COMPENSATION OF COHERENT TUNE SHIFT OF BETATRON OSCILLATION IN STORAGE RINGS

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Abstract

Relativistic beam of charged particles circulating in finite conductive vacuum chamber (VC) of storage ring produces electromagnetic fields. These fields influence on beam dynamics. It results in coherent tune shift of betatron oscillation and also can limit number of particles in beam due to "resistive wall" instability. In this paper results of coherent tune shift measurements are described. New technique of coherent tune shift elimination which is based on wake fields compensation is also demonstrated. This technique can lead to considerable increase of maximum beam current in accelerators and storage rings with small aperture, when beam - wall interaction is important.

1. Introduction

A magnetic field in VC can be produced by beam current and also by currents induced in walls of VC. Wall currents' decreasing due to finite conductance of wall material results in different behavior of electric and magnetic fields versus time. Just after injection of beam into VC the electric and magnetic forces, acting on beam particles are mutually compensated as $1/\gamma^2$ (γ - Lorentz's factor). But later magnetic field from wall currents decreases and consequently the force acting on particles increases. When time tends to infinity mean wall current will be totally damped, beam magnetic field will diffuse out of VC. The maximum transverse force for the beam displaced from axis of round VC is determined by the mean current I:

$$F = x * \frac{2Ie}{ca^2} \qquad (1)$$

where c-speed of light, a-inner radius of VC, x- beam deviation from the VC axis. After bunch passing trough any cross-section of VC the field of wall currents remains on the orbit. This field slowly decreases as $1/\sqrt{t}$ up to the moment $\tau = (2\pi\Delta a\sigma)/c^2$ (Δ - wall thickness, σ - conductance) and later this field will fall exponentially with time constant τ. This wake field produce force which acts on the next bunches. Limitations of maximum number of particles in accelerators due to such fields were discussed in many papers (see, for example [1,2]).

In all below for the convenience the coherent tune shift of betatron oscillation will be normalized on it's maximum value, corresponding to the force (1).

At fig.1 coherent tune shifts calculated for two type of VCs are shown.

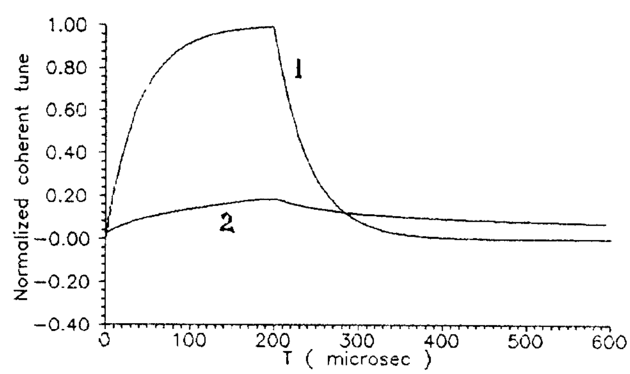

Fig.1 Calculated normalized coherent tune for two copper VC with D=50 mm: Δ=0.1 mm(1) and Δ=20 mm(2). Used formulas from [2].

Several traditional methods are used to overcome these limitations. For example increasing of betatron frequencies spread in beam leads to Landau damping, or using of feedback systems which suppress coherent movements of bunches (see [3]).

The method would be proposed allows to compensate the wake field, i.e., to cancel the origin of limitations.

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2. Measurements of coherent tune shift

Scheme of measurements is shown at fig.2. For coherent tune shift measurements we use two coils placed inside cylindrical VC. The first coil is long and flat with approximately 20 turns and size 20×2 cm and it was used to create magnetic dipole field in the VC, which is equivalent to field of bunch deviated from VC axis. This excitation coil is fed by current pulses with duration 0.1-0.3 ms and amplitude up to 1 A. A second coil was small (1 cm in diameter) and it was used to measure the magnetic field. It was fixed at the center of the first coil. Due to small size of the second coil measured field is not disturbed. Inductance L of second coil was 3 milliHenry. Induced in the measuring coil current was shunted by resistance R=100 Ohm.

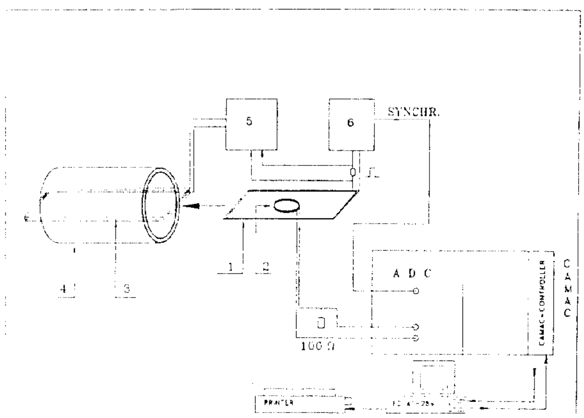

Fig.2 Scheme of measurements: 1,2,3-exitating, measuring, compensating coils, 4-VC model, 5,6-current generators.

Signal from the shunt was digitized by CAMAC ADC with interval T=1 microseconds and was stored in computer memory. Signal from the measuring coil U(iT) was processed according to the formula:

$$H(iT)=U(iT)+\sum_{j=1}^{i} U(jT)*T/T_0,\quad T_0=L/R,\quad i=1..512 \quad (2)$$

Integrating time T_0 was about 30 microseconds.

Fig.3 shows measured magnetic field H(iT) during and after excitation current pulse in different conditions: 1- in free space, 2- in the thin copper VC with diameter 50 mm and wall thickness 0.1 mm, 3- in the thick aluminium VC with inner diameter 50 mm and wall thickness 20 mm. If one subtract from the field a rectangular pulse of magnetic field arising at the first moment - analog of beam own field (shown at fig.3 by the dashed line) - and normalize it on the field in free space then one get normalized coherent tune shift for different kinds of VCs as we said above (see fig.4). Small additional pulses on the figures are caused by the errors of digitized rectangular pulse of free space magnetic field subtracting.

One can see from these figures that in the thick wall VC fields decrease slowly after bunch passing. It results in accumulation of coherent tune shift in multibunch regime. In the VC with thin walls a big coherent shift for single bunch is observed, but fields decrease faster so the influence of one bunch to another one is smaller. Right choose of optimal wall thickness depends on many factors [4].

3. Compensation of the coherent shift by external currents

We suggest rather effective and simple technique for compensation of magnetic wake

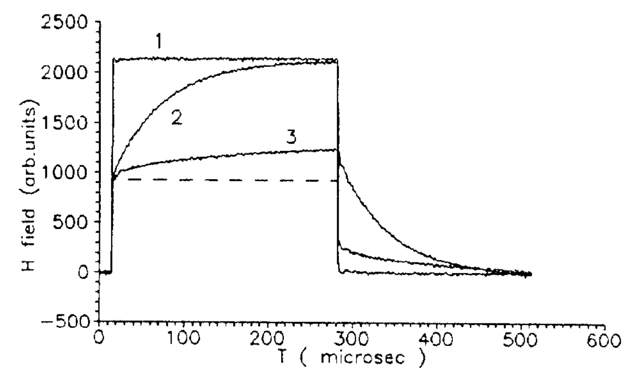

Fig.3 Magnetic field inside different VCs.

