Longitudinal impedance tuner using high permeability material

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Abstract

In a high intensity proton machine, the space charge effects induce the beam instability. For canceling these effects, the "impedance tuner" which consists of high permeability material, FINEMET, was developed. We installed it in the KEK proton synchrotron (PS) main ring and observed the canceling effect.

1. Introduction

In a high intensity proton synchrotron, the emittance growth and the beam instability are caused by space charge effects. In the longitudinal phase space, the space charge force weaken the RF focusing force below the transition energy. When a short bunch is required, for example in a proton driver of a muon collider, the effects are further enhanced and they limit bunch length.

It is clear that an inductive device in a ring can cancel the space charge force since the space charge impedance is capacitive. The electric field created by the inductance has the opposite sign to the field of the space charge. Several methods have been proposed, such as a helical wire and a ferrite cavity. No successful results, however, came out as far as we know.

Recently a very high permeability material, FINEMET, becomes available. It turns out that the material has enough permeability at the beam frequency region and possibly cancels the space charge impedance. We designed a device, called "impedance tuner", consisting of FINEMET and installed it in the KEK PS main ring.

We will describe the characteristics of FINEMET and a setup of impedance tuner in the KEK PS main ring. At the end, experimental results up to date will be presented.

2. Characteristics of FINEMET

The space charge impedance of the KEK PS main ring at the injection energy of 500MeV is around Z/n=440 ohms. A high permeability material is indispensable to achieve a cancellation of the space charge capacitive impedance in limited space in the ring. Inductance of ferrite cores is not large enough for the purpose.

Recently, a new material, FINEMET(FT3M), is utilized as the magnetic cores of an rf cavity[1]. It has very high permeability and low quality factor (Q). We adopted that material for the cores of the impedance tuner.

The FINEMET is available as a toroidal core with the outer diameters of 340 mm, the inner diameter of 140 mm, and the thickness of 25 mm. The inductance is measured and shown in Fig.1. The measurement was carried out for a single core using a test cavity[2], which consist of a conductor going through the core and a variable condenser. The resonance point was searched for frequencies between 0.3 and 10 MHz. Also the bias current from 0 to 48 A was applied. As shown in Fig.1, the inductance decreases when the bias current increases. That makes it possible to control the inductive impedance, namely *impedance tuner* can be realized.

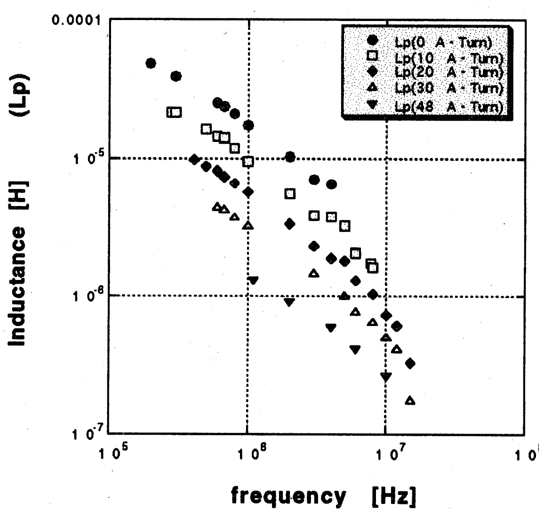

Fig.1 Inductance of FINEMET for different bias currents as a function of frequency.

3. Experimental setup

The impedance tuner consists of eight cores of FINEMET with 6 turn bias coil as shown in Fig.2. The bias coil has "8" shape to eliminate the beam induced RF currents. All the cores are installed in a cylindrical vacuum chamber. The bias current is varied from 0 to 30 A (0 to 180 A · Turn).

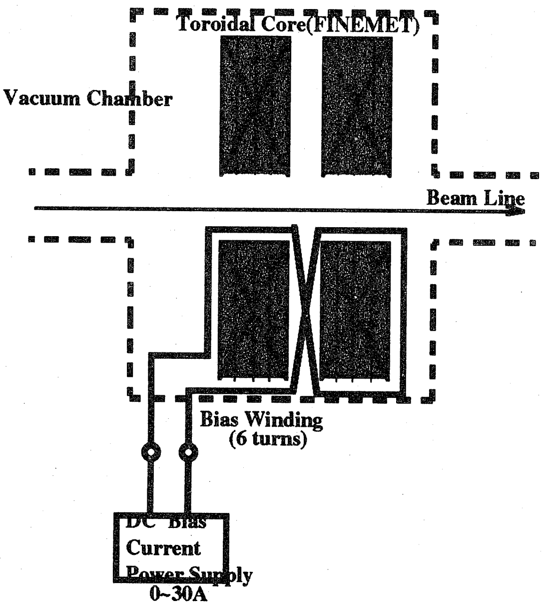

Fig.2 Experimental setup of the impedance tuner installed in the KEK PS main ring

4. Measurements

The incoherent synchrotron oscillation frequency is perturbed by the potential of the space charge and the inductive wall impedance. The perturbed frequency is written by,[3]

$$f_s^2 = f_{s0}^2\left\{1 - \frac{3ef_oN}{\pi^2 hV_0\cos\Phi_s}\left(\frac{2\pi R}{1}\right)^3\left[\frac{g_0Z_0}{2\beta\gamma^2} - \left|\frac{Z}{n}\right|\right]\right\}.$$

In terms of the frequency shift,

$$\frac{\Delta f_s}{f_{s0}} = -\frac{3ef_o}{2\pi^2 hV_0\cos\Phi_s}\left(\frac{2\pi R}{1}\right)^3\left[\frac{g_0Z_0}{2\beta\gamma^2} - \left|\frac{Z}{n}\right|\right]N.$$

Each symbol and the nominal values in the KEK PS are listed in Table 1.

