MEASUREMENTS OF THE COUPLING IMPEDANCE OF THE SNS EXTRACTION KICKERS*

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Abstract

The Spallation Neutron Source (SNS) Accumulator ring extraction system includes 14 modules of ferrite kicker magnets with window-frame geometry [1]. Among all ring components, the extraction kickers make the single largest contribution to the coupling impedance budget. A prototype was constructed and various design options impacting the transverse coupling impedance have been thoroughly studied. Bench as well as system measurements were performed to determine the benefits from an external circuit resistance, from using different ferrites material, and from adding a novel ferrite winding. The results presented in this paper confirm that a resistive termination in the external circuit yields a solution with sufficiently reduced transverse coupling impedance. In order to determine the total contribution of all modules, an equivalent circuit and a simple scaling law was derived from measurements of full and half size magnets.

1 INTRODUCTION

The Spallation Neutron Source (SNS) Accumulator ring extraction system [1] includes 14 modules of window-frame ferrite kicker magnets pulsed with a rise time of 200 ns. The transverse coupling impedance of the 14 extraction kickers is expected to be the largest single contribution to the impedance budget of the SNS accumulator ring. In this paper the bench measurements of the longitudinal and of the transverse impedance are presented. Various options were tested, including the effect of a resistive termination in the external circuit and that of a different ferrite type. Since the various kickers have different apertures, a scaling law has been used to establish the total impedance contribution of the smaller kickers by extrapolation from the measured full size prototype.

Figure 1: SNS extraction kicker prototype in its vessel.

The SNS extraction kicker prototype is shown in Fig. 1. In particular, it is possible to see the high voltage feed-thru to which the PFN circuit is connected, the eddy current stripes, and the ceramic structure to keep the kicker assembled. The aperture dimensions are h = 246 mm in the vertical plane and w = 146 mm in the horizontal one, the bus-bar is 0.4 m long. The ferrite bricks are 31.8 mm thick.

2 EXPERIMENTAL RESULTS

Bench measurements on the prototype were made using the standard method [2], in which a single, or a twin-wire "Lecher" line, is inserted into the kicker. By definition, the vertical impedance is measured with the two-wire plane perpendicular to the bus-bar plates.

2.1 Longitudinal Impedance

The forward transmission coefficients S_{21} of the "Device Under Test" and of a coaxial reference line is interpreted according to

$$Z_{\parallel}^{DUT} = -2Z_L \ln\left(S_{21}^{DUT} / S_{21}^{REF}\right) \tag{1}$$

with Z_L the characteristic impedance of the coaxial line. As shown in Fig. 2, the value of the impedance is $Z_{\parallel}/n = 0.3 + j2.5\ \Omega$ at 10 MHz. Copper stripes (eddy current stripes) are placed at the middle plane of the side ferrite bricks to break the longitudinally induced flux through the ferrite. The copper stripes reduce both, longitudinal impedance and induced ferrite heating. Indeed, Fig. 2 shows the increase of impedance when those eddy current stripes are removed.

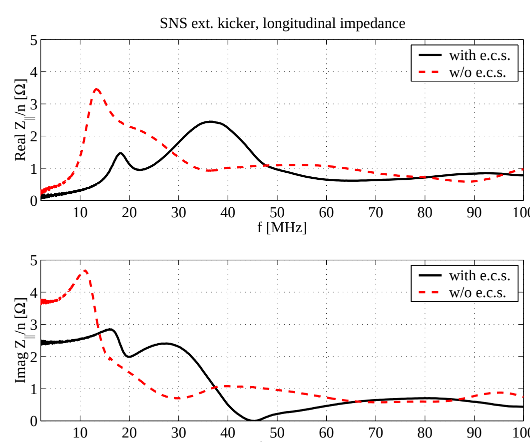

Figure 2: Longitudinal impedance. The dashed curve is the impedance without the eddy current stripes.

2.2 Vertical transverse impedance

In analogy to the longitudinal measurement, the transverse impedance follows from:

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

with Δ being the spacing of the two wire and Z_L ,the characteristic impedance of the two-wire line. The transverse coupling impedance behavior of window frame magnets can be accurately modeled with the equivalent circuit shown in Fig. 3.

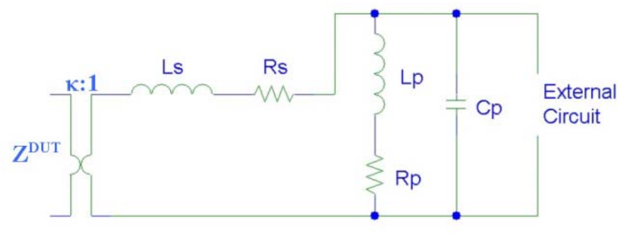

Figure 3: Equivalent circuit for the transverse impedance.

