

HOW TO STABLY STORE ELECTRON BEAM IN A SYNCHROTRON RADIATION FACILITY FROM THE POINT OF VIEW OF AN RF SYSTEM DESIGN

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Abstract

In any synchrotron radiation facility, the users wish that electron beam were stably stored without beam abortion for as long as possible. It must be recognized that RF system is a main cause of beam abortion. In order to store beam stably, it is necessary for staffs in charge of RF system to foresee various beam instabilities and to take measures. Before discussing coupled-bunch instability problems, one should understand some trivial issues such as ion trapping and fundamental acceleration frequency modulated by high voltage ripple. The former causes transverse mode instability and the latter shakes stored electron beam longitudinally in RF cavities. In newly designed synchrotron radiation facilities, those issues mentioned above should be suppressed before beam commissioning. As for other issues relating with RF system, we would like to state the importance of a water-cooling system with stable temperature for cavities, and the electric earth problem of low level RF system and high voltage power equipment of a klystron. We describe how we have managed those issues in designing of SPring-8 RF system of the storage ring.

INTRODUCTION

Those who design and construct synchrotron radiation facilities have to understand what kind of beam instabilities exist. So far various instability problems taking place in hadron and electron storage rings have been fairly discussed and solved well. However, it seems that some problems have not yet been solved or have not yet been understood at synchrotron radiation facilities in the world. We think that the most serious problem is those who are related to the accelerators do not recognize the problems. In this article, we intend to review on fundamental beam instabilities in an electron storage ring. First of all, ion trapping, which transversely shakes stored electron beam, is a typical and popular problem. When all RF buckets in a storage ring were filled with electron beams and beam intensity is over a threshold level, the ion-trapping phenomena consequently would be observed. To suppress the ion trapping, some RF buckets should not be filled with beam. To do that, a precise timing system to control beam injection correctly from a linac to a storage ring must be constructed. The timing system is also useful to make various beam filling patterns in a storage ring. As a next serious problem, we

can say the problem of fundamental accelerating mode in a cavity. When a fundamental RF is amplified by a klystron, the ripple produced by a high voltage power supplier for a klystron modulates the RF. The RF becomes one of the sources of various longitudinal instabilities. If synchrotron oscillation is resonated with the modulated RF, stored beam must be aborted completely. Thus the stabilization of a fundamental RF is important issue, however people hardly know this problem. If two problems mentioned above could be suppressed, famous instability such as coupled-bunch instability would appear. In this article, we do not mention about higher order mode issues, but would state how we solved trivial problems and other problems basing on the experience of the designing and construction of SPring-8 RF system.

TRANSVERSE INSTABILITY (TIMING SYSTEM TO SUPPRESS ION TRAPPING)

The problem of ion trapping would be observed in a storage ring of electron beam. The stored electron beam, as one knows well, is shaken transversely by ions with positive charges, and the light as a synchrotron radiation consequently twinkles. We assume that vacuum pressure is low enough in discussing about ion-trapping problem. To suppress this problem completely, one has to construct a precise timing system, which controls beam injection from a linac to a circular accelerator. It is also very important point that the timing system has to be easily able to make various beam filling patterns in a storage ring. The simplest combination of a synchrotron radiation facility consists of a linac and a storage ring. A more complex facility is inserted a booster synchrotron between them. The two kinds of facilities exactly exist at the site of SPring-8, named NewSUBARU and SPring-8. The former facility is managed by Hyogo University, and the latter belongs RIKEN. Both storage rings are supplied electron beam from the same linac. The NewSUBARU storage ring directly accepts the beam from the linac. The SPring-8 storage ring is injected the beam via the booster synchrotron. In both storage rings, electron beam from the linac is injected into a targeted RF bucket correctly [1]. Thus an arbitrary beam-filling pattern can be easily realized in both storage rings. Furthermore, the booster synchrotron equips RF knockout system to make a single bunch, so that the SPring-8 storage ring can set up almost

perfect single-bunch mode [2]. To solve the ion-trapping problem, it is well known that some RF buckets in a storage ring should not be filled with electron beam. With the precise timing system, one should investigate the best beam-filling pattern, which suppresses the ion trapping adequately. Thus, the timing system with low time jitter of picoseconds to correctly control beam injection can avoid the ion-trapping problem. To see ion effects, we have intentionally made various beam filling patterns in the SPring-8 storage ring by using the timing system. And we could observe beam size expansion and also related effects [3]. Thus we can completely control the ion-trapping problem with the precise timing system.

