J. Synchrotron Rad. (1998). **5**, 369–371

Installation of new damped cavities at the Photon Factory storage ring

Masaaki Izawa,[a]* Tadashi Koseki,[b] Shyogo Sakanaka[a] Takeshi Takahashi,[a] Klaus Hass,[c] Shuichi Tokumoto[d] and Yukihide Kamiya[b]

[a]Light Source Division, Institute of Materials Structure Science, High Energy Accelerator Research Organization, Oho 1-1, Tsukuba-shi, Ibaraki 305, Japan, [b]Institute for Solid State Physics, The University of Tokyo, Roppongi 7-22-1, Minato-ku, Tokyo 106, Japan, [c]National Synchrotron Research Center, Suranaree University of Technology, Nakhon Ratchasima, Thailand, and [d]Accelerator Division I, Accelerator Laboratory, High Energy Accelerator Research Organization, Oho 1-1, Tsukuba-shi, Ibaraki 305, Japan. E-mail: isawa@mail.kek.jp

(*Received 4 August 1997; accepted 31 October 1997*)

New damped cavities have been installed in the Photon Factory (PF) storage ring and successfully operated in the last scheduled user run of 1996. The new damped cavity is a simple single-cell cavity with somewhat large beam-duct holes. The part of the beam duct that is attached to the cavity is made of SiC, which works as a microwave absorber and damps the higher-order modes excited in the cavity. Because of its simple structure, the operation of the cavity is very stable and also a high power input of more than 150 kW is possible. No coupled-bunch instabilities due to the new cavity were observed during operation.

Keywords: RF systems; damped cavities; higher-order modes; coupled-bunch instabilities; microwave absorbers; SiC.

1. Introduction

We have developed a damped structure RF cavity for two low-emittance electron/positron storage rings. One ring is a high brilliance configuration of the PF storage ring (Katoh *et al.*, 1995); the other is a third-generation VUV-SX synchrotron radiation source, which is a future project of the University of Tokyo (Kamiya *et al.*, 1994; Takaki *et al.*, 1996). For these storage rings, the coupled-bunch instability due to higher-order modes (HOMs) in the RF cavity is a serious problem when a stable beam with high current is required. The damped cavity has a large beam duct, part of which is made of an SiC microwave absorber. The HOMs propagating out from the cavity through the beam duct are expected to be damped by the SiC microwave absorber. Low-power measurements using a cold model of the cavity showed that the SiC beam ducts strongly reduce the Q values of HOMs in the cavity (Koseki *et al.*, 1994; Koseki, Izawa & Kamiya, 1995; Koseki, Kamiya & Izawa, 1995). The design parameters of the accelerating mode of the damped cavity calculated using *SUPERFISH* (Halbach & Holsinger, 1976) are summarized in Table 1. The nominal operating voltage of the cavity system is 1.5–1.7 MV for both the PF ring and the VSX ring. In the case of the PF ring, four cavities are used. Therefore, the nominal gap voltage per cavity is about 0.4–0.45 MV. Taking into account the reduction of the Q value of 10% for the actual cavity, the gap voltage requires a power of about 30 kW to be dissipated in the cavity. The value of the wall loss of 150 kW has a large safety margin and operational flexibility.

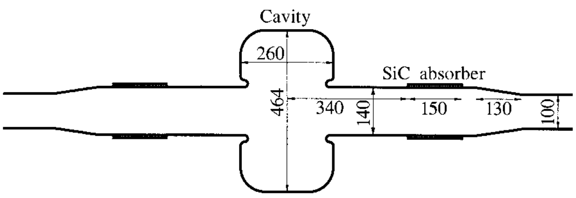

Figure 1
Schematic view of the damped cavity. Lengths are in millimetres.

Table 1
Design parameters of accelerating mode.

Frequency	500.1 MHz
Shunt impedance	7.68 MΩ
Unloaded Q	44 000

2. Damped cavity

The high-power model cavity was manufactured at Keihin Product Operations of Toshiba Corporation (Miura *et al.*, 1995). Fig. 1 shows a cross-sectional view of the high-power model. The main part of the cavity was made of class-1-OFHC copper which had previously been treated using a hot isostatic press (HIP). A cooling-water flow of 200 l min^{-1} is available with a pressure drop of 0.4 MPa. The cavity has two beam ports and four side ports for an input coupler, a movable tuner and two fixed tuners. U-tight seal gaskets are adopted as RF contacts between each port and the attached equipment.

