UPGRADING OF A RF SYSTEM OF THE NewSUBARU STORAGE RING

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Abstract

The maximum stored beam current reached to the radiation safety limit (500mA) at 1.0 GeV at NewSUBARU. The optimisation of parameters of the RF system was one of the keys for the achievement. In order to overcome high beam loading, a coupling coefficient of the input coupler was changed from 3.4 to 5.5. A time constant of a voltage feedback control was changed from 0.9 ms to 4.8 ms in order to stabilize the synchrotron oscillation. An adjustment of water temperature of the cavity and an adjustment of tuning angle were important to avoid HOM instabilities. Additional feedback loops in low-level control system effectively reduced a ripple of the klystron power supply and reduced a phase ripple of the stored beam. A SPring-8 type movable tuner (plunger) was installed and is used to avoid HOM instabilities.

INTRODUCTION

The synchrotron radiation facility NewSUBARU [1, 2] is an EUV and Soft X-Ray light source at the SPring-8 site. Laboratory of Advanced Science and Technology for Industry (LASTI), at the University of Hyogo (previously the Himeji Institute of Technology) is in charge of its operation, collaborating with SPring-8.

The ring has two operation modes for users. In 1.0 GeV top-up mode, the beam current is kept at 250±0.3 mA by an occasional injection with the gaps of the undulators closed. In 1.5 GeV mode, the beam is accelerated to 1.5 GeV and stored.

NewSUBARU has one KEK-PF type RF cavity with SiC absorber ducts [3] powered by a 500MHz/180kW klystron. The main parameters of the storage ring and the RF system are listed in Table I. The shunt impedance of the cavity is lower than the design value because of an accident at the initial commissioning.

In November of 2001 the permission of a new condition of radiation safety raised the safety limit for the stored beam current from 100 mA to 500 mA [4]. Some improvements and parameter adjustment followed the permission and we soon achieved a highest beam current of 300 mA in May of 2002, by adjusting chromaticity. However adjustments of parameters of the RF cavity was necessary in order to realize a stable operation with higher current than 200 mA and to reach to 500 mA. The maximum stored beam current of 500 mA was achieved in June 2002.

Here we report our experiences of some improvements of the RF cavity in these two years.

Table 1: Main Parameters of NewSUBARU in March 2004

Ring Parameter	
Energy	0.5 - 1.5 GeV
Circumference	118.73 m
Betatron Tune: ν_X / ν_Y	6.30 / 2.23
Chromaticity: ξ_X / ξ_Y	3.2 / 5.8
Momentum Compaction Factor: α	0.0014
RF Parameter	
Number of RF Cavity	1
RF Frequency: f_{RF}	499.956 MHz
Harmonic Number	198
Shunt Impedance: Rs	5 MΩ
Q value	28000
Coupling Coefficient of Coupler	5.5
Beam Parameters at 1 GeV	
Maximum Current; single bunch multi bunch	50 mA 500 mA
Acceleration Voltage: V_{RF}	120 kV
Radiation Loss Per Revolution: U_0	33 keV
Synchrotron Oscillation Frequency	6 kHz
Natural Emittance: ε_X	38 nm
Natural Energy Spread	0.047%
Linear Coupling	1 %
Damping Time: $\tau_H / \tau_\varepsilon$	22 ms / 12 ms

OPTIMIZATION FOR HIGH BEAM CURRENT

Coupling Coefficient of the Input-Coupler

In April 2002 the stored beam was not stable over 200 mA. The beam current dependence of the reflected power from the cavity (*Pr*), shown in Fig. 1, was not like that expected from the conventional model. The minimum *Pr* calculated from the tuning angle (-4 degrees) was 0.044 kW, which was larger than the observed. This difference can be explained by an imperfection of the directional coupler set at the wave-guide. However we have no explanation for the rapid increase of *Pr* with larger fluctuation at above the minimum. Anyway a reduction of the beam loading effect stabilized the beam. One way to stabilize the beam, an increase of the RF acceleration voltage (V_{RF}) was not accepted because it would have reduced the phase acceptance of the RF bucket and made the injection efficiency worse [5]. Our choice was the change of the coupling coefficient (β) of the input-coupler.

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In May 2002 the β was changed from 3.4 to 5.5. This β = 5.5 was the maximum coupling as far as we use the present coupler. This change pushed up the coherent synchrotron oscillation frequency (*fs*) and raised the Robinson's stability limit [6] to higher than 500 mA as shown in Fig. 2.

