MEASUREMENT OF THE KICKER COUPLING IMPEDANCES IN THE SIS AND ESR AT GSI

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Abstract

At high particle intensities coherent transverse beam oscillations may be excited due to the coupling of the beam to individual accelerators components. The characteristic values to describe these beam instabilities are the longitudinal- and transverse coupling impedances. One reason for this beam instability is the inductive interaction between the beam and the lumped kicker magnets. The type of the magnet, e.g. window-frame magnet or C-magnet, and his external electric network are the most important quantities to identify the coupling impedances below the cut-off frequency (for wavegiude modes) of the beam pipe. For the kicker modules in the **SIS** and **ESR** accelerators at **GSI** theoretical calculations and measurement are presented.

1. COUPLING IMPEDANCES OF LUMPED KIKKER MAGNETS

A beam that oscillates with an amplitude $\pm \mathbf{x_0}$ induces differential currents on the walls of the beam pipe. These currents produce a transverse magnetic field **B** and an electric field **E,** which deflect the beam. The threshold for beam instability and the growth rates depend on the coupling impedances.
The general definitions of the longitudinal and transverse coupling impedance $\mathbf{Z_\parallel}$ and $\mathbf{Z_\perp}$ are:

$$\mathbf{Z_\parallel(\omega) = -\frac{\oint E_\parallel(\omega, s)\cdot ds}{I_B}} \quad (\Omega) \tag{1}$$

$$\mathbf{Z_\perp(\omega) = \frac{j}{\beta}\cdot\frac{\oint\left[\vec{E}+\vec{v}\times\vec{B}\right]_\perp\cdot ds}{I_B\ x_0}} \quad (\Omega/m) \tag{2}$$

Where $\mathbf{I_B}$ is the beam current, $\vec{\mathbf{v}}$ is the beam velocity, and $\boldsymbol{\beta} = \mathbf{v/c}$. As for a lumped kicker magnet the electric deflection can be neglected, only the magnetic contribution is considered.
As an approximation the longitudinal and transverse coupling impedances of a lumped and a window frame kicker magnet with the length **l** and a gap height of **2a** can be calculated with the following relations [1]:

Window frame magnet:

$$\mathbf{Z_\parallel(\omega) = \frac{\omega^2\ \mu_0^2\ x_0^2\ l^2}{4\ a^2\ Z_k}} \quad (\Omega) \tag{3}$$

$$\mathbf{Z_\perp(\omega) = \frac{c\ \omega\mu_0^2\ l^2}{4\ a^2\ Z_k}} \quad (\Omega/m) \tag{4}$$

C-magnet with a constant gap height:

$$\mathbf{Z_\parallel(\omega) = \frac{\omega^2\ \mu_0^2\,(x_0+b)^2\ l^2}{4\ a^2\ Z_k}} \quad (\Omega) \tag{5}$$

$$\mathbf{Z_\perp(\omega) = \frac{c\ \omega\ \mu_0^2\ l^2}{4\ a^2\ Z_k}} \quad (\Omega/m) \tag{6}$$

with

$$\mathbf{Z_k = j\omega L + Z_g}$$

where **L** is the magnet inductance and **Zg** is the contribution of the external circuit. Note that the longitudinal impedances strongly depend on the beam position $\mathbf{x_0}$.In the relations 3-6 one effect is neglected:
There is a relatively large longitudinal impedance due to the induced flux that circulates within the core. It is mostly inductive, with a resistive component due to core losses. This flux does not link the magnet winding, and so is independent of the external electric network of the kicker.
At GSI both at the synchrotron SIS and the storage ring ESR lumped kicker magnets are in operation. Whereas at SIS window-frame modules are used, C-shaped modules are installed at the ESR. The electrical circuit of every modul is based on a 25 Ohm system and the maximum cable load voltage is 80 kV. Figure 1 shows the external electrical circuit part which gives a significant contribution to the coupling impedance. Only those parts of the electric circuit are included, that may be coupled to the circulating beam. For this circuit the impedance **Zg** is defined as:

$$\mathbf{Z_g = \frac{U_{V-Test}}{I_{V-Test}}} \tag{7}$$

The parasitic capacites CD-1 and CD-2 of the HV-terminator in figure 1 are not negligible as they reduce the coupling impedances.

