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Test Results and Design Considerations for a 500 MHz, 500 kWatt Vacuum Window for CESR-B*

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SUMMARY

A previous paper [1] described the design of a vacuum window proposed for use in WR-1800 waveguide. This work details the results of a high power test of the completed prototype window. The window passed all design goals when operated into a short-circuited load. For the case of a matched load, the travelling wave power reached a maximum of 260 kWatts CW with vacuum bursts as a limiting factor. In addition to the results from the high power tests, some results from low power tests using a network analyzer are given. Some general conclusions are drawn concerning the design of vacuum windows in rectangular waveguide.

INTRODUCTION

The Laboratory of Nuclear Studies is proposing an upgrade to the existing CESR electron positron storage ring to make possible the study of CP violation of B meson decays. This "B-Factory", because of the required luminosity and the resultant high beam current, will require very high RF power levels to replace the synchrotron radiation and the higher order mode energy losses of the beam. The proposed design requires vacuum windows in WR-1800 waveguide which can handle 500 kWatts at 500 MHz.

There are two different operating scenarios for the window. The first is the case of total reflection from the cavity. During beam injection or after the beam has been lost, nearly all the power incident on the cavity will be reflected due to the low wall losses of the superconducting cavity (approx. 100 Watts). This scenario may exist up to a maximum of 125 kWatts incident (and reflected). Thus the window must be designed to operate in a standing wave resulting from an incident and reflected wave of 125 kWatts. This standing wave may shift in position according to the phase characteristics of the load. The second scenario is the case of no reflection from the cavity. This corresponds to maximal delivery of power to the beam. For this case there is almost no reflected power from the cavity. To survive in this scenario the window must be designed to operate in a travelling wave of 500 kWatts.

Two identical prototype windows were constructed. Fig. 1 shows the basic design of each. The waveguide from the klystron is standard WR-1800 (9 in. by 18 in.). It was reduced in height by means of an aluminum taper to 5.5 in. by 18 in. Three beryllium oxide disks were brazed into a water cooled copper frame which was welded on the end of a copper plated stainless steel waveguide 5.5 in. by 18 in. The beryllium oxide was chosen for its high thermal conductivity. A matching post was placed approximately 18 in. from the disks in the waveguide on both sides of the disks.

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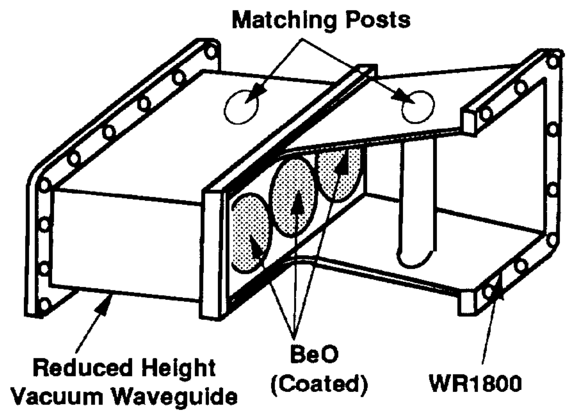

Fig. 1 500 kWatt, WR-1800 waveguide window for use at 500 MHz

II. LOW POWER TESTS

Each of the windows was measured using a vector network analyzer. The analyzer was calibrated in WR-1800 waveguide using the Thru-Reflect-Line method. A waveguide section two wavelengths long tapering from the reduced 5.5 in. height to the full 9 in. height was added to the window. The window and added taper were then measured together. The resulting VSWR is shown in Fig. 2. The system responds like a three element filter (post, windows, post). Fig. 3 shows the voltage transmission coefficient of the system.

III. HIGH POWER TESTS

A full power test was performed on the proposed window design. The test setup used two windows back-to-back with a vacuum region between as shown in Fig. 4. The input VSWR of this configuration is shown in Fig. 5.

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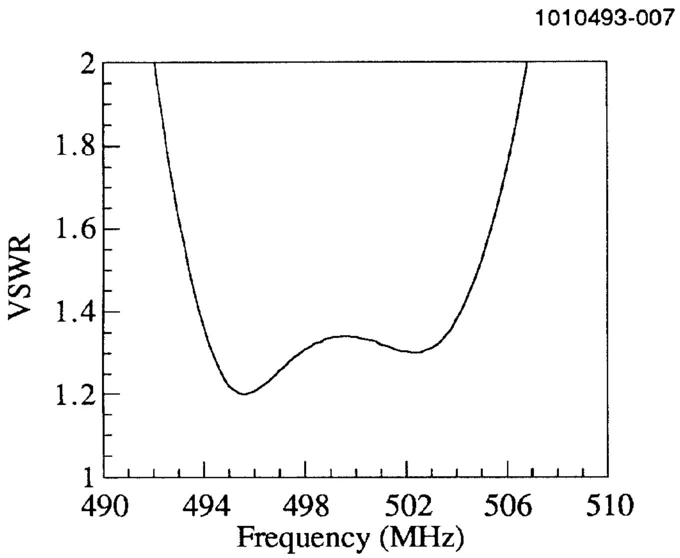

Fig. 2 Input VSWR of the waveguide window.

