STATUS OF THE RF SYSTEM FOR THE 6.5 GEV SYNCHROTRON LIGHT SOURCE PF-AR

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Abstract

In this paper, we report the operations, troubles, and modifications of an rf system for the 6.5 GeV synchrotron light source PF-AR for the past two years. It includes a strange trouble in one of the cavities, our efforts to recover this cavity, and the work of transferring two cavities from the west to the east rf section.

INTRODUCTION

The PF-AR [1] is a 6.5 GeV synchrotron light source at KEK. Unique full-time single-bunch operation of the PF-AR allows us to provide users with intense pulse X-rays. A maximum beam current of 60 mA is stored with a single bunch. Synchrotron radiation loss is 6.66 MeV/turn. Beams are injected at 3 GeV and are ramped to 6.5 GeV.

The 508-MHz rf system [2] for the PF-AR comprises six alternating-periodic-structure (APS) cavities [3], two 1.2-MW klystrons [4], and rf distribution networks. Each APS cavity consists of 11 accelerating cells and 10 coupling cells, which is operated with a $\pi/2$-mode. The cavity is approximately 3.4 m long. Each accelerating cell is equipped with a rod-type higher-order-mode (HOM) coupler [5]. The six cavities can produce a typical rf voltage of 15 MV under beam operations.

During the past two years, the PF-AR was operated for about 5000 hours per year. The rf system worked fairly well except for some troubles. The most serious trouble happened in April, 2003 (see the next section), which interrupted user runs for eleven days. We also experienced such troubles as vacuum leaks in some HOM couplers and overheating in old HOM cables.

During a summer shutdown in 2004, we transferred two cavities from the west to the east rf section for leaving a space for new undulators.

TROUBLE IN CAVITY W-3

Four cavities (numbered W-1 to W-4) were located in the west rf section while the other two in the east section. On April 4, 2003, a vacuum leak happened in one of the cavities, No. W-1. The leak was caused by a burn in one of the HOM cables. We quickly replaced both a damaged HOM coupler and a cable, evacuated the west rf section, and carried out rf conditioning of up to 190 kW/cavity. The conditioning progressed smoothly, however, we experienced frequent trips in another cavity, No. W-3, under beam operations. These trips were due to spikes of reflected power from the cavity, which were accompanied by sudden pressure rises; it showed typical signs of internal discharges. Strangely, these trips occurred only under beam operations at a high beam energy (6.5 GeV); they did not occur without beams, or with beams at a low energy (3 GeV). At an rf voltage of 16 MV, we could hold the beams only for 10-60 minutes.

Figure 1 shows a typical operation of the cavity (W-3) at a low beam current of 15 mA. We observed periodic spikes in both the reflected power and the vacuum pressure. These spikes eventually triggered a cut in the input power due to protection, where a threshold for the reflected power was initially 40 kW/cavity and was raised afterward. The period between the spikes tended to be short at high currents. Typical reflected signals at the spikes are shown in Fig. 2. We also monitored picked-up signals from the HOM couplers, and then observed dips in the HOM signals from the accelerating cells of No. 4 (most frequently), 5, and 8 at the events of the spikes. A typical observation is shown in Fig. 3. This suggested that the discharges might happen near these cells.

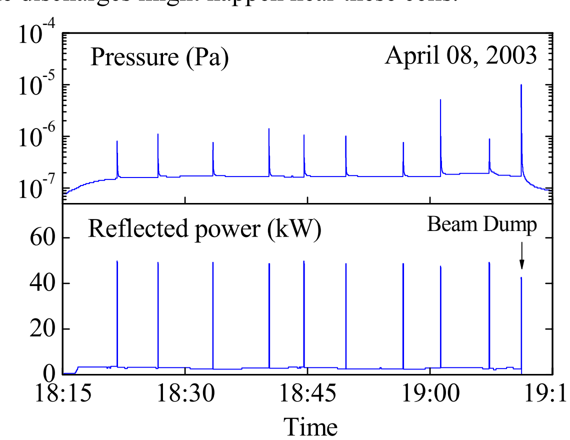

Figure 1: Vacuum pressure in the cavity (W-3) and reflected power from two cavities (W-3 and W-4). The beam energy was ramped at 18:16 with a beam current of 15 mA. An rf voltage was 16 MV with 6 cavities.