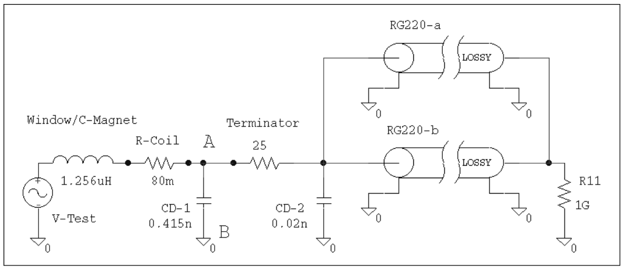

Figure 1: Equivalent electrical circuit for one kicker generator with a test voltage source.

2. MEASUREMENTS

For the calculation of the coupling impedances, based upon equal 3-6, the impedance **Zg** has been determined. As the magnet is installed in a vacuum tank, it is not easy to measure these impedances directly; the only electrical connection outside of the vacuum, is between the points A and B shown in figure 1. For additional measurements the 25 Ohm teminator resistor can be disconnected from the magnet and the cables (length 45m) from the terminator resistor.

To determine **Zg** two measurements of the S(1,1) parameter (reflection-factor) have been performed:

- with terminator and cables, but without the magnet (M1);
- with the magnet and terminator but without the cables (M2).

The correlation between **Z** and **r** is

$$\mathbf{Z} = \mathbf{Z_0}\frac{\mathbf{1+r}}{\mathbf{1-r}} \qquad (8)$$

with $\mathbf{Z_0 = 50\,\Omega}$.

With the first measurement M1 the unknown capacites CD-1 and CD-2 (fig. 1) could be determined by a mathematical comparision with the replaced electrical circuit. With the measurement M2 the total network is determined and the unknown impedance **Zg** has been calculated. The longitudinal and transverse coupling impedances can be calculated with the equation 3-6. The results for the real part of the impedances up to 40 MHz are shown in the lower figures 2 und 3. The resistance of the magnet coil and the dispersion of the rf cables in this frequency range can be neglegted; the parasitic capacites CD-1 and CD-2 are replaced by a 100 pF capacity (voltage divider) between the points A and B (fig 1).

For this case the real part of calculated coupling impedances are shown in the upper figures 2 and 3. Note that the vertical scaling is different for the calculated and measured results.

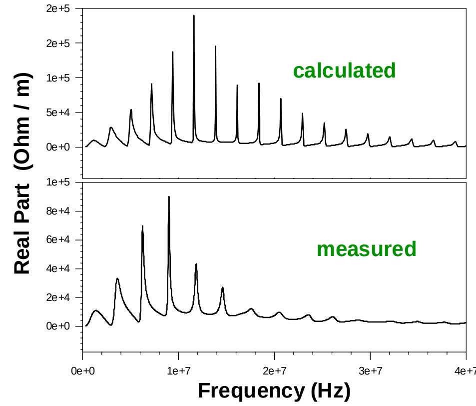

Figure 2: Calculated and measured transverse coupling impedance of one **ESR**-kicker modul.

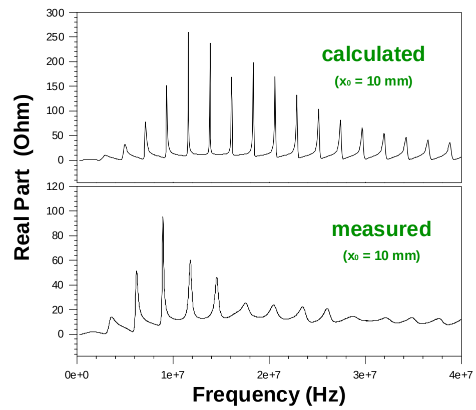

Figure 3: Calculated and measured longitudinal coupling impedance of one **ESR**-kicker module.

The measured coupling impedances are lower than calculated, especially above 15 MHz. The parasitic capacites CD-1 and CD-2 (fig. 1) reduce the influence of the cabels with increasing frequency, this positive effect is also observed in the imaginary part. Impedance measurements at a **SIS** kicker module (window frame) show the similar results.

3. CONCLUSIONS

A method has been described to determine the coupling impedances of the **SIS** and **ESR** kicker module by combining analytical formula and impedance measurements. The measured results are a good basic to calculate beam instabilites. An advantage of this procedure is, that all measurements could be performed at the installed kicker outside of the vacuum.

4. REFERENCES

[1] G. Nassibian, F. Sacherer, ‘Methods for measureing transverse coupling impedances in circular accelerators’, CERN / ISR-TH/77-61, 1977