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UTILIZING THE HIGH SHUNT IMPEDANCE TM020-MODE CAVITY IN THE DOUBLE RF SYSTEMS FOR THE STORAGE RING OF THE THAILAND NEW LIGHT SOURCE

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Abstract

The utilization of the TM020-mode cavity for the storage ring based light source was pioneered by SPring-8 with its high quality factor and hence its high shunt impedance. KEK-LS has also studied the possibility of using this type of cavity for their storage ring. The TM020-mode cavity has larger transverse dimension compared to the traditional TM010-mode cavity, but with its higher shunt impedance it can be designed to fit in the new low emittance storage ring regardless. The new storage ring based light source project in Thailand aims to optimum the low emittance beam in nanometers region with the energy of 3 GeV. The TM020-mode cavity was considered as the main cavity and the harmonic cavity for the storage ring. They have been designed to have their pipe aperture fits the storage ring beam ducts. The main cavity has a high shunt impedance of 8.3 MΩ with the 51,000 unloaded quality factor. The harmonic cavity has a high shunt impedance and an unloaded quality factor of 2.45 MΩ and 36,000, respectively. The damping mechanism of the parasitic modes and the tuning mechanism of the operating mode of these cavities were also studied. There will be four main cavities and six harmonic cavities in the new storage ring. Detailed design and study of these cavities will be presented.

INTRODUCTION

Synchrontron Light Research Institute (SLRI) has got an official approval to construct the new light source project, unofficial namely the SPS-II. It is the ring-based light source with the electron energy of 3 GeV. The maximum stored electron beam current is 300 mA with the emittance less than 1 nm rad [1] . The radio frequency (RF) system of the storage ring is based on the 500 MHz frequency system. The RF cavity utilizes the normal conducting technology. The main RF cavity for an electron beam energy compensation should provide the total cavity voltage of 2.2 MV [2]. The third harmonic cavity will also be used in the storage ring to lengthen the electron bunch for prolonging the beam lifetime.

In order to get a total high cavity voltage with less energy consumption, one should design the cavity with as high as possible the shunt impedance. The TM020-mode RF cavity was originally proposed by Ego *et al.* [3, 4] to realize a high quality factor (Q) and a sufficient shunt impedance for accelerating the beam. This TM020-mode cavity was designed for the storage ring of the SPring-8 upgrade project [4] and will be utilized in the new Japanese 3 GeV light source project in Sendai area [5]. KEK-LS has also studied the possibility of using this type of cavity for their storage ring [6–8]. The TM020 resonant mode cavity has a high unloaded-Q and a low value of shunt impedance over quality factor (R/Q) compare to the conventional TM010-mode cavity. The multiply of Q and R/Q gives the shunt impedance of the cavity. This makes the TM020-mode cavity has a high shunt impedance despite its low R/Q. With a high shunt impedance, the cavity will require less RF power to produce the accelerating voltage. It reflects the lower electricity consumption of the storage ring.

MAIN RF CAVITY DESIGN

The frequency of the main RF cavity is 500.12 MHz. The cavity design was based on the SPring-8 TM020-mode cavity [3]. The diameter of beam port was reduced from 70 mm to 40 mm in order to fit vacuum duct's diameter of the storage ring. Superfish 2D cavity design code [9] was used for tuning of cavity dimension. The 2D cavity design was later verified by simulations using the 3D software, CST Microwave Studio [10], for a realistic cavity shape with ports, tuners, and couplers.

The first design was a modified SPring-8 TM020-mode cavity [3]. The cavity was tuned to get the SPS-II frequency. RF properties are listed in Table 1. This cavity has 70 mm beam port aperture, which is larger than the vacuum chamber diameter. The new design was optimized to fit the 40 mm diameter of beam port. The new cavity has diameter of 960 mm and 160 mm accelerating gap as the cavity profile shown in Fig. 1. It has the R/Q of 163 Ω, the unloaded Q of 51,000, and the 8.3 MΩ shunt impedance. Cavity properties are listed in Table 1. With this high shunt impedance, there will be four cavities installed in the SPS-II storage ring. These four cavities can produce a required cavity voltage of 2.2 MV by operating each cavity at the cavity voltage of 550 kV.

Frequency Tuner Design

Frequency tuners has been added in 3D simulation to investigate the tuner behavior of the cavity. The tuner is a copper rod with diameter of 95 mm. Two tuners are required to get the cavity frequency in range of ±0.5 MHz by moving each tuner in range of ±50 mm as the relation curve illustrated in Fig. 2.

