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Reduced Transverse Impedance of SNS Ring Extraction Kickers I

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Abstract

In this report it is presented a way to reduce the transverse impedance contribution of the fourteen extraction kickers for the SNS accumulator ring. This is done by increasing the vertical aperture of the kickers, namely the equivalent pole width. The gap distances between the pole surfaces are almost untouched instead. With respect to the old dimensions, almost a factor two of reduction is achieved for the transverse impedance. The total contribution of fourteen kickers at 2 MHz, with 25 Ω termination, is now:

$$Z_y = (38.15 + j\ 118.3)\ k\Omega/m$$

I. Introduction

The transverse coupling impedance of a circular accelerator or storage ring can cause beam instabilities and must be carefully monitored in order to keep its value within the impedance budget. The success of the SNS (Spallation Neutron Source) will largely depend on reducing the transverse coupling impedance of the accumulator ring. Next to the resistive wall impedance, the biggest contribution is made by the ferrite kicker magnets. Thus, an extensive experimental and theoretical program was carried out to achieve this design goal [1,2,3].

The extraction system of the SNS accumulator ring has 14 kickers and the apertures of those kickers were adjusted with the betatron function to yield the overall SNS ring acceptance [4].

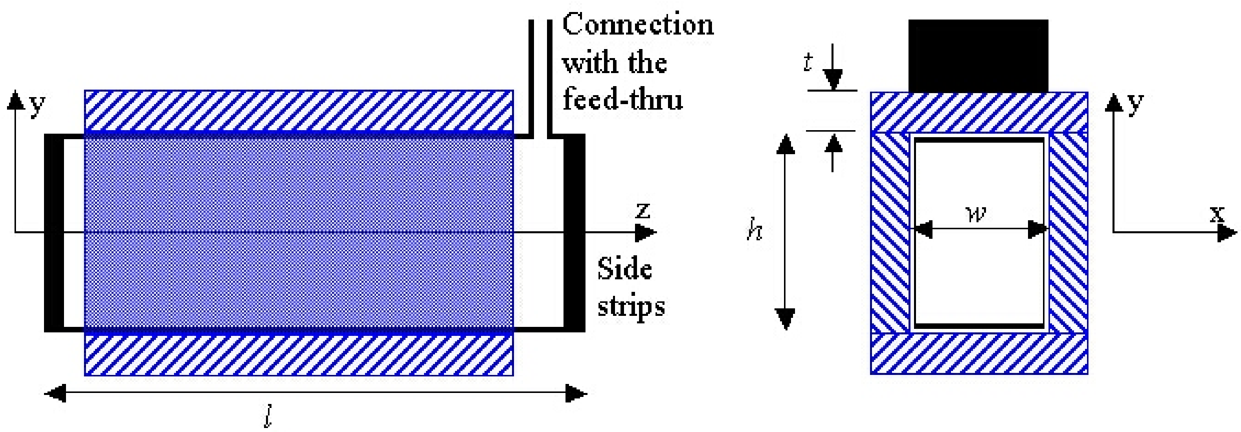

Fig. 1. Schematic view of SNS window frame extraction kicker. Blue frames represent ferrite blocks. “z” is the beam axis. *h* is the aperture height, *w* is the width, *l* is the bus-bar length and *t* is the ferrite thickness.

A prototype of one of the fourteen SNS extraction kickers was made and measured with the twin-wire technique [5]. A schematic view of that kicker is shown in Fig. 1. The kicker dimensions are: *h* = 24.8 cm, *w* = 15.9 cm, *l* = 36 cm and *t* = 2.54 cm. The ferrite is CMD5005 type [6] and the two bus-bar plates are connected through side strips. A half-size bus-bar, h = 12.4 cm, was also made; in the following we refer to it as half-size kicker. The connections to the feed-thru are made by a prolongation of the bus-bar. In order to damp the natural kicker resonance, a 25 Ω power resistor is placed in parallel with the external circuit.

In the next section, the measurements of the full and half-size kickers, and a scaling law for the transverse impedances, are presented. In the third section, the new dimensions of the kickers are presented and commented and in the last section, an equivalent formula for the transverse impedance is introduced.

II. Scaling law

The analysis of the bench measurements performed on the SNS extraction kicker prototype [1,2] led to an equivalent circuit for window frame kickers and some important properties of those structures were easily derived from it [7]. One of the most interesting one is the scaling law with kicker height, h:

$$Z_{\perp 1} \cdot (h_1)^2 = Z_{\perp 2} \cdot (h_2)^2 \tag{1}$$

namely the product of the impedances with the square of the aperture heights is constant.

