MEASURED TRANSVERSE COUPLING IMPEDANCE OF RHIC INJECTION AND ABORT KICKERS*

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Abstract

Concerns regarding possible transverse instabilities in RHIC and the SNS pointed to the need for measurements of the transverse coupling impedance of ring components. The impedance of the RHIC injection and abort kicker was measured using the conventional method based on the S_{21} forward transmission coefficient. A commercial 450 Ω twin-wire Lecher line were used and the data was interpreted via the log-formula. All measurements were performed in test stands fully representing operational conditions including pulsed power supplies and connecting cables. The measured values for the transverse coupling impedance in kick direction and perpendicular to it are comparable in magnitude, but differ from Handbook predictions.

1 INTRODUCTION

Performance limitations in RHIC due to collective effects were studied at the 1988 Workshop [1] and are discussed in the May 1989 Conceptual Design Report [2]. Since instabilities depend on ion mass number, A, and charge, Q, as A/Q^2, it was assumed that the impedance contributions can be held to a level that would not limit the heavy ion performance but may well impact the proton operation. Limits on the RHIC longitudinal impedance are primarily given by the passage through transition and limits on transverse impedance by the so-called resistive wall instability at injection. A program to control impedance contributions was implemented [3, 4] with emphasis on longitudinal impedance measurements [5, 6].

The Spallation Neutron Source (SNS) is a high intensity machine with an average and peak current expected to reach 39 kA and 95 kA respectively. The main sources of coupling impedances in the SNS were identified and an estimate of their impact was made [7,8]. The extraction kicker is expected to present a problem and various solutions to minimize its transverse impedance are under study [9]. Awaiting the availability of a full size prototype, measurements on comparable kicker magnets must serve as guide. Initial measurements were done on an AGS Booster dump kicker [10].

In this paper results for the RHIC injection and abort kickers are presented. The importance of their impedance contribution is best evaluated by comparison with the resistive wall impedance, which has been estimated in the "two -pipe" model [3] to be $Z_\perp \approx 5.9(1+j)/\sqrt{n}$ MΩ/m with the mode number $n=\omega R/c$ and n=1 corresponding to the revolution frequency, f ~ 78 kHz. The corresponding SNS value is [7] $Z_\perp \approx 5.9(1+j)\big/\sqrt{n}$ kΩ/m with f = 1.056 MHz.

2 MEASUREMENTS

Transverse impedance measurements on the RHIC kickers were made using the standard method [11], in which a twin-wire "Lecher" line is inserted into the kicker. The forward transmission coefficients S_{21} of the "Device Under Test" and of a reference line of equal length is interpreted according to

$$Z_\perp = \frac{cZ_{DUT}}{\omega\Delta^2} = -2\frac{cZ_L}{\omega\Delta^2}\ln\left(S_{21DUT} / S_{21REF}\right),$$

with Δ being the spacing of the two wires and Z_L the characteristic impedance of the line.

Obtaining valid results, i.e. the impedance seen by the beam, requires high $Z_\perp$ with thin wires narrowly spaced in contrast to the requirements of the electrical measurements. Preliminary measurements with the conventional 300 Ω TV cable did not yield sufficiently strong signals and were replaced with a commercial 450 Ω cable CQ551, which has a spacing of Δ = 13/16 in. = 2.064 cm. Matching of the 450 Ω line to the 50 Ω is achieved by means of a transformer (North Hills 0600BB) with a center-tapped secondary winding which serves as 180° hybrid. The use of homemade cables assembled from rigid tubes with characteristic impedance from 100 to 300 Ω is under study.

The measurements were made with the network analyzer, Agilent 8753ES, set for a logarithmic frequency range from 30 kHz to 100 MHz, 1601 points, a 100 Hz bandwidth, and averaged over 3 sweeps. The transformers are rated only for frequencies above 100 kHz, and measurement results at lower frequencies become suspect and must be used with care. In fact, the results presented here are given only for frequencies above 500 kHz.

Common mode suppression at frequencies up to ~100 MHz was improved by measuring Z_{DUT} with the line rotated by 180° and all results quoted represent the average of these two measurements.

3 INJECTION KICKER

In RHIC there are at present two types of injection kickers. The "blue" ring is equipped with the original dielectric loaded traveling wave structure, which is fully described in [12]. Future experimental requirements require 120 bunch injection into RHIC and consequently faster kickers. All-ferrite magnets have been installed into the yellow ring and are awaiting confirmation of the expected reduced rise time [13]. The all-ferrite magnet is

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constructed by replacing the dielectric blocks with ferrite blocks while retaining the overall geometry. As a consequence, the all-ferrite magnet must still be considered as a traveling wave structure, but with a characteristic impedance of ~ 50 Ω.

