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OPTIMIZATION OF THE PARASITIC-MODE DAMPING ON THE 1.5 GHz TM020-TYPE HARMONIC CAVITY*

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Abstract

Bunch-lengthening harmonic cavity is one of the essential tools to mitigate the intrabeam scattering in the 4th-generation synchrotron light sources. For this purpose, we proposed a normal-conducting 1.5 GHz harmonic cavity [1] of TM020-type [2, 3]. In this cavity, harmful parasitic modes can be heavily damped by installing RF absorbers where no magnetic field of the TM020 mode exists. However, some of the parasitic modes, e.g. TM021 and TM120 modes, are difficult to damp because their field patterns are similar to that of the TM020 mode. To damp such modes effectively, we optimized the cavity inner shape by tailoring the curvature at the cavity equator, the shape of the nose cones, and introducing "bumps" on the inner wall. In this paper, we describe the process of the optimization and its result

TM020-TYPE HARMONIC CAVITY

TM020-type cavity was first suggested by Ego *et al.* as main RF cavities for the SPring-8-II upgrade [2, 3]. Thanks to its large cavity volume, the TM020-type cavity has lower R_{sh}/Q_0 and higher unloaded Q as compared to those of conventional TM010 cavities. Using this cavity, we can reduce the bunch gap transient effect, and thus, can improve the quality of bunch lengthening in double rf systems [1].

In order to damp harmful parasitic modes (that are, the lower and higher order modes other than the TM020 mode), we investigated two types of damping structures, that are, rod type [4] and slot type [2] structures. The results were compared in [5]. We finally chose the slot-type damping structure as shown in Figs. 1 and 2.

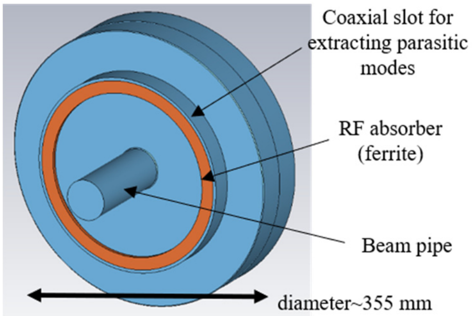

Figure 1: Schematic view of the TM020-type harmonic cavity (Model A).

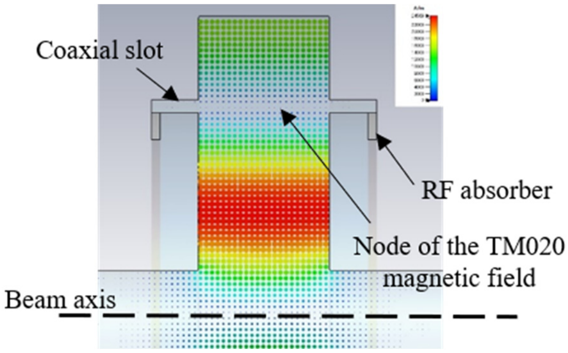

Figure 2: Magnetic field distribution of the TM020 accelerating mode in the Model A.

Coaxial slots for extracting the parasitic modes are installed at the node of the magnetic field of the TM020 mode and terminated by RF absorbers. Most of the harmful parasitic modes are heavily damped while the TM020 accelerating mode is hardly affected by the RF absorbers because of its field pattern. We set our goal to use five TM020 harmonic cavities with active operation [1] in the future KEK Light Source plan [6].

Issue on the Parasitic-Mode Damping Mechanism

Figure 3 shows some examples of the magnetic field distributions of typical parasitic modes in a simple cavity shape, that is named Model A, shown in Figs. 1 and 2.

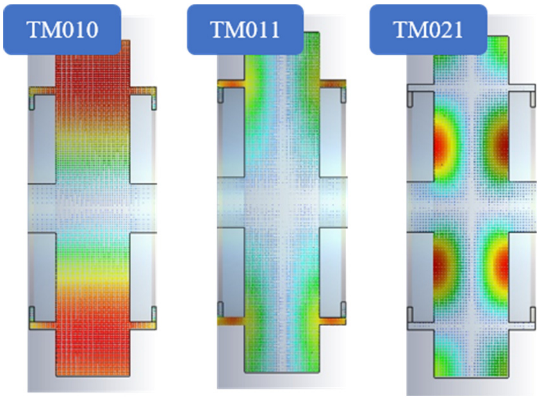

Figure 3: Magnetic field distributions of some parasitic modes in the Model A.

Concerning the TM010 and TM011 modes, a part of the magnetic field is extracted into the coaxial slots, and they are heavily damped. On the other hand, the TM021 mode hardly couples to the coaxial slots, and thus, it is hardly damped. This is because the field pattern of the TM021

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mode is similar to that of the TM020 mode, and thus, the node of the TM021 magnetic field is located at almost the same position as the TM020 mode. For a similar reason, it is also difficult to damp the parasitic modes such as TM022, TM120, TE121, and others in this simple shape (Model A). In order to damp these parasitic modes more effectively, we optimized the inner shape of the cavity.