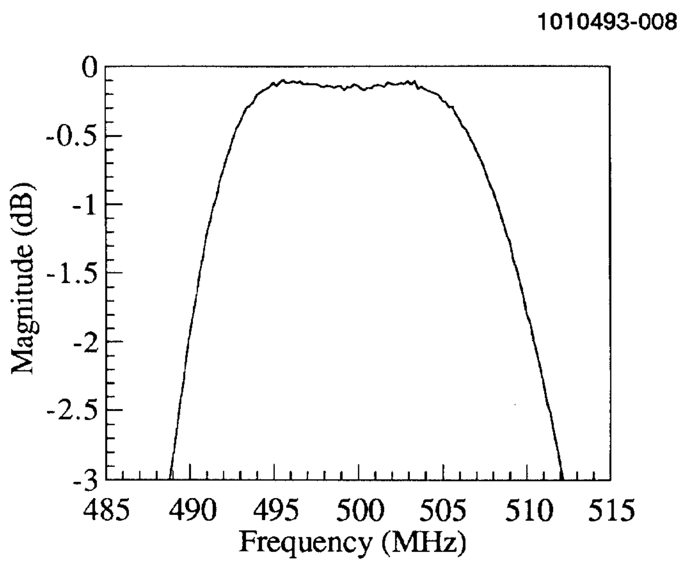

Fig. 3 Voltage transmission coefficient of the waveguide window.

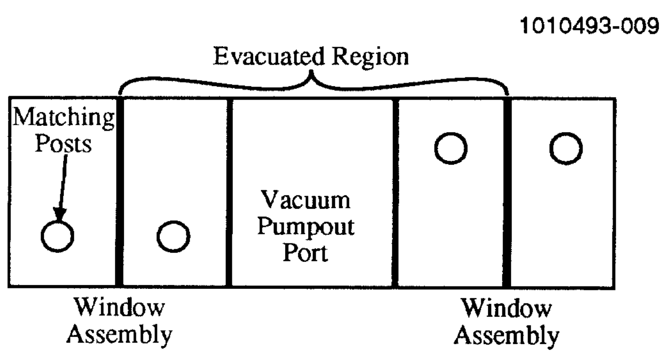

Fig. 4 High power test setup

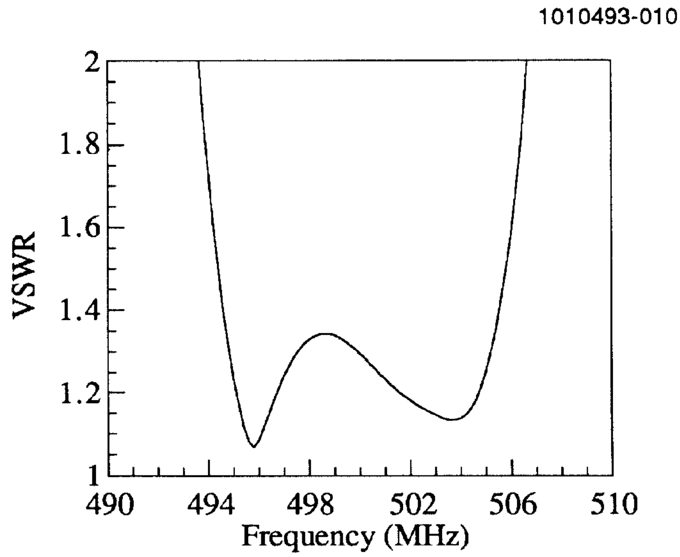

Fig. 5 Input VSWR of the test setup in Fig. 4.

The output side was first terminated with a high power matched load. A maximum CW power of 260 kWatts was achieved at a vacuum level of 1.5×10^{-8} Torr. The walls of the vacuum section between the post and the window frame rose to about 60 °C at this power level. Increasing RF power resulted in degraded vacuum due to the heating of the waveguide walls. The temperature of the beryllium oxide windows rose less than 5 °C at the full 260 kWatts power level.

A second set of tests was performed with varying distances between the windows and a short circuit as a load. Because nearly all of the incident power was reflected back to the klystron, the ultimate power was limited by the circulator protecting the klystron. In all cases a power of 100 kWatts CW was achieved. For some positions of the short the circulator allowed testing up to 125 kWatts.

Further high power tests will be carried out after completion of the beam test of the superconducting cavity.

IV. General Design Considerations

Several conclusions can be drawn from our experience with this design for a window in large rectangular waveguide.

First, because the frame holding the beryllium oxide windows was such a poor match to the waveguide, the posts were necessