BEHAVIOR OF SYNCHRONOUS PHASE ANGLE AT SUDDEN RF VOLTAGE CHANGE

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Abstract

The SPring-8 storage ring is equipped with four RF stations, which can provide 16MV acceleration voltage. The stored beam of 100mA is lost when the operation of an RF station of 4MV is interrupted due to some interlocks such as large reflection from cavity. The decrease in accelerating voltage of 4MV (quarter of 16MV) in adiabatic condition does not make a reduction of the lifetime, but the sudden change of the voltage causes transient behavior and the stored beam is lost. We developed a new method to moderate this transient phenomenon by adjusting the phase of the RF reference signal when an interlock system is triggered. We report preliminary result on the test using this method.

INTRODUCTION

SPring-8 is a 3rd generation X-ray source. Its beam energy is 8GeV. The harmonic number is 2436 and the revolution time is 4.8μs. The stored beam current is kept constant at 100mA by top-up injection [1]. Four RF stations (A, B, C and D) are evenly distributed along the ring. The reference RF signals of 508.58MHz are delivered using optical fiber from a master oscillator. Fig. 1 shows a schematic diagram of the RF system. The acceleration voltage at one RF station is 4MV by using eight single-cell cavities and total acceleration voltage is 16MV. One klystron is used at each RF station except the A station, where two klystrons are used. The energy loss per turn by bending magnets is 9.2MeV. And the beam loss with minimum gap positions for all insertion devices (ID) is over 2MeV. But in usual user operation the loss is around 1MeV depending on their gap positions.

There is an interlock system at each station to protect a klystron or a cavity input coupler from arcing or large reflected power. When an interlock signal is received from one of the four cavities at the A station, the power of the klystron connected to the cavity is cut off and the acceleration voltage is changed from 16MV to 14MV. This voltage reduction does not affect to the stored beam current of 100mA. But if an interlock signal is received at the one of the B, C and D station, the total acceleration voltage is reduced from 16MV to 12MV and the stored beam is lost. This makes an interrupt of the X-ray user's experiments, and reduces the availability of the facility, which should be avoided. One direct solution to prevent the beam loss is to increase the number of klystrons and reduce the voltage change in case of the power off due to an interlock signal. But it is very expensive and needs long shutdown period for the facility. So we try to develop another counter measure for this beam loss.

The possible mechanism of the beam loss is as follows. When an interlock signal is detected, the output power from the klystron is cut off. Then the acceleration voltage of the RF station is reduced with a time constant of the filling time of the cavity, and the decelerating voltage is appeared at the RF station induced by the stored beam. The stored beam feels the reduced accelerating voltage and starts synchrotron oscillation. As the beam moves to the higher synchronous phase, the loadings for the cavities at the remaining RF stations are increased. This makes the reduction of the accelerating voltage of the remaining station because the klystron output power is almost constant in a time range of milliseconds. This makes the further increase of the synchronous phase angle. If the voltage is enough high to keep the beam within the momentum acceptance of the ring (about 2%), the beam is not lost. But if the beam energy loss exceeds the acceptance, the beam is lost.

The cause of beam loss is energy loss of the beam, which causes an excursion of synchronous phase angle. So if we can provide enough voltage to the beam by adjusting the synchronous phase, the energy reduction will be minimized and the beam will be within the acceptance.

During the user time, we activate a feedback loop to suppress the coherent synchrotron oscillation [2] where the FM modulation is applied to the master oscillator

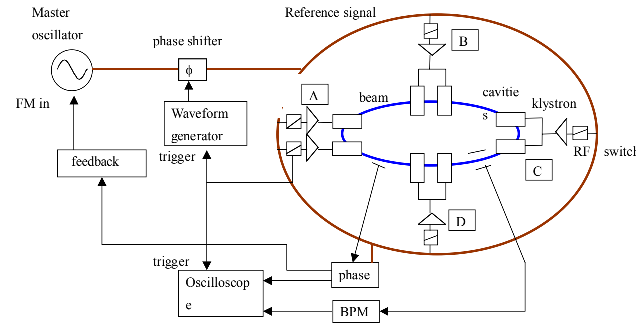

Figure 1: The schematic diagram of the RF system.

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using the beam phase signal. We expect this system will also work to suppress the transient beam phase movements.

