THE FEEDBACK SYSTEM FOR ELIMINATION THE FAST HEAD-TAIL INSTABILITY AT STORAGE RING VEPP-4M.

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Abstract

In this paper a feedback system for suppressing fast head-tail instability is described. The experimental results of the feedback affecting the current threshold are presented. The effects of the reactive and resistive feedbacks on the current threshold are discussed.

1 INTRODUCTION.

The most fundamental limit for the current at the VEPP-4M facility is presently the vertical fast head-tail instability. The beam losses is usually observed in a few tens of milliseconds after injection (this corresponds approximately to the time of radiation damping). The threshold current is 10÷12 mA.

The fast head-tail instability occurs when frequency of the head-tail mode 0 is shifted sufficiently to couple to the -1 mode. In order to increase an instability threshold it is usually suggested introduce the reactive feedback to compensate for the frequency shift of the mode 0. However, as it follows from experiments [1] its turned out that the introducing of the pure active negative feedback increases the threshold current up to substantially higher values.

This effect can be understandable if one can find the eigen modes of particle oscillations in the bunch. As it shown below on simplest two particles model, in the vicinity of instability threshold these modes are approximately the same, they have close eigen frequencies and each mode has the approximately equal amplitudes of the dipole and quadrupole components. When switching the negative active feedback an energy extraction occurs from the eigen modes of oscillations excited by the head-tail interaction in a bunch through the dipole degree of freedom, thereby preventing the instability growth. Such an interpretation is additionally supported by the experimental data given below.

Some parameters of the VEPP-4M facility are the following: revolution frequency *Frev* = 0.82 MHz, accelerating voltage frequency *Frf* = 222·*Frev*, radiation damping time of longitudinal and transverse oscillations at injection - 35÷60 ms, bunch length - 20 cm, fractional part of relative frequency of vertical oscillations - 0.57, relative frequency of synchrotron oscillations - 0.018.

MODE ANALYSIS OF THE TWO PARTICLE MODEL.

In our consideration we will, partically, refer to A.W.Chao [2].

Let y_1 and y_2 be complex amplitudes of the betatron oscillations of the 1-st and the 2-nd particles.

In the first half period of synchrotron oscillation first particle is leading and excites by its wake transverse oscillation of the second one. Due to the resonance excitation complex amplitude of the second particle at the time t is

$$y_2(t)=y_2(0)\cdot e^{j\omega t}- \; j\cdot W\cdot t\cdot y_1(0)\cdot e^{j\omega t}$$

Here W - factor defined by wake field induced in environment by first particle.

After the first half period of the synchrotron oscillation $T/2$ complex amplitudes are transformed as follows (in matrix form)

$$\begin{vmatrix} y_1 \\ y_2 \end{vmatrix}_{t=\frac{T_s}{2}} = e^{j\cdot\omega_s\cdot\frac{T_s}{2}} \bullet \begin{vmatrix} 1 & 0 \\ -j\eta & 1 \end{vmatrix} \bullet \begin{vmatrix} y_1 \\ y_2 \end{vmatrix}_{t=0},$$

where $\eta = W\cdot T_s/2$.

In the second half period particles interchange by its leading and trailing roles so transformation is

$$\begin{vmatrix} y_1 \\ y_2 \end{vmatrix}_{t=T_s} = e^{j\cdot\omega_s\cdot\frac{T_s}{2}} \bullet \begin{vmatrix} 1 & -j\eta \\ 0 & 1 \end{vmatrix} \bullet \begin{vmatrix} y_1 \\ y_2 \end{vmatrix}_{t=\frac{T_s}{2}},$$

After the whole period we will have

$$\begin{vmatrix} y_1 \\ y_2 \end{vmatrix}_{t=T_s} = e^{j\cdot\omega\cdot T_s} \bullet \begin{vmatrix} 1 & -j\eta \\ 0 & 1 \end{vmatrix} \bullet \begin{vmatrix} 1 & 0 \\ -j\eta & 1 \end{vmatrix} \bullet \begin{vmatrix} y_1 \\ y_2 \end{vmatrix}_{t=0} =$$

$$= e^{j\cdot\omega\cdot T_s} \bullet \begin{vmatrix} 1-\eta^2 & -j\eta \\ -j\eta & 1 \end{vmatrix} \bullet \begin{vmatrix} y_1 \\ y_2 \end{vmatrix}_{t=0}.$$

