IMPEDANCE OF THE PULSE POWER CONVERTER FOR THE SIS100 BIPOLAR EXTRACTION KICKER SYSTEM

K. Samuelsson*, V. Hinrichsen, TU Darmstadt, Darmstadt, Germany
U. Blell, P. Spiller, GSI, Darmstadt, Germany

Abstract

SIS100 will be operated with high intensity heavy-ion and proton beams. In order to avoid coherent beam instabilities, the reduction of the overall ring impedance is of great importance. The extraction kicker system is one of the main contributors to the overall ring impedance. This paper focuses on the contribution of the external electrical network to the kicker impedance. Previous calculations as well as measurements of the kicker impedance have already been carried out for the SIS18 and ESR kickers and these showed a significant contribution to the impedance influencing the beam [1].

The SIS100 extraction and emergency kicker magnet system will be equipped with a bipolar pulse power generator. Thereby, the beam can be deflected in two directions by the same kicker magnets. Depending on the desired deflection direction, the current fed into the magnet has a positive or negative polarity. A Pulse Forming Network (PFN) will be used as energy storage. To provide the different polarities of the current the PFN is connected to a transformer. This transformer is also needed to isolate the PFN and the kicker magnets galvanically from each other. Since this setup is new in several ways it is important to determine its contribution to the coupling impedance of the kicker system.

THEORETICAL CONSIDERATION

The ion beam circulating in SIS100 will induce a voltage within the kicker magnet. A well known technique to represent the frequency components of this induced voltage is a schottky spectrum. The induced fields in the kicker may affect the particle motion by itself. The threshold for beam instability and growth rate is dependent on the transverse coupling impedance. In accordance to [2] only magnetic deflections are further considered.

In SIS100, the kicker magnet is designed as a window frame magnet, compare figure 1.

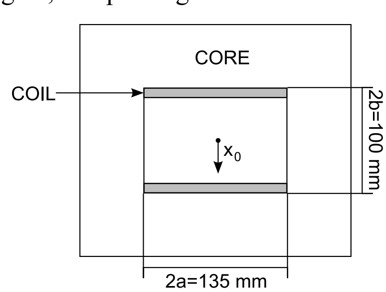

Figure 1: Sketch of the cross-section of a SIS100 window frame kicker magnet.

As described by Nassibian and Sacherer in [2] two effects are observed when particles pass a kicker magnet. Firstly, a longitudinal impedance is generated by a magnetic flux induced in the core. This impedance is mainly inductive but has also a resistive part due to core losses. Since it is not linked with the magnet coil this magnetic flux is independent of the external network load impedance $\underline{Z}_g$. Secondly, there is a differential flux induced in the core which results in a transverse impedance. This impedance is partially originated by the core losses and partially by the coupling to the magnet winding and thereby to the electrical circuit of the kicker magnet system. If the impedances arising from core losses are not considered, the longitudinal and transverse impedances respectively can be derived as describe in [2] to

$$\underline{Z}_L = \frac{\omega^2 \mu_0^2 x_0^2 l^2}{4a^2 \underline{Z}_k} [\Omega]$$

$$\underline{Z}_T = \frac{c \omega \mu_0^2 l^2}{4a^2 \underline{Z}_k} [\Omega/\mathrm{m}]$$

with l as the length of the kicker magnet and with $\underline{Z}_k$ defined as $j\omega L + \underline{Z}_g$ in which L is the inductance of the magnet and $\underline{Z}_g$ is the external network load impedance. It should be noted that the longitudinal impedance is strongly influenced by the distance x_0 between the magnet centre and the particle (cf. figure 1) of the beam.

SIMULATED CIRCUIT

The favorized electrical circuit for the bipolar kicker pulse power generator is shown in figure 2. The kicker magnets are spatially separated from the thyratrons and the PFN, thus a 100 m long transmission line is included.

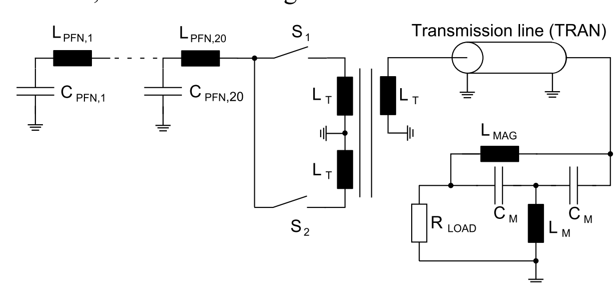

Figure 2: Electrical circuit for the favorized set-up of the kicker power supply.

