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SIDEBAND CAVITY FOR NIJI-Ⅲ

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Abstract

A sideband cavity was developed for the purpose of suppressing longitudinal coupled bunch instability. The main parameters of the sideband cavity were measured before its insertion into the NIJI-Ⅲ. It was concluded that the all parameters were satisfactory with the specifications. The longitudinal coupled-bunch instability was suppressed successfully in the test experiment. Additional instability was not observed as the expectation based on the preceding estimations.

Introduction

NIJI-Ⅲ is a superconducting compact storage ring at the energy of 600 MeV, which was constructed for the purpose of several industrial applications[1]. A longitudinal coupled-bunch instability(LCBI) was observed in this ring. This is unfavorable for the users who require sharp and stable light sources.

A damping system to prevent this problem with a decoupling method is considered. The decoupling method is one of the passive damping systems. A synchrotron frequency is spread by modulating the rf acceleration voltage, and individual bunches are decoupled by this method. We made the sideband cavity(SBC) which is the second cavity for suppressing LCBI. This is a re-entrant type cavity, and its resonant frequency is 289.1MHz. The characteristics of SBC were estimated and after that, it was installed into the ring.

In this paper, the results of the estimation of SBC, measurements of its higher-order mode resonances(HOMs) and present state of the experiments are reported.

Design of SBC

SBC is a re-entrant type cavity shown in Fig. 1. It is made of SUS 304. It does not have any cooling devices because the power inputted into SBC is low as written later, which contributes to reduce its cost. This cavity has two tuning plungers which make it possible to change resonant frequencies of a dominant mode independently to that of higher order modes

The design value of the resonant frequency is 289.1MHz which is $\frac{15}{8}$ times as much as the main rf frequency of 154.2MHz.

The rf voltage of SBC is decided by the request of damping time τ_i. We take the following equation[2]:

$$\Delta\omega_s \sim \frac{4}{\tau_i}. \tag{1}$$

Another equation of $\Delta\omega_s$ is given by

$$\Delta\omega_s = \frac{1}{2}\omega_s\frac{nh\pm 1}{h}\frac{V_a}{V}. \tag{2}$$

Eq.(1) and Eq.(2) lead to the V_a, where $\Delta\omega_s$ is the synchrotron frequency spread, ω_s the synchrotron angular frequency, h the harmonic number, V_a the peak voltage of SBC and V the peak voltage of rf main cavity. Assuming that $\tau_i\sim$1ms and V=100kV, we obtain V_a=1.2kV. Q-value and shunt impedance R_{sh} are estimated 2200 and 80kΩ, respectively, from the calculation. According to the calculation of V_a and R_{sh}, rf power of more than 20W is necessary for suppressing the instability.

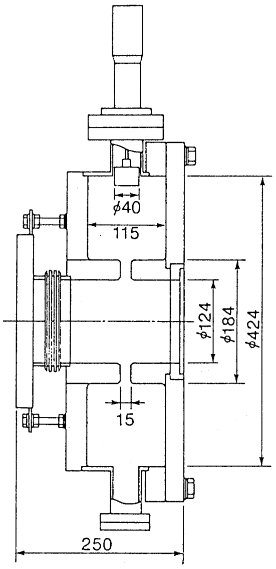

Fig. 1 A schematic cross section of SBC.

In the process of the system design, two types of cavities were considered, a strip line type and a sideband cavity type. It is reported that the acceleration voltage put into the cavity was not sufficient to suppress the instability using the former type[3]. On the other hand, the acceleration voltage in the latter type is higher than that of the former. Therefore we adopted the latter in this experiment.

Estimation of SBC Characteristics

Resonant frequency and Q – value

The measured value of the resonant frequency f was 289.15MHz. Q-value was estimated from the extrapolation of the curve which plotted loaded Qs to the coupler angle. It was shown in Fig. 2 and the value of 2100 was obtained.

Variation range of resonant frequency by shifting tuning plungers was +0.8MHz and −0.4MHz(summed value of automatic and manual plungers) shown in Fig. 3.

Shunt impedance

A shunt impedance R_{sh} was measured by *the bead perturbation method*[4]. The results are shown in Fig. 4. This is obtained when the volume of the ball is brought to zero(Fig. 4), and its value is about 60kΩ.

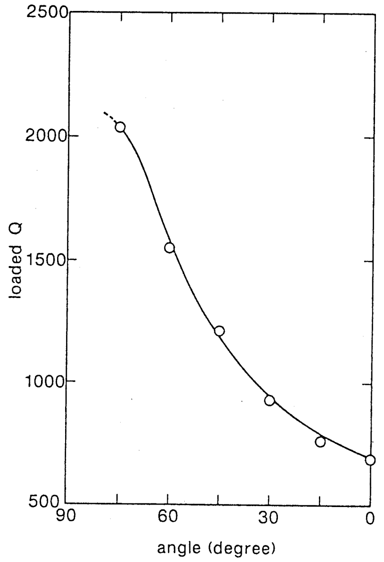

Fig. 2 Loaded Qs to the input coupler angle (pick up loop was fixed at 60°).

