HOM SUPPRESSION OF THE CAVITIES WITH PLUGER TUNER BY THE TEMPERATURE TUNING

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Abstract

New storage ring cavity temperature system was successfully operated for the Pohang Light Source (PLS) and increased the stable maximum beam current up to 200 mA. The storage ring cavity for PLS has the plunger-type tuner which is controlled by the phase feedback loop to always tune the resonant frequency.
Optimum temperature windows for the PLS cavities were obtained by intensive but tiresome measurements. The measured results is compared to the calculation based on the relations expressed as a function of the tuner position.

1 INTRODUCTION

Temperature tuning of the storage ring cavities has been used effectively for shifting the dangerous cavity HOMs at the Elettra[1, 2] and couple of other third generation light sources. At the Pohang Light Source (PLS) a new temperature control system[3] for the cooling water of the cavities was installed and has been actively used for suppressing amplitudes of HOMs. A clear difference of the PLS cavities from the Elettra is the tuning mechnism; the plunger-type tuner. Effects of the temperature change on the HOM frequency shift should consider the plunger movement controlled by the resonant frequency feedback circuit. This makes the analysis cumbersome. At Photon Factory an elaborate length adjustment of a fixed block was used in stead of the temperature tuning[4].

Here a systematic approach to temperature tuning of RF cavities with plungers is presented in the following sections and a comparison with the initial operation results will be given.

2 DERIVATION

The parameter, Critical Temperature, defined as the cavity temperature for which the frequency of the HOM exactly overlaps the frequency of the coupled bunch mode[2] is adopted here for a systematic analysis. According to the definition of the critical temperature, the operating temperature of the cavities should not be near the critical temperature, where the coupling is at maximum.
There are several parameters to shift HOM frequency at the cavities. Cavity volume changes caused by thermal expansion, by change in the dissipating power or by change in beam loading are typical. Change in rf frequency obviously shift HOM frequency. In cavities with plunger-type tuner all these changes affect tuner position since a phase loop always tune the cavity to the proper rf frequency by adjusting the tuner position. The change in tuner position can be written as

$$\Delta l_{total} = \Delta l_{thermal} + \Delta l_{beam\ loading} \cdots\cdot$$

It should be noted that each term in the RHS does not couple to each other. The frequency shift of HOM becomes

$$\Delta f_{HOM} = -\left(\frac{f_{HOM}}{f_{rf}}\right)\left(\frac{df_{rf}}{dl}\right)\Delta l_{thermal} + \left(\frac{df_{HOM}}{dl}\right)\Delta l_{total}\ .$$

The first term in the RHS represents the HOM frequency shift due to the thermal expansion and the second term is caused by the tuner position adjustment[4]. Note that different Δl is used for each term.
Now we describe Δl as a known parameters. For thermal expansion, it is known as[4]

$$\Delta f = -\alpha \cdot \Delta T \cdot f$$

where α is the thermal expansion coefficient of copper. Since tuner always moves to tune to the resonant frequency, the rf frequency shift can be written as
Therefore

$$\Delta f_{rf} = -\left(\frac{df_{rf}}{dl}\right)\Delta l_{thermal}\ .$$

In a similar fashion the tuner position change due to the

$$\Delta l_{thermal} = \frac{\alpha\ f_{rf}}{df_{rf}/dl} \cdot \Delta T.$$

beam loading can be obtained as
where all the parameters are represented with the conventional notations. Now the HOM frequency shift

$$\Delta l_{beamloading} = \frac{R_s\ f_{rf} \cos\psi_s}{\theta(1+\beta)V_c}\frac{1}{df_{rf}/dl}\Delta I_b\ ,$$

can be expressed as a function of the temparature change as well as the beam loading. These two are major factors shifting frequency by changing the tuner position accordingly. The frequency shift of HOM can be written in terms of these two parameters, ΔT and ΔI, as follows.

$$\Delta f_{HOM} = (\alpha \Delta T)\left(- f_{HOM} + f_{rf} \frac{df_{HOM}/dl}{df_{rf}/dl} \right) + \frac{R_s \cos\psi_s}{Q(1+\beta)V_c} f_{rf} \frac{df_{HOM}/dl}{df_{rf}/dl} \Delta I_b .$$

Here the accelerating voltage is defined as $V_c \cos \Psi_s$. ΔT and ΔI are the variations from the preset reference points and other parameters should have values at the reference point. By equating this to the condition for invoking a multi-bunch instability mode, the critical temperature can be calculated as

$$T_c = \frac{1}{\alpha}\left[-\frac{R_s \cos\psi_s}{Q(1+\beta)V_c}\frac{\delta_{HOM}}{\delta_{rf}} f_{rf}\Delta I_b + \left(f_{l,n} - f^0_{HOM}\right)\right] \Big/ \left(\frac{\delta_{HOM}}{\delta_{rf}} f_{rf} - f^0_{HOM}\right) + T_0 ,$$

where δ is the derivative of frequency change with respect to the tuner position and the superscript zero means the values at the reference temperature, T_0. Since all rf parameters could only be measured at cases without beam, the reference point for the beam current is set to zero and for the temperature set to 30^0C.