To create an impedance matched lumped kicker, a bridge-T network is connected in parallel to the kicker

*samuelsson@hst.tu-darmstadt.de

magnet, with the components dimensioned according to [3]. The electrical parameters of the circuit are summarized in table 1.

Table 1: Component Parameters

Parameter	**Value**
L_{PFN}	1 µH
C_{PFN}	30 nF
S_1, S_2	Thyratron
L_T	4 mH
Z_{TRAN}	5.7 Ω
C_{TRAN}	1.05 nF
L_{TRAN}	33.7 nH
L_{MAG}	3.3 µH
C_M	49.9 nF
L_M	825 nH
R_{LOAD}	5.7 Ω

The switches of the external network are open when the kicker magnet is non-active, thus the circuit components of the PFN cannot influence the beam. The current of a beam passing the kicker magnet induces a voltage in the magnet. Thus, for simulation purposes, the impedance representing the magnet is replaced by a voltage source. In figure 3, the equivalent circuit is shown.

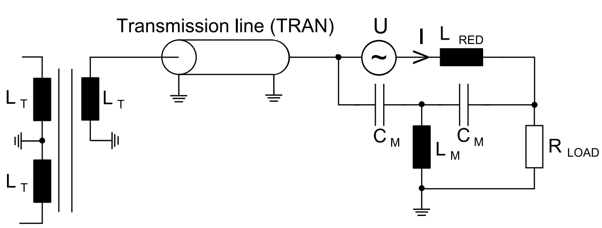

Figure 3: Equivalent electrical circuit used for impedance calculation of the kicker power supply including an additional inductivity L_{RED} to reduce the coupling impedance.

The impedance $\underline{Z}_g$ is then given as

$$\underline{Z}_g = \frac{\underline{U}}{\underline{I}}.$$

A simulation was performed for an AC sweep from 1 kHz to 100 MHz.

It is advantageous to keep the impedance influence of the external kicker network low. One way to reduce the coupling impedance contribution of the external network is to place an additional inductivity, L_{RED}, in series to the kicker magnet. This increases the impedance of the external circuit and therefore leads to a reduction of the coupling impedance of the magnet. This can be seen in the formulas for $\underline{Z}_L$ and $\underline{Z}_T$ mentioned before. During kicker operation, this inductivity should be saturated at a current significantly lower than the peak current. Since the inductivity is strongly reduced by the saturation, it will not dramatically influence the kicker pulse.

RESULTS

The real and the imaginary parts of the simulated transverse impedance are shown in figure 4 and 5 respectively with and without an additional 50 µH inductor L_{RED} which reduces the impedance. To improve the beam stability, especially the real part of the transversal impedance should be as low as possible. Therefore introducing the additional inductivity L_{RED} has a very beneficial effect. For low frequencies (<50 kHz) L_{RED} shows no significant influence.

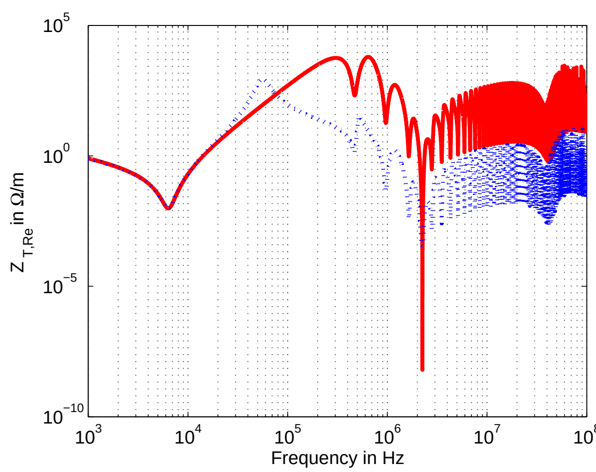

Figure 4: Real part of transverse impedance. In red without the additional inductor and in blue with the additional inductor.

