Development of L-band Pillbox RF Window

Y.Takeuchi, S.Fukuda, H.Hisamatsu and Y.Saito
National Laboratory for High Energy Physics (KEK)
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan
A.Takahashi
Mitsubishi Heavy Industries, Ltd. Mihara Machinery Works
5007 Itozaki-cho, Mihara-shi, Hiroshima-ken, 729-03, Japan

Abstract

A pillbox RF output window was developed for the L-band pulsed klystron for the Japanese Hadron Project (JHP) 1-GeV proton linac. The window was designed to withstand a peak RF power of 6 MW, where the pulse width is 600 μsec and the repetition rate is 50 Hz. A high power model was fabricated using an alumina ceramic which has a low loss tangent of 2.5×10^{-5}. A high power test was successfully performed up to a 113 kW RF average power with a 4 MW peak power, a 565 μsec pulse width and a 50 Hz repetition rate. By extrapolating the data of this high power test, the temperature rise of the ceramic is estimated low enough at the full RF power of 6 MW. Thus this RF window is expected to satisfy the specifications of the L-band Klystron.

Introduction

Several R&D studies have been being carried out for the 1-GeV proton linac of the JHP. There will be 36 L-band pulsed klystrons (f=1296MHz) used in the high-β section of the JHP linac. The klystron will be required to supply a RF peak power of 6 MW (600 μsec, 50 Hz) [1]. A prototype of the klystron is being developed at KEK [2]. As a part of this work we have developed an L-band pillbox RF output window for the klystron. This window can be used also as an input RF window for the high-β coupled-cell cavity.

Pillbox-type RF windows are widely used for high power klystrons. Figure 1 shows a schematic drawing of a pillbox RF window. We made two types of high power test windows which have different alumina ceramics. Two windows of type A and two windows of type B were made with the alumina ceramic HA95 and HA997, respectively. These ceramics were supplied by NTK co..

HA95 was adopted for the first model (type A) to establish the fabrication techniques such as brazing between a ceramic disk and a copper sleeve. because the cost of this ceramic was much lower than the high purity alumina ceramic HA997. But the type-A window had a large temperature rise of 78.5 deg. at an average power of 93.75 kW with a RF peak power of 5 MW, (375 μsec, 50 Hz). And the temperature rise of ceramic at full RF power was estimated to exceed 100 deg.. Since the thermal shock fracture resistance of the alumina ceramic decreases abruptly when the thermal shock exceeds 200 ~300 deg., the alumina ceramic should not be used over 200 °C. When we take into account the safety factor, the temperature rise of the ceramic should be less than 100 deg.. Therefore, we had to reduce the temperature rise of the ceramic disk.

For the second model (type B), we adopted HA997 ceramic disk, the loss tangent of which is 2.5×10^{-5} and about 1/10 of that of HA95 (3×10^{-4}). The type-B windows were tested up to the average power of 113 kW.

The design procedures of these two types of windows and the performance of the high power test models of the type-A windows were already reported precisely [3,4]. In this paper we mainly discuss the performance of the type-B windows.

Matching solutions of pillbox RF window

A pillbox window shown Fig. 1 can be expressed by an equivalent circuit such as Fig. 2, where B1 is a susceptance provided by the step from the rectangular waveguide to the circular one; Y1, Y2 and Y3 are the characteristic admittances of the WR650 rectangular waveguide, the circular waveguide and the circular waveguide filled with the ceramic material, respectively. It is assumed that only the TE_{10} mode can propagate in the rectangular waveguide and only the TE_{11} mode in the circular waveguide.

