THE KICKER PARAMETERS ESTIMATION FOR LONGITUDINAL INSTABILITY DAMPING OF THE BEAM AT SR STORAGE RING "SIBERIA-2"

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Abstract

The coupled-bunch instabilities can limit a maximum beam current and lead to a beam loss in some cases at the storage ring "Siberia-2". To cure this problem we have to develop a longitudinal feedback (LFB) system based on a high impedance kicker. In the article a result of the high order mode (HOM) spectrum measurements and the main kicker parameters are presented. Besides, an interaction of the beam with three cavities is considered theoretically.

INTRODUCTION

The RF system of the Kurchatov Institute Synchrotron Radiation storage ring "Siberia-2" consists of three cavities (181 MHz). Each of them has two HOM tuners. The fundamental mode in the cavities is tuned by feedback loops in accordance with a beam loading and temperature changes. The HOM frequencies are not controlled automatically.

Due to a shunt impedance and a quality factor of HOMs are high, the beam-cavity interaction leads to the instability and the beam loss as the result. It is not possible to reduce the HOM influence on the beam motion due to unavailability of the HOM automatic controller and an additional waveguide load for the HOM-damping. To suppress coupled-bunch instabilities we'll plane to establish the longitudinal feedback system at the storage ring. For example of the longitudinal kicker, a model of the DUKE kicker cavity will be taken.

LONGITUDINAL MOTION

For estimation of the HOM influence on the beam motion it is convenient to consider a circulating electron beam. Each bunch of the beam, represented as macroparticle, performs the small dipole synchrotron oscillations

$$\ddot{\varphi} + 2\alpha\dot{\varphi} + \omega_s^2\varphi = 0,$$

where ω_s is the synchrotron frequency, α is the growth rate. The stability synchrotron motion is determined by a sign of the growth rate, which consist of

$$\alpha = \alpha_{rad.} + \alpha_{rf} + \alpha_{kick.},$$

$\alpha_{rad.}$ is the synchrotron radiation growth rate, α_{rf} is the instability growth rate due to HOMs, $\alpha_{kick.}$ is the growth rate of the LFB system. If the growth rate, α, is positive, the longitudinal motion is stable. The sign of α_{rf} is depend on whether the Robinson stability condition is satisfied [1].

The radiation damping is small to compensate the harmful HOM influence. The necessary damping is set by the LFB system. The coefficients of α_{rf} and $\alpha_{kick.}$ [2] are expressed as

$$\alpha_{rf} = -\frac{e}{2T_0E_0}\alpha_c\sum_{p=1}^{+\infty}\frac{2I_p^2}{I_0}\frac{p\omega_0}{2\omega_s}(Z_r^+ - Z_r^-),$$

$$\alpha_{kick} = \frac{1}{2}f_0\frac{V_{kick}}{\Delta E},$$

where f_0 - the revolution frequency, E_0 - the beam energy, α_c - the momentum compaction factor, I_0 - the average beam current, I_p - the harmonic beam current, V_{kick} - the kicker voltage, ΔE - the maximum energy oscillation amplitude, $Z_r^+ \, u \, Z_r^-$ - the real parts of the HOM impedance at $p\omega_0 + \omega_s$, $p\omega_0 - \omega_s$ frequencies, respectively.

In our case at the storage ring there are three cavities, then α_{rf} has additional terms under the sum

$$\alpha_{rf} = -\frac{e}{2T_0E_0}\alpha_c\sum_{p=1}^{+\infty}\frac{2I_p^2}{I_0}\frac{p\omega_0}{2\omega_s}[(Z_r^+ - Z_r^-)\cdot (1+\cos\omega_s\tau_{12}+\cos\omega_s\tau_{13}) + (-2Z_i^0 + Z_i^+ + Z_i^-)\cdot (\sin\omega_s\tau_{13}+\sin\omega_s\tau_{12})].$$

where τ_{12} and τ_{13} - the time of the bunch passage from the first cavity to the second and the third, respectively. If to take into account the parameters of the high order mode of all cavities are the same and the passage time is small, then the HOM influence on the beam motion is increased in three.

To damp the instabilities, the energy kick should be applied to each bunch of the beam. The necessary output kicker voltage is limited by the amplifier power [3]

$$V_{kick} = \sqrt{2P_{out}R_{sh}},$$

where P_{out} - the maximum output power of the amplifier, R_{sh} - the effective shunt impedance of the kicker cavity.

We should take into account a RF power loss between the amplifier and the LFB kicker, a group delay, a nonlinearity of the phase and gain of the LFB system, to calculate the kicker voltage. Hence, the estimated amplifier power should be taken larger, then it is necessary in practice [4].

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MEASUREMENTS

The RF cavities of "Siberia-2" have bimetal walls, 7 mm of the stainless steel and 8 mm of the copper. The design of the RF cavity is presented in Fig. 1. Each of them has a water cooling channel located in a surface layer of the steel. In the design there are two operating mode frequency tuners (1), two HOM tuners (2), a inductive RF probe for the gap voltage measurements (3), a coaxial input power coupler (4) and a flange for the vacuum pump (5). The cavities operate in the TM_{010} mode.

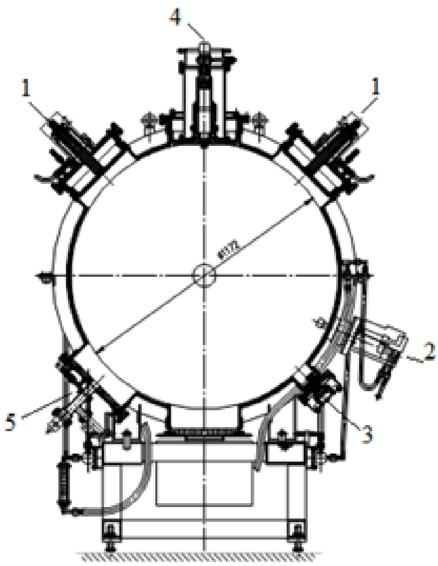
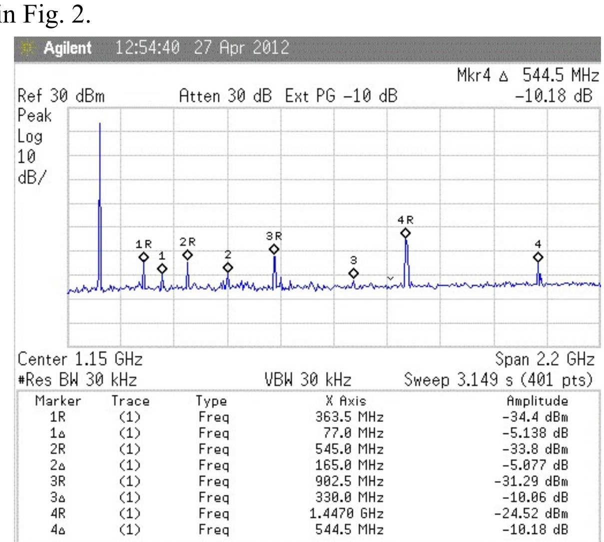
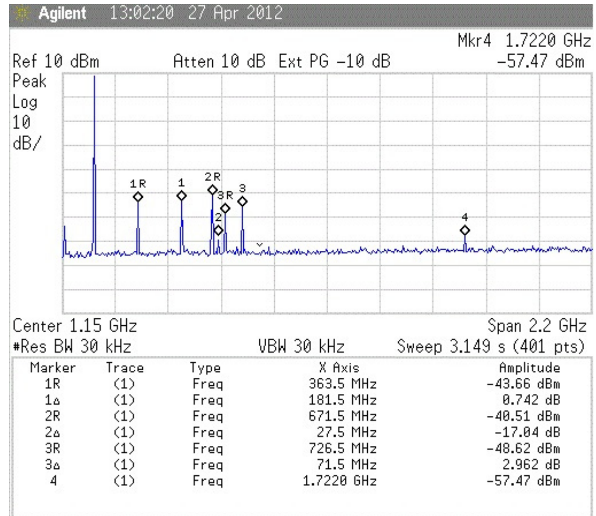


Fig. 1: Design of the RF cavity of "Siberia-2".

To found the most dangerous HOMs the field spectrum measurements were made with a wideband (up to 13.5 GHz) spectrum analyzer. The experiments were conducted at the energy 450 MeV and 2.5 GeV with a different distribution of the bunches. For measurements the signals from coupling loops in the cavities were used. The picture of the field spectrum of each cavity is given in Fig. 2.



a.