Table 1

symbol	nominal value
N ; number of particles per bunch	$1*10^{12}$ ppb
R ; machine average radius	54 m
l ; full bunch length	60 nsec
g_0 ; form factor	4
V_0 ; RF voltage	120 kV
h ; harmonic number	9
ϕ_s ; synchronous phase	0 degree
f_0 ; revolution frequency	$6*10^6/9$ Hz

Although the incoherent frequency shift is not observed by the dipole oscillations, it can be inferred from the quadrupole oscillation frequency. There is the following relation between two oscillation frequencies[4].

$$\frac{\Delta f_{2s}}{f_{2s0}} = \frac{1}{4}\frac{\Delta f_s}{f_{s0}}.$$

The slope of the quadrupole oscillation frequency shift as a function of the beam intensity gives the impedance of the space charge and inductive wall.

The qadrupole oscillations are caused by a mismatch in the longitudinal phase space at the injection to the KEK PS main ring. The oscillations are observed as shown in Fig.3.

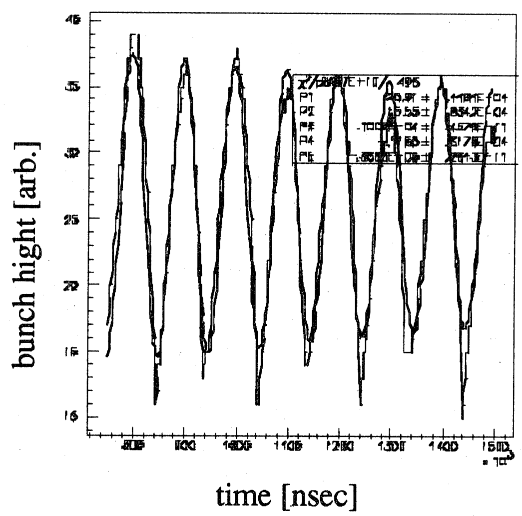

Fig.3 Fitting of observed quadrupole oscillation

The bunch shape is obtained from the signal of wall current monitor. The signal is transferred to the digitizer.

The envelope of the bunch amplitude oscillations (Fig.3) is fitted with a function of

$$y = p1 + p2 * \cos(2\pi * p3 * t + p4) * \exp(p5 * t).$$

Fitted value of "p3" is the frequency of quadrupole oscillations.

Those procedures are simulated by a particle tracking as shown in Fig.4. The validity of the fitting was clarified in the simulation.

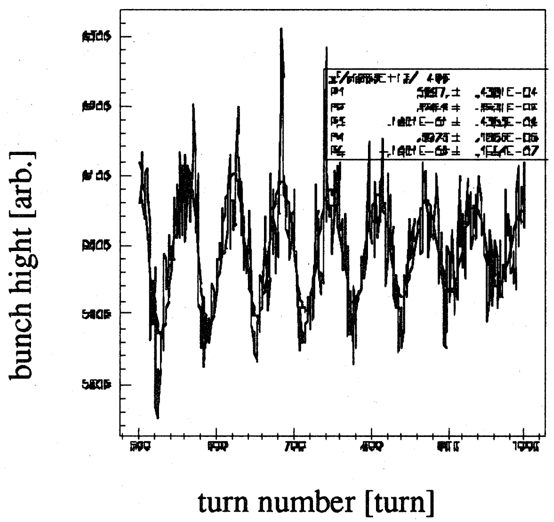

Fig.4 Fitting of the calculated quadrupole oscillations.

5. Results

The frequency shift as a function of intensity is plotted in Fig.5. The dashed line is a fitted line of a data before installation and the solid line is that after the installation. The slope of dashed line can be solely explained by space charge impedance, that is calculated as 440 ohms. On the other hand, the slope of solid lines is halved. Therefore, the inductive impedance made by the FINEMET cancels the half of the space charge impedance.

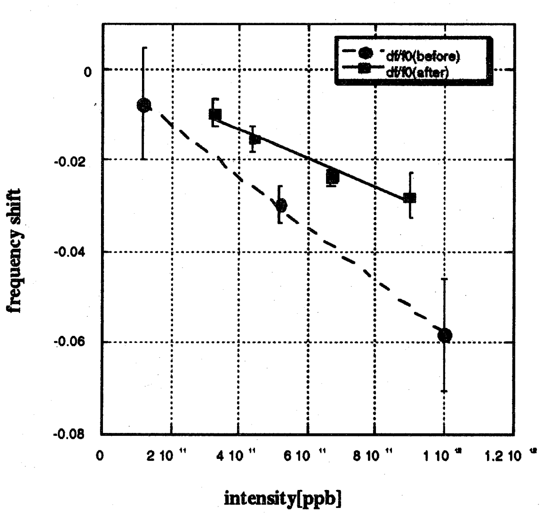

Fig.5 The measured frequency shifts of the quadrupole oscillations as a function of the beam intensity are plotted.

6. Summary

We installed a prototype of the impedance tuner made of FINEMET in KEK PS main ring. We observed that the half of the space charge impedance is canceled by the impedance tuner. It was 440 ohms before the installation and become ~200 ohms after installation. We will install a full size device in November 1997.

References

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