LONGITUDINAL INSTABILITY (FUNDAMENTAL RF MODULATED BY THE HIGH VOLTAGE POWER EQUIPMENT OF A KLYSTRON)

Fundamental RF is modulated by high voltage ripple of klystron power equipment and enters into a cavity. As a result, stored beam is longitudinally shaken by the fundamental acceleration mode. As the worst case, when the cycle of longitudinal beam movement coincided with a synchrotron frequency, the beam stored would be aborted completely. We thought that this was one of the most serious problems. So we took attention on this issue in designing the SPring-8 RF system and searched articles concerning this problem. However, we knew that nobody had yet solved this important problem quantitatively as well as mathematically. We thought that we had to, first of all, solve the general differential equation including white noise. Fortunately, our colleague who is a theorist of physics challenged this problem and at last the difficult problem was completely solved [4]. According to the calculation, even white noise makes beam emittance larger by around 10 %.

Let us explain the phenomenon qualitatively. A fundamental RF is usually amplified by a klystron. High voltage ripple of klystron power equipment modulates electron beam in a klystron tube and the phase of the fundamental RF is also modulated, so we call it frequency modulation (FM). If one wants to observe the signal of the modulated RF with the use of a spectrum analyzer, one can see so many side band frequencies around the fundamental RF. The phase of the 508.58MHz fundamental frequency amplified by a klystron at SPring-8 is shifted depending on the cathode high voltage. For instance, the phase shifts for the cathode voltage change of the klystron is around 15° /kV. To control the output power of a klystron, one wants to use thyristor as a part of high power equipment because of easy handling. However, the thyristor largely distorts the waveform of alternating current. The rectified high voltage is consequently not smooth, but is accompanied with so many ripples [4]. Thus we never recommend using the thyristor as a part of klystron high power equipment.

OTHER SOURCES OF INSTABILITIES

Temperature of Water-cooling System for Cavity

Normal cavity installed in a storage ring is cooled down by pure water of which temperature has to be as stable as possible. The amount of temperature change is limited by the revolution frequency of a storage ring and the cavity quality factors of higher-order modes (HOMs). We have measured the relation between the frequency shifts of HOMs and the body temperature of a cavity. We covered a single-cell cavity with baking heater and changed the body temperature from 22°C to 57°C. During the measurement, the resonance between the cavity and the fundamental accelerating frequency was automatically maintained with a movable tuner. The inside of cavity, of course, was in vacuum. Obtained data is shown in Fig. 1. The TM111 mode is the most sensitive to the temperature change. One-degree rise changes the frequency by -18kHz. The frequency of the mode is 1077MHz and also its unloaded Q-values gives 44,000. Thus the half-power bandwidth is 24.5kHz and its shunt impedance is 13.7M Ω [5]. The full-power bandwidth at the point of 30 dB down from the peak value becomes around 77kHz. On the other hand, the revolution frequency of the SPring-8 storage ring is 208.78kHz. Under these conditions, the variable range of water temperature was severely limited. Thus we designed the water-cooling system with the accuracy of less than $30 \pm 0.2^\circ\text{C}$. The constructed system actually attained the accuracy of $30 \pm 0.01^\circ\text{C}$. The water-cooling system for the SPring-8 storage ring is shown in Fig. 2. The total flow rate is almost 1000 liters per minute. The water of about 100 liters per minute is supplied in each cavity. The water passing through cavities is cooled down with heat exchanger and led to a huge tank with the volume of over 13 m³. Even if 400 kW-power losses in eight cavities are suddenly stopped due to the power reflection from a cavity, the change of water temperature is less than 0.08°C, because the tank with huge volume plays as a buffer. The most characteristic thing is that water temperature is always constant at $30.00 \pm 0.01^\circ\text{C}$. The condition of water temperature on beam operation is shown in Fig. 3.