From the graphical analysis of this equivalent circuit on a Smith chart using typical parameters determined by measurements of a cold test model, we have obtained the following characteristics of the matching solutions [5]. 1) When $T<\lambda_g/2$ and $l_1, l_2<\lambda_g/2$, l_1 must be equal to l_2, where λ_g is the guide wavelength. Here we define l_0 as $l_0=l_1=l_2$. 2) When $T\leq\lambda_g/4$, $l_0<\lambda_g/2$ and T is small enough, two values of l_0 satisfy the impedance matching. Figure 3 shows these solutions. Here we define T_1 as $T_1=T\leq\lambda_g/4$. 3) When $\lambda_g/4\leq T<\lambda_g/2$, $l_0<\lambda_g/2$ and T is large enough, two values of l_0 satisfy the impedance matching. Here we define T_2 as $\lambda_g/4\leq T_2=T<\lambda_g/2$. 4) There exist the maximum value of T_1 and the minimum value of T_2 which satisfy the impedance matching. Then $T_1+T_2=\lambda_g/2$. If T_1 goes to the maximum value, two solutions of l_0 merge into one solution. Figure 4 shows this solution. Because the line L1 is tangent to the circle C2 when T is the maximum value in Fig. 4, the VSWR is not sensitive to the small deviation of l_0 from the solution. Therefore, this solution makes it possible to relax the tolerance for l. 5) When $T=\lambda_g/2$ and $l_1, l_2<\lambda_g/2$, there exist solutions (usually $l_1\neq l_2$). 6) Each of the solutions of l_1, l_2 and T has the periodicity of $\lambda_g/2$. This means that if T is a solution, $T+N\times\lambda_g/2$ is a solution too (where N=0,1,2,....).

From the results of this analysis, the solution which has the maximum value of T_1 ($T_1<\lambda_g/4$) was adopted for the windows of type B to relax the tolerance for l.

Performance of high power test model

Two windows of type B (d=190 mm, T=5.6 mm and l=38 mm) were fabricated for the high power test. Figure 5 shows the VSWR curve for one of the windows.

A vacuum side of the ceramic disk was coated with titanium nitride to suppress multipactoring. A 60 Å-thick coating and a 100 Å-thick coating which were performed by ULCOAT co. were adopted, because the optimum thickness of the TiN coating performed by ULCOAT was found to be 60 to 150 Å for the window ceramic of the UHF klystron used in TRISTAN [6].

The TiN coating by ULCOAT contains oxygen atoms and has a columnar grain structure. These properties play an important role to make the resistivity of this coating high [7]. We measured the loss tangent of the window ceramic by using an L-band cavity to confirm these properties and estimate the dielectric loss in the ceramic. Table 1 shows the results of these measurements. The coating did not affect the loss tangent. On the other hand the pure TiN coating has a low resistivity. And the thickness of the pure TiN coating was optimized 5~15 Å for the S-band RF window by measuring the effective loss tangent after TiN coating [8]. In this case the coating with a low resistivity affected the effective loss tangent. And this effect made the upper limit of the optimum thickness. By the measurements of the loss tangent, the property differences between the TiN coating by ULCOAT and the pure TiN coating were clearly confirmed.

Figure 6 shows the layout of the high power test. Each window was connected with an H-plane corner, the space between two windows was evacuated. The vacuum pressure was 10^{-10} Torr after a 72-hour baking at 100 °C. Other spaces were filled with SF_6 with a 1.5 kg/cm^2 absolute pressure. Three sapphire viewing ports were mounted to monitor glow emitted by discharge on the ceramic during the conditioning and to measure the ceramic temperature using an infrared thermometer.

Two H-plane corners were cooled by water jackets to keep the waveguide at room temperature. This condition is necessary to compensate the background emission when we measure the ceramic temperature using the infrared thermometer. (In the type-A windows test, waveguides were not cooled thus the compensation of the background emission has some errors and the measured temperature rise of ceramic may be larger than the actual temperature rise.) It is difficult to measure the ceramic temperature accurately using the infrared thermometer in this test system because 1) temperature rise is small compared with an amount of inaccuracy which comes from the calibration of the effect by the sapphire viewing ports and the effect by the background emission, 2) a few of the infrared rays can penetrate the high purity alumina ceramic disk such as HA997.