The growth rate of a longitudinal coupled bunch mode instability for a beam current I_b stored in M uniformly filled and spaced bunches and for a high Q cavity HOMs can be approximated by[2],

$$\frac{1}{\tau_\parallel} = \frac{\eta I_b}{4\pi Q_s (E/e)} \omega_{l,n} \Re(Z_\parallel(\omega_{l,n})) e^{-(\omega_{l,n}\sigma_t)^2} ,$$

where,

$$\frac{\omega_{l,n}}{\omega_{HOM}} = \frac{(lM+n+Q_s) f_{rf} / h}{[\alpha(T-T_0)]\left[-f^0_{HOM} + f_{rf}\frac{\delta_{HOM}}{\delta_{rf}}\right] + \frac{R_s\cos\psi_s}{Q(1+\beta)V_c} f_{rf} \frac{\delta_{HOM}}{\delta_{rf}} f_{rf}\Delta I_b + f^0_{HOM}} ,$$

$$Z_\parallel(\omega_{l,n}) = \frac{\left(\frac{R}{Q}\right)^0_{HOM} Q_{HOM}}{1 + iQ_{HOM}\left(\frac{\omega_{l,n}}{\omega_{HOM}} - \frac{\omega_{HOM}}{\omega_{l,n}}\right)} .$$

3 APPLICATION TO THE PLS CAVITIES

To apply the above analysis to PLS cavities, necessary parameters were measured in situ. Since it is impossible to measure frequencies with rf power on, measured values without rf power should be converted to the reference values, which are extrapolated by considering the effects of rf power-on at temperature T_0 without beam current. Before going further three points should be examined for checking the usefulness of this analysis. First it should be checked whether the total tuner position movement is just a summation of contributions from each factor. Second check whether the tuner position is linearly proportional to the temperature and beam current. Third the effect of balance mismatch of the beam loading

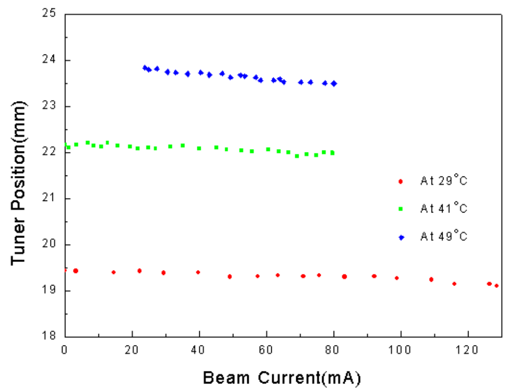

Figure 1. Tuner position as a function of beam current at three different cavity temperatures which shows that the thermal expansion and beam loading independently contribute to the total displacement.

between cavities should be checked. Checking the first point, tuner position was measured as a function of the amount of beam current stored and the cavity temperature as shown in Fig. 1. In the figure, the slope of the tuner position as the stored current increases does not change at different temperatures. This clearly represents that two factors (thermal and beam loading) are decoupled as assumed. The slope is also linearly fitted, which means that the second point is satisfied for the beam loading factor, whereas the effect of the thermal expansion was already tested in the Ref [5]. Testing third point requires a bit more speculation. Relations between Δl and ΔI are for the case with the optimum tuning, i.e. ψ_s is the tuning angle for the case of the minimum reflected power. If there is any balance mismatch, then ψ_s is not optimum any longer. In this case, relations between Δl and ψ_s are very important. If the balance between cavities changes,

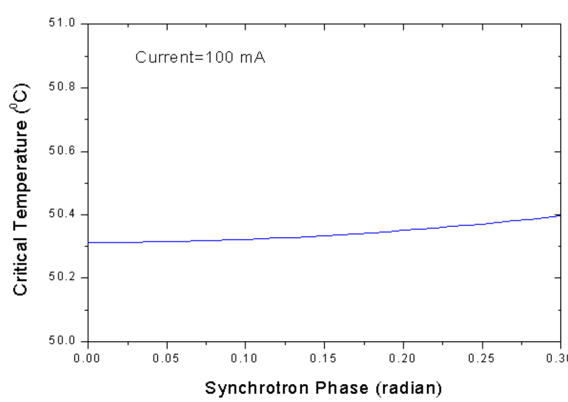

Figure 2. Change of the critical temperature as a function of the tuning angle. Large change in tuning angle due to the unbalanced beam loading between stations does not affect much on the critical temperature calculations.

