Measurement of the Longitudinal Coupling Impedances using Short Electron Bunch

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Abstract

The longitudinal coupling impedance in modern storage rings has to be limited to ensure beam stability. To determine the real part of the narrow band impedance we suggest to measure the loss factor of the resonant modes using short electron bunch passing through the tested element. This method is also suitable for the measurement of the longitudinal impedances for nonrelativistic particles, that is important for some modern projects of ion storage rings designed to achieve ordered structure in the ion beam. The desired value of relativistic parameter γ can be chosen by adjusting energy of the electron bunch. The impedance of the fundamental mode of the wall current monitor was measured using $60ps$ electron bunch from photogun. The dependence of impedance on beam energy is measured in the range $25 \div 50kV$. Comparison of experimental data with computer simulation is done.

1 METHOD OF MEASUREMENT

The longitudinal impedance $Z_n(\omega)$ of a narrow band element of beam environment can be described in resonant approximation [1]:

$$Z_n(\omega) = \frac{R_n}{1 + iQ_n(\frac{\omega}{\omega_n} - \frac{\omega_n}{\omega})}, \quad (1)$$

where R_n is shunt impedance, Q_n is quality factor, ω_n is resonant frequency of the n-th mode.
Q_n and ω_n can be easily measured using standard RF methods. For R_n measurement we suggest to measure the loss factor of the resonant modes using short electron bunch passing through the tested element.

Let us define the loss factor of the n-th mode K_n through the equation:

$$W_n = K_n q^2 \mid F(\omega_n) \mid^2 \quad (2)$$

where W_n is energy stored in the n-th mode after bunch pass, q is the total charge of the bunch, and $\mid F(\omega_n) \mid$ is the spectral density of the bunch current. If the bunch length is much shorter than mode wavelength, then $\mid F(\omega_n) \mid \approx 1$.

After bunch pass, the electromagnetic energy excited in the cavity is dissipated partly inside the cavity and radiated partly to external measuring line. The energy balance can be described by equation:

$$\frac{dW}{dt} = -\frac{W_n}{\tau_n} = -(P_0 + P_{out}) \quad (3)$$

where $\tau_n = Q_n/\omega_n$ is decay time of the mode, P_0 is power dissipated inside the cavity, P_{out} is power radiated to measuring line.
If $\beta_n = P_{out}/P_0$ is the coupling coefficient, then

$$P_{out} = \frac{W_n \beta_n}{(1+\beta_n)\tau_n}. \quad (4)$$

The dependence of voltage U in measuring line upon total beam charge q can be derived substituting (2) to (4):

$$U = \sqrt{2P_{out}R} = q\sqrt{\frac{2RK_n\beta_n}{(1+\beta_n)\tau_n}} = q \cdot r \quad (5)$$

where R is the impedance of the line. If the slope r of the measured dependence U upon q is known , loss factor K_n can be calculated using equation :

$$K_n = r^2 \frac{(1+\beta_n)\tau_n}{2R\beta_n} \quad (6)$$

and shunt impedance can be derived:

$$R_n = \frac{2K_n Q_{0n}}{\omega_n} \quad (7)$$

Summing all mentioned above, the general scheme of the impedance measurement is following:

1. Coupling loop or antenna is installed inside the tested element;
2. Using the standard RF methods (NetWork Analyzer), Q_n and β_n are measured for each mode;
3. The tested element is installed in the bench and dependence of the voltage in measuring line on the frequency of the n-th mode upon the electron bunch charge is measured;
4. Loss factor and longitudinal coupling impedance are calculated from the slope of measured curve.

2 EXPERIMENTAL RESULTS.

In order to prove the possibility of impedance measuring by the method described above we carried out test experiment using the short electron bunch generated by photogun. The description of experimental setup can be found in [2]. The wall current monitor installed in the beam channel is used as tested element. This monitor has metal shielding box which forms a cavity connected with beam through the gap in vacuum chamber. The fundamental mode of wall current monitor is chosen for measurement because its frequency is in the band of used oscilloscope LeCroy 9360. The resonant frequencies of the next modes are out of the oscilloscope bandwidth and do not influence the measurements. Coupling antenna is installed into the cavity and main parameters of fundamental mode are measured: resonant frequency $f_0 = 422.5MHz$, loaded quality factor $Q_l = 128$, unloaded quality factor $Q_0 = 142$. Coupling coefficient is calculated from these values:

$$\beta = \frac{Q_0}{Q_l} - 1 = .11$$

After that the voltage induced in the measuring line by the passing electron bunch is measured with oscilloscope for different bunch charges. The typical measured dependence of the voltage upon the charge is shown in fig.1. The solid line gives the result of linear fit which is in good agreement with expression (5). Loss factor and shunt impedance were calculated using formulas (6, 7).
Measured dependence of the shunt impedance on the beam energy is shown in fig.2. The shunt impedance is also calculated using computer code URMEL and result is presented in fig.2 by dashed line. Real shape of the tested cavity is complex and is approximated with some accuracy for calculation , dielectric permeability of ceramic installed inside the cavity is not well known, that may lead to the difference between measured and calculated curves.

3 CONCLUSION

The preliminary test experiments show that suggested method for narrow band impedance measurements in non-relativistic case can be realized in practice. All measured dependencies are in the good agreement with analytical predictions. The measured value of shunt impedance near $1.5k\Omega$ is quite small but far above the practical limit of the method.

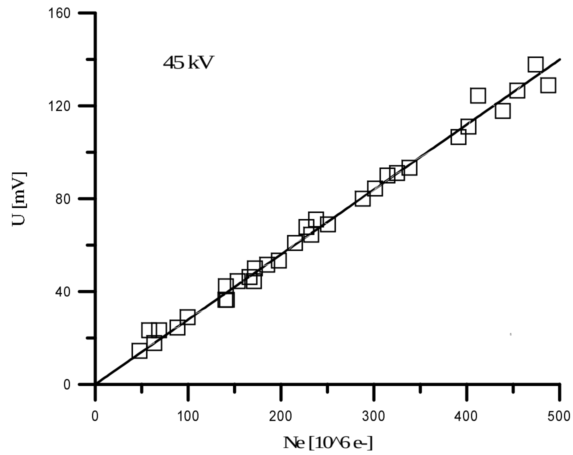

Figure 1: Dependence of voltage induced in measuring line upon bunch charge.

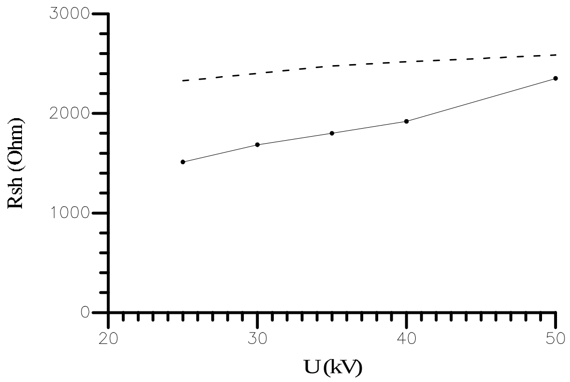

Figure 2: Dependence of measured shunt impedance upon bunch energy (solid), dashed line - calculation using URMEL code.

4 REFERENCES

[1] S.A.Heifets and S.A.Kheifets, Coupling impedance in modern accelerators. SLAC-PUB-5297, September 1990.

[2] A.V.Aleksandrov et. al. Proc. of BIW'94, Vancouver, p. 452-58