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MASTER

COUPLING-IMPEDANCE AND RESPONSE-CHARACTERIZATION MEASUREMENTS OF A PROTON STORAGE RING WALL-CURRENT MONITOR*

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Abstract

This paper describes a method to measure the response of a beam current monitor and reports response and impedance measurement results for a Proton Storage Ring (PSR) wall current monitor.

Introduction

We have reported a Through-Short-Delay (TSD) calibration method for making coupling-impedance measurements.¹ We now describe extending this method to measure the response of a current monitor that is imbedded within hardware that interfaces to a network analyzer (Fig. 1). We utilize error correction parameters that are generated using the TSD-calibration to calculate the actual current present at the current monitor.

Fig. 1. Physical representation of experiment. Note that the matching sections on either side of the test device do not necessarily represent a low SWR.

Method

The measurement has five steps:

1. Perform the TSD calibration (Fig. 2). This yields the scattering parameters of the two error networks, SA and SB.

Fig. 2. Error correction network to perform TSD calibration. Note that the error networks SA and SB include all effects starting from the reference plane (the plane of insertion of the test device) all the way back into the network analyzer.

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2. Insert the current monitor (Fig. 3), terminating its readout terminals in their respective characteristic impedances. Measure the s-parameters and apply the calibration (de-imbed S, the s-parameters of the current monitor, from the measured s-parameters using SA and SB).

Fig. 3. Measure S, the s parameters of the current monitor.

3. Calculate I , the current at the monitor. This can be done by analyzing the flow diagram of the three networks (Fig. 4) to yield the forward (a) and reverse (b) waves at the reference plane. Analyzing the flow diagram yields the following:

$$\frac{a}{a_{in}} = \frac{S_{21A} S_{21}}{D}$$

and

$$\frac{b}{a_{in}} = \frac{S_{21A} S_{21} S_{11B}}{D}$$

where

$$D = 1 - S_{22A} S_{11} - S_{11B} (S_{22} - S_{22A} Det S)$$

Fig. 4. Flow diagram for current monitor imbedded in error networks A and B.

The current and voltage at the reference plane are then

$$I_{ref} = \frac{a - b}{Z_0} \quad \text{and} \quad V_{ref} = \frac{a + b}{Y_0}$$

where Z_0 is the characteristic impedance of the transverse electromagnetic (TEM) line formed by the center conductor and the test device.

4. Next, the current is transformed to the plane of the actual pickup element within the current monitor. Using the ABCD matrix,

$$\begin{bmatrix} \frac{v_{\text{corrected}}}{a_{\text{in}}} \\ \frac{i_{\text{corrected}}}{a_{\text{in}}} \end{bmatrix} = \begin{bmatrix} \cos \beta \ell & j Z_1 \sin \beta \ell \\ \frac{j \sin \beta \ell}{Z_1} & \cos \beta \ell \end{bmatrix} \begin{bmatrix} \frac{v}{a_{\text{in}}} \\ \frac{i}{a_{\text{in}}} \end{bmatrix}$$

the corrected current is calculated:

$$\frac{i_{\text{corrected}}}{a_{\text{in}}} = j \left(\frac{v}{a_{\text{in}}} \right) \frac{\sin \beta \ell}{Z_1} + \left(\frac{i}{a_{\text{in}}} \right) \cos \beta \ell$$

5. Finally, the network analyzer is connected to the output signal port of the current monitor (Fig. 1), the disconnected end is terminated in its characteristic impedance, and transmission T is measured, yielding

$$T = (v_{\text{out}} / \sqrt{Z_0}) / a_{\text{in}}$$

where Z_0 is the characteristic impedance of the network analyzer. The response is then

$$\frac{v_{\text{out}}}{i} = \frac{v_{\text{out}} / a_{\text{in}}}{i_{\text{corrected}} / a_{\text{in}}}$$

where

$$\frac{v_{\text{out}}}{a_{\text{in}}} = T \sqrt{Z_0}$$

Measurement Results

Figure 5 is a diagram of the wall current monitor that we measured. It has eight 50 Ω pickups. The entire monitor is enclosed in a box lined with ferrite. Four of the pickups are connected to one four-way combiner, the other four to another four-way combiner. Then, the outputs of the two four-way combiners are connected to a two-way combiner. The monitor was measured both with the combiners and without (terminating connectors at the case). A wire of diameter 1.59 mm was used for the center conductor, yielding a line impedance $Z_1 = 248 \Omega$. The line impedance in the regions where ceramic is present are slightly different, $Z_1 = 257 \Omega$.

Fig. 5. Diagram of PSR wall current monitor

Figures 6 through 9 show the results of the coupling impedance measurement. Without combiners, the measured resistance agrees well with the expected value, calculated from the resistance of thirty-two 200 Ω and eight 50 Ω resistors in parallel. The reactance resulting from the

Fig. 6. Real part of coupling impedance, case only

Fig. 7. Real part of coupling impedance, case and combiners

Fig. 8. Imaginary part of coupling impedance, case only

ceramic and steps in the outer conductor at the ceramic insets is $10\ \Omega$ at 300 MHz. The response for a single pickup is shown in Fig. 10. The response for the combined pickup signals is shown in Fig. 11. These are corrected data, as described in the methods section. In addition, all data has been corrected for line attenuation between the pickup port and the network analyzer.

Fig. 9. Imaginary part of coupling impedance, case and combiners

Fig. 10. Corrected response of current monitor, single pickup at case

Fig. 11. Corrected response of combined pickups using custom two-way splitter

The results show a marked increase in impedance that is due to the cables and combiners.

References

1. L. S. Walling, D. E. McMurry, D. Neuffer, and H. A. Thiessen, "Transmission Line Impedance Measurements for an Advanced Hadron Facility," Los Alamos National Laboratory report LA UR 88 3533, submitted to *Nucl. Instrum. and Methods*