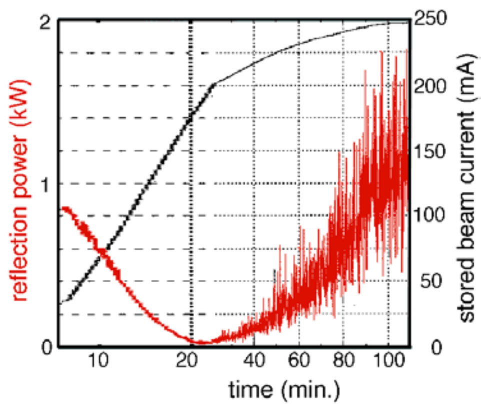

Figure 1: RF power reflected from the RF cavity (*Pr*) and the stored beam current before the change of the coupling constant (β). The RF acceleration voltage was V_{RF} = 117kV. The reflected power was not stable at over the current with minimum *Pr* (200mA).

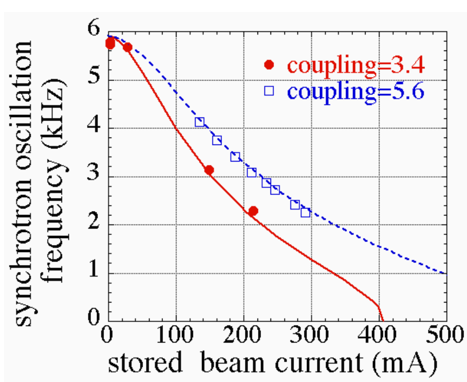

Figure 2: Synchrotron oscillation frequency (*fs*) shift by the beam loading. The shaded circles with β= 3.4 and the open squares with β= 5.5, both with V_{RF} = 107 kV. The solid and broken lines are the results of theoretical calculations. The *fs* is zero at the Robinson's stability limit.

ALC Feedback

The next step was the parameter adjustment of the low-level control. When the f_S was low the automatic voltage level control (ALC) enhanced the phase modulation and excited the coherent synchrotron oscillation [7].

We changed the time constant of the ALC feedback loop from 0.9 ms to 4.8 ms. With the new parameter the increase of the synchrotron oscillation amplitude at over 250mA disappeared as shown in Fig. 3.

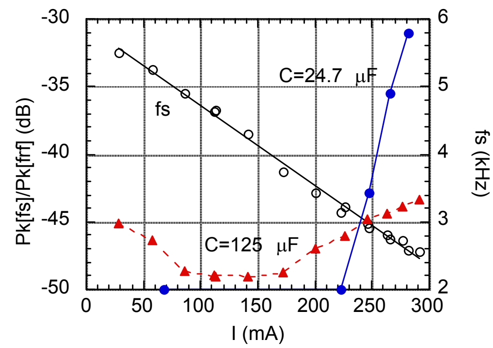

Figure 3: Enhancement of the synchrotron oscillation by ALC. The shaded triangles and the circles are relative amplitude of synchrotron oscillation side bands to the main RF acceleration frequency, at before (capacitance *C* = 24.7 μF, time constant = 0.9 ms) and at after the change (*C* = 125 μF, time constant = 4.8 ms). The open circles are *fs*. With the small *C* the oscillation amplitude increased at *fs* < 3 kHz. At this time V_{RF} = 116kV and β= 5.5.

Cavity Temperature and HOM

In fall of 2002 we found a correlation between the storable beam current and the cooling water temperature, which is shown in Fig. 4 (a). In January 2003 the temperature was raised up to 36 ^{O}C, which was close to the power limit of the temperature control system. The amplitudes of HOM, frequencies of 790MHz (vertical TM110) and 795MHz (maybe longitudinal TM011), decreased with the rise of the temperature (Fig. 4 (b)). This change was necessary for the stable beam accumulation up to 500 mA.

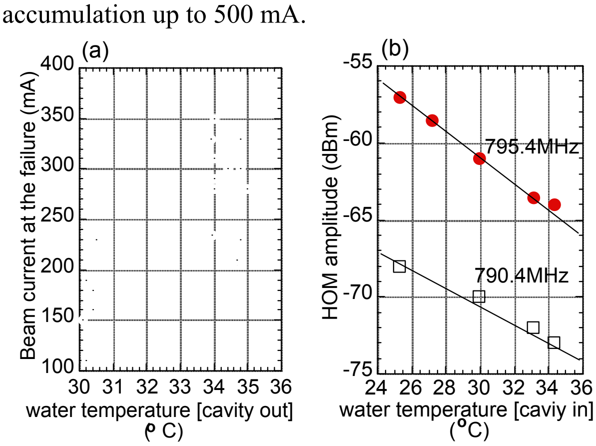

Figure 4: The effect of the water temperature.
(a) Storable beam current vs. temperature of cooling water of the cavity. (b) Water temperature vs. amplitude of HOM signals picked up from the cavity.