OPTIMIZATION OF THE CAVITY INNER SHAPE

Process of the Optimization on the Inner Shape

In this study, we investigated two classes of cavity inner shapes, named "Model B" and "Model C". In the Model B, we mainly optimized the curvature of the cavity equator and the shape of the nose cone so that harmful parasitic modes can be damped well. The optimized inner shape is shown in the left figures of Figs. 4 and 5.

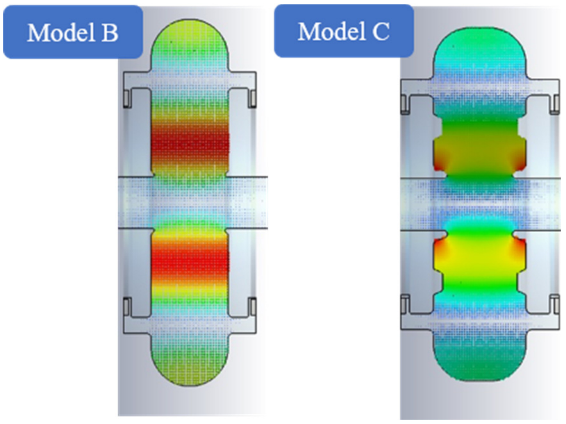

Figure 4: Magnetic field distribution of the TM020 accelerating mode in the Model B and C.

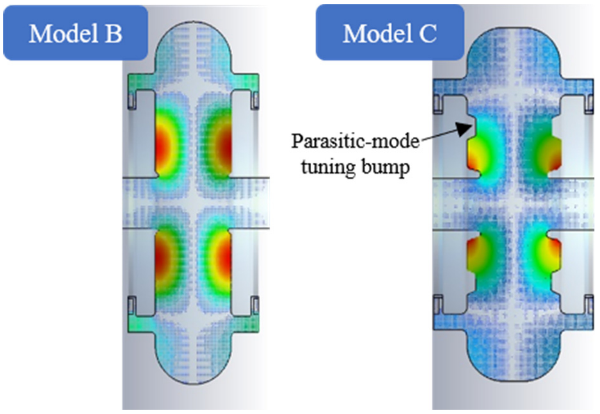

Figure 5: Magnetic field distribution of the parasitic TM021 mode in the Model B and C.

Note that the final shape of the Model B is almost the same as that given in Fig. 2 of [5]. As shown in Fig. 4 (left), the node of the TM020 magnetic field is exactly located at the position of the slots, and then, the accelerating mode holds a high Q value even after the optimization. On the other hand, we can see in Fig. 5 (left) that the node of the TM021 magnetic field is shifted from the slots mainly because of the curvature of the equator. As a result, the TM021 mode couples to the coaxial slots and is effectively damped by the RF absorbers. The other monopole modes are also damped well. However, we found that the damping of some of the dipole modes are insufficient, as is shown later. Then, we tried a further optimization.

In the other classes of Model C, we introduced parasitic-mode tuning bumps (PTBs) on the inner wall of the cavity. The dimensions of the PTBs can be used as additional degrees of freedom during the optimization. We also changed the cavity longitudinal length, the outer curvature, the shape of the nose cone, and the height of the coaxial slot during the optimization. The optimized shape is shown in the right figures of Figs. 4 and 5. Similarly to the Model B, we can see that the TM020 mode is not affected by the RF absorbers (Fig. 4, right) while the TM021 mode couples with the slots and is damped well (Fig. 5, right).

The parameters of the TM020 accelerating mode with the final shapes of Models A-C are summarized in Table 1. Note that the R_{sh}/Q_0 is highest and the $Q0$ is lowest in the Model C. The shunt impedance is defined by $R_{sh} = Vc^2/Pc$.

Table 1: Parameters of the TM020 Accelerating Mode in the Three Models

	Model A	Model B	Model C
Frequency		1.5 GHz (3rd harmonic)	
R_{sh}/Q_0	66 Ω	68 Ω	81 Ω
Unloaded Q	32,000	34,100	31,700

Evaluation of Coupling Impedances

During the optimization, we evaluated the performances of parasitic-mode damping by calculating the coupling impedances. The calculation results of the coupling impedances for the final shapes of the three models (A to C) are shown in Fig. 6. We primarily estimated the coupling impedances from the time-domain simulations of the wake potentials using the Wakefield Solver of the CST Particle Studio [7]. For some of the parasitic modes having high Q values, we estimated the coupling impedances using the Eigenmode Solver of the CST MW Studio, because such modes damp very slowly, and hence we need to simulate too long time in the time-domain simulation.

In order to avoid the coupled-bunch instabilities (CBIs) in the KEK light source [6], the coupling impedances per harmonic cavity should be less than about $f{\cdot}R < 2.4$ [kΩ·GHz] and $R_T < 23$ [kΩ/m] in the longitudinal and transverse planes, respectively. These threshold impedances are shown in Fig. 6. Here, we assumed the machine parameters such as the average beam current of 500 mA, the radiation damping times of τ_z = 22.6 ms (longitudinal) and τ_T = 38.3 ms (transverse; vertical), both of which are without any insertion devices, and five harmonic cavities used.