Fig. 2 shows the input coupler of the cavity. The coupler was newly designed based on the coupler of the 508 MHz APS cavity of the TRISTAN ring, KEK. We changed the shape of the top of the coaxial line where a coupling loop is placed and optimized the positions of the short plates of the rectangular waveguide and the coaxial line in order to obtain low reflection for 500 MHz (Nagatsuka *et al.*, 1995). The movable tuner is of a similar type to that used in the PF cavity. The fixed tuner is a cylindrical copper block with an ICF-flange to pad the port of the cavity. Two fixed tuners are attached to the bottom port and the side port of the cavity. These fixed tuners are used for the frequency shift of the HOMs by properly choosing the length of the copper block. As

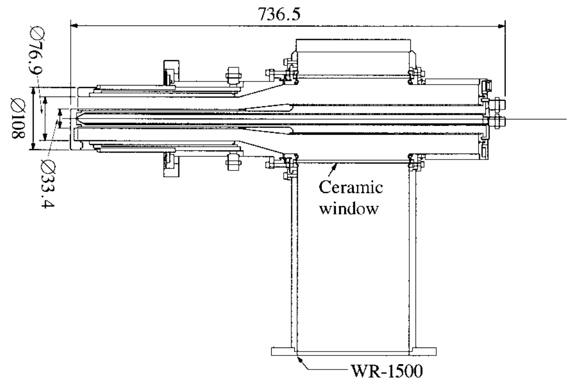

Figure 2
Newly designed input coupler.

Table 2
Measured resonance frequencies and Q values of dangerous HOMs.

The name of the HOM is shown as the resonance frequency followed by h or v or L (standing for the horizontal, vertical and longitudinal modes, respectively). Calculated r/Q values are also listed. r is the coupling impedance.

Name of HOM	Frequency (MHz)	Q value	r/Q (Ω, $\Omega\,m^{-1}$)	Mode
706h	703	40000	6.5	TE111
706v	706	10300	6.5	TE111
790v	789	9000	255.0	TM110
790h	793	43600	255.0	TM110
794L	794	35900	52.0	TM011
990h	989	22000	415.0	TM111
990v	991	23200	415.0	TM111
1310L	1312	8500	9.2	TM020
1370L	1373	26800	9.0	–

mentioned above, HOMs whose frequencies are above the cut-off frequency of the beam duct propagate out to the beam duct and are absorbed by SiC. HOMs below the cut-off frequency of the beam duct still remain in the cavity with high Q values. Among these HOMs, dangerous ones that have the possibility of introducing coupled-bunch instabilities are listed in Table 2. However, these can be detuned so as not to introduce any coupled-bunch instability. This frequency-shift method (Izawa *et al.*, 1988; Kobayakawa *et al.*, 1989), using two fixed tuners to detune the HOMs, was first developed at the Photon Factory. Fig. 3 shows an example of frequency mapping of detuned HOMs.

The unloaded Q value of the accelerating mode was 39500 with all the equipment described above attached. The shunt impedance of the accelerating mode was estimated to be 6.9 MΩ from the value in Table 1. The SiC is made by Toshiba Ceramics Co. Ltd under the trade name CERASIC-B and is fabricated by sintering in an argon atmosphere under normal pressure. The dimensions of the SiC are inner diameter 140 mm, outer diameter 160 mm and length 150 mm. The resistivity of the SiC was about 50 Ω cm in the frequency range 1–5 GHz. The SiC is fixed inside the copper duct by a shrink-fit process (Izawa *et al.*, 1995, 1996). The copper duct has a water-cooling channel on the outer surface. Since the SiC has a good thermal conductivity of 100 W mK^{-1}, the rise in temperature of the SiC duct is negligible under usual operation of the PF ring.

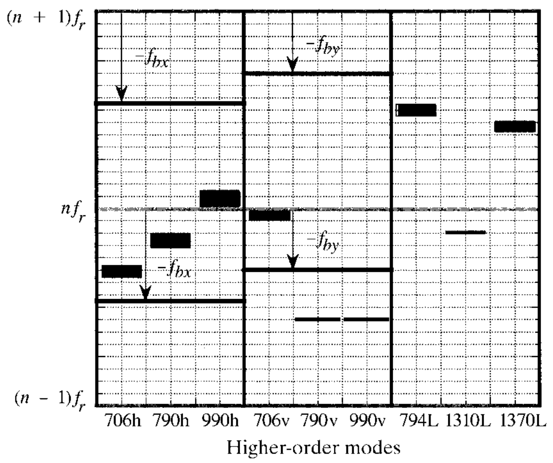

Figure 3
Mapping of the resonance frequencies of detuned HOMs. f_r: revolution frequency; n: integer; f_{bx} and f_{by}: fractional parts of the horizontal and vertical betatron frequency.

3. Installation and beam test

During the summer shutdown in 1996, two of the four cavities were replaced by new ones. Fig. 4 shows these cavities installed in the ring. Between two cavities, an evacuation chamber is placed, which has two 400 l s^{-1} ion sputter pumps, two titanium sublimation pumps, three vacuum gauges and a quadruple residual gas analyser. The base pressure was 10^{-10} torr after baking. Conditioning of these cavities was carried out in both CW and pulse modes. An RF power of up to 90 kW (CW) and 120 kW (pulse) was injected into the cavities during the conditioning. The remaining two cavities were replaced by new ones in July 1997. The two new damped cavities that were first installed, together with two old ones, were successfully operated during the last scheduled user run from October to December 1996. High current storage was also attempted on 12 December 1996.

