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HIGH-POWER TESTS OF THE COMPACTLY HOM-DAMPED TM020-CAVITIES FOR A NEXT GENERATION LIGHT SOURCE

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Abstract

A TM020-mode normal conducting acceleration cavity with built-in ferrite absorbers was developed to attenuate the coupling impedances of its higher-order modes (HOMs), which make the beam unstable in high-current storage rings. The cavity was adopted for the storage ring of the new 3-GeV synchrotron radiation source Nano-Terasu. The cavity has a shunt impedance of 6.8 MΩ and generates an accelerating voltage of 825 kV at a 100 kW input. The cavity has a slot-type input coupler with a variable-length stub to match its coupling degree with change in beam loading during the operation. Four cavities were fabricated and **c**ould be operated at the RF nominal power of 100 kW. During the conditioning operation, the end plates of the cavity were deformed inward, and the resonant frequency changed -60 kHz lower. We speculate that residual stresses of the end plates may have been released. During the previous test, discharge occurred at the ceramic window. This could be suppressed by applying a magnetic field to the ceramic window and by conditioning up to 250 kW separately from the cavity. Thus, high power operation of the HOM-damped cavity was established.

INTRODUCTION

Recently, low-emittance storage ring light sources have been constructed in many countries. In these storage rings, the higher-order modes (HOM) induced by the stored beam in the acceleration cavity often causes coupled-bunch instabilities of the stored beam [1]. Many methods have been taken to avoid HOM. One method is installation of HOM absorbers in the beam pipe, in the waveguide or in the coupler [2-4]. Another method is to use a shape with a low impedance of the HOM, such as a bell shape [5]. However, these cavities have low shunt impedance or require extra space.

At SPring-8, we have developed a cavity with a HOM absorber in the TM020-mode cavity, as shown in Fig. 1 [6, 7]. The cavity has a simple and innovative structure to damp HOMs and to make the cavity body super-compact. Because the HOM absorbers are directly attached into the cavity body, the cavity requires no waveguide or pipe overhanging from the cavity body. The compactness enables four cavities to be installed in a short straight section of the storage ring. The cavities have high Q-values in the beam-accelerating mode and generate a sufficient beam-accelerating voltage.

The new 3-GeV synchrotron radiation facility Nano-Terasu, which is under construction by QST in Sendai, has adopted this TM020-mode cavity as an acceleration cavity for the storage ring [8]. The four cavities were fabricated sequentially by Mitsubishi Heavy Industries Machinery Systems. They had the performance as we designed in low-power RF measurement. The cavities were tested with a high-power operation at the SPring-8. In this paper, we report the results and the experience of the high-power test.

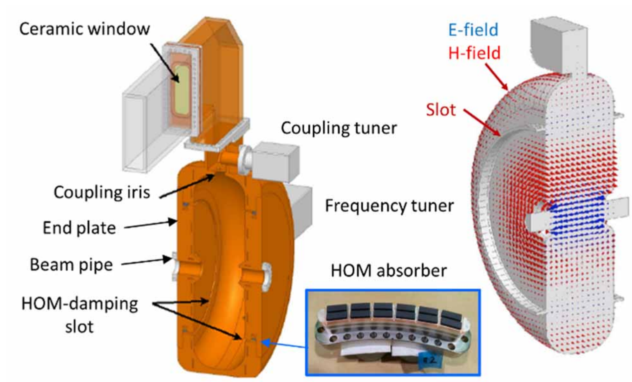

Figure 1: Schematic of the TM020-mode cavity, and the electric field (blue) and magnetic field (red) distribution.

CAVITY DESIGN

The schematic of the cavity and the field distribution are shown in Fig. 1. The design parameters are summarised in Table 1. The cavity is a normal conducting type resonating in the TM020 mode for beam acceleration with nose cones to enhance the acceleration electric field. The HOM-damping structure compromises two shallow slots opened in the cavity inner-wall and RF absorbers inside the slots. The point is that the HOM slots are located at the nodes of the magnetic field in the TM020 mode. This means that there is almost no magnetic field near the slot. The slots are perpendicular to the end plates and parallel to the direction of the electric field of TM020 mode. Thus, no electric field penetrates deep into the slot. For these reasons, the absorber at the back of the slot does not affect the electromagnetic field of the TM020 mode, but only absorbs the other HOMs. The absorber consists of ferrite (TDK HF70) blocks brazed to a copper block, which are cooled by water cooling of the copper block.

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The cavity is made of oxygen-free high-conductivity (OFHC) copper, cooled with cooling water. A frequency tuner is mounted on the side of the cavity to keep the resonant frequency despite thermal expansion of the cavity and beam loading. The cavity is directly connected to the external waveguide circuit through a slot at critical coupling. The coupling tuner is mounted near the coupling slot and can change its coupling factor ranging from 1 to 5 during high-power operation [9]. An RF window made of low-loss ceramic (Kyocera A479B) is provided in the middle of the waveguide upstream of the cavity [10]. The cavity is evacuated by a NEG combined pump (NEXTorr D500 starcell) installed in the waveguide and the beam duct sections to maintain an ultra-high vacuum.