Tuning Angle and HOM

The next was the HOM with frequency of 792MHz (horizontal TM110). At the lower current of 50 -100 mA it made the beam injection unstable (we saw a small jittering of *Pr* in Fig.1). At the higher current it caused an abrupt beam loss when the V_{RF} was raised for the acceleration.

A survey of stable area made it clear that the beam was not stable with the tuner position (horizontal plunger) from 6.2mm to 7mm as shown in Fig. 5. A change of tuning angle of the cavity, from -5^{O} to -21^{O}, shifted the working area of the tuner position out of the unstable area. Here we defined the tuning angle as the angle between the generator voltage supplied by the klystron and the cavity voltage. With the new angle parameter, we could start the user operation at 1.5GeV at over 300 mA.

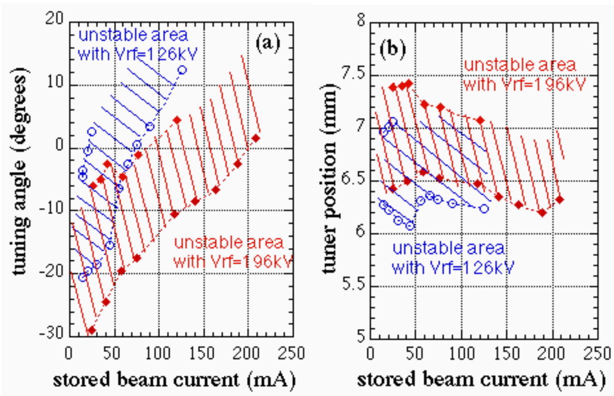

Figure 5: Unstable area of 792MHz HOM (a) with parameters of tuning angle, stored beam current, and the RF acceleration voltage (V_{RF}). (b) The same area with the parameter of tuner position instead of the tuning phase.

The shift of the unstable area in (b) was made by a shift of the cavity temperature by the cavity power loss.

Installation of HOM Tuner

Using the summer shutdown of 2003 we installed the remote-controllable vertical plunger, we refer it by 'HOM tuner', instead of the Cu block (fixed tuner). This was a new knob in order to avoid HOM. An adjustment of HOM tuner position increased the tolerance for the bunch filling. The R&D of the optimisation of HOM tuner position is still under way.

OTHER IMPROVEMENTS

Klystron Feed-back Loops

In the summer shutdown of 2002 we installed the additional low-level feedback loops in order to cancel the effect of the ripple of the klystron power supply. Before the installation there had been feedback loops to compensate the beam loading and we had observed a fluctuations of the beam timing. The fluctuation amplitudes agreed with the calculation from the voltage ripple of the power supply.

Fig. 6 shows the effectiveness of the new loops. They almost eliminated the ripple peaks at the low frequency region.

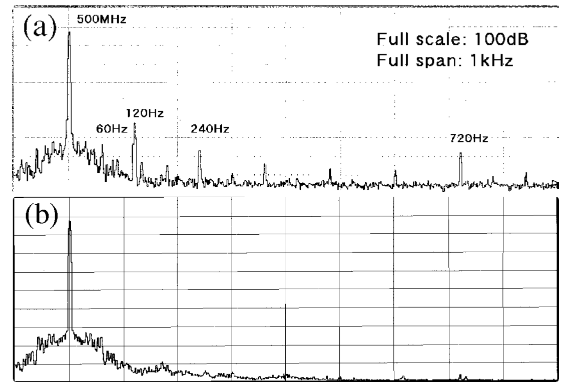

Figure 6: Side bands of the RF frequency of the beam signal without (a) and with (b) the klystron feedback loops. The vertical scale is 10dB/div. The horizontal axes are the same for (a) and (b), 100Hz/div. The highest narrow peaks are the RF frequency.

Phase Modulation System

In 2002 we installed a phase modulation system to excite a longitudinal quadrupole-mode bunch oscillation developed by S. Sakanaka *et al.* [8]. It was expected to separate the stable synchrotron oscillating state into three (two oscillating states and one non-oscillating states) and improved the Touschek lifetime. The improvement of the total beam lifetime was about 10% at 1.5 GeV. However it is not used at 1.0 GeV top-up mode because we could not inject the beam with the phase modulation.

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