The measured impedance, Z^{DUT} is "scaled" to the circuit elements at the bus-bar through the formula

$$Z_{CIRCUIT} = Z^{DUT}\frac{1}{\kappa^2} = Z^{DUT}\left(\frac{h}{\Delta}\right)^2 \qquad (3)$$

with the coupling coefficient κ given by the geometric ratio of the aperture height and the wire spacing, *h/Δ*.
The two elements Ls and Rs represent the impedance due to the flux which does not couple to the external circuit, and are identified with the measurement of the impedance with a short-circuit termination. The elements, Lp, and Rp, represent the magnetic flux coupled with the external circuit, whereas Cp represents local capacities, primarily that of the bus-bar and feed-thru [3]. It is apparent that a resistor in parallel with the external circuit will damp the resonance, reducing the coupling impedance seen by the beam, as it is shown in Fig. 4. In case of a 25 Ω termination, the peak of the open termination resonance is damped by a factor 6. However, the resonance is shifted lower leading to higher impedance at low frequencies (f<10 MHz).

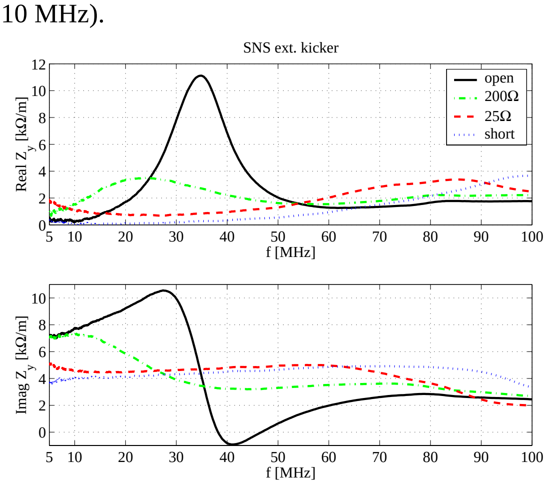

Figure 4: Vertical transverse impedance. Effect of a resistive termination on the external circuit.

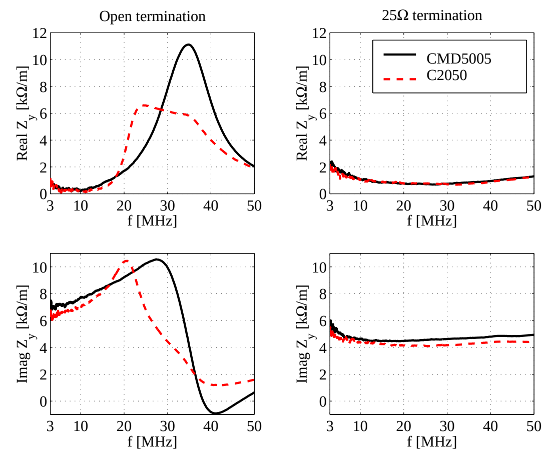

Figure 5: Vertical impedances with different ferrites.

It is worth noting that the external circuit is decisive for the coupling impedance of the kicker. For the SNS case, the resistive termination is placed in the service building and the kicker is fed through two 90 m long coaxial cables (Z_0= 50 Ω) in parallel connected to the feed-thru [4]. Tests showed that small mismatches allow the resonant peaks of the coaxial line to show up in the coupling impedance. Furthermore, the 20.5 pF equivalent capacitance of the feed-thru is responsible for a shift of the resonant frequency from about 35 MHz to 23 MHz [5].

The standard ferrite material used at BNL is CMD5005 [6]. Bench measurements were performed on the magnet with a different type of ferrite material, C2050, which is characterized by a lower initial permeability, better loss factor, but a higher DC conductivity with respect to the standard material.

For the low-μ ferrite, the resonance peak of the open termination case is reduced by almost a factor 2, which seems in contrast with the better loss factor property, but which can be explained by a sheared permeability due to the air-gap [8]. This fact points to the possibility of resonance damping for open-terminated kickers, but with a 25 Ω resistive termination the impedance is unchanged, as it is shown in Fig. 5.

2.3 Scaling law

The extraction system of the SNS ring has 14 kickers and the their apertures are adjusted with the betatron function to yield the overall SNS ring acceptance (480π) [7]. Therefore, a scaling law is needed to predict the impedance budget for all of the 14 kickers. Following the reasoning that led to the equivalent circuit of Fig.3, one can write:

$$Z_{\perp 1}\left(H_1\right)^2 = Z_{\perp 2}\left(H_2\right)^2 \qquad (4)$$

namely the product of the impedance with the square of the aperture height is constant.

In order to verify this law, a half-size model was assembled with the existing ferrite bricks and a new simplified bus-bar and a factor 4 was expected. The results of the measurements are shown in Fig. 6. The agreement is very good for the resonance peak (15%

error) and for the real part of the 25Ω termination at low frequencies. The imaginary parts are different, as well as the resonant frequency, because of the changed half magnet inductance and bus bar.