3.1 Traveling Wave Injection Kicker

The measurements here presented were performed with a single unit on the test stand, ready for installation into the ring, i.e. with full-length cable connections to the blumlein pulser at the input, with a 16 Ω termination at the output end, and with a ceramic beam tube. The impedance budget for the ring must take into account that injection requires 4 units per ring. The results for the transverse impedance applicable during RHIC operation of a single unit are shown in Fig. 1 for the vertical kick direction. Ignoring results below 1 MHz, one sees that the transverse impedances are largest in the range below ~10 MHz.

The effect of the cable termination on the vertical impedance is clearly visible at frequencies up to ~15 MHz. On the other hand, results without cable represent in effect an upper limit on the impedance if all other parameters are kept unchanged.

Note that the transverse impedance remains finite in the limit of low frequencies in contrast to the Handbook predictions. Estimates for the transverse impedance of traveling wave kickers are given in the Handbook as [14]

$$Z_\perp = \frac{Z_c l}{hw}\left[\frac{1-\cos\Theta}{\Theta} + j\left(1 - \frac{\sin\Theta}{\Theta}\right)\right]$$

with the Z_c the characteristic impedance, *h, w, l* the height, width and length of the kicker, and the electrical length

$$\Theta = \frac{hZ_0}{wZ_c}\frac{\omega l}{c}$$

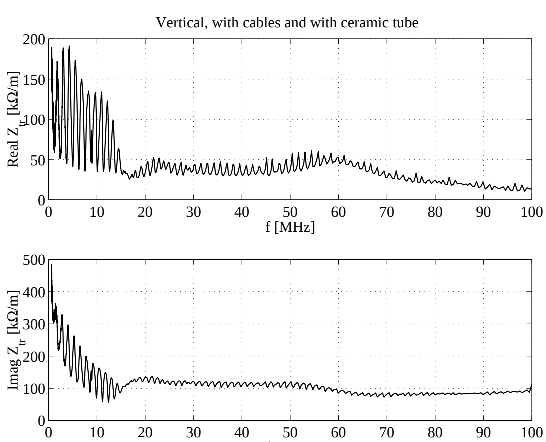

Fig.1. Vertical transverse impedance of TW injection kicker.

For the RHIC injection kicker, with Z_c = 25 Ω, follows in the low frequency limit $Z_\perp \to 0$ and an upper limit of $Z_\perp \approx 12.2\,\mathrm{k}\Omega$/m. This estimate is of limited value since it assumes fully matched loads and gives only results for the transverse impedance in the kick-direction and ignores the perpendicular direction. In any case, this expression is qualitatively different from the experimental results shown below.

The transverse impedance in the horizontal direction is shown in Fig. 2. As expected, the presence of cables is not observed. But it must be emphasized that the horizontal transverse impedance is evidently not negligible and of the same magnitude as the vertical impedance.

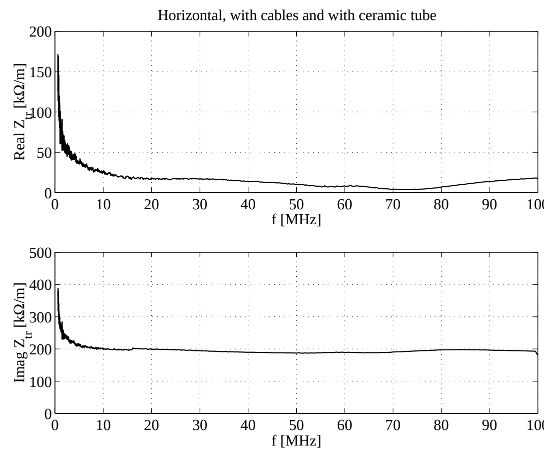

Fig. 2. Horizontal transverse impedance of the TW injection kicker

3.2 All-Ferrite Injection Kicker

Measurements on the all-ferrite kicker were performed in parallel with those on the TW kicker involving the same instruments and kicker test stand. The results confirm the similarity of both kicker types [15]. Only the imaginary (inductive) component of the transverse impedances has become about 20% larger for the all-ferrite magnet.