In the NanoTerasu storage ring, an acceleration voltage of 3.3 MV is required to ensure a sufficient lifetime at 400 mA storage current [8]. An RF power of 100 kW per cavity is required to generate a voltage of 825 kV. The beam-loading power is up to 110 kW per cavity. Therefore, the maximum power input to each cavity is 210 kW. A klystron (Cannon Electron Tubes and Devices, E3732) with a maximum power of 1.2 MW can supply RF power required to the four cavities.

Table 1: Design Parameters of the HOM-damped Cavity for NanoTerasu Storage Ring

RF mode	TM020
Frequency	508.76 MHz
Unloaded Q	60,000
Coupling to waveguide	1- 5 (variable)
Shunt impedance	6.8 MΩ
Cavity voltage	825 kV
Input power for cavity	100 kW (no beam)
	210 kW (400 mA)
Number of cavities	4

HIGH-POWER TEST

Setup

To confirm the performance of the cavities, high power tests and conditioning were conducted at the SPring-8 test stand. Figure 2 shows the configuration for the tests, assuming the actual NanoTerasu machine. To observe the increased temperature of the ceramic window, a radiation thermometer was installed at a view port of the waveguide from the air side. An arc sensor was installed at the view port from the vacuum side to detect electrical discharges around the windows. The cavity, the ceramic window, the tuners and so on were cooled with water at 25°C. The total flow rate was 120 L/min.

After the cavity was evacuated, baking was performed using dedicated mantle heaters. In baking, the temperature was maintained at a maximum of 120 °C for 20 hours, and NEG activation was also performed during the temperature reduction. Baking sometimes caused the vacuum leaks at such as the mounting flanges of the ceramic window and the HOM absorbers. These leakages were easily eliminated by retightening the bolts fastening the flanges. The vacuum pressure was about 1e-6 Pa before high-power feeding.

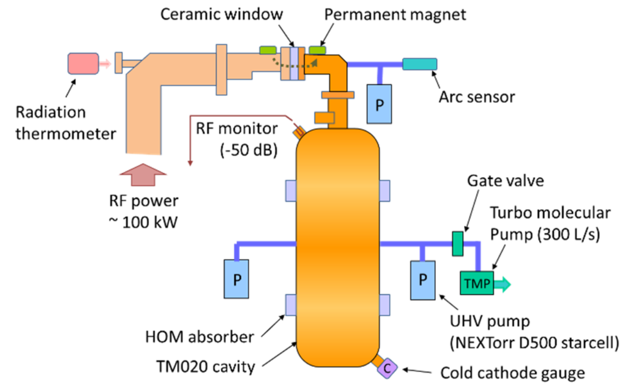

Figure 2: Configuration of the high-power test.

Conditioning Process

Figure 3 shows the evolution of the power and vacuum pressure in the cavity #4 in operation for 40 days. RF conditioning of the cavity was performed by starting with a power of about 1 kW and gradually increasing the power. The target of 100 kW was reached after about 20 days by increasing the power step by step. As the conditioning process were proceeding, the frequency of these trips decreased, and finally the system was operated for 11 days without stopping at all. The final vacuum pressure at the 100 kW operation was 7e-7 Pa, which is within the acceptable range for the storage ring. Similar conditioning runs were conducted for the other cavities, and finally it was confirmed that steady-state operation at 100 kW with almost no shutdowns was possible.

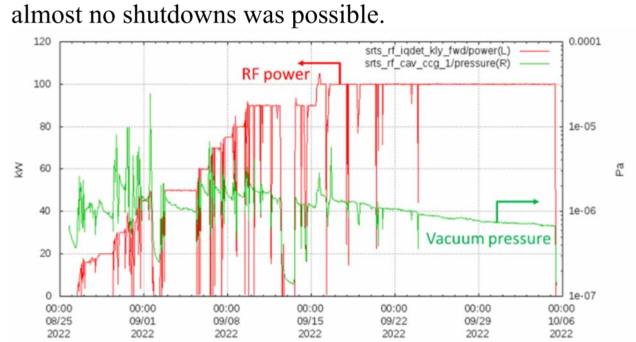

Figure 3: RF power and vacuum pressure of the cavity #4.

Deformation of the Cavity

During the high-power test, we found that as we increase the RF power, the resonant frequency of the cavity decreases and does not return to its original level. The resonant frequency of the cavity #1, which was tested first time, dropped 114 kHz when operated up to 100 kW, and dropped another 47 kHz when operated up to 150 kW. Position measurement of the spacing between the two end plates showed that the spacing had moved closer together, by approximately 1 mm, since the initial delivery (see Fig. 4). This deformation is consistent with the change in resonant frequency. The cavity was taken back to the manufacturing factory. The end plates were machined again, and the

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frequencies were re-matched. Thermo-structural analysis was done to find the source of this deformation. The result showed that the cooling of the end plates was insufficient, and the temperature rose up to 37 K, which may cause the end plates to distort inward due to thermal expansion. To cool the end plates, a joint was added to divide the water channel in two, and the flow rate of cooling water was increased to four times the initial level. After this countermeasure, the temperature rise of the end plate surface was reduced to be about 10 K, as shown in Fig.4.

