RHIC BEAM POSITION MONITOR CHARACTERIZATION*

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Abstract

Techniques and results of RHIC BPM measurements are presented. These include wire scanner measurements of uncalibrated and calibrated BPM position and roll accuracy, preliminary measurements of the coupling between adjacent striplines to permit in situ offset calibration of the BPM signal cables and electronics, frequency dependence of the location of the BPM electrical center, and antenna measurements of the installed position of the electrical center relative to the cryostat fiducials. We also present results of simulations and measurements of cryogenic signal cable heating, and testing of the cryogenic feedthrus.

I. INTRODUCTION

The RHIC BPM performance requirements, design details, and fabrication techniques are in the literature[1,2]. Production is underway. The 42 Injection Line BPMs are complete, calibrated, and installed. The first 130 of the 480 RHIC BPMs are complete and ready for installation. The first 20 of these were calibrated with a wire scanner. The remainder of the BPMs will be installed uncalibrated. The precise location of their electrical centers relative to the cryostat fiducials will be determined with an antenna.

II. WIRE SCANNER MEASUREMENTS

The calibration technique previously described[1] yielded the stripline at the hinge where it joins the flange to bring the electrical center into alignment with the mechanical center. Because of the exceptionally good accuracy of the uncalibrated BPMs, it has been possible to refine this technique with the removal of the nickel bellows spring contact from the end of the contact post. The position of the stripline is now determined by the rigid contact post rather than the bumping operation. This simplifies the calibration procedure, reduces the inductance of the stripline-to-feedthru transition (improving the impedance match), diminishes stripline movement during thermal cycling, and permits baking of the BPM in warm bore regions. The function of the spring contact is now served by the cantilevered stripline, which can be seen in Figure 1. With the stripline thinned to an 0.8 mm hinge where it joins the flange, the spring constant at the contact post is about 0.1 N/micron (8 oz/mil). Typical stripline deflections are about 200 microns. The BPM is calibrated by adjusting the length of the contact posts. Data for the uncalibrated and calibrated positions of the electrical center was taken for 80 BPM measurement planes before the calibration operation was stopped. Sigma of the separation between electrical and mechanical centers is about 100 microns before and 25 microns after calibration.

Unlike position, the roll accuracy of the BPM cannot be calibrated. Data was also taken for 80 measurement planes. Sigma of the difference in orientation of the mechanical and electrical axes of the BPM is about 1 mrad.

To permit the possibility of making offset calibrations of the BPM signal cables and electronics using external means[4], the observed position of the electrical center when signal is injected on the adjacent orthogonal striplines (instead of the wire) is being measured for all dual plane BPMs, using the setup shown in Figure 2. The transfer function for this measurement can be approximated analytically[5] to be about 3 dB/mm. Using this transfer function, the data that has been taken on 12 dual plane BPMs has a sigma of about 100

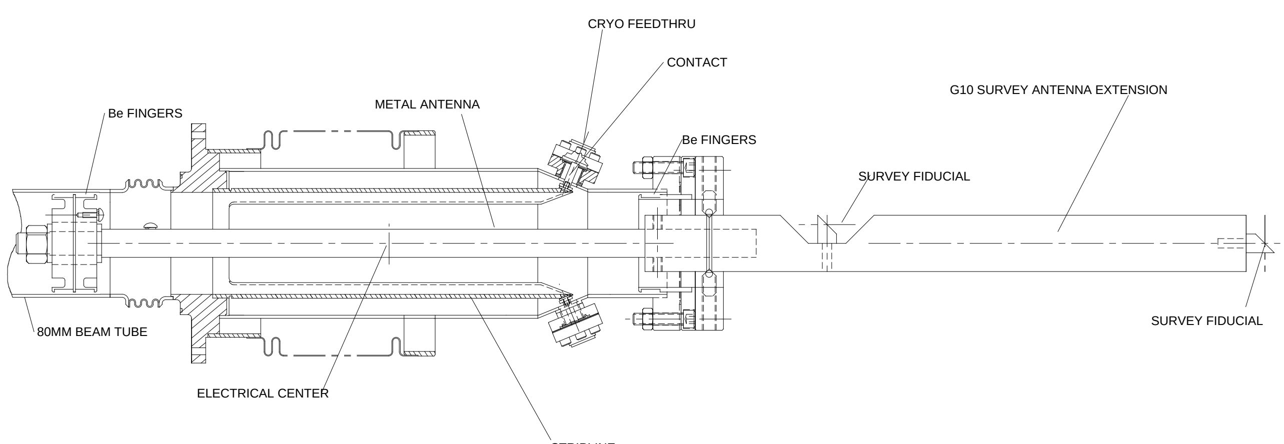

Figure 1. BPM with antenna installed

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microns. This agrees well with the sigmas of the uncalibrated position of the electrical center and orientation of the measurement plane about the roll axis using the wire, and suggests that the same construction tolerances govern all three distributions.