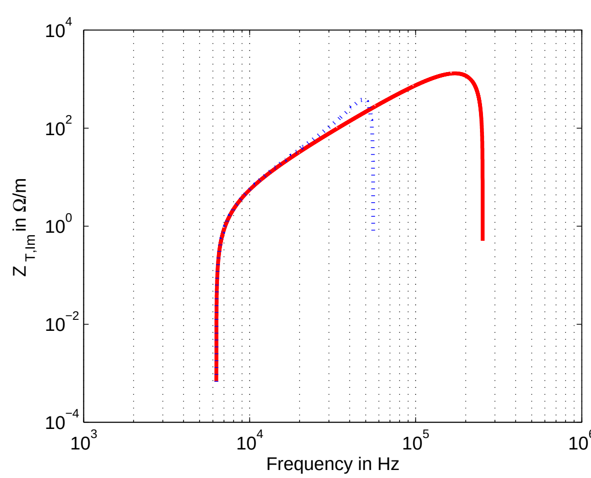

Figure 5: Imaginary part of transverse impedance. In red without the additional inductor and in blue with the additional inductor.

In figure 6 and 7 the simulation results for the real and the imaginary parts of the longitudinal impedance are shown for a beam at a distance $x_0 = 10$ mm from the magnet centre without and with the inductor L_{RED}. Also for the longitudinal impedance, the beneficial effect of the additional inductivity is clearly visible.

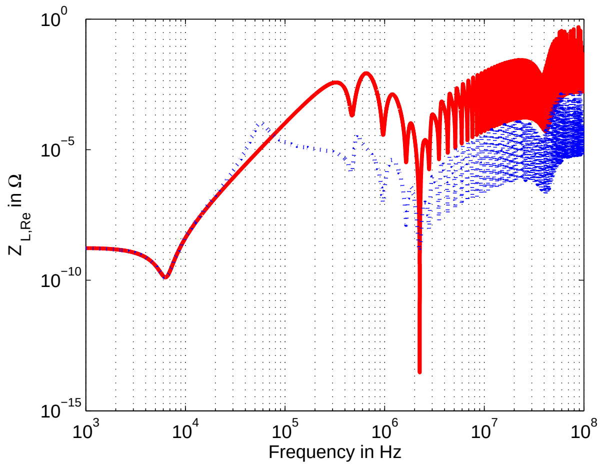

Figure 6: Real part of longitudinal impedance for $x_0 = 10$ mm. In red without the additional inductor and in blue with the additional inductor.

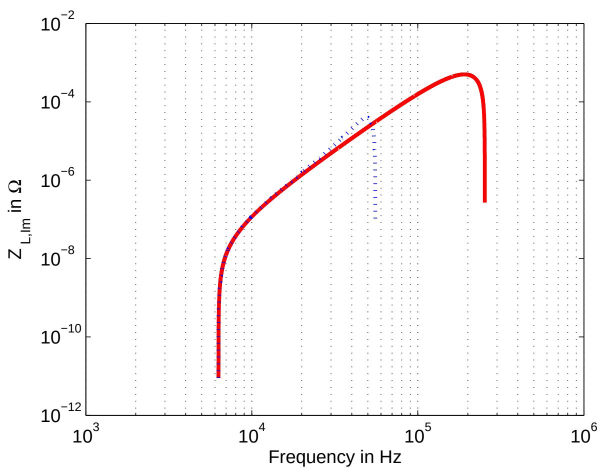

Figure 7: Imaginary part of longitudinal impedance for $x_0 = 10$ mm. In red without and in blue with the additional inductor.

Simulations for different values of L_{RED} between 1 μH and 100 μH have been performed. In a real setup, a compromise between a high inductivity and a low saturation current has to be found. While a high value of L_{RED} is beneficial to reduce the coupling impedance, the inductor shall not interfere with the kicker pulse. The value of 50 μH, as shown in the figures 4 to 7, seems reasonable.

CONCLUSIONS

Simulations for the impedance contributions of the external network of the kicker magnet have been performed. To reduce the beam influencing impedances, an inductivity in series with the kicker magnet was introduced in the simulation. For the real kicker magnet module, this inductivity has to saturate at low currents to minimize its influence to the extraction current peak. To achieve a reasonable compromise between a low influence on the kicker current and a significant reduction of the coupling impedance, the inductivity has to be designed carefully. The necessary development has just started.

REFERENCES

[1] U. Blell, "Measurement of the kicker coupling impedances in the SIS and ESR", PAC'97, 7V035, p. 1727.

[2] G. Nassibian and F. Sacherer, "Methods for measuring transverse coupling impedances in circular accelerators", CERN / ISR-TH/77-61, 1977

[3] T. Oki, "The bridged-T network lumped kicker: A novel fast magnetic kicker system for a compact synchrotron", Nuclear Instruments and Methods in Physics Research A 607, 2009, p. 489-497.