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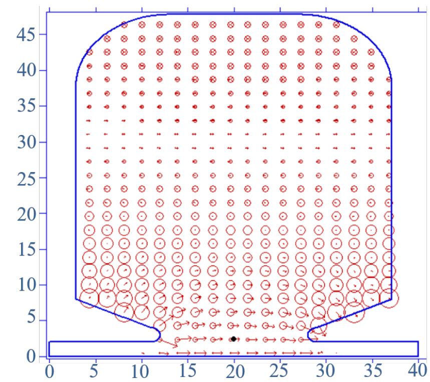

Figure 1: Cavity profile of the SPS-II TM020-mode main RF cavity with arrows and circles represent electric and magnetic fields, respectively.

Table 1: RF Properties of the SPS-II TM020-mode Main RF Cavity

Properties	**SPring-8 modified**	**New design**
Frequency (MHz)	500.12	500.12
Quality factor	57,000	51,000
R/Q (Ω) [definition of $V^2/\omega U$]	126	163
Shunt impedance (MΩ)	7.2	8.3
Maximum cavity voltage (kV)	900	800
Cavity diameter (mm)	1040	960
Insertion length (mm)	500	500
Beam port diameter (mm)	70	40

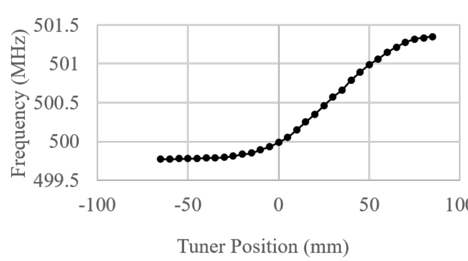

Figure 2: Tuner range of the TM020-mode main RF cavity. The positive position means tuner is beyond the inner cavity surface toward the cavity axis.

Power Coupler Design

The standard WR-1500 waveguide will be utilized to deliver the RF power from the RF transmitter to the cavity through the power coupler. The waveguide input coupler with a coupling tuner concept [11] was applied for the SPS-II cavity. The coupling slot was optimized to have the critical coupling ($\beta = 1$). The optimized coupling slot size is 24 mm x 154 mm with the corner rounding radius of 5 mm. The slot is 10 mm away from waveguide wall. The power coupling factor can be tuned by adjusting length of the coupling tuner post, which has diameter of 70 mm and is located 70 mm above the coupling slot as inset in Fig. 3. The results of varying tuner post length is shown in Fig. 3. The length of tuner post of 40 mm gives the coupling factor $\beta = 2.4$.

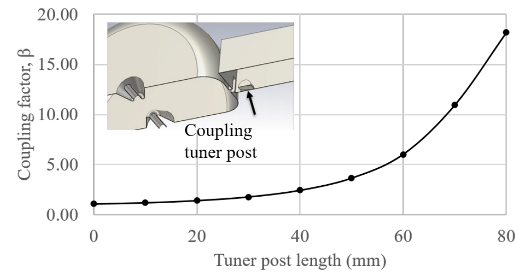

Figure 3: Power coupling tuner range of the WR-1500 waveguide coupler. Inset shows the configuration of coupling slot and the coupling tuner post.

Parasitic Modes Damping Design

The parasitic modes of the TM020-mode cavity were also studied and the mechanism to mitigate these modes out of the cavity were also investigated. The slot-type damped mechanism [3] and the rod-type damped mechanism [8, 12] were investigated. From investigation, the slot-type damped mechanism has higher efficient mitigating the parasitic modes than the rod-type, so only the slot-type will be discussed. The damping slot is located at the position where there is a less coupling of the TM020-modes electric field, which is at the radius of 310 mm from cavity axis. The slot width, slot length, and the ferrite dimension were optimized to get as low as possible the damping of parasitic modes. The loaded Q of the selected parasitic modes, which has a high effects to the beam, from this optimized slot-type configuration is shown in Fig. 4. This slot damped mechanism mitigates the parasitic modes with the loaded Q in range of 10-1,000.

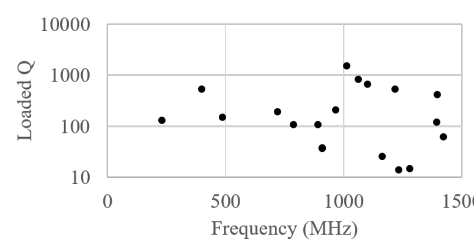

Figure 4: The parasitics mode loaded Q of the cavity equipped with the ferrite slot-type damped mechanism.