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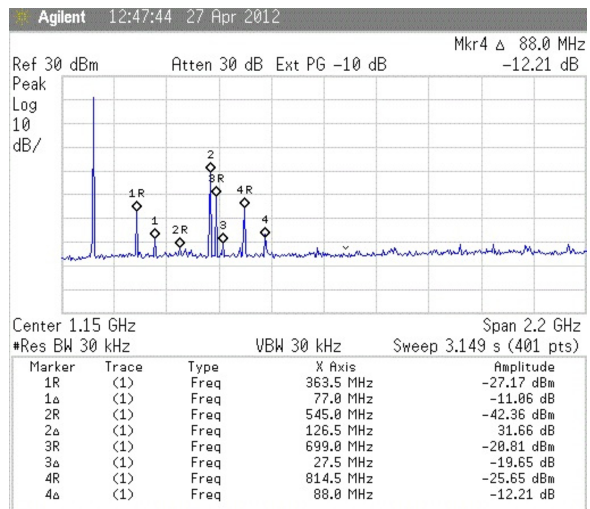

c.

Fig. 2: The field spectrum in cavities: a. - the first, b. - the second, c. - the third. The electron beam energy is 2.5 GeV, the total beam current is 39.45 mA.

The coupled-bunch instabilities limit the beam intensity. It depends on a kind of the coupled mode some bunches loss the particles on the vacuum chamber walls. It is illustrated in Fig. 3. To cure this problem we need to establish the LFB system.

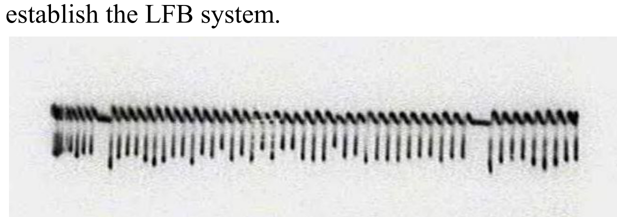

Fig. 3. The circulating electron beam of the 36 bunches.

The measurements allowed to found a constant set of HOMs, generated by the different distribution beam, and an independence of the frequency spectrum from the energy. The comparison of the results with cool

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measurements of the cavities allowed to determine the most strong HOMs in the frequency range from 300 MHz to 1600 MHz.

LONGITUDINAL KICKER

To estimate the necessary kicker parameters we took the model of the DUKE kicker as an example. It was re-simulated by means of a special program. The kicker has a frequency $5.25f_{RF}$, a quality factor - 10.6, a bandwidth - 90 MHz. The calculation gave the value of the effective shunt impedance about 1255 Ω for the aluminum walls of the kicker and the transit time factor is 0.698.

To define the amplifier power, we have calculated the instability growth rate due to HOMs.

The parameters of the storage ring "Siberia-2" are given in Table 1.

Table 1: The storage ring parameters

Energy, MeV	450
Operating energy, GeV	2.5
Beam current, mA	300
Revolution frequency, MHz	2.415
RF frequency, MHz	181.125
RF voltage, kV	380
Synchrotron frequency, kHz	24.6
Number of bunches	75
Momentum compaction factor	0.0104

The calculations were performed for the Gauss bunches, interacting with the found set of the most harmful HOMs of all cavities. The results, according to a bunch length, are given in Table 2. For "Siberia-2" at 450 MeV, a dependence of the bunch length of a single-bunch current can be calculated as

$$\sigma_p\ [ps] \approx 54.5 \cdot I_b^{1/3}\ [mA],$$

where I_b is the single-bunch current.

Table 2: The instability growth rate

I_b, mA	σ_p, ps	α_{rf}, 1/c
4	86.5	736.8
12	124.8	729.4
20	148.0	696.1

The LFB system will be designed for a total multi-bunch current of 300 mA. It should be effective for a wide range of bunch length. Hence, to damp the HOM influence of three cavities the power amplifier of 200 W is enough for the beam current of 300 mA and a bunch length of 148 ps.

CONCLUSIONS

To study the beam-cavity interaction the dipole synchrotron bunch oscillation model was used. The influence of HOMs of the RF cavity was calculated. The basic kicker parameters estimation was presented. To damp the longitudinal instabilities for the presented kicker model we'll plane to take two power amplifier of 100 W.

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