High power tests of cavities #2, #3 and #4 were conducted after the end plate cooling modification. When operated up to 100 kW, the frequency change left about 50-60 kHz in any cavity. Cavity #1 with modified end plates was also tested again at high power up to 100 kW. The frequency change during 100 kW operation was as small as 21 kHz. This means that once deformation is experienced, deformation is unlikely to occur at a second time. Based on these circumstances, we speculate that the current deformation of the remaining cavity is due to residual stress remaining in the end plate welds, etc., and that this stress is released. Although the current deformation is within the adjustment range of the frequency tuner and can be used, the structure and manufacturing method should be reconsidered for future production.

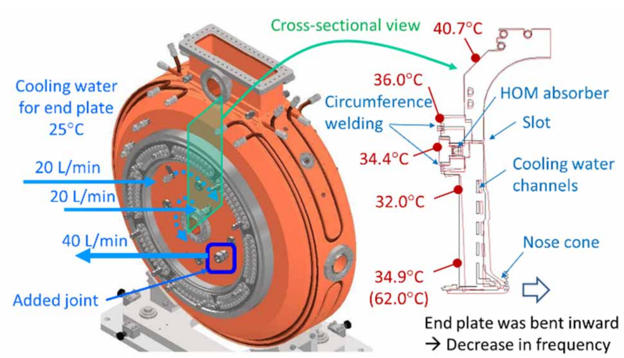

Figure 4: Description of the end plate deformation of the cavity. Cooling water channels and temperatures of various parts are also illustrated. The temperatures in parentheses indicate the temperatures before the joint was added and when only 9 L/min. was flowing.

High Power Conditioning of the Ceramic Window

During high-power testing of the prototype cavity, discharges occurred at the vacuum side of the ceramic window, and sometimes interrupted the cavity operation by excessive reflected power or vacuum deterioration arising from the discharges. Therefore, we conditioned of ceramic windows independently. Figure 5 shows the schematic of the set-up. A vacuum waveguide with two ceramic windows at both ends was assembled and located between the klystron and a dummy load. The output RF power of the klystron was gradually increased, and if there were reflections at the window or deterioration of the vacuum, the RF output would be stopped by an interlock. As a countermeasure against the discharges on the ceramic surfaces, we applied magnetic fields perpendicular to the ceramics surface by using permanent magnets. When multipactor discharges occur on the ceramic surface, the magnetic fields can change the orbits of secondary electrons and suppress the discharges. The application of the magnetic field worked effectively, and the frequency of discharge and vacuum deterioration was very low, allowing a smooth increase in RF power. Figure 6 shows an example of the steady rise of the transmitted RF power up to 250 kW. We could finally establish a continuous operation for 5.5 days at 250 kW. The temperature of the ceramic measured by a radiation thermometer was 39°C, which is low enough. We conditioned all ceramic windows in a similar manner.

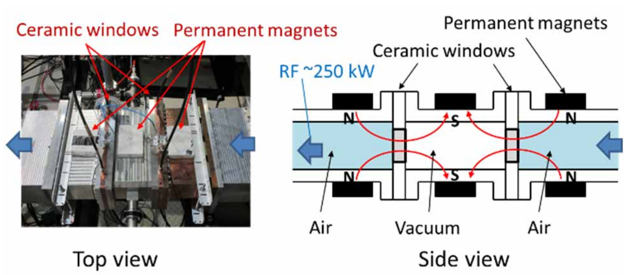

Figure 5: Schematic of the high-power conditioning of the ceramic window.

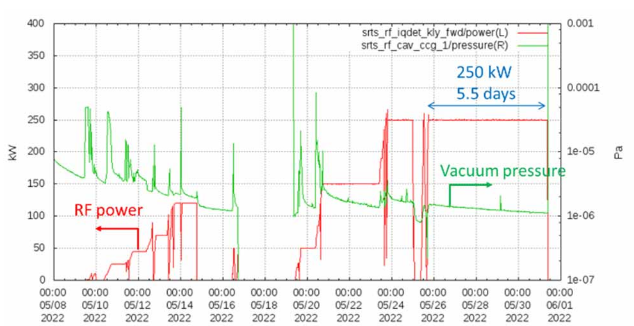

Figure 6: RF power and vacuum pressure during the high-power conditioning of the ceramic window.

CONCLUSION

HOM-attenuated TM020 cavities have been developed to suppress HOM, which is a problem in high-current electron storage rings. 4 cavities were tested at high power up to 100 kW and confirmed the stable operation. The ceramic window inserted in the middle of the waveguide was also tested for passage up to 250 kW and confirmed the high-power performance. These cavities and ceramic windows have been installed at the 3GeV synchrotron radiation facility NanoTerasu and are being prepared for RF operation starting in end of May.

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