HARMONIC CAVITY DESIGN

The harmonic cavity is used in the storage ring of the light source for lengthening the electron bunch. Lengthening bunch increases the bunch volume and hence a lower bunch charge density. This helps prolonging the electron beam lifetime. For the SPS-II storage ring, the harmonic cavity will resonate at the third harmonic of the the main cavity, which is 1500.36 MHz. The efficiency of bunch lengthening is proportional to the shunt impedance of the cavity [6, 7],

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so the TM020-mode type cavity was studied for using as the harmonic cavity. The cavity shape is utilized the pill box cavity to ease fabrication similar to the KEK-LS harmonic cavity [8]. Superfish and CST MWS was used in design process. The designed harmonic cavity has the 354.514 mm diameter with a 90 mm effective cavity length. The shunt impedance is 2.45 MΩ with the 36,000 quality factor as the cavity profile illustrated in Fig. 5. The properties of the harmonic cavity are listed in Table 2. There will be six harmonic cavities installed in the SPS-II storage ring. The total shunt impedance is 14.7 MΩ. With this shunt impedance, the lifetime improvement factor of the 3 GeV 300 mA electron beam is 4.

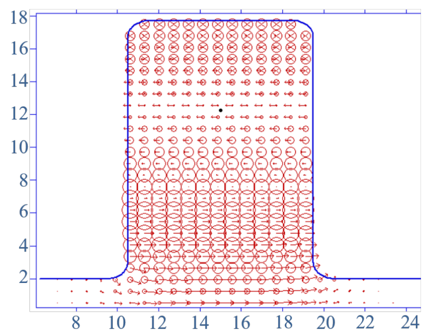

Figure 5: Cavity profile of the SPS-II TM020-mode harmonic cavity with arrows and circles represent electric and magnetic fields, respectively.

Table 2: RF Properties of the SPS-II TM020-mode Harmonic Cavity

Properties	**SPS-II TM020 HC**
Frequency (MHz)	1500.36
Quality factor	36,000
R/Q (Ω) [definition of $V^2/\omega U$]	68
Shunt impedance (MΩ)	2.45
Cavity diameter (mm)	354.514
Insertion length (mm)	300
Beam port diameter (mm)	40

Frequency Tuner Design

The plunger frequency tuner was design for the harmonic cavity. The diameter of the plunger rod is 30 mm. Two plunger tuners are required to get the ±0.5 MHz frequency range with the plunger moving range ±25 mm as the relation illustrated in Fig. 6.

The harmonic cavity will be operated in passive mode, so there is no RF power supplying to the cavity. But for the completeness of the design, the power coupler was also designed for the case of the active mode operation. The coupler is the coaxial loop-type coupler. The coupling factor can be adjusted by rotating the angle of coupling loop.

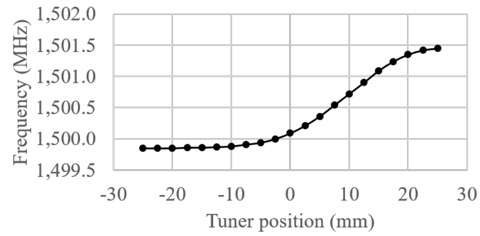

Figure 6: Tuner range of the TM020 harmonic cavity. The positive position means tuner is beyond the inner cavity surface toward the cavity axis.

Parasitic Modes Damping Design

Both methods of mitigating the parasitic modes, which were investigated in the main RF cavity, were also studied for the harmonic cavity. The slot-type damped mechanism is the effective method to mitigate the parasitic modes compare to the rod-type, which is similar to the study of KEK-LS harmonic cavity [12]. The slot is located at the radius of 125.5 mm from cavity axis. With the optimization of slot width, slot length, and the ferrite dimension, the proper damped mechanism configuration can be obtained. The optimized slot damped mechanism lowers the loaded Q of parasitic modes inside the harmonic cavity to the range of 10-1,000 as shown in Fig. 7.

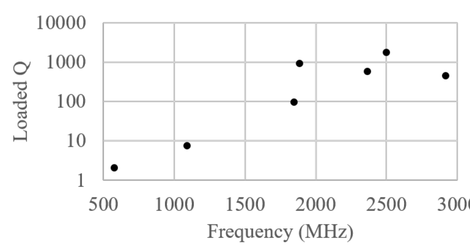

Figure 7: Parasitics modes loaded Q of the harmonic cavity equipped with the ferrite slot-type damped mechanism.

CONCLUSION

The detailed design of the main RF cavity and the harmonic cavity for the storage ring of the SPS-II light source is presented. The frequency tuner, the input power coupler, and the damping mechanism of the parasitics modes of both cavities were also discussed. These cavities utilize the high shunt impedance properties of the TM020 resonant mode cavity. The main cavity has 8.3 MΩ shunt impedance while the harmonic cavity shunt impedance is 2.45 MΩ. There will be four main RF cavities and six harmonic cavities installed in the storage ring of the SPS-II project.

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