The sleeve of the ceramic disk was water-cooled. In measurements of power loss in the ceramic the most reliable method in this case was to measure the temperature rise and the flow rate of the cooling water in the water jacket of the pillbox. The temperature rise was measured using the quartz thermometer and the flow rate was calculated measuring the water volume which flowed during 1 minute. The both rectangular waveguide ports of the pillbox window were cooled by water jackets and kept their temperature equal to that of the pillbox to cut off thermal flow across the cross-sections of A-A' and B-B' in Fig. 6.

RF power was fed by an L-band 5 MW klystron (THOMSON TH2104A). The windows were conditioned up to a peak power of 5MW with a pulse width of 375 μsec and a repetition rate of 50 Hz, and operated up to the average power of 113 kW with a RF peak power of 4 MW (565 μsec, 50 Hz), which was the maximum average power that the klystron could drive at that time.

During the conditioning, sudden gas bursts and emissions of blue-white glow were observed frequently. After the sufficient conditioning few gas bursts or few emissions of the glow were observed.

Figure 7 shows the dependence of the ceramic temperature and the power loss in the pillbox (the dielectric loss in the ceramic and the wall loss in the pillbox) on the transmitted power (375 μsec, 50 Hz). The open circles represent the measured temperatures. The closed circles represent the measured power loss. The temperature data by the infrared thermometer have some errors because these data are not calibrated yet. Since these curves in Fig. 7 are almost linear to the RF power, multipactoring was suppressed effectively by the TiN coating. We did not observe a significant difference between a 60 Å-thick coating and a 100 Å-thick one.

Since a traveling wave in the pillbox window can be expressed as a superposition of two standing waves with the even and odd parities, we can estimate the dielectric loss in the ceramic and the wall loss in the pillbox by calculating both modes using MAFIA [9]. Table 2 shows the estimated and measured data of the power loss in the pillbox and the temperature rise at the center of the ceramic at a peak power of 5 MW (375 μsec, 50 Hz). The estimated temperature rise in the Table 2 was calculated by assuming the uniform power loss distribution in the ceramic disk.

In this table, the measured power loss of the type-B window (100 Å TiN coated) is about 2.7 times as large as calculated one. The thermal flow from the heated SF_6 gas was considered as a cause of this disagreement. However, if the measured power of 45.8 W was lost only in the ceramic in the worst case, estimated temperature rise would be about 21 deg. and the extrapolated temperature rise at the full RF power would be about 40 deg., which is much less than the criterion of 100 deg.. Therefore, the window of type B has sufficient capability to withstand the full RF power.

Conclusion

A pillbox RF window for the JHP L-band pulsed klystron has been developed. The type-B windows with HA997 ceramic disks were conditioned up to a 5.0 MW peak power with a 375 μsec pulse width and a 50 Hz repetition rate. And these were operated up to a 113kW average power with a peak power of 4 MW (565 μsec, 50 Hz). The power loss in the pillbox window was measured and compared with the calculation by using MAFIA. From these data, the temperature rise of the ceramic is extrapolated at the full RF power to be less than 40 deg.. Therefore this window is expected to satisfy the specifications of the JHP L-band pulsed klystron.

Acknowledgments

We would like to thank Dr. S. Michizono for the measurement of the loss tangent. We also acknowledge valuable discussions with Dr. S. Yamaguchi.

References

[1] Report of the design study on the proton linac of the Japanese Hadron Project,No.1,JHP-10,KEK Internal 88-8,Sep. 1988.
[2] S.Fukuda et al., "L-band Pulsed Klystron for the JHP", presented in this symposium.
[3] Y.Takeuchi, "L-band output window", Report of the design study on the proton linac of the Japanese Hadron Project,No.2,JHP-14,KEK Internal 90-16,June 1990, pp. 259-277.
[4] Y.Takeuchi et al., "Development of L-Band Pillbox RF Window" Proc. of 6th symp. on accelerator science and technology, RIKEN, Wako, Saitama, Nov.,1991.
[5] Y.Takeuchi, to be published.
[6] S.Isagawa et al., "Development of high power CW klystrons for TRISTAN", Proc. of the IEEE particle accelerator conference, Washington, D.C., March,1987.
[7] S.Isagawa and Y.Takeuchi, "Suppression of multipactoring on high power RF ceramic windows by TiN coating " , Proc. of annual meeting of the surface finishing society of Japan, Nov. ,1991.
[8] S.Michizono et al., "TiN film coatings on alumina radio frequency windows", J. Vac. Sci. Technol. A 10(4), Jul/Aug 1992, pp. 1180-1184.
[9] S.Yamaguchi, Private communication.