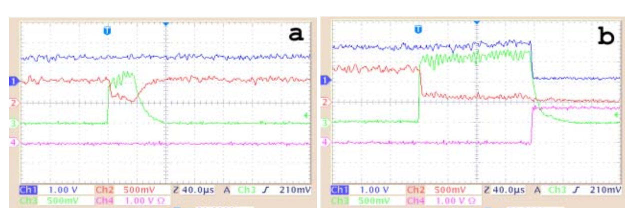

Figure 2: Detected rf signals from the cavity W-3 at the spikes, where typical two cases are indicated. The beam was held in case (a) while it was lost in case (b). Ch1 (blue): an input rf to the cavity, ch2 (red): a signal from the cavity pickup, ch3 (green): a reflected rf from the cavity, ch4 (pink): rf on/off status. Horizontal scale: 40 μs/division.

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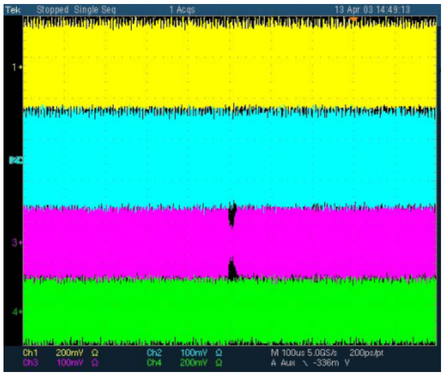

Figure 3: Picked-up signals from the HOM couplers at a spike event. The traces (upper to lower) show the signals from the cells of No. 2, 3, 4, and 5, respectively. Horizontal scale: 100 µs/division.

We first guessed that this cavity should be contaminated with some gases due to the previous leak. Aiming at cleaning these gases, we carried out the following work: (i) rf conditioning for 38 hours both with a constant power of 190 kW/cavity and with sweeping the power, (ii) a beam storage for 9 hours at 3 GeV, and (iii) outgassing for 26 hours by beam-induced fields while fully sweeping a tuner position under beams of up to 40 mA at 3 GeV. However, the situation did not improve at all. We then decided to suspend an operation of this cavity. For this purpose, we constructed an unique three-way rf distribution system [6] where the other three cavities in the west section were driven by a klystron. This operation continued until summer, 2004.

Efforts to Recover the Cavity

Every time we had a scheduled shutdown, we made efforts to recover the wrong cavity, W-3, as described below. (1) In September, 2003, we replaced old ion pumps which were attached to the accelerating cells of No. 4 and 8. We checked some tuners, and replaced them of the cells No. 4 and 5. We inspected the inside of the cavity using a fiber scope, but found no particular problems. (2) In January, 2004, we carried out a fine tuning of the $\pi/2$-mode of the cavity so that the fields in coupling cells were hardly excited. (3) In March, 2004, we replaced an input coupler. We also inspected all HOM couplers and found no problems. After every work of (1)-(3) we tried to operate this cavity again; however, the trips did not diminish at all. Furthermore, such studies with beams as described below indicated no signs of improvement: (i) additional outgassing by means of tuner scans, (ii) changes in the cavity cooling-water temperature within 20-28°C, a change in the cavity-water flow from 260 to 130 liters/min., changes in the rf frequency within ±20 kHz, and (iii) a two-bunch operation with a symmetric filling.

Finding a Clue

In April, 2004, we tried to impose a closed-orbit bump in a bending magnet which located upstream the west cavities. When we imposed a vertical angular bump of more than 0.3 mrad, the trips of the cavity disappeared even under high beam currents at 6.5 GeV. This was reproduced very well. From this result, we presume that these trips should be triggered by the synchrotron radiation (SR) which impinged upon the cavity surface. Note that the above angle of 0.3 mrad corresponded to a shift in the SR of about 3 mm at the cavity.

We should also notice the following facts: (a) in upstream locations from the wrong cavity W-3, there were two other cavities which should be irradiated more by the SR, and (b) before the previous leak in another cavity W-1, the cavity W-3 worked well. From these facts, we consider that some defects should have existed in the cavity W-3, which could be activated by the previous leak. Then, the irradiation of the SR onto the possible defects should trigger the discharges under high power operations. To confirm the above assumption, we plan to investigate the inside of the wrong cavity.