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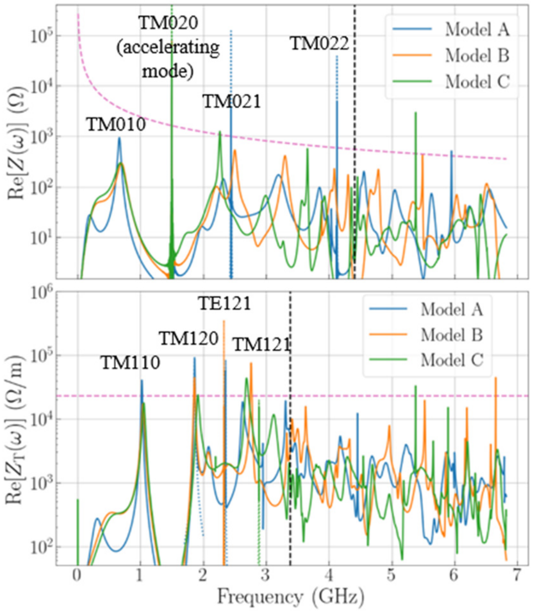

Figure 6: Coupling impedances in the longitudinal and transverse planes per harmonic cavity calculated by Wakefield Solver (solid line) and Eigenmode Solver (dotted line). The pink dashed line shows the CBI threshold. The black vertical line shows the cut-off frequencies of TM01 mode and TE11 mode of the beam pipe.

We define the coupling impedances of a resonant mode, labelled a, as R = (1/2)($R_{sh,a}/Q_{0,a}$)$Q_{L,a}$ in the longitudinal plane and R_T = (1/2)($R_{T,a}/Q_{0,a}$)$Q_{L,a}$ in the trans-verse plane, where $Q_{L,a}$ is the loaded Q, and ($R_{sh,a}/Q_{0,a}$) and ($R_{T,a}/Q_{0,a}$) are the geometrical factors.

We can see in Fig. 6 (upper figure) that the coupling impedances of the TM021 and TM022 modes are lower than the CBI threshold in both Models of B and C. However, in the Model C, there appears a trapped mode exceeding the threshold at about 5.4 GHz.

In the transverse plane as shown in Fig. 6 (lower figure), the Model B is less effective for damping the TE121 and TM121 modes. Especially for the TE121 mode, it was difficult to lower its loaded Q by using the slot-type damping structure. Hence, in the Model C, we lowered the geometrical factor ($R_{T,a}/Q_{0,a}$) of the TE121 mode by adjusting the nose cone and the cavity length. By optimizing the nose cone, the cavity length, and the PTBs, the transverse impedance could be lowered in the Model C as compared to that in the Model B.

Choice of the Model

Concerning the TM020 accelerating mode, the Model C has the lowest unloaded Q and the highest R/Q. This is disadvantageous to reduce the bunch-gap transient effect on the harmonic RF voltage during its operation.

Concerning the parasitic-mode damping, the Model B is advantageous in damping longitudinal modes while the Model C is advantageous in damping transverse modes.

Generally, it will be more difficult to damp the longitudinal beam oscillations using a bunch-by-bunch feedback system than the transverse oscillations in the 4th generation light sources. This is because the longitudinal oscillation is much slower than the transverse ones, and thus, it will take longer time to damp the longitudinal oscillation. In addition, the longitudinal oscillation becomes strongly non-linear with harmonic cavities, which impose another issue in the feedback system. From this point of view, the Model B is preferable to the Model C.

Based on the above-mentioned considerations, we finally adopted the optimized cavity shape of the Model B. In Table 2, we summarized the principal parameters of the parasitic modes of the Model B. Although the impedances of TM120, TE121 and TM121 modes exceed the CBI threshold, we anticipate that we can avoid the transverse CBI by introducing other measures such as a frequency tuning of the TE121 mode or a bunch-by-bunch feedback system.

Table 2: The Principal Parasitic Modes in the Model B

Mode	**f_{res} (GHz)**	**Q_L**	**R (Ω) or R_T (kΩ/m)**
TM010	0.71	5.0	234
TM021	2.50	48	505
TM110	0.99	14	11.4
TM120	1.86	84	47.1
TE121	2.33	11,800	348
TM121	2.76	162	72.2

CONCLUSION

We have optimized the cavity inner shape of the TM020-type harmonic cavity in order to achieve excellent parasitic-mode damping. As a result of the optimization, we have finally chosen the Model B as shown in Figs. 4 and 5 (left figures). In the final design, the longitudinal coupling impedance is lower than the CBI threshold. Although some of the transverse modes exceed the CBI threshold, we think that we can manage them using other measures.

In order to confirm the simulation results on both of the parasitic-mode damping and the performance of the accelerating mode, we have fabricated a low-power model cavity. We are on the way to measure the parasitic modes and the accelerating mode.

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