Fig. 5 shows the vacuum pressure and the output power of the klystron during the first beam storage after the installation of the new cavities. Since each cavity was driven by one klystron, the klystron power in the figure shows the input power to each cavity. The stored current is given in the figure. The vacuum pressure was in the region of 10^{-8} torr before an elapsed time of about 5 h, and 10^{-7} torr after that time. As can be seen in the figure, the vacuum pressure became higher with increasing stored current, and then gradually decreased. Apart from such a slow change of the vacuum pressure, there existed burst outgassing. The worst such burst took place after an elapsed time of about 3.5 h; however, the peak pressure did not exceed 10^{-7} torr. About 10 h after the first beam injection, a stored current of more than

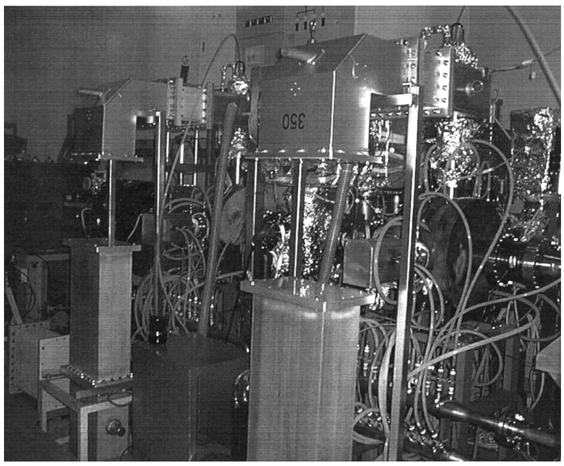

Figure 4
New damped cavities installed in the ring.

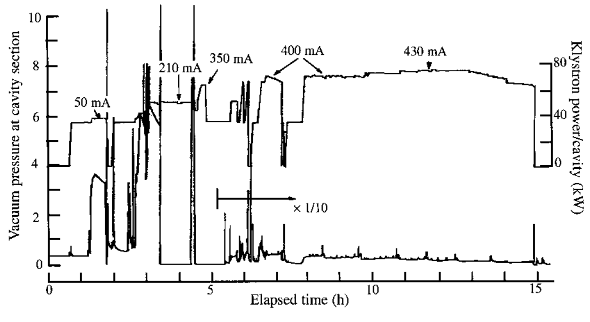

Figure 5
Change of vacuum pressure during the first storage.

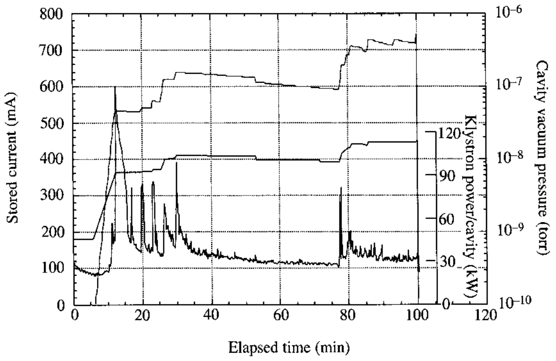

Figure 6
Change of vacuum pressure at a high stored current.

400 mA was attained without any serious RF or vacuum problem. The conditioning using a beam continued for 4 d with a maximum stored current of 500 mA. After the conditioning, the base pressure decreased to 10^{-9}–10^{-10} torr at a stored current of 350 mA, the nominal stored current in a user run. No burst outgassing was observed during usual operation after conditioning.

Detuning of the HOMs was quite successful. We could not detect any transverse coupled-bunch instability. The longitudinal coupled-bunch instability was still observed. However, it is considered to have been due to the old-type cavities, since the frequency of the beam spectrum was different from the resonance frequency of the HOMs in the new cavities.

At the end of the scheduled user run in 1996, we tried to store the electron beam as much as possible. The record stored current reached in the PF ring has so far been around 500 mA. Fig. 6 shows the new record that was achieved. As mentioned above, CW conditioning of the cavities was performed below an input power of 90 kW. During the operation, the vacuum pressure began to rise when the input power exceeded 90 kW, which included wall dissipation and beam loading. Since the cavity gap voltage during this operation was lower than that under conditioning, it was suggested that the outgassing came from the input coupler. A maximum stored current of 773 mA, a new record at the PF ring, was achieved, although the beam was down at 743 mA in the figure. No transverse coupled-bunch instability was observed up to the maximum current. A longitudinal instability was clearly seen on the spectrum analyser, though it was not very harmful. The injection rate did not decrease drastically, and the quality of the beam seen in the synchrotron radiation light monitor was not so different from that at a low stored current. In the scheduled operation which will start in October 1997, the longitudinal coupled-bunch instability due to the old-type cavities is expected to disappear. We could not find any difficulties in operating the ring at such a high current, except for the lifetime of the beam, which could be overcome by conditioning under high current operations.

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