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COMPACT HOM-DAMPED RF CAVITY FOR A NEXT GENERATION LIGHT SOURCE*

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Abstract

A beam-accelerating RF cavity with a new HOM-damping structure was designed in order to suppress coupled-bunch instabilities in a next generation light source with an ultra-low emittance and supplying X-rays approaching their diffraction limits. The TM020 mode at 508.58 MHz is selected as a beam-accelerating mode because it has a high Q-value of 60,000 and a shunt impedance sufficient for beam acceleration and brings a compact HOM-damping structure to the cavity differently from massive types of cavities with waveguides or pipes extracting HOM power. Two shallow slots are cut on the cavity inner wall and materials absorbing RF waves are directly fitted into them. They work as HOM dampers without affecting the RF properties of the beam-accelerating mode. A prototype cavity of OFHC copper was fabricated to demonstrate the HOM-damping and generating an accelerating voltage of 900 kV in the cavity. Since the cavity was successful in operation up to 135 kW, the feasibility of both the high-power operation and the damping structure was proved. Four actual cavities were produced and installed to the new 3-GeV synchrotron radiation facility, NanoTerasu in Japan.

INTRODUCTION

Coupled-bunch instability (CBI) arising from high coupling impedances of higher-order modes (HOMs) in beam-accelerating RF cavities is one of the serious problems in the next generation storage ring. Therefore, RF cavities against the CBIs are indispensable for stable beam operation of the ring. We developed a new and compact type of HOM-damped cavity shown in Fig. 1 [1-3]. The beam-accelerating resonant mode of the cavity is the TM020 mode. This mode enables HOM-absorbing materials to be directly embedded into the cavity body without using special waveguides or pipes usually occupying large spaces. Our HOM-damping structure makes the cavity body extremely compact and reduces the spaces occupied with the cavities in the storage ring packed in with accelerator components.

In the next section, we show the cavity structure, its RF characteristics and the HOM-damping mechanism. The last section represents the measurements on RF characteristics of the fabricated prototype cavity and the results of its high-power tests up to 135 kW.

Figure 1: RF cavity with the compact HOM-damping structure.

HOM-DAMPING MECHANISM

Cavity Structure

Figure 2 shows the schematic cross-sectional view of the cavity with the HOM-damping structure. The cavity has an inner diameter of 1040.4 mm and a beam-gap length of 206 mm. The cavity is a reentrant type with nose cones around the beam gap on the cavity inner wall. The cavity length between the beam-pipe flanges is 452 mm and we can accommodate plural cavities in short straight sections in a storage ring.

Two slots are opened in the cavity inner wall along the nodes of the axially symmetric magnetic fields of the TM020 mode. 16 HOM dampers with 12 ferrite bars shown in Fig. 3 are directly bolted to the cavity body and the ferrite bars are exposed in the slots.

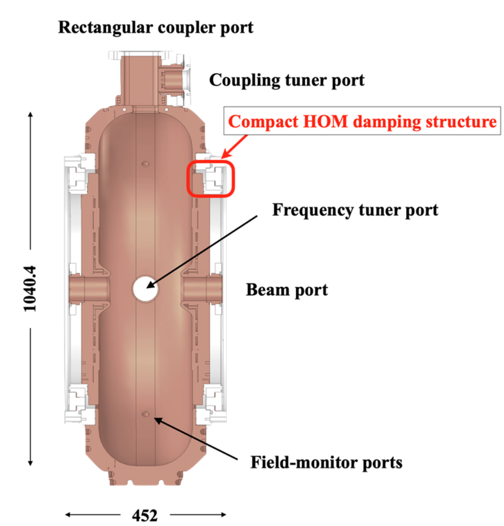

Figure 2: Cross-sectional view of the cavity.

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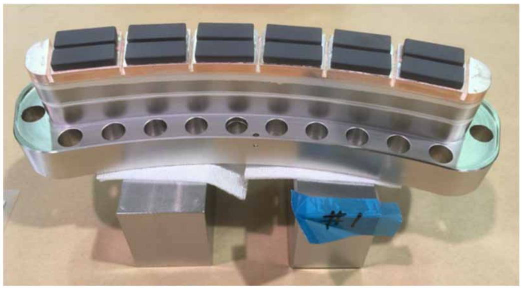

Figure 3: HOM damper with 12 ferrite bars.

