity of 111, 20 cm RMS bunches for the three types of BPMs.

TABLE 1: Maximum beam displacements to avoid cable damage with the upgraded beam for the 3 types of BPMs.

BPM Type	# of planes	Location	Radius (mm)	Max. Δx (mm)
#1	1	Arcs	34.5	7.3
#2	2	Arcs	34.5	10.4
#3	2	Triplets	53.7	16.1

These results are more detailed than- but in general agreement with the ones obtained before [1, 2]. As shown in Fig. 10 and Table 1, operation with the upgraded beam should be possible provided excessive beam position excursions can be precluded by the use of beam abort interlocks. In practice, we note that there is some performance uncertainty due to crimping of the cable ends in the early days of RHIC [6]. In the future, we plan to verify the temperature rise predictions presented here with measurements using thermocouples

REFERENCES

- [1] P. Cameron, et. al. 1995 PAC Proc., p. 2458
- [2] P. Cameron and M. Morvillo, RHIC/AP/68, BNL, 1996.
- [3] W. Fisher, et. al. STATUS OF HEAD-ON BEAM-BEAM COMPENSATION IN RHIC. ICFA Mini Workshop on Beam-Beam Effects in Hadron Colliders (BB2013); Geneva, Switzerland, 2013.
- [4] http://cryogenics.nist.gov/MPropsMAY/OFHC%20Copper/OFHC_Copper_rev.htm
- [5] Particle Studio, Computer Simulation Technology
- [6] C.J.Liaw, R. Sikora, R. Schroeder Proceedings of PAC07, MOPAS095, page 649
- [7] http://www2.dupont.com/Teflon_Industrial/en_US/assets/downloads/h96518.pdf