Table 1 Measurement of Loss Tangent

	Loss Tangent (before coating)	Loss Tangent (after coating)
60 Å coating	2.36×10^{-5} (1110MHz) 2.45×10^{-5} (1648MHz)	2.51×10^{-5} (1110MHz) 2.37×10^{-5} (1648MHz)
100 Å coating	2.97×10^{-5} (1110MHz) 2.49×10^{-5} (1648MHz)	2.73×10^{-5} (1110MHz) 2.41×10^{-5} (1648MHz)

Table 2 Power loss in Pillbox Windows

(Peak Power=5MW, PulseWidth=375μsec, Repetition Rate=50Hz.)

	Loss tangent	Dielctric loss	Temperature rise of ceramic	Power loss in pillbox
TypeA (HA95)	3×10^{-4} (Catalog)	54.6 W (Calculated)	44.6 deg. (Calculated)	67.6W (Calculated)
TypeB (HA997)	2.5×10^{-5} (Measured)	4.2 W (Calculated)	1.9 deg. (Calculated)	17.1W (Calculated) 45.8W (Measured)

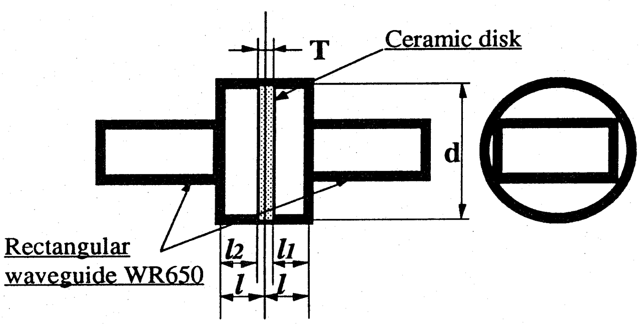

Figure 1 Structure of Pillbox RF Window

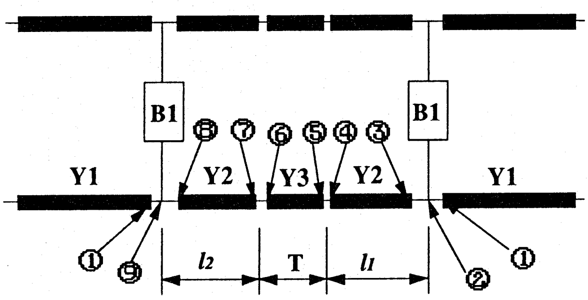

Figure 2 Equivalent Circuit of Pillbox RF Window

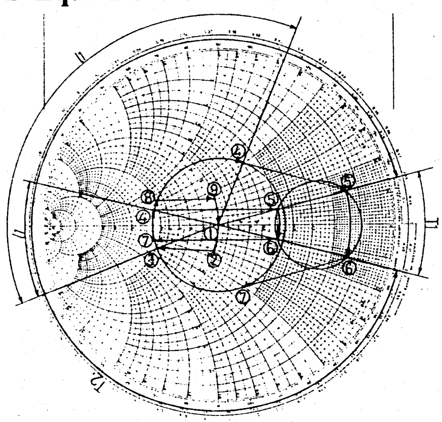

Figure 3 Matching solutions on Smith Chart

Admittance chart. l_1=15.8, 61.0 mm where d=190mm, T_l=3.0mm, εr=9.9, B1/Y1=0.318, Y1/Y2=1.97, and Y2/Y3= 0.2286.

