DEVELOPMENT OF C-BAND HIGH-POWER MIX-MODE RF WINDOW

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Abstract

A high-power C-band (5712 MHz) rf system (40 MW, 2 µs, 50 Hz) is under consideration for an electron-linac upgrade aimed for the super KEKB project. An rf window, which isolates the vacuum and passes rf power, is one of the most important components for the rf system. The window consists of a ceramic disk and a pill-box housing. The mix-mode rf window is designed so as to decrease the electric field on the periphery of the ceramic disk. A resonant ring has been assembled in order to examine a high-power transmission test. The window was tested up to a transmission power of 300 MW. The rf losses were also measured during rf operation.

INTRODUCTION

An upgrade of the KEKB injector linac is under consideration for the SuperKEKB project [1]. C-band rf sources (5712 MHz, 2 µs, maximum 50 MW) will be installed in the upgrade for a higher acceleration gradient of more than 40 MV/m [2]. The rf power (~40 MW) will be transmitted through an rf window and a pulse compressor, and delivered to acceleration structures. The rf window consists of an alumina ceramic disk and pill-box housing, which enables us to transmit the rf and separate the vacuum, which is one of the important components for this upgrade. A surface discharge due to electron emission at the edge of the ceramic under high rf fields results in excess surface heating, leading to punctures.

In this paper, the design of a mix-mode window [3], where the electric fields at the edge of the ceramic decrease, is described. The results of high-power tests using a resonant ring are also summarized.

DESIGN OF THE RF WINDOW

The new rf window is required to transmit rf power of 50 MW (2 µs, 50 pps). The criteria of the new C-band rf window are determined based on the electric fields of the S-band rf window. The S-band window has a long life with an MTBF of more than 100,000 hours [4] under an rf transmission of 50 MW (2856 MHz, 4 µs, 50 pps), and is reliable for long-time rf operation, even though leakage of the klystrons is one of the reasons for klystron failures. The electric field at the edge and center of the ceramic disk should be less than that of the S-band disk (84 mm in diameter and 3.2 mm in thickness). The bandwidth of the rf window should be more than 100 MHz, which is sufficiently wider than the performance of the klystron and/or the acceleration structure. The calculated values are given in Table 1. The electric fields at the edge and at the center of the ceramic are about 1.7 MV/m and 3.7 MV/m, respectively. In order to satisfy these requirements, it is necessary to enlarge the diameter of the alumina ceramic disk compared with the wavelength of the C-band, which indicates the transmission of the higher modes, such as a TM_{11} mode. By mixing the TE_{11} mode and the TM_{11} mode, lower electric fields can be accomplished, thus making a 'mix-mode window'. A high-purity alumina ceramic of HA-997 (99.7% purity, NTK Co.) having a high durability for the transmission of high power [5] has been adopted. A diameter of 78 mm and a thickness of 4 mm were chosen in order to avoid any resonant frequencies around the operation frequency (5712 MHz).

Table 1: Electric properties of the S-band rf window

Center of the ceramic	3.7 [MV/m@50MW]
Edge of the ceramic	1.7 [MV/m@50MW]
Maximum electric field on the surface of the ceramic	5.5 [MV/m@50MW]
Bandwidth (VSWR<1.2)	600 [MHz]

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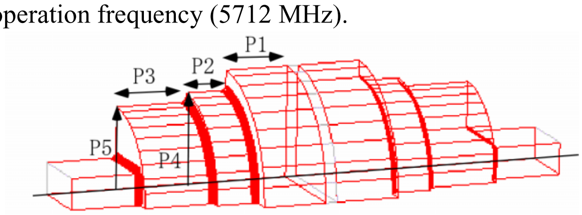

Figure 1: Schematic of the C-band window. The length of the first ring (P1), second ring (P2), third ring (P3) and inner radius of second (P4) and third ring (P5) are the parameters to be optimized.

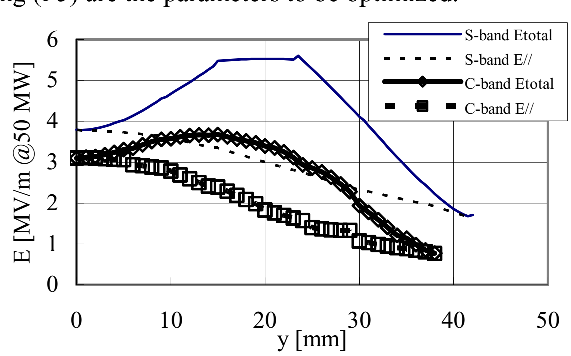

Figure 2: Electric fields on the ceramic disk calculated for C-band and present S-band rf window.