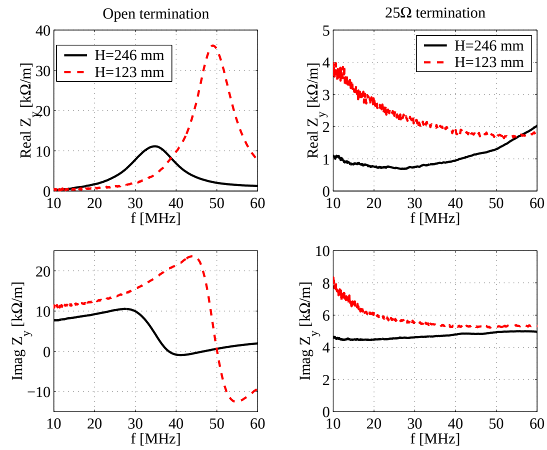

Figure 6: Scaling law verification.

2.4 Displaced transverse coupling impedance

In the SNS ring kickers the beam closed orbit is not centered with respect to the geometrical kicker center, in order to reduce the kicker aperture when the beam is deflected [1]. Thus, it is important to make bench measurements with a displaced two-wire line, to check the effect on the transverse impedance. Fig. 7 shows the case when the line is displaced by 25.4 mm with respect to the geometrical center. The differences in the impedance resonance peak are about 15%.

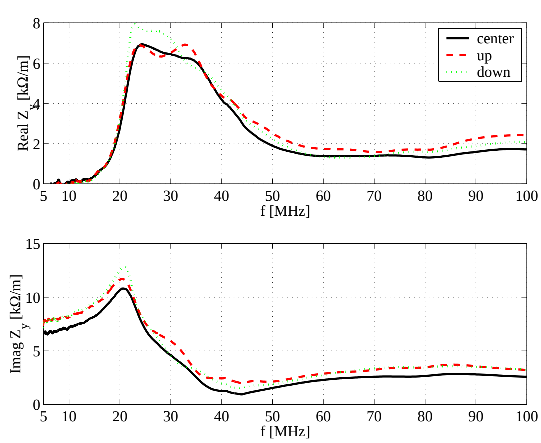

Figure 7: Displaced (25.4 mm) coupling impedance. Ferrite blocks are C2050 type.

2.5 Ferrite winding measurements

Numerical analysis of a novel wide conductor winding around the ferrite, behind the kicker bus-bar, suggested a significant reduction of the kicker transverse and longitudinal coupling impedances [9]. Experimental verification has been performed on the kicker prototype both for the case of 25 Ω and open termination. A clear reduction of the impedances was obtained only above 32 MHz [5]. This allowed the conclusion that the effectiveness of using a ferrite winding loop is not obvious, at least not in the present realization, and that more engineering studies will be needed to realize the promises and potential advantages of this idea and to arrive at an optimized kicker design.

2.6 Horizontal coupling impedance

The horizontal transverse coupling impedance of the kicker is shown in Fig. 8. This impedance is not of concern for the impedance budget. Its contribution to the real part is negligible up to f= 30 MHz and the almost constant imaginary part is due to the inductive behavior of the magnet.

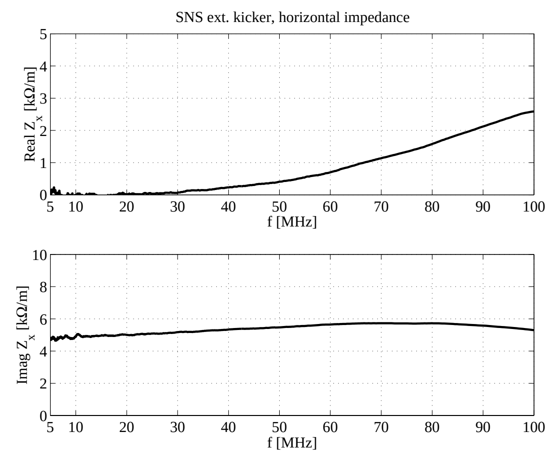

Figure 8: Horizontal transverse impedance.

3 ACKNOWLEDGEMENTS

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4 REFERENCES

[1] N. Tsoupas, M. Blaskiewicz, Y.Y. Lee, et al. “Beam Extraction from the SNS Ring and Design of Extraction Kickers”, EPAC’00, Vienna, June 2000, p. 2270.
[2] F. Caspers, in Handbook of Accelerator Physics and Engineering, ed. A.W. Chao and M. Tigner, (World Scientific, Singapore, 1998), p. 571.
[3] D. Davino, H. Hahn, in preparation.
[4] Jian-Li Mi et al., these proceedings.
[5] D. Davino, H. Hahn, “Measurements and analysis of the transverse coupling impedance of the SNS extraction kickers”, BNL/SNS Tech. Note No. 102, BNL, (2001). http://server.ags.bnl.gov/bnlags/bnlsns/102.pdf
[6] Ceramic Magnetics inc., Fairfield, NJ, USA.
[7] J. Wei et al, Phys. Rev. ST-AB 3, 080101 (2000).
[8] H. Hahn, D. Davino, these proceedings.
[9] S.S. Kurennoy, D. Davino, Y.Y. Lee, “Reducing beam coupling impedances in SNS ring extraction kickers”, PAC’01, Chicago, June 2001.