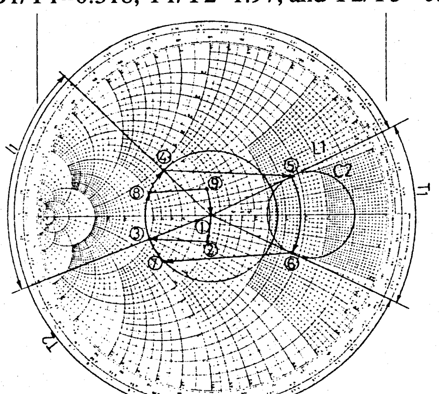

Figure 4 Matching solution on Smith Chart

Admittance chart. l_1=29.8 mm where d=190 mm, T_l=5.45 mm, εr= 9.9, B1/Y1= 0.318, Y1/Y2= 1.97, and Y2/Y3= 0.2286.

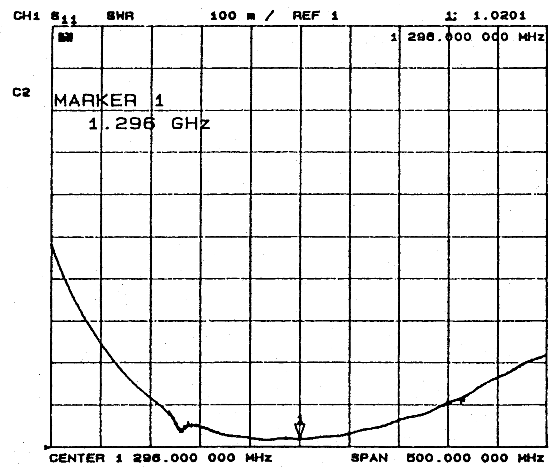

Figure 5 VSWR Curve of Type-B Window

Measurement of the type-B #2 window (100 Å TiN coating). Horizontal range, 1046~1546 MHz. Vertical range 1.0~2.0.

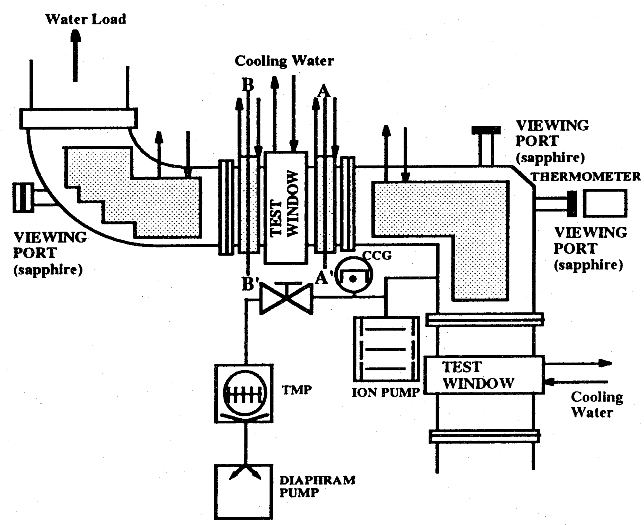

Figure 6 Layout of High Power Test

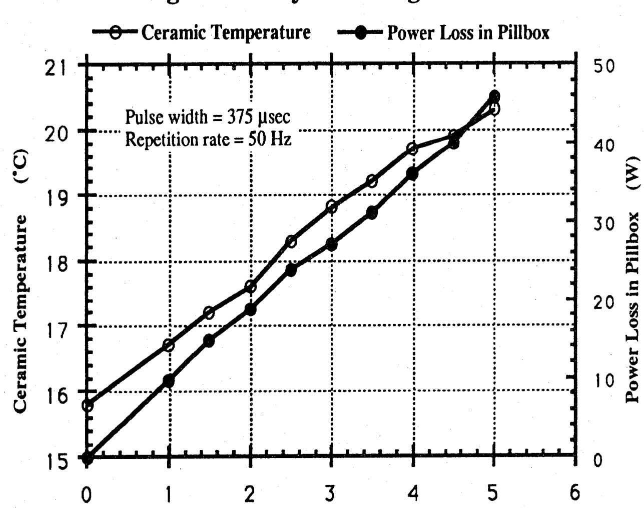

Figure 7 Ceramic Temperature and Power Loss in Pillbox vs. RF Power

Measurements of the type-B #2 window (100Å TiN coating).