The window is constructed with a combination of three rings. Five parameters (Figure 1), which are necessary to match the two different modes in a same length, are optimized using HFSS. In order to avoid any volume resonance of TE_{012}-like and TM_{014}-like modes, the rf waves do not propagate as complete travelling waves in the ceramic disk (quasi-travelling wave). However, the electric fields at the center and edge of the disk are about 20% and 50% lower than the present S-band window, respectively, as shown in Figure 2. This indicates that that the electric fields at the power of 50 MW at C-band correspond to those at a power of 35 MW at the S-band, so that a longer MTBF will be expected compared with the present S-band window.

LOW LEVEL MEASUREMENTS

Several types of first and second rings having different P1 and P2 parameters were prepared for determining the final dimensions. The electric fields were measured by a perturbation method [6] using this low-level model. A cubic (3 mm) of Rutile having high permittivity is used in the measurements due to the low electric fields around the ceramic surface. The measured fields are shown in Figure 3. The electric fields were measured from the center of the rectangular waveguide (z=-100 mm) to the center of the ceramic disk (z=0). The measured and calculated data show good agreements.

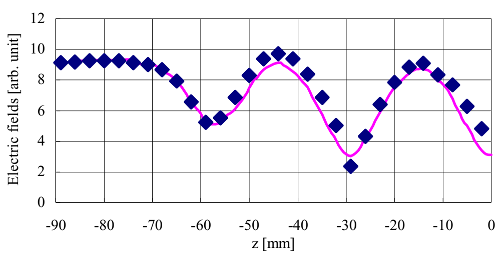

Figure 3: Measured electric fields at the center of the axis from the ceramic to the rectangular waveguide.

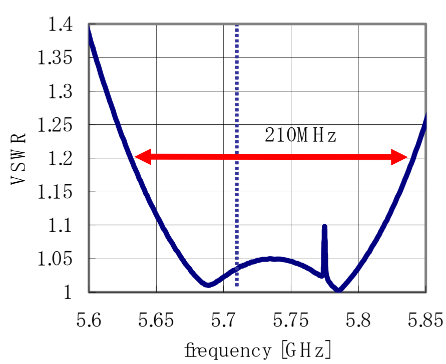

Figure 4: Bandwidth of the C-band rf window.

Table 2: Volume resonances near to the operation frequency

	Calculation	Measured
TM_{014}-like [GHz]	5.78	5.77
TE_{012}-like [GHz]	>5.85	>5.8

A window for high-power usage was coated with TiN films for multipactor suppression [7]. The measured band-width (VSWR < 1.2) is more than 200 MHz, as shown in Figure 4, which agrees well with the calculation. The volume resonances were also measured, as shown in Table 2. The TM_{014}-like mode locates at about 50 MHz higher than the operation frequency, and the resonance frequency is almost the same as the predicted one, based on a calculation using HFSS. Figure 5 shows a photograph of this C-band mix-mode window.

HIGH-POWER TEST USING A RESONANT RING

Resonant Ring

A resonant ring is designed for a high-power test of the rf window. A schematic of the ring is shown in Figure 6. The main characteristics of the ring are determined by the coupling ratio of the hybrid [8]. In this resonant ring, a coupling ratio of 14 dB is adopted, and a maximum of 18-times higher power than the klystron output is available in the ring.

The total length of the ring should be an integer of the wavelength. A rough adjustment was carried out inserting a spacer in the ring with a preciseness of 10 mm. Fine tuning was done by adjusting the operation frequency, which was 5710.2 MHz at a high-power test of the rf window. The resonant ring is evacuated by two non-evaporating getter pumps (NEGs) and two ion pumps located on both sides of the rf window. The base pressure was less than 10^{-7} Pa.

High Power Tests

High power tests were carried out with a waveguide instead of an rf window at first in order to progress the conditioning of the resonant ring. A maximum circulating power of 400 MW (2 μs) was achieved after about 10

Figure 5: Photograph of the C-band rf window.