4 ABORT KICKER

The RHIC abort kicker deflects the beam horizontally and is constructed as a lumped magnet, with its geometry described elsewhere [16]. The magnet proper is assembled with ferrite pieces, each 20.32 cm long, for a total length of 122 cm. The kicker magnet is located in a tubular vacuum vessel having an i.d. of 26.4 cm. The electrical connection with the PFN pulser is through a coaxial feedthru at the middle of the magnet. The RHIC abort kicker resembles in its construction the SNS extraction kicker and thus is being studied in greater detail than required for RHIC.

The impedance measurements were performed on a spare abort kicker unit in a test stand fully reflecting the operational conditions, i.e. with the PFN pulser connected. The results for the horizontal (in kick direction) transverse coupling impedance are shown in Figs. 3 with the PFN pulser connected. The kicker without external load is shown in Fig. 4. It is worth pointing out that the PFN, although only capacitively coupled via the non-conducting thyratron, is clearly visible in the impedance and that the PFN terminating resistor of ~ 2 Ω, in general, lowers the coupling impedance.

It is to be noted that the measured impedance cannot be reconciled with the Handbook predictions [4]. By comparing these results with the RHIC and SNS resistive wall impedance, one sees that, at frequencies in the MHz range, the kickers dominate the transverse impedance.

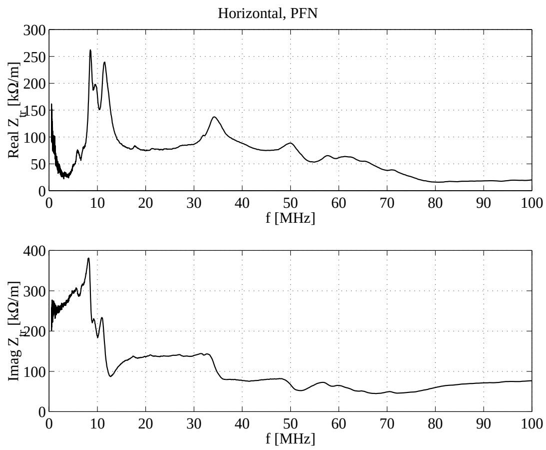

Fig.3. Horizontal transverse impedance of abort kicker with the PFN pulser connected.

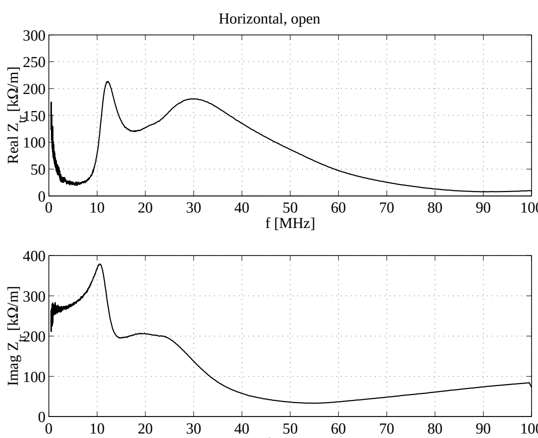

Fig. 4. Horizontal transverse impedance of abort kicker without external load.

The measured vertical impedance, perpendicular to the kick direction, is shown in Fig.5. Due to the lack of an applicable expression, a simple model based on e.m. field analysis has been developed in order to establish the parameter dependence on permeability and dielectric constant. Using for the kicker ferrite (Ceramic Magnetics CMD5005) a dielectric constant ε =12 and measured $\mu = \mu' - j\mu''$ values [17] yields general agreement with impedance measurements [18]. However, in the limit of low frequencies, below ~5MHz, the model shows a vanishing real and constant imaginary part. This contrasts with measured data and further studies are required.

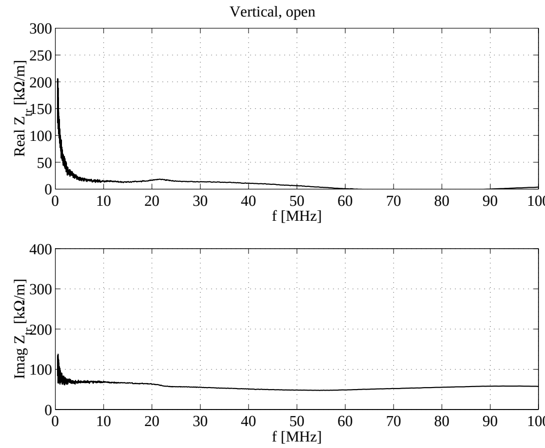

Fig.5. Vertical coupling impedance of abort kicker without external load.

5 ACKNOWLEDGEMENTS

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