In order to verify this law, a half-size model was assembled and measured with the existing ferrite bricks and a new simplified bus-bar. The results are shown in Fig. 2 where the measured impedances of the full and half-size kickers are compared. The half-size impedance is supposed to be four times higher than the full-size one. The agreement is very good for the resonance peak (15% error) and for the low frequency real part of the 25 Ω termination case. The imaginary parts are different, as well as the resonant frequency, because of the half magnet inductance for the half-size kicker.

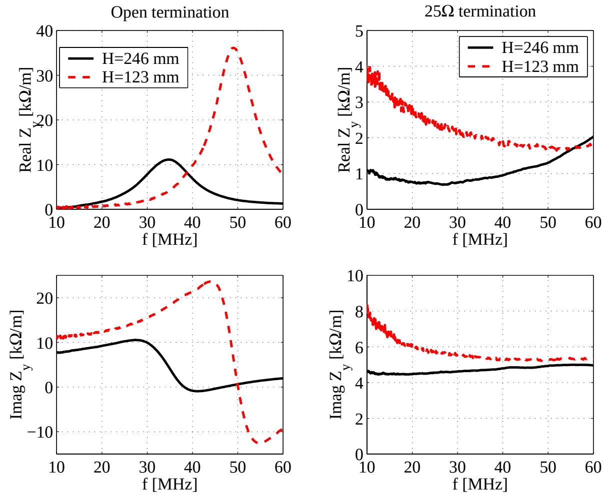

Fig. 2. Transverse impedances with open termination at the bus-bar port (left) and 25 Ω (right)

Therefore, the impedance contribution of all the fourteen kickers with transverse aperture able to accommodate the beam size, was trustfully calculated to be 32.2 times the one of the measured kicker [2], leading to:

$$Z_y = (74+j209)\ k\Omega/m \qquad \text{for} \qquad f < 10\ \text{MHz},$$
$$Z_y = (45+j164)\ k\Omega/m \qquad \text{for} \qquad f \sim 50\ \text{MHz}.$$

But, another important aspect of the scaling law is that it shows a way to reduce the transverse impedance contribution of the extraction system: by taking into account the other constrains to the kickers geometry (voltage, current, rise time, etc.), one can reduce the total transverse impedance by maximizing the kickers height, *h*.

III. Electrical aspects and new kickers dimensions

Fourteen magnets will be individually energized by fourteen BPFN type (Blumlein Pulse Forming Network) high voltage modulators. There are two 50 Ω coaxial cables connected in parallel to transfer the current pulse from BPFN to the ferrite magnet. Then, the cables are matched with the 25 Ω resistor connected at the cable BPFN side. We chose BPFN operation voltage at 35 kV, in order to increase the system operation reliability and to be optimal at the PFN cost. According to the simulation and the prototype tests, the magnet operating current pulse will be less than 2.5kA while the BPFN operating at 35 kV. At this current pulse, the magnetic field B is estimated to be from 142 to 251 Gauss, depending on the magnet aperture horizontal dimensions. More details about this subject can be found in [8].

The proton beam extraction function should move the beam from the accumulation ring to the beam transfer line completely and cleanly. So, it is necessary to establish the extraction magnet field during the 250nS beam gap. The current pulse rise time from 1 to 95% is set at around 200nS to guarantee the beam is kicked from the accumulate ring to beam transfer line totally.

In order to reduce the magnet pulse current rise time, the magnet inductance has to be limited to meet the BPFN impedance and the magnet current pulse requirement. The magnet inductance mainly relies on the magnet dimensions and magnet feedthrough. The total magnet and feedthrough inductance is limited at 1.1 μH to meet the pulse rise time constraint.

With respect to the previous arguments, the ferrite magnet dimensions can be re-estimated. The main modifications are at the first seven magnets where the vertical dimensions are increased. The new ferrite magnet dimensions are listed in the following table. From the table, the magnet operating currents are still limited below 2.5kA.

kicker	Horiz. *w* (m)	Vert. *h* (m)	Length *l* (m)	Kick (mrad)	I (kA)	B/sect (Gauss)	L= $\mu_0 hl/w$ (μH)
K11	0.120	0.166	0.40	1.78	2.40	251	0.695
K12	0.145	0.200	0.40	1.47	2.39	208	0.693
K13	0.145	0.200	0.40	1.47	2.39	208	0.693
K14	0.178	0.195	0.51	1.52	2.40	170	0.702
K15	0.178	0.195	0.51	1.52	2.40	170	0.702
K16	0.211	0.233	0.51	1.28	2.40	143	0.708
K17	0.211	0.233	0.51	1.28	2.40	143	0.708
K21	0.162	0.233	0.43	1.43	2.44	189	0.777
K22	0.162	0.233	0.43	1.43	2.44	189	0.777
K23	0.162	0.233	0.43	1.43	2.44	189	0.777
K24	0.162	0.233	0.43	1.43	2.44	189	0.777
K25	0.151	0.243	0.39	1.40	2.44	203	0.789
K26	0.151	0.243	0.39	1.40	2.44	203	0.789
K27	0.151	0.243	0.39	1.40	2.44	203	0.789