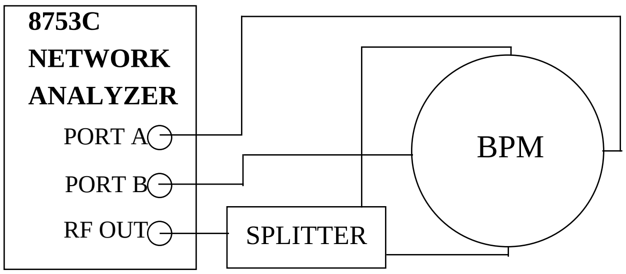

Figure 2. signal injection block diagram

The location of the measured position of the electrical center varies by about 50 microns (.035 dB) over the range from 1 Mhz to 100 Mhz. This variation is attributed to reflections resulting from imperfect terminations and coupling into the room resulting from imperfect shielding. In the wire scanner calibrations the effect of this offset can be eliminated by rotating the BPM 180 degrees. In the antenna measurements this variation will be reduced when the prototype antenna is replaced by the production antenna, which is now being fabricated.

The measured transfer function is about is about 0.7 dB/mm. The 4 pole Bessel low pass filter in the analog front end of the BPM electronics[3] has its 3 dB point at 70 MHz, with a rolloff of 24 dB/octave. Calibrations are done at 50 MHz.

III. ANTENNA MEASUREMENTS

As construction and measurement of BPM/magnet assemblies progressed, the need for direct measurement[6,7] of the positions of the electrical center of the BPM and the magnetic centers of the quadrupole and sextupole became increasingly clear. To accomplish this in the case of the installed BPM, the antenna shown in Figure 1 is driven by the RF output of a network analyzer, and the ratio of the signals at the BPM ports is used to locate the electrical center of the BPM. Surveyors using the ManCat system then survey the location of the external fiducials and project back to the hidden location of the electrical center of the antenna, thereby locating the electrical center of the BPM relative to the cryostat fiducials. Antenna measurements have been made on 30 BPM/magnet assemblies. The relative difference between the measured electrical center and the surveyed position of the antenna has a sigma of less than 50 microns. A more absolute measurement is repeatability. Two BPM/magnet assemblies were re-surveyed two months after their initial measurements. The locations of the electrical centers relative to the cryostat fiducials agreed within 50 microns.

IV. CRYOGENIC SIGNAL CABLE

The cryogenic signal cables are stainless steel outer conductor, Tefzel (ETFE) dielectric, silver-plated copper center conductor, with male SMA connectors at both ends. They have been extensively analyzed using a custom program written in LabVIEW. The thermal circuit is shown in Figure 3. The program does a finite difference analysis of heat flow in 1 cm steps along the 122 cm length of the cable. Heat flow occurs because of the thermal conductance of the cable and RF heating from the signal current. Results of a typical analysis are shown in Figure 4. This analysis uses a variable gaussian bunch length convoluted onto the frequency response of the BPM to determine the spectral content of the signal in the cable. Frequency and temperature dependent skin depths and electrical resistivities, and temperature dependent thermal conductivities of the cable and the thermal anchors, are determined at each iteration of the calculation.

Figure 4 shows a plot of the temperature profile along the cable at an intensity of 3 x 10^{11} charges per bunch and 114 bunches in the machine (RHIC upgrade intensity), with a bunch length of 0.6 nsec and the beam 1 cm off axis. The maximum permissible operating temperature for the cables is around 400 K. It is possible to operate RHIC off-momentum, with the beam displaced as much as 2 cm, and with more high frequency content in the bunch, either because of shorter bunch lengths or bunch structure which is not gaussian. The intensity/bunch length limit for RHIC is set by magnet quenching due to heating of the beampipe by