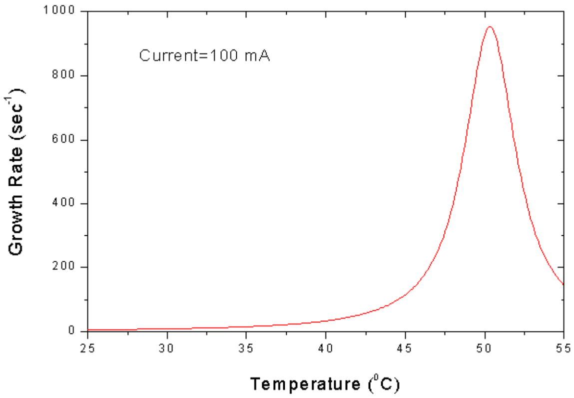

Figure 3. Growth rate calculated for TM011 mode of #2 cavity.

ψ_s changes, too. Thus sensitivity should be analyzed. Figure 2 shows the change in critical temperature as a function of tuning angle for a typical case. The critical temperature does not change much for a relatively large change in tuning angle.

Back to the main subject, parameters required to calculate the critical temperature and the growth rate were measured and recalculated. Let us take TM011 mode of the second cavity as an example. The HOM frequency is 757.857 MHz at 30°C. The derivative δ_{HOM} was measured of –59.19 kHz/mm. For ΔI is 100 mA, the critical temperature is calculated as 50.86°C. Since the critical temperature has a current dependence, it changes from 52°C to 45°C as the current increases from zero to 200 mA, respectively. The growth rate can be also calculated as shown in Fig. 3. By comparing the growth rate with the natural damping time the treshold current can be determined for this mode at certain temperature. Though not seen in the Figure, the threshold current at the critical temperature is about 60 mA, which agrees quite well with the experimental observations. Also this growth rate decreases above 160 mA since the plunger tuner position continuously moves out as the current increases, which shifts the HOM frequency towards a favorable region again.

Since the critical temperature changes as the beam current does so, the calculated growth rate at the critical temperature for a given current is always the largest. Therefore the growth rate at a fixed temperature is normally smaller at any current except the current at which the fixed temperature equals to the critical temperature. This is shown in Fig. 4. When T is below 40°C, the growth rate for this mode is lower than the natural damping rate up to 200 mA.

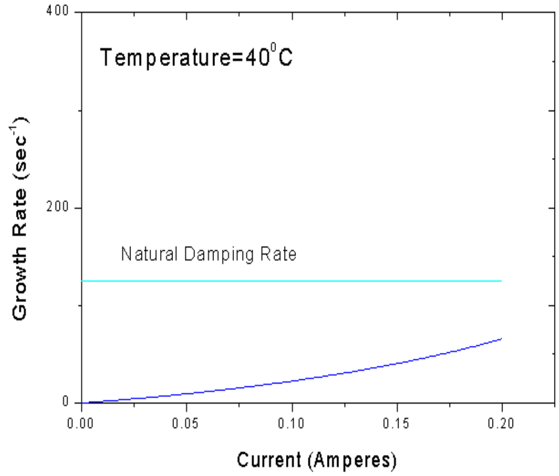

Figure 4. Threshold current for the second cavity at 40oC temperature.

As an another example, we take same mode at the cavity 1. Unlike the previous one, this mode does not have a dependence of the tuner position on the frequency, i.e. δ_{HOM}=0. Even though tuner does not purturb this mode, the thermal expansion of the cavity body can shift the mode frequency. This fact clearly show the difference between cavities with and without plunger-type tuners in response to a thermal disturbance. The calculation in this case also shows similar characteristics. From this analysis, the optimal operating temperature can be determined after overlapping all the contributions from all HOMs. In PLS the temperature tuning improved the stable operation current up to 200 mA. Above that current, a strong transverse instability appeared to limit the maximum stored current. The active feedback system will be installed in PLS, but the temperature tuning can still provide flexible and useful operating modes such as operation with longer lifetime. The system also contribute very much to reduce the power requirement of the feedback system by decreasing HOM impedances substantially even at higher beam current.

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