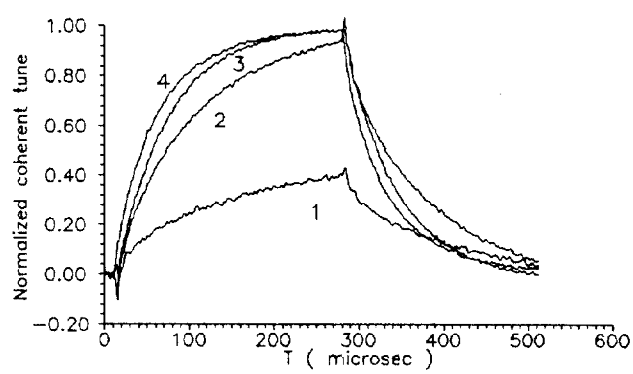

Fig.4 Coherent tune for different VCs: 1 -20 mm aluminium, 2 - 3 mm steel over 0.1 mm copper, 3- 0.1 mm copper, 4- 3 mm steel.

fields in VCs - to generate electric currents in conductors on outer surface of a VC. These currents should be equivalent to image currents in the walls, i.e., to be analogously distributed on the VC cross section outer perimeter and to be proportional to beam current.

We carried out an experiment for demonstration of this technique (see fig.2). A signal from the current shunt in the excitation coil is proportional to magnetic dipole field inside the VC. A current generator is controlled by this signal and produce current in external coil. The last one lays in the excitation coil plate. Image currents in the walls disappear if currents inside and outside the VC have equal values but opposite directions. Fig.5 shows measured coherent shift for thin copper VC (thickness 0.1 mm, diameter 50 mm) in this case. One can see that the compensation decreases value of the shift to few per cent level.

Practically coherent shift compensation system for accelerators and storage rings can use multi-electrodes pick-ups for beam position measurements. Signals from electrodes control the current generators for corresponding external conductors proportionally to image charges on inner surface of VC (see fig.6). Each bunch produces current pulse in the conductors with time of decreasing τ (see upper) distributed according to bunch displacement from VC axis. Summary current in conductors should be equal to mean current.

Apparently if one take six conductors one will get good compensation of main (dipole and quadrupole) components of magnetic field.

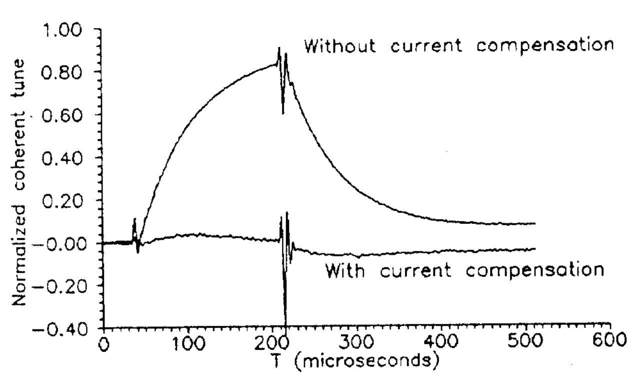

Fig.5 Coherent tune shift for 0.1 mm copper VC with and without current compensation.

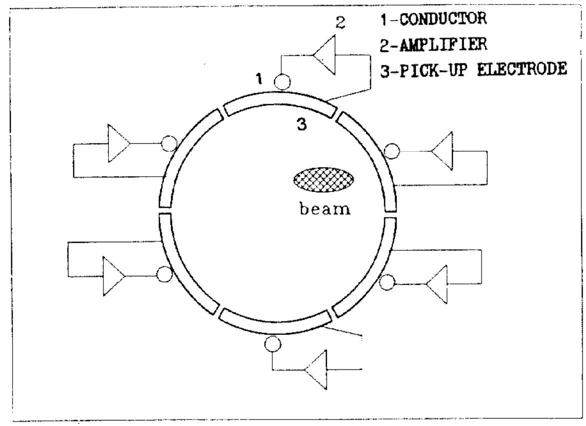

Fig.6 Scheme of coherent tune shift current compensation.

Length of each system should be noticeably less than particles' betatron oscillation wavelength. It is possible in principle to concentrate correction coils near the multi-electrodes pick-ups but it should lead to increasing of currents and power of compensation system. And also the compensation along all chamber allows to eliminate influence of ferromagnetic elements because in this case magnetic field in external space of VC would be completely absent.

High degree of compensation can be achieved with thin walls of VC when image currents are compensated by currents in conductors on outer surface of VC.

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