The stability is determined by eigenvalues of the transforming matrix. The last are the roots of an equation

$$\begin{vmatrix} 1-\eta^2-\lambda & -j\eta \\ -j\eta & 1-\lambda \end{vmatrix} = 0 \qquad \text{or}$$

$$\lambda^2-2\,(1-1/2\cdot\eta^2)\cdot\lambda+1=0.$$

The roots of this equation (eigenvalues) are

$$\lambda_{1,2} = 1 - \frac{\eta^2}{2} \pm j \cdot \eta \cdot \sqrt{1 - \frac{\eta^2}{4}}.$$

As easy can be seen their product is equal to unity

$$\lambda_1 \cdot \lambda_2 = 1.$$

Secondly,

$$|\lambda_{1,2}| = 1$$

if $\quad 1 - 1/4 \cdot \eta^2 \geq 0$, $\quad$ i.e. $\quad \eta \leq 2$.

At $\eta > 2$ module of certain eigenvalue becomes greater than unity, for instance, $|\lambda_1| > 1$, and instability of the "fast head-tail" type arises.

For design of feedback to increase the threshold of instability it is useful to find eigenmodes i.e. some relations between complex amplitudes of transverse oscillations of two particles belonging to the same eigenvalue.

Eigenmodes amplitudes satisfy uniform system of linear equations

$$(1-\eta^2-\lambda)\cdot y_1 \quad - j\cdot\eta\cdot y_2 \quad = 0$$

$$-j\cdot\eta\cdot y_1 - (1-\lambda)\cdot y_2 \quad = 0$$

This system has nontrivial solution if λ is one of eigenvalue. If it is so this system determines the ratio of the variables y_1 and y_2. From the second equation, for instance, we have:

$$y_1 = \frac{\lambda_{1,2} - 1}{j\eta} \cdot y_2$$

Substituting here eigenvalues we obtain

$$y_1 = \left(\frac{1}{2} \cdot j\eta \pm \sqrt{1 - \frac{1}{4} \cdot \eta^2} \right) \cdot y_2 .$$

The expression in parentheses has the following properties. Below of the instability threshold ($\eta < 2$) its module is equal to unity, i.e. the oscillation amplitudes of particle oscillations are equal. At $\eta \to 0$ macro particles oscillates in the same phase for one mode and in opposite phase for another mode. If $0<\eta<2$ the phase shift increases with η, and at $\eta = 2$ the both modes merge in one the phase shift between particles oscillations is $\pi/2$. At further growth of η the phase shift in modes remains $\pi/2$. But oscillation of one mode increase with time and another decrease (amplitudes of oscillations of particles are unequal).

One can see from this that near instability threshold the center of gravity of each mode performs the oscillations. This oscillations can be detected by pick-ups and used for suppression of instability by feedback, resistive, in particular.

Description of System

The block diagram of the feedback system over the vertical dipole oscillations of a beam is given in Fig.1.

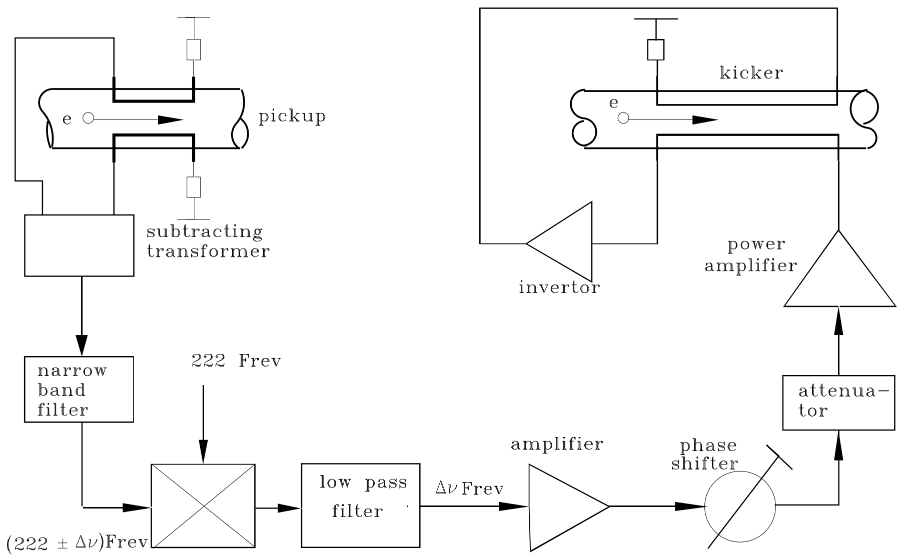

Fig.1. Feedback system block diagram.