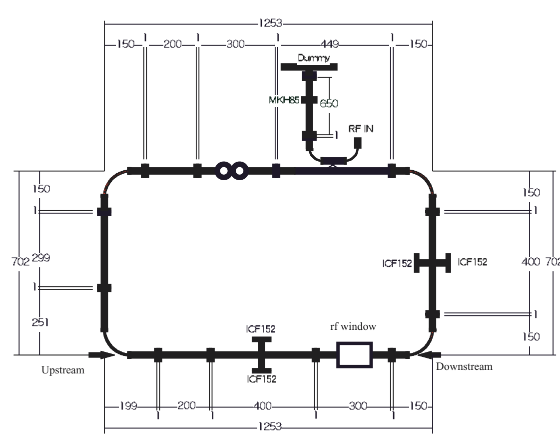

Figure 6: Schematic of the resonant ring.

days of operation. High power tests of the rf window were examined up to 300 MW (2 µs), finally. Figure 7 shows the rf power and vacuum pressure during 8 hours of operation. The rf trips took place only 3-times during operation.

The optical emission was measured during rf operation. Emission took place between about 70 MW and about

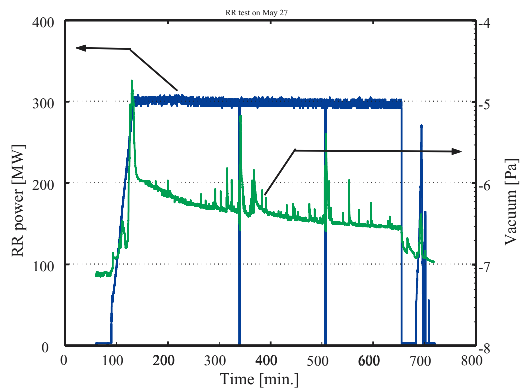

Figure 7: Rf transmission power through the rf window and vacuum pressure during 8 hours of operation.

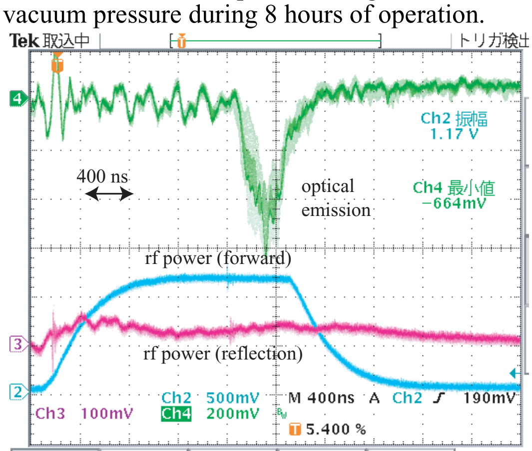

Figure 8: Rf transmission power together with the optical emission.

150 MW. The region of the optical emission depends on the past records, and it is considered that the surface charging of the ceramic disk affects the emission [9]. The spectrum of the optical emission was also measured, and it was confirmed that the emission was cathodoluminescence (luminescence induced by electron irradiation) from the alumina ceramic, caused by oxygen defects such as the F^+ center [5]. The optical emission was observed at a higher power than that of the present S-band window, probably caused by the lower electric field at the edge of the ceramic disk. The emission took place at the end of the rf pulse, as shown in Figure 8. A longer time is probably necessary to accumulate a sufficient number of electrons contributing to the optical emission.

The rf losses were measured by the increase in the temperature of the cooling water. The results are shown in Figure 9. The loss was 10 W at a transmission power of 10 kW, which is almost the same as the present S-band window. Since the ceramic thickness is 30% thicker than the S-band window, the effective rf losses per unit length

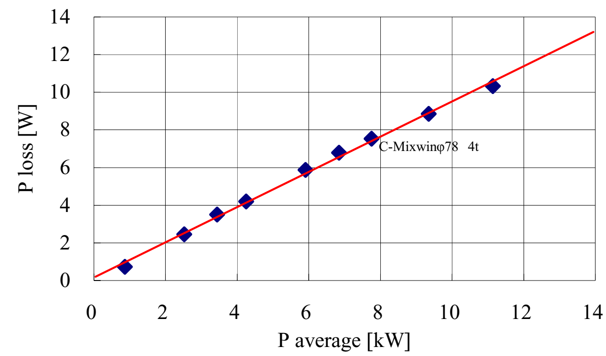

Figure 9: Rf losses at the ceramic disk measured by the temperature increase of the cooling water.

are smaller than that of the S-band window, which indicates the lower rf fields in the ceramic disk.

SUMMARY

The C-band rf window was designed based on a mix-mode structure. The electric fields at the edge of the ceramic, which are related to electric breakdown, become about half compared with that of the present S-band window. High-power tests were carried out with a resonant ring. The ring was evacuated to less than 10^{-7} Pa and was successfully operated up to 300 MW, which is about 6-times higher than the specification.

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