The PF-AR was originally designed as a booster for the TRISTAN main ring, assuming relatively low beam currents. In addition, producing the shadows against the SR for the 3.4-m long cavities requires removable masks due to their narrow apertures (about 19 mm at a minimum). According to these reasons, we did not have any SR masks for the cavities, however, we plan to install them in the near future.

MODIFICATIONS OF THE RF SYSTEM

Transferring Two Cavities

In order to leave a space for installing new undulators in the latter half of the west rf section, we transferred two cavities from the west to the east rf section during a summer shutdown in 2004. The change in the arrangement of the cavities is shown in Fig. 4. We transported the cavities along the ring tunnel with rollers, as shown in Fig. 5. At the same time, we replaced the wrong cavity (W-3) with a spare one. In addition, we adjusted coupling coefficients of input couplers from 1.2 to 1.6 in order to fit them for high beam currents.

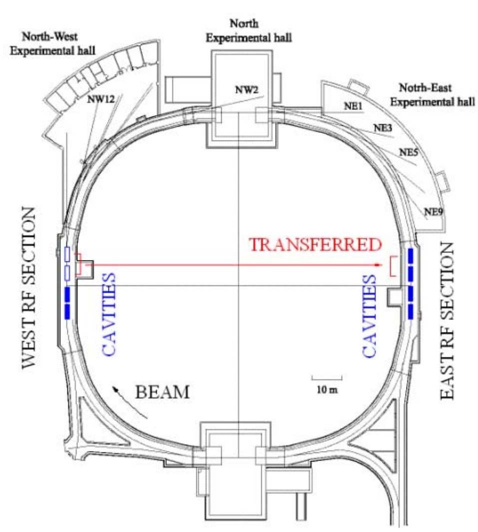

Figure 4: Change in the arrangement of the cavities.

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Figure 5: Transporting the cavity in the PF-AR tunnel.

Figure 6: Common driving mechanism for the tuning plungers of the APS cavity.

To accommodate the rf system to these changes, we modified our cooling water plant for the cavities, rf distribution networks, and control software. The modified rf system commissioned in October, 2004.

Degradation in Q-value of the Spare Cavity

During replacing the wrong cavity with a spare one, we experienced a degradation of Q-value of the spare cavity. This cavity had a Q-value of 39,000 for an accelerating π/2-mode before transportation, but the Q-value reduced to 32,000 after installation. We first checked the inside of the cavity using a fiber scope, but found no particular problems. After some inspections, we found that a field distribution of the π/2-mode was distorted considerably; this was found by a perturbation measurement using tuners. Because the coupling cells having low Q-values were excited considerably, the Q-value was degraded. After we tuned the π/2-mode, the Q-value recovered to 37,500.

It was guessed that an iron beam used to drive the tuners commonly (see Fig. 6) should be inclined during the installation, and it should cause the distortion in the field distribution.

Other Improvements

There are two high-voltage power supplies for the klystrons. By means of gas analysis of their insulating oils, we found abnormal signs in both step-up transformers (with rectifiers) of the power supplies in April, 2004. One of the transformers in the east station indicated a typical gas spectrum of internal arcing while the other in the west station indicated a sign of overheating. Because these power supplies were about 20 years old, we renewed both the transformers, remaining iron cores and cases.

During user runs, we experienced overheating in some HOM cables and HOM couplers. We replaced these wrong components. Since the overheating was mostly caused by the deterioration in old HOM cables, we plan to renew them step by step.

CONCLUSIONS

During the past two years, the rf system for the PF-AR worked fairly well except for some troubles. The most serious trouble happened in one of the cavities, W-3, which suffered from frequent trips under beam operations. We identified that these trips should be due to a combination of possible defects in the cavity and an irradiation of synchrotron radiation. From April 15, 2003 to the summer of 2004, we operated the PF-AR using the other five cavities with comparable beam currents of 50-60 mA to those under the previous operations. In summer, 2004, we replaced the wrong cavity with a spare one, and transferred two cavities from the west to the east rf section.

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