TOP-UP INJECTION CONTROL USING BUNCH CURRENT MONITOR AT SPRING-8

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Abstract

We developed bunch current monitor system used for top-up operation at the SPring-8. The requirement from X-ray user is to keep the bunch currents stored in the ring constant within 10% peak to peak. The minimum bunch separation is 2ns. So the monitor system must have a wide analogue bandwidth, high accuracy and high reliability. We use an oscilloscope to measure the signal from button electrodes. The reproducibility of the system is less than 1%. This bunch current monitor is used for injection control and the deviations of bunch currents are kept within the required value.

INTRODUCTION

The SPring-8 is one of the third-generation X-ray sources [1]. To cope with high brilliance and long effective lifetime, top-up operation has been applied for user time since May 2004. In this mode frequent beam injection is done to keep the total stored beam current constant. This operation mode was introduced firstly at APS [2] and at SLS [3,4]. Many other synchrotron radiation facilities are also planning to introduce this mode. The X-ray users in the SPring-8 require many kind of filling patterns [5]. In a filling of multi-bunch pattern, the injection bucket is selected according to the injection table every five minutes during top-up operation. Some users want a pattern of equally spaced single bunches with high current. In these several bunch modes, the injection is done to the bucket where the deviation from the nominal value is largest with an interval of one minute. For these filling patterns, measurement of bunch current is indispensable. It requires measurement of bunch current for all buckets within short acquisition time. We developed bunch current monitor system using button electrodes and an oscilloscope with wide analog bandwidth [6]. The following shows the brief review of the system and experience using the system in the beam injection control.

BUNCH CURRENT MEASUREMENT

At the SPirng-8 the bunch spacing is about 2ns and the number of the total buckets is 2436. The bunch length is around 40ps. To distinguish the current of each bunch, wide analogue bandwidth is required for the current monitor. Figure 1 shows the schematics of the monitor system. We use an oscilloscope TDS7404 made by Tektronix. Its analogue bandwidth is 4GHz and the sampling rate is 20Gs/s. Figure 2 shows an example of measured pulse shape from the button electrode with the condition that a single bunch is stored in the ring. Figure 3 shows its spectrum measured by using a HP70004A spectrum analyzer. The pulse width is mainly determined by the capacitance of the electrode, which is about 8pF. The roll off in higher frequency region is determined by both the effect of the finite bunch length and the attenuation by the coaxial cable (Suhner SPE cable with the length of 25m). The revolution signal from the timing control system is used for the trigger signal of the oscilloscope [7]. The revolution signal is obtained dividing the RF reference signal by the harmonic number 2436. As can be seen in the Fig. 2 the signal level is recovered within 1.5ns, which is shorter than bunch interval of 2ns. So the bunch separation is enough for our use.

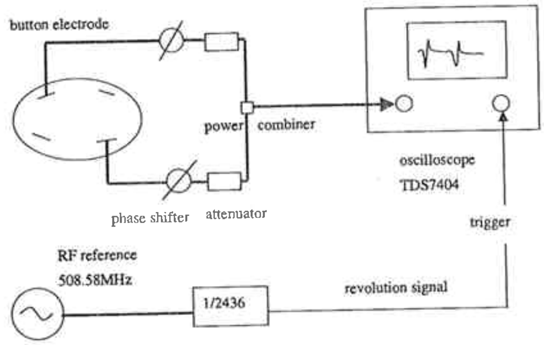

Figure 1: The schematics of RF signal connection in the bunch current monitor system.

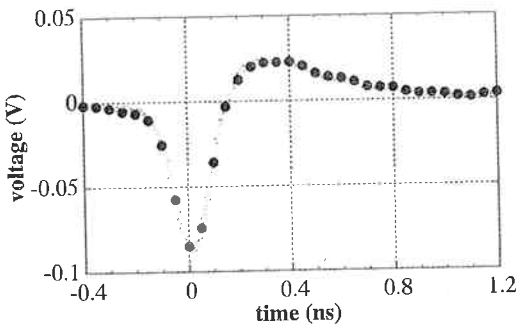

Figure 2: An example of waveform from the button electrode. Single bunch beam was stored.

For measuring the bunch current, it is needed to reduce the effect from the transverse beam oscillation. For this purpose, signals from two electrodes located in opposite direction are summed up by using a power combiner. The

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attenuators and phase shifters are installed and the amplitude and the timing of these signals were carefully adjusted. To reduce the fluctuation further the data is taken in the average mode with average number of one hundred.