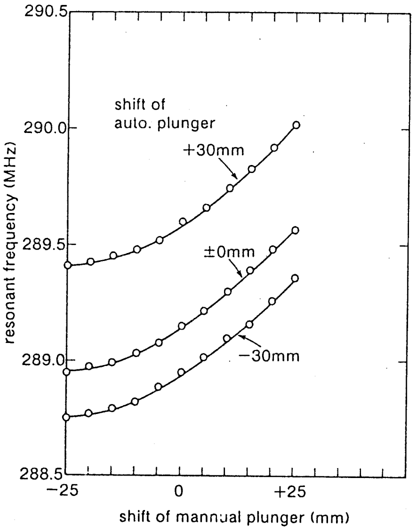

Fig. 3 Variation of the resonant frequencies to the length of two tuning plungers inserted into the cavity.

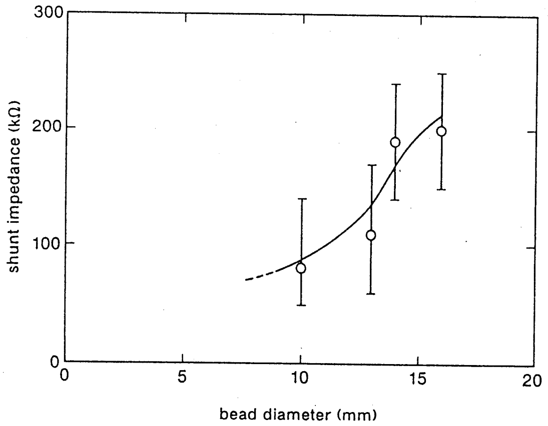

Fig. 4 Variation of the shunt impedance to the bead diameter inserted into the cavity.

Power test

The cavity was let the vacuum and the resonant frequency shifted to 288.9MHz. It is possible for this shift range to be tuned up by plungers. The difference between the power obtained from the amplifier and that reflected from the SBC were measured. It was found that the power of until 100W was able to be inputted in SBC. As a result, acceleration voltage is available until 3.5kV.

The above results are shown in Table I with calculation values. It is considered that the decrease of the values of Q and Rsh are due to the ports of SBC. The acceleration voltage is enough above 1.2kV.

Table I. Characteristics of parameters.

parameter	calculation	measurement
f (MHz)	289.05	289.15
V_a (kV)	1.2*	3.5
Q	2200	2100
R_{sh}(kΩ)	80	60
P (W)	20*	100

*required value

Measurements of HOMs

HOMs existing in a cavity may possibly cause the instability by coupling with synchrotron and betatron oscillation. It is necessary, therefore, to search for HOMs and to estimate which cross over the synchrotron and betatron frequencies.

Measurements were pursued in the range of 200~1300MHz. The Q-value of each HOM was estimated and their mode was identified. Results are shown in Table II.

Table II. The identification of HOMs' modes.

frequency(MHz)	mode	Q-value
289	TM_{010}	640
705	TM_{110}	840
1048	TM_{011}	250
1206	TM_{111}	1340
1269	TM_{020}	530

Next the coupling impedance of each HOM was calculated, and the examination of the possibility of their inducing instability or not. The longitudinal and transverse coupling impedances are given by

$$Z_{longi}(\omega^{\pm}) = \frac{R_{sh(\|)}}{1 + jQ_L(\omega^{\pm}/\omega_a - \omega_a/\omega^{\pm})}, \tag{3}$$

$$Z_{trans}(\omega^{\pm}) = \frac{R_{sh(\perp)}}{1 + jQ_L(\omega^{\pm}/\omega_a - \omega_a/\omega^{\pm})}, \tag{4}$$

where ω_a is the resonant frequency of HOM. The angular frequency components $\omega^{\pm}$ are defined as follow^5:

$$\omega^{\pm} = 2\pi f^{\pm} = nBf_{rev} \pm (\mu f_{rev} + f_{osc}), \tag{5}$$

where B is the number of bunches, f_{rev} the revolution frequency, n the harmonics of Bf_{rev}, μ the integer corresponding to the mode number of the coupled-bunch instability and f_{osc} the product of the fractional tune by f_{rev}. Approximately the growth rates of longitudinal and transverse coupled-bunch oscillations are proportional to the difference between the real part of $Z(\omega^+)$ and that of $Z(\omega^-)$:

$$\frac{1}{\tau} \propto \Re Z_{longi}(\omega^+) - \Re Z_{longi}(\omega^-) \equiv \Re(Z_L), \tag{6}$$

$$\frac{1}{\tau} \propto \Re Z_{trans}(\omega^-) - \Re Z_{trans}(\omega^+) \equiv \Re(Z_T). \tag{7}$$

Therefore, if the right hand side of Eq.(6) is positive, the instability grows.