Figure 4 shows the cavity assembly and cut-off view schematics. The cavity was made of class-1 OFHC copper (ASTMF68 class-1). The cavity consists of three parts: a main body and two plates with the nose cones and the beam pipes. The plate is called the nose-cone plate in this paper. The nose-cone plates have SUS flanges which are tightened to the main body by bolts and are easily detachable from the main body. Aluminum U-tight rings are used for vacuum sealing. The HOM-damping slots are formed between the nose-cone plate and the body flange as shown in Fig. 2. The flange of each nose-cone plate has eight bending slots to attach the HOM dampers by using bolts. This structure is capable of reassembling with some merits: it is easy to precisely adjust the resonant frequency of the TM020 mode by machining the inner surfaces of the nose-cone plates even after brazing the main body: the inner surface can be inspected after high-power operation: the HOM dampers can be replaced with any other ones improved. The RF coupler port is rectangular with dimensions of 381 mm x 100 mm and has a rectangular iris with dimensions of 100 mm x 75 mm in the common wall of the cavity as shown in Fig. 2. A cylindrical port with a diameter of 73 mm is opened in front of the iris. The degree of cavity coupling can be changed by using a movable cylindrical plunger installed in the port. The plunger is called a coupling tuner [4].

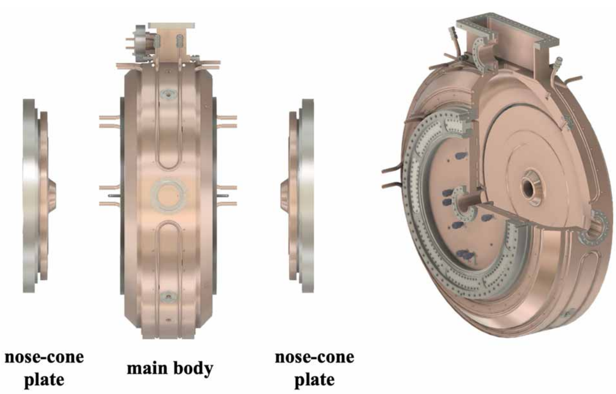

Figure 4: Schematics of the cavity assembly (left) and the cut-off view (right).

HOM-damping Structure

The RF characteristics of the cavity were estimated by using the simulation codes, MAFIA, CST STUDIO [5] and ANSYS HFSS [6]. The resonant frequency was set at 508.58 MHz because of the operating frequency of the high-power facilities in the RIKEN SPring-8 promoting the R&D on the cavity [3, 7]. The shunt impedance, R_a, and unloaded Q-value, Q_a, are 6.8 MΩ and 60,300, respectively. The gap voltage or beam accelerating voltage, V_a, is defined in this paper as

$$V_a = \sqrt{R_a P_w}\,, \tag{1}$$

where P_w is the wall-loss power in the cavity. V_a of 900 kV is assumed in our design. R_a/Q_a is set at a low value of 113 Ω and reduces the transient cavity-voltage modulation arising from bunch gaps provided to avoid beam instabilities such as ion trap in the storage ring [8, 9]. Figure 5 shows the electromagnetic field distributions in the TM020 mode. Since the HOM-damping slots are located along the nodes of the magnetic fields, there is no magnetic field near and inside the slots and only electric fields are present in front of the slots. The electric fields are parallel to the slots and are also unable to enter the slots. Therefore, the TM020 mode is not affected by the slots.

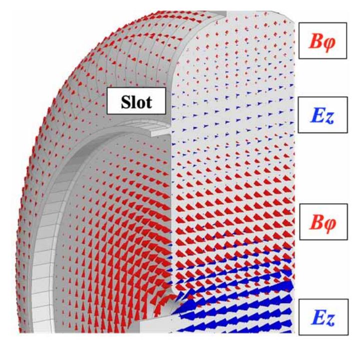

Figure 5: Field distributions of the TM020 mode. Blue and red arrows show the electric and magnetic fields, respectively.