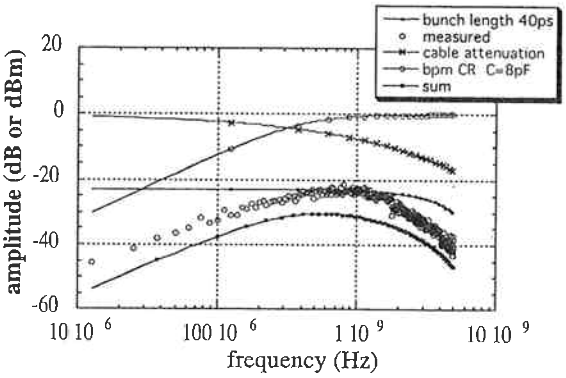

Figure 3: Spectrum of the beam signal measured by using a spectrum analyzer.

To calculate the bunch current from the measured voltage data, we extracts the minimum voltage of the beam signal. The linearity was checked by measuring both the minimum voltage from the oscilloscope and the reading value of the DCCT with various values of the stored current. Figure 4 shows the result. The variation from the linear line was less than a few percent. In the user operation the actual bunch currents ranges from 0.3mA to 1.5mA.

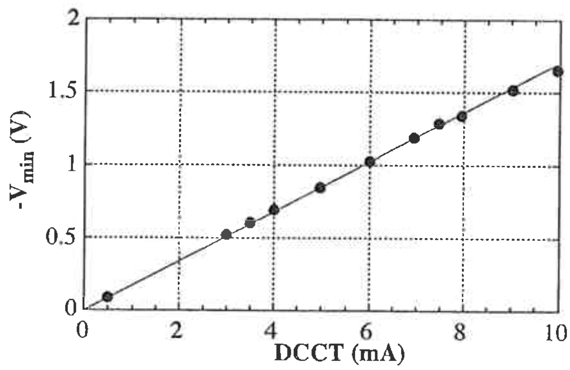

Figure 4: The minimum voltage measured by the oscilloscope and the reading of the DCCT.

The software program for the bunch current measurement is running on a UNIX workstation. Schematic diagram of the program is shown in the Fig. 5. The program is based on a framework named MADOCA, which is developed by the SPring-8 control group [8]. The control commands are sent to the oscilloscope by GPIB interface. The voltage data of 101kpoints is saved in a NFS mounted disk. The sampling rate of 20Gs/s is not enough to evaluate the minimum voltage of the pulse. The peak may be located between the sample points. So we make interpolation by using sin(x)/x function and the equivalent sampling rate is increased to 120Gs/s. Figure 2 shows both the measured points (filled circle) and interpolated points (open circle). Using this method the system is robust against timing problems. Trigger signal may have jitter of several tens picoseconds. The signal from the beam also changes according to the beam loadings produced by the ID gaps changes and changes of the filling patterns. Even if the timing movement reaches to a few hundreds picoseconds the interpolation recovers the minimum value. The bunch currents are calculated multiplying the minimum values by the conversion coefficients and are recorded in the online database [9].

Elapsed time for one measurement is about 24 seconds. Its contents are a) one second for reading the minimum value using a oscilloscope intrinsic function and setting the vertical scale, b) eleven seconds for averaging of one hundred times, c) nine seconds for file transfer by NFS, d) one second for interpolation, e) one second for writing data to the online data base. The time for one measurement is shorter than the injection interval of one minute.

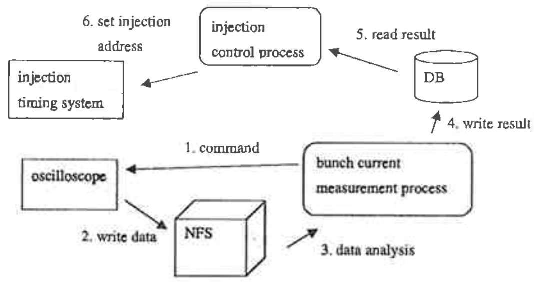

Figure 5: Schematic diagram of the bunch current measurement program.