MEASUREMENTS

We made measurements on the energy and the synchronous phase angle of the stored beam. The beam energy was corresponded to the horizontal beam position at a dispersive section. The signals from four button electrodes were detected by a diode detector and the beam position was calculated from these signals using analog summing and dividing circuits. The 3dB bandwidth of this BPM system is 100kHz, which is wide enough to measure the 2kHz synchrotron oscillation. The averaged beam phase was measured by detecting the components of 508.58MHz signal from the button pickup electrode using a phase detector [3]. The 3dB bandwidth of the phase detector is 100kHz.

The behavior of the beam at the sudden RF voltage change was checked by the following procedure. The RF switch of one RF station was cut off by an artificial interlock signal. The status of the RF switch was sent through an optical fiber to the room where master oscillator was located to activate the phase compensation in the reference line. The compensation was made using a waveform generator triggered by this status signal. The status signal was also sent to the monitoring room and used to trigger the oscilloscope for data acquisition of the beam phase and the beam energy. As for the compensation waveform, we applied a saw tooth waveform. The rise time (10%-90%) was about 12µs. And fall time was 50ms (10200turns), which is much longer than the synchrotron oscillation period of 0.5ms. The delay time to send the status signal was about 20µs. The filling time of the cavity was about 12µs.

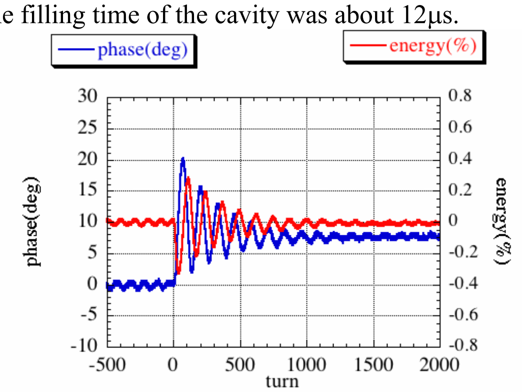

Figure 2: The beam energy and phase signal without phase compensation at a condition of 2MV RF voltage change for 100mA multi bunch stored beam.

RESULTS

The transient motions of the beam phase and energy were measured at a condition of the stored current of 100mA with a multi-bunch filling pattern where twelve 160-bunch-trains were stored. The RF voltage was initially 16MV and one RF switch at the A station was turned off which resulted in 2MV reduction of total acceleration voltage. The result was shown in Fig. 2. The beam energy was reduced nearly 0.35% and the beam started synchrotron oscillation. The maximum deviation of the synchronous phase reached about 12degrees from new steady state of +8 degrees. The oscillation of the center of mass for the beam was damped with a time constant of 0.8ms.

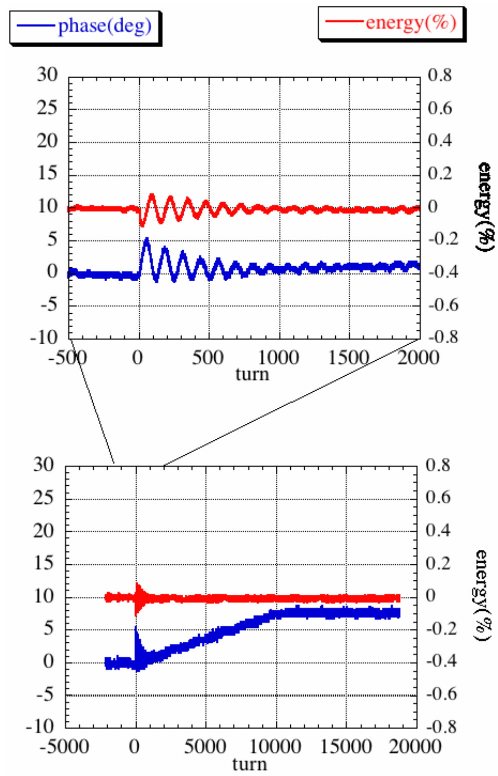

Figure 3: The energy and the phase signal with phase compensation at a condition of 2MV RF voltage change for 100mA multi bunch stored beam.

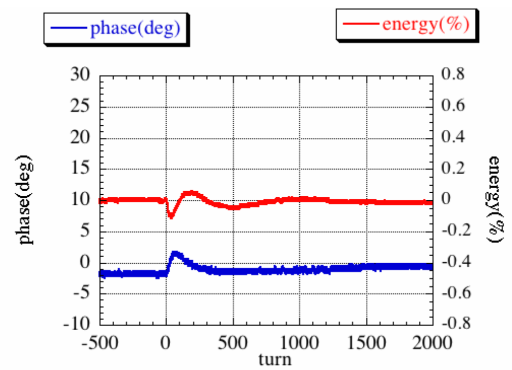

Figure 4: The beam and phase signal with phase compensation and with activating the feedback loop for suppression of coherent synchrotron oscillation. Other conditions are same as the case in Fig. 3.