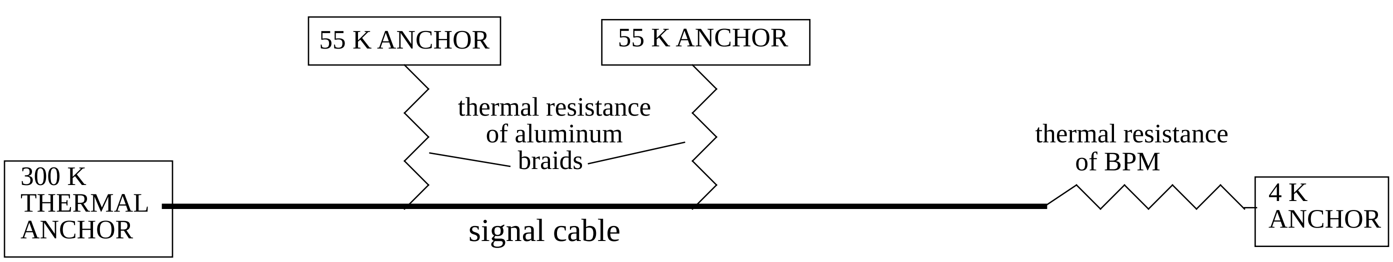

Figure 3. Signal cable thermal circuit

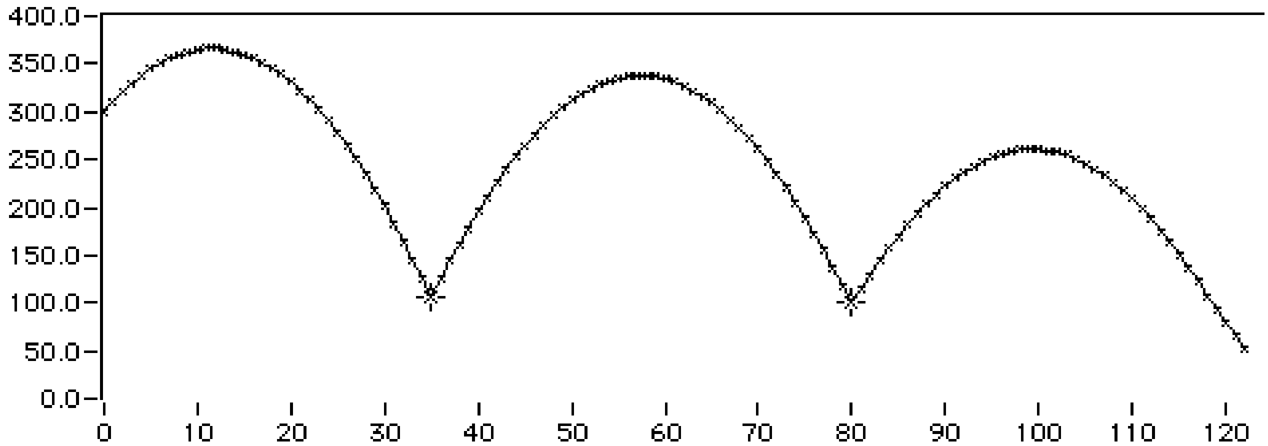

Figure 4. Typical signal cable temperature profile [degrees K vs cm]

the beam image current. Our simulations indicate that in continuous operation, the possibility exists that the signal cables can be overheated before a magnet will quench. In the case of transients, the situation is worse. The time constant for the cable is about 1 degree K/sec. The time constant for the magnet coil is about 0.01 K/sec. Operational constraints must be placed on beam offset and bunch spectral content. This problem remains under study.

Heat load per cable to 4 K at RHIC upgrade intensity and 0.6 nsec bunch length is 170 mW, comprised of 50 mW of conduction and 120 mW of RF heating. Heat load per cable to the 55 K heat shield is 660 mW, 290 mW conduction and 370 mW heating.

Attenuation in the cables is dependent on temperature, and therefore on intensity, position, and bunch length (or more generally the spectral content of the beam). Despite the rather dramatic temperature profile shown in Figure 4, the correction amounts to only about 0.08 dB or 60 microns in this example.

V. CRYOGENIC FEEDTHRU

The ‘glass-ceramic’ cryogenic feedthru design (which uses lithium silicate glass dielectric doped to match the expansion coefficient of stainless steel) has proven reliable under cryogenic shock testing. About half of the 1400 cryogenic feedthrus have been subject to five shock cycles into liquid nitrogen, followed by vacuum baking at 300 degrees C and UHV leak checking with no failures. This design is more simple, more economical, and has better RF properties than the conventional ceramic/kovar design.

VI. CONCLUSIONS

The exceptionally good accuracy of the uncalibrated BPMs has permitted the refinement of calibration techniques, and contributed to their eventual abandonment in favor of the antenna measurement of the position of the BPM electrical center. Heating of the cryogenic signal cables might represent a constraint on RHIC operation, and remains under study.

VII. REFERENCES

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