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Monitoring system for a synthesizer at SPring-8 synchrotron radiation facility and obtained results

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ABSTRACT

Beam orbit distortion in all dispersive sections was observed in the SPring-8 storage ring during beam commissioning. In order to confirm the stability of the radio frequency (RF) synthesizer, a monitoring system was developed. The system consists of a frequency counter referenced to a global positioning system (GPS) receiver. With this system, the output of the synthesizer, which uses an external 10 MHz-Rubidium atomic clock with the time accuracy of $\Delta t/t = 10^{-12}$, is correctly monitored with 11 digits absolute accuracy, verifying that the synthesizer works well. Measurement of the circumference of the SPring-8 storage ring reveals the effect of tidal forces and seasonal temperature variations on beam orbit. To maintain the center axis of photon radiation in experimental beam lines, a beam energy correction is carried out. The frequency of the RF synthesizer is changed every 5 min with 10-digit accuracy. This corresponds to an energy accuracy of $\Delta E/E = 1.16 \times 10^{-6}$. The monitoring system for the synthesizer and obtained results are described.

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1. Introduction

Construction of SPring-8 (Super Photon Ring-8 GeV) synchrotron radiation facility [1,2] was almost completed by the end of 1996 with beam commissioning for the storage ring beginning in March of 1997. User operation was started in October of the same year on schedule at the designed beam energy of 8 GeV. Initial beam current of 20 mA was increased up to the nominal value of 100 mA by May 1998. As an accelerator complex, SPring-8 consists of three parts: 1-GeV Linac, Booster synchrotron and Storage ring [2]. The circumference of storage ring is 1435.95 m long. The storage and booster synchrotron rings are operated at 508.58 MHz, while the Linac operates at 2856 MHz and is completely synchronized with 508.58 MHz [3]. Therefore there is only one synthesizer to control electron beam. The radio frequency (RF) of 508.58 MHz is also supplied for synchrotron radiation users in the experimental hall, and the accuracy including time jitters is maintained less than a few picoseconds throughout the SPring-8 site. This has been verified by measuring the correlation between laser system and synchrotron radiation pulses from the beam [4]. Under those conditions, a phenomenon of horizontal global shift of beam orbit in all dispersive sections of the storage ring was observed. We initially suspected the stability and accuracy of RF generated by the synthesizer. In order to check the synthesizer, we assembled a monitoring system using a frequency counter. This verified that the synthesizer had been working correctly, and the shift of beam orbit was due to tidal forces as observed in LEP [5,6].

Since the SPring-8 storage ring is one of the synchrotron radiation facilities, it is not always required to maintain the beam energy to be constant. However, the stability of center axis of radiated photon should be maintained at all times. In particular, some synchrotron radiation users make use of single bunch beam and require time accuracy of a few picoseconds to detect radiation from the excited states of samples. The expansion and contraction of the ground due to tidal forces and annual temperature change of the ground at the SPring-8 site result in the coherent movement of all apparatuses: magnets and beam lines, and the orbit center of stored beam is shifted from the center of beam orbit. The best way to correct beam energy is to change the fundamental radio frequency. This is done automatically on a period of around 5 min. With this method, beam energy is corrected with an accuracy of $\Delta E/E = 1.16 \times 10^{-6}$. The influence of changing RF shifts the arrival timing of synchrotron radiation from a single bunch beam as well as electron gun trigger timing in a linac depending on RF. However, a 508 MHz-synchronous universal counter (508 MHz SUC) [11] completely cures those problems.

Historical observation of horizontal beam orbit distortion in the SPring-8 storage ring is mentioned in Section 2. The monitoring system for the synthesizer is explained in Section 3. Since we

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obtained a few issues related with the synthesizer using the monitoring system, we describe them in the same Section 3. The method of beam energy correction is mentioned in Section 4. In the same section, we discuss the influence of changing the fundamental radio frequency on the Booster ring, the Linac and experimental beam lines in the storage ring. Stored beam energy in a circular electron–positron collider is affected by terrestrial tides resulting in variation of beam energy up to 120 ppm [5]. The method presented in this paper is useful to suppress the influence down to 1 ppm, which is discussed in Section 4. Results obtained from the monitoring system show clear signals for two cycles per day tidal period as well as seasonal change of the circumference of the SPring-8 storage ring. We also describe results obtained by Fourier analysis for the variation of RF signal quantitatively, which is consistent with the geophysical components of earth tides. This is also discussed in Section 4.