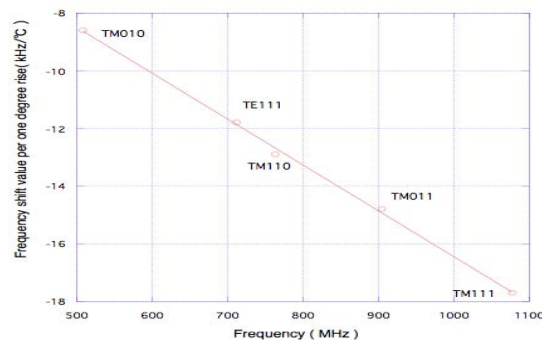


Figure 1 : Relation between the temperature of a cavity body and the change of HOM frequencies

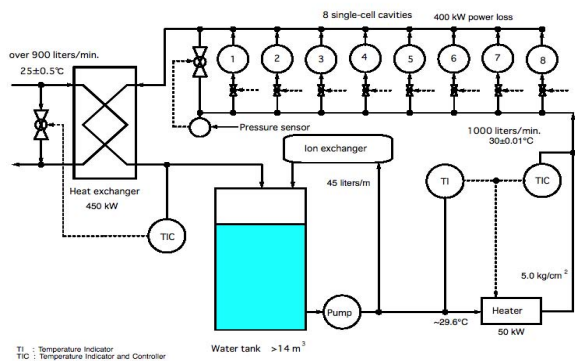


Figure 2 : Water-cooling system for cavities in the storage ring.

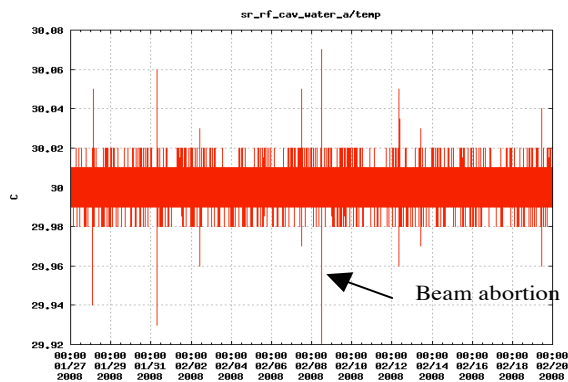


Figure 3 : Actual data of water temperature during beam operation time.

Electric Earth Problem

Electric earth between low-level RF system and high voltage power equipment of a klystron should be completely isolated. All buildings at SPring-8 were constructed on rigid rock. So electric impedance became higher value of a few ohms than we expected. To make the impedance lower, the floors in the construction area of high power equipments were made from electro conductive concrete. After the improvement, the impedance measured decreased around 0.1 ohm. On the other hand, the earth of installation rooms of low-level RF systems was connected to the girders of main building. As for various signal cables connecting between the room of low-level RF system and the outer rooms, coaxial cables were inserted DC cuts as shown in Fig. 4. Another analogue signals were completely isolated by using isolation amplifiers.

The distances between vacuum pressure gauges in the installation area of RF cavities and their controllers are about 30 meters long. And the headers of pressure gauges are connected with vacuum chamber in the storage ring. On the other hand, the gauge controllers are set up at klystron gallery. The stored beam current is changed from 0 to 100 mA. Thus the correct vacuum pressure is not always indicated because of earth problem and the other problem [6]. To solve the former problem, we connected the earth of vacuum controllers to the earth of vacuum

chamber in the storage ring. And even at any beam current from zero to 100 mA, the induced current on the earth cable connecting the pressure gauge to its controller did not change at all. We also set up isolation transformers for AC 100 and 200 volts to isolate the earth of ion pumps and vacuum pressure gauges from the earth of AC power supplied by utility side.

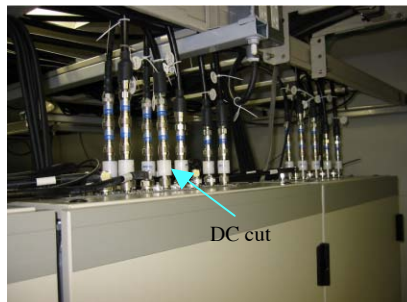


Figure 4 : DC cuts are inserted coaxial RF signal cables.

SUMMARIES

There are various beam instabilities. In particular, the ripple of a klystron power supply causes very serious problem. However, it still seems that nobody notices that the fundamental RF becomes the source of beam instability. And also ion-trapping problem can still be seen in some synchrotron radiation facilities. Those who are concerning synchrotron radiation facilities should suppress these fundamental problems before discussing about more complex coupled-bunch instability problems. In the SPring-8 storage ring, beam abortion rate due to RF system is very low throughout a year. For instance, last year 2007, RF system aborted the stored beam two times, of which number corresponds to only 2 % of total number of abortions. The causes of beam abortion due to RF system were arc discharge in a circulator and power reflection from a cavity, respectively. Thus RF system in the SPring-8 storage ring has been stably working. We hope this article makes you recognize about fundamental beam instabilities, again.

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