The cavity is operated in the TM020 mode and has lower-order resonant modes (LOMs) with high coupling impedances such as TM010, TM011, TM110 and so on. Monopole and dipole HOMs and LOMs have the field distributions different from those of the TM020 mode. Figure 6 shows the electromagnetic fields of the TM110 and TM011 modes, for example. Their magnetic fields enter the slots and attenuate markedly by installing materials absorbing RF waves in the slots. Figure 7 shows the estimated distributions of coupling impedances and Q-values of the monopole and dipole modes below the beam-pipe cutoff frequency of 3.3 GHz in TM mode. The red block in Fig. 7(a) indicates the RF absorber. Black and red dots in Figs. 7(b) and (c) represent the cases without and with the RF absorber in the slot, respectively. In this estimation, the electrical conductivity of the RF absorber was assumed to be 5.8 S/m. The Q-values of the modes except the TM020 mode are markedly attenuated by the RF absorber. The coupling impedances are reduced in the similar way. Resultantly, the slot with the RF absorber becomes the compact HOM-damping structure.

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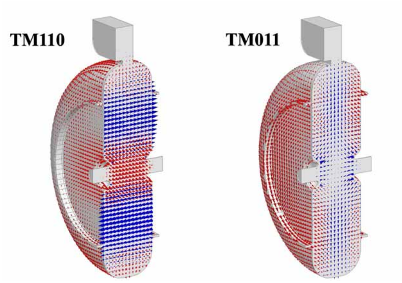
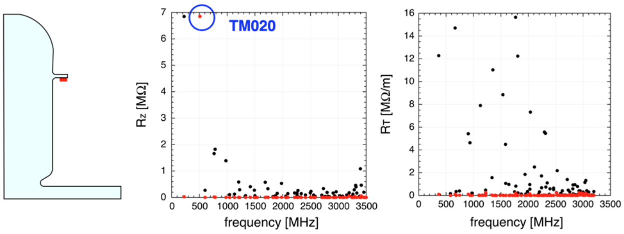


Figure 6: Field distributions of the TM110 mode (left) and the TM011 mode (right).



(a) (b) (c)

Figure 7: (a) Cavity simulation model, (b) impedance distributions of (b) monopole modes and (c) dipole modes.

DEMONSTRATIONS

HOM-damping Performance

In the actual operation of beam acceleration, we will install the HOM dampers in all slots. In the tests of the design demonstration, we mounted the four HOM dampers to each nose-cone plate. The resonant frequency and Q_a of the TM020 mode and the harmful resonant modes with high impedances were measured. Some results are shown in Table 1. The deterioration in Q_a of the TM020 mode was subtle. On the other hand, the Q-values of the harmful modes were markedly reduced. Therefore, the HOM-damping mechanism works as designed. Further attenuation is expected when all slots are full of HOM dampers.

Table 1: Measured RF Properties with the HOM Dampers

Mode	Frequency [MHz]	Q
TM020	508.3	59,100
TM010	222.4	420
TM110	363.6	760

High-power Operation

The cavity baking was processed by flowing hot water through the cooling channels of the cavity before feeding high power to the cavity. Although it was planned to raise the water temperature up to 150°C, the temperature raising was stopped at 80°C due to malfunctions of our heater unit.

RF high-power tests were performed by placing the cavity in a concrete shield of the SPring-8 RF test bench. The cavity was connected to the WR-1500 system via an E-bend vacuum waveguide, a ceramics window of plate type [10] and a waveguide transformer. At first, bending flanges without a ferrite bar were attached to the cavity and high-power tests were conducted. Vacuum deteriorations were repeated for about 12 hours at less than 1 kW. A lot of power reflection happened around 20 kW, 70 kW, and 100 kW, but they improved as progress of RF conditioning and finally reached continuous operation of 135 kW. Since the cavity without a HOM damper became to stably operate up to a power of 135 kW, we carried out the power feeding to the cavity with the HOM dampers in four slots of each nose-cone plate. After RF conditioning for about 58 hours, the cavity with the HOM dampers was able to stably operate up to 135 kW.

SUMMARY

The RF cavity with a compact and effective HOM-damping structure using the TM020 mode was newly designed. The manufactured cavity demonstrated the RF properties of the TM020 mode as we expected. The HOM dampers with ferrite bars were installed in the cavity and markedly attenuated the Q-values of the HOMs and LOMs related to CBIs. This represents that the newly designed compact HOM damping mechanism works effectively. Four cavities revised from these research results were installed and have begun to accelerate a beam in the 3 GeV storage ring of NanoTerasu [11-13].

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