2. Observation of horizontal closed orbit distortion and its verification

During beam commissioning of the SPring-8 storage ring, an excess movement of the horizontal orbit was observed with a period of a little longer than one day. The periodicity of the change became apparent when operation of the machine for the first time continued for more than two days in May 1997 [6]. At that time, the stability of synthesizer was suspected. If the frequency generated by the synthesizer were drifting slowly, it would not be strange to observe a closed orbit distortion (COD) at dispersive sections. To test the stability of synthesizer (a Rohde Schwartz SMHU58), we decided to make a monitoring system. The details are mentioned in next section. This system, which consists of a reference clock generator and a frequency counter with the time accuracy of $\Delta t/t = 10^{-12}$, was setup by the end of 1997. At that same time, automatic 1 Hz data collection from the frequency counter began. One week passed and we checked the obtained data, and found that the synthesizer had been working correctly. The Rohde Schwartz SMHU58 has a good time accuracy of $\Delta t/t = 10^{-8}$, which just corresponds with the specification. Thus it was shown that the synthesizer itself was not the cause of the excess movement of horizontal orbit. It was concluded that the movement of beam orbit was attributed to the effect of the tidal forces [6].

3. Monitoring system for the synthesizer

In order to monitor the synthesizer of Rohde Schwartz SMHU58 with the time accuracy of $\Delta t/t = 10^{-8}$, a reference clock with time accuracy at least one order of magnitude better is required. We found that the Global Positioning System (GPS) is convenient and inexpensive. As all satellites for GPS equip with Cesium atomic clocks, of which time accuracy is around $\Delta t/t = 10^{-15}$, we decided to adopt GPS system as a reference clock for the monitoring system. The final monitoring system is schematically shown in Fig. 1. The system consists of three parts: an antenna, a receiver of GPS signal and a frequency counter. In the figure, one can see the different type of synthesizer. We actually used a Rohde Schwartz SMHU58 at the beam commissioning time. The monitoring system in Fig. 1 is not original one. In the beginning time, we did not use a Rubidium atomic clock as an external one for the synthesizer. In order to suppress the phase noise of fundamental acceleration frequency generated by high voltage power supplier for a klystron, we made a feedback system [7]. Since then, we have been using an Agilent 8257D signal generator. We also added an external reference clock generated by Rubidium atomic clock for the synthesizer. The accuracy of the Rubidium atomic clock was tested using a frequency counter as shown in Fig. 1 and verified to be $\Delta t/t = 10^{-12}$. The result obtained implies that the RF monitoring system as shown in Fig. 1 has a better accuracy than $\Delta t/t = 10^{-12}$.

To monitor the frequency generated by the synthesizer, we adopted a frequency counter with 12-digit accuracy: HP53132A. A GPS referenced frequency of 10 MHz was fed to the frequency counter as shown in Fig. 1. Data from the frequency counter is transferred through GP-IB interface to VME system, which is not shown. As we mentioned, we initially used a Rohde Schwartz SMHU58. With this device, the frequency counter of the monitoring system indicated that the first eight digital numbers were stable and the ninth digit momentarily varied. It should be noticed that even if one wants to set nine or more digital numbers, the SMHU58 does not have the capability. When we were considering to adopt

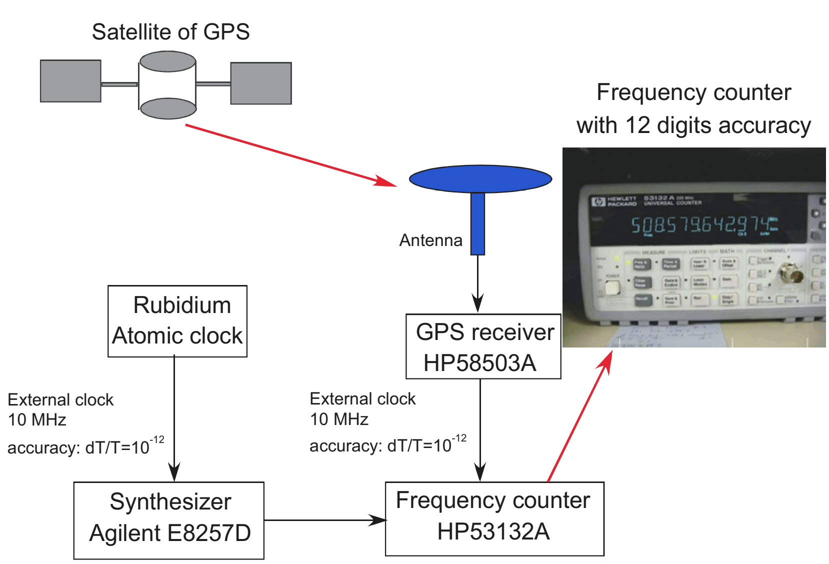

Fig. 1. A monitoring system to check the output signal from a synthesizer is shown. At the beam commissioning time, Rohde Schwartz SMHU58 as a signal generator had been used. Agilent 8257D was later adopted to suppress the beam energy oscillation in the synchrotron frequency. The Rubidium atomic clock was also introduced at the same time when Agilent 8257D was installed. The antenna is set up on the roof of the building and the GPS signal is transferred to the GPS receiver through a co-axial cable. The frequency data measured by a frequency counter is transferred through GPIB interface to VME system.