The relation of HOMs with the synchrotron and betatron frequencies are also estimated. The results are shown in Fig.5. The vertical axis shows the $\Re(Z_L)$ and $\Re(Z_T)$, and the horizontal axis shows the difference between the resonant frequency of each HOM f_{res} and the harmonics of the revolution frequency nearest to the HOM. It was normalized by the f_{rev}. It is found that the TM_{020}-like mode is likely to excite the transverse oscillation. This mode, however, has no electric field transverse to the beam direction. It is, therefore, expected that the TM_{020}-like mode does not induce the instability. The other modes also do not because of their small coupling impedances. From the above considerations, it is concluded that the HOMs up to 1300MHz will not influence the longitudinal and/or the transverse oscillations.

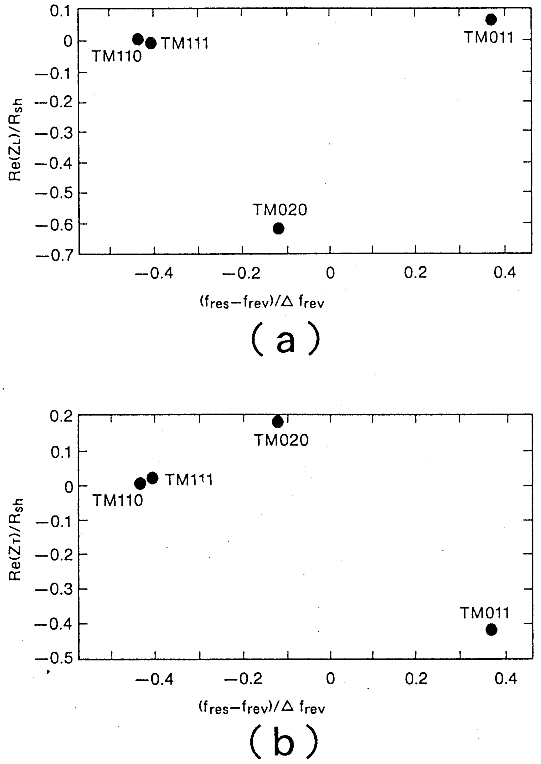

Fig.5 The coupling impedances of HOMs and the relations between HOMs and the harmonics of f_{rev}, (a) longitudinal and (b) transverse.

Test Experiment

SBC was installed into the rings. Experiments to verify the effect were implemented. A block diagram of the rf system in this experiment is shown in Fig. 6.

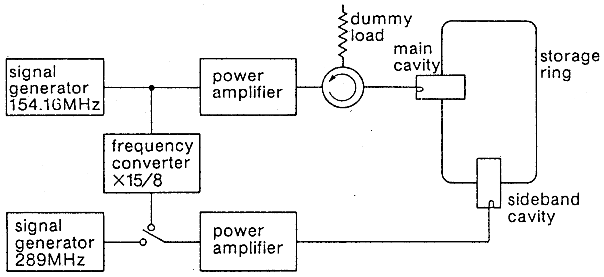

Fig. 6 A block diagram of the rf system.

The powers can be inputted in the main rf cavity and SBC independently because it is not necessary to adjust the phase of the acceleration voltage between these two cavities. The simplification of the system is realized and sufficient power can be inputted in each cavity.

Figure 7 shows the spectrum of the beam signal with and without the inputted power. Synchrotron sidebands observed are clearly suppressed with this system.

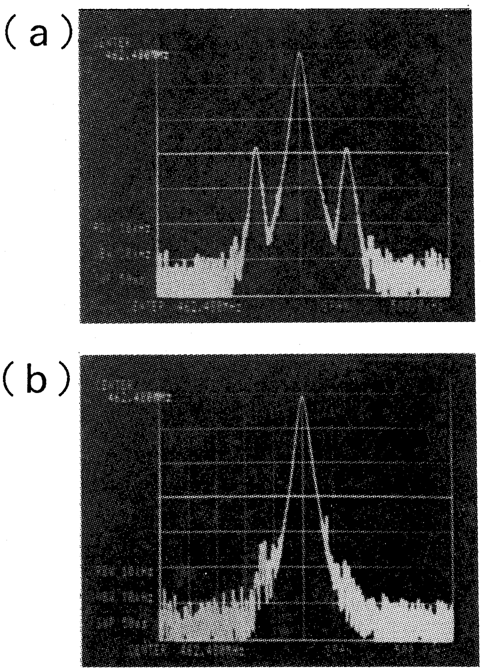

Fig. 7 Spectra of the synchrotron sideband at the stored beam current of 16 mA, (a)without and (b) with the inputted power of $V_a/V \sim 2\%$.

Conclusion

We made the sideband cavity to suppress the longitudinal coupled-bunch instability by the decoupling method for NIJI-Ⅲ. The characteristic parameters are in agreement with the designed values. Higher-order mode resonances identified in the measurements showed that little influence was imposed on the beam. Actually in the first experiment, the instability could be suppressed with this system successfully.

We have demonstrated the usefullness of the sideband cavity. The behavior of the beam under the condition of still higher powers will be investigated in future experiments

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