The 50 Ohm striplines are used as the pickup of transverse oscillations. The signals from the opposite striplines are applied to the subtracting transformer having the input impedance equal to the wave impedance of striplines that enable us to separate the signals from the electron and positron bunches. The length of striplines was chosen in such a way that the their sensitivity has maximum values in the frequency range 150÷250 Mhz.

The suggested system is made selective with the frequency conversion. The preliminary processing of signals is performed at a frequency $(222\pm\Delta\nu)\cdot$*Frev* in the vicinity of the pickup sensitivity maximum and the formation of frequency characteristics and kicker power supply at low frequency $\Delta\nu\cdot$*Frev*.

The differential signal from the transformer output is applied to the selective filter tuned at a frequency of 222·*Frev* and then to the frequency converter. The heterodyne voltage for the converter is a signal from the accelerating system (*Frf*=222·*Frev*). In the low frequency part the feedback system has a filter with a range 0÷0.5·*Frev*, preamplifier, phase shifter, attenuator, and the power amplifier. The phase is regulated within the range $0\div2\cdot\pi$ thus enabling the realization of both the active and reactive feedback.

A pair of the 50 Ohm diametrically opposite matched striplines of 1 m length is used as a kicker thus providing the separate action on the bunches of electrons and positrons. The power supply of striplines is in series with the use of the inverter transformer. The inter-lines maximum voltage is limited by the power of an output amplifier to the value of 400 V.

Experimental results

The finite dynamic range of the feedback system poses the limit to the decrement at injection where the bunch oscillation amplitude is quite large because of errors in the injection systems. In our case, at a current of 10 mA this value was approximately 0.02·*Frev* and for low amplitudes of oscillations it could be increased up to 0.06·*Frev* . The coherent tune shift, introduced by feedback, corresponding to these two modes of operation was $2\cdot\pi$ times lower. The eigen coherent tune shift caused by the bunch interaction with the storage ring components was 0.012·*Frev* at the same current value. Unfortunately, this value is larger than that the feedback could provide, therefore in our experiments we could not compensate for the eigen coherent tune shift especially during injection.

Fig.2 shows the dependence of a current captured on the VEPP-4M of the phase of the feedback circuit (there is one-turn injection in VEPP-4M). The pure negative feedback corresponds to the zeroth phase and purely reactive feedback corresponds to $\pm90^0$.

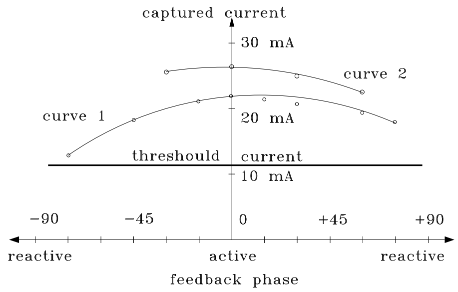

Fig.2. Dependence of a captured current of the feedback phase.

It is seen that the maximum captured current is achieved at the zeroth phase and it decreases with nearing to $\pm90^0$. For obtaining the experimental points at each phase value the gain in the feedback circuit was selected in such a way to provide the maximum of captured current. One should note that the maximum captured current in our case was limited not by the feedback capabilities but by the maximum current of injected bunch. The 1-st curve represents the first run results, the 2-nd curve - the second run results (after more careful tuning the injection system). As one can catch from the figure the maximum captured current exceeds the thresholds current more than two times.

The results give evidence an efficiency of the active feedback in the fight against the fast head-tail instability and can be used at other installation for the development of similar systems.

References

[1] S.Myers,'Stabilization of fast head-tail instability by feedback' Proc. of IEEE Particle Accelerators 1987.

[2] A.Chao, SLAC-PUB-2946,June 1982

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