Then the phase compensation was applied. The peak amplitude of the compensation waveform was adjusted to correspond the difference between the synchronous angle at 16MV and that at the 12MV, i.e. 8 degrees. The beam phase and energy movement at these conditions were shown in Fig. 3. The excursion of the phase was reduced from 12degrees to 2degrees and that of the energy was reduced from 0.35% to 0.1%. The amplitude was reduced about factor 3. After the initial small oscillation, the synchronous phase was reached to new steady state smoothly after about 10000turn.

The effectiveness of the feedback loop system for suppression of coherent synchrotron oscillation was checked. Fig.4 shows the measured result for activating the loop and other conditions are same to the case in Fig. 3. Comparing the Fig. 3 (feedback off) and Fig. 4 (feedback on) the effectiveness of the feedback was confirmed.

Then the voltage change was increased to 4MV by turning off the RF at B station. Fig. 5 shows the beam phase and energy excursion with the several stored current from 1mA to 100mA. The compensation works well until the current of 70mA, but at 80mA the current was reduced to 1mA. And at 100mA the stored current was completely lost. A fast oscillation in the beam phase with 80mA current after 200turn is due to the synchrotron oscillation of the remained 1mA beam.

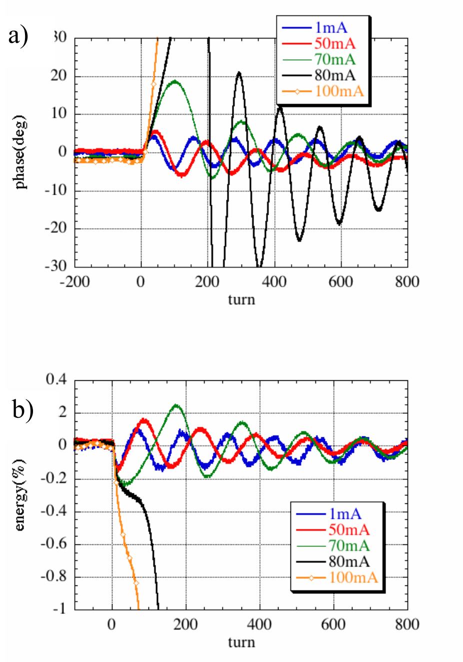

Figure 5: The time evolution of the beam phase (a) and energy (b) with several stored current at 4MV RF voltage change with activating the reference RF phase compensation.

DISCUSSION

The period of the synchrotron oscillation becomes longer as the stored current is increased from Fig. 5. This is due both to the increase of the induced voltage by the beam at the turned off cavities, and to the decrease of the accelerating voltage by the beam loading at the remaining cavities whose input power is kept on. At the current of over 80mA the energy loss of the beam exceeds the momentum acceptance.

It is very important to activate the compensation as fast as possible because it is no use to increase the acceleration voltage after the energy loss of the beam exceeds the momentum acceptance. We use a waveform generator to make the compensation pattern and it has a finite memory. To generate the 50ms decay pattern, the clock frequency can not be high and this makes slow rise time of the waveform and large delay from the start trigger. We are preparing a new dedicated circuit to generate this compensation waveform to reduce the rise time and the dead time of the system.

An implementation of this phenomenon to the ring model [4] is in progress. The analysis of the cavity voltage change, reflected power from the cavity is under way. By using a simulation code we will check the effectiveness of slight increase of the operation voltage, increase to 4.5MV/station for example.

CONCLUSION

We measured the beam phase and the energy at a sudden voltage change. The transient oscillation amplitude in longitudinal direction was so large that the stored beam was lost at a 4MV voltage change with stored current of 100mA. There is a possibility to keep the beam current by compensating the phase angle of the reference RF signals fed to the remained RF stations. At present we could not prevent the beam loss with this scheme with 100mA current. Counter measures are under consideration. Reduction of dead time in phase compensation system is one candidate. A slight increase of the acceleration voltage may cure the beam loss. We also check the procedure to turn on the stopped cavities and the margin of klystron power with ID gaps closed. We will check whether the phase compensating system increase the phase noise, which is important not to increase the effective energy spread of the beam. This system will be cost effective to improve the reliability on RF failures and may be adapted to other facilities with heavy loading and with plural RF stations.

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