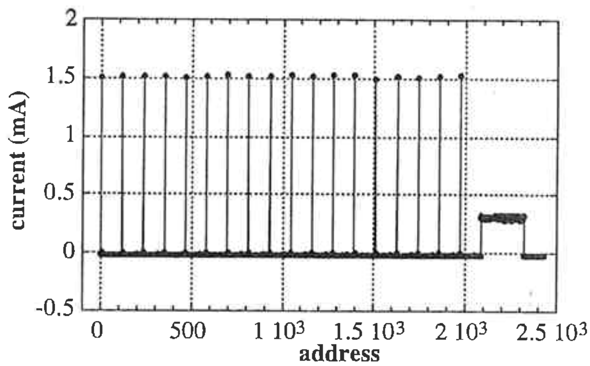

Figure 6: An example of the filling pattern at the SPring-8. 18 single bunches and 116bunch train.

INJECTION CONTROL

During the top-up operation mode, the beam injection is done when the total stored beam current is decreased less than a set value (usually 99.0mA). The injection control program executes the bunch current monitor process, calculates the maximum deviation from the nominal value and decides which bucket to be injected.

Figure 6 shows an example of the filling pattern at the SPring-8. Equally spaced 18 single bunches with 1.5mA and successive 116 bunches (bunch train) were filled to the ring. In this filling pattern, the beam is injected to the bucket of the singles whose current is lower than a threshold value. If the all single bunches are over the threshold value, the beam is injected to the bucket with minimum current in the bunch train.

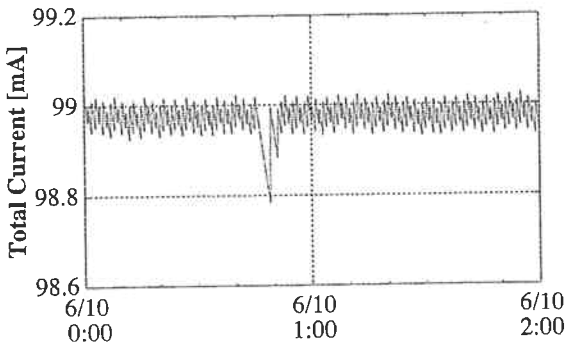

Figure 7: Trend graph of the total stored current for two hours.

Figure 7 shows the trend of the total stored current. The values were between 98.94mA and 99.02mA except the values at 0:45 to 0:55 when the top-up was stopped by some operational reasons. The trends of the bunch current for 18 single bunches are shown in Fig. 8. The deviations of the bunch currents are kept less than three percent.

Another example of the deviations of the bunch currents is shown in Fig. 9. In this case the variation is less than four percent over one week.

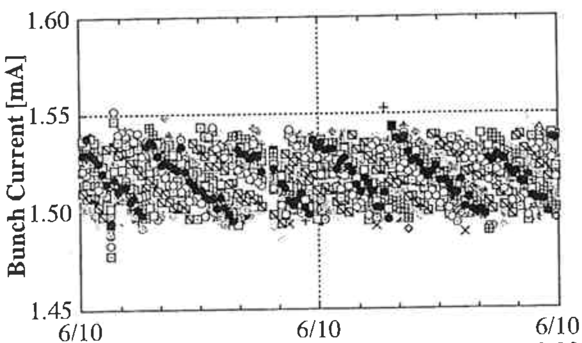

Figure 8: Trend of the bunch currents for singles.

CONCLUSION

The bunch current measurement system is working stably at the SPring-8. The current deviation is kept less than 10% peak to peak in usual top-up operation. To speedup the acquisition of bunch current data, new program is under test. In this new program, data processing is done within the oscilloscope using the cpu of the Windows OS. Another point of the new program is that the results are written into the database directly. In this method, we do not need NFS mount and reduce the processing time from 24 seconds to 7 seconds. Long-term test is almost finished. Using new bunch current monitor system, more frequent beam injection will be possible and the current deviation can be reduced further.

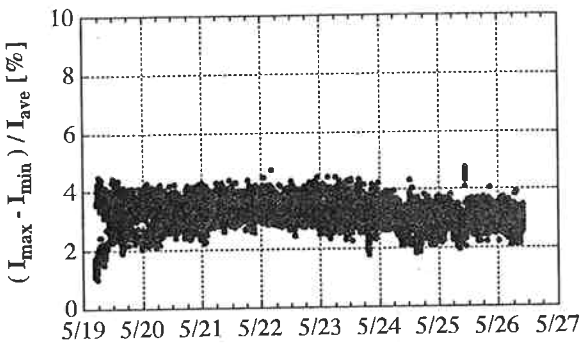

Figure 9: An example of the deviations of the bunch currents.

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