IV. Equivalent Models for simulations

By using the scaling law (1) for the measured prototype and the kickers new vertical dimensions, one obtains a factor 18.2 for the fourteen kickers. Since the measured transverse coupling impedance at 2 MHz with a 25 Ω resistive termination is (2.1+j 6.5) kΩ/m, then the contribution of all the 14 kickers will be:

$$Z_y = 18.2 \cdot (2.1+j\,6.5)\ \text{k}\Omega/\text{m} = (38.15+j\,118.3)\ \text{k}\Omega/\text{m}$$

therefore, the total contribution is reduced by almost a factor 2 with respect to the old vertical dimensions.

The simplest way to represent the transverse impedance of the measured kicker is by means of a RLC resonator model plus a lossless series inductor:

$$Z_y^{25\Omega} = \frac{c}{\omega h^2}\left\{\left[1/R + 1/(j\omega L) + j\omega C\right]^{-1} + j\omega L_s\right\} \tag{2}$$

where R =23.89 Ω , L =0.7 μH , C =21.7 pF and L_s =0.62 μH and h =0.248 m for the measured prototype.

Following the same arguments of the previous paragraphs, the fitting curve of the total of 14 kickers can be obtained by considering 18.2 times (scaling factor) the one represented by the eq. (2). But, it is worth noting that the changes of the aperture dimensions do change the resonator parameters too. For instance, the inductance is in first approximation given by $L = \mu_0 hl / w$, and then, by assuming the same capacitance (mainly given by the termination to the PFN) and losses for all the kickers, one obtains 14 resonators with slightly different resonant frequency. Fig. 4 shows all the transverse impedance curves of them.

In Fig. 5, the sum of previous curves is compared with the 18.2 times scaled contribution of one kicker. The approximation by considering only one resonator is relatively small, and for the sake of simplicity, one can consider one resonator model in numerical beam-instability codes.

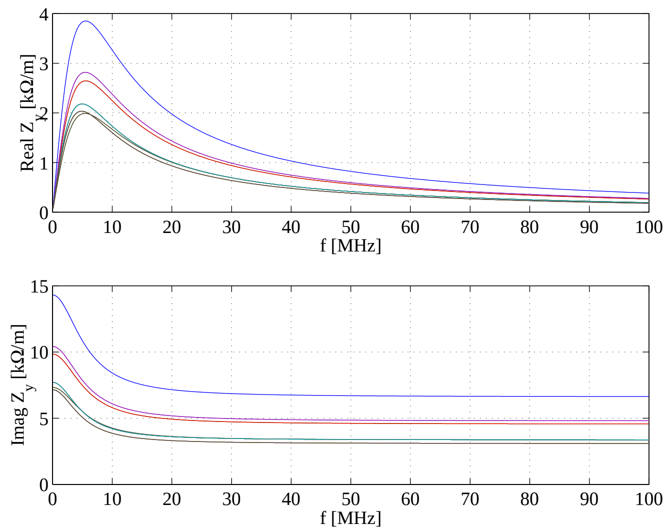

Fig. 4. The transverse impedances of all the 14 kickers with aperture-scaled inductances.

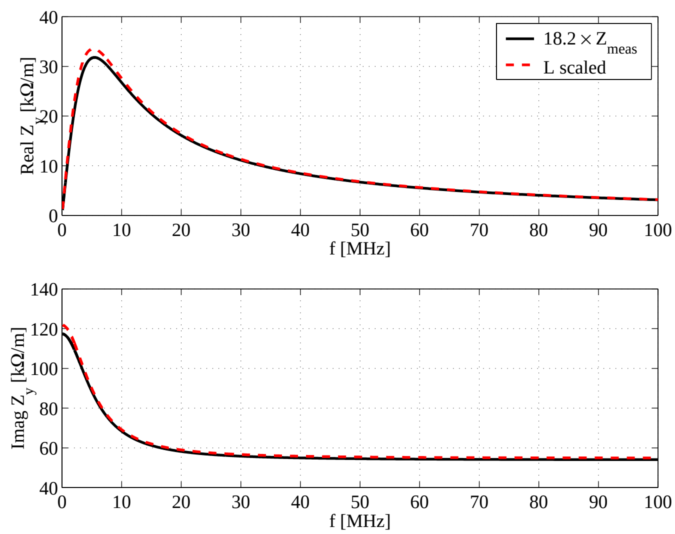

Fig. 5. The sum of the transverse impedance of the 14 kickers with aperture-scaled inductances (L scaled curve) and the scaled measured impedances ($18.2\times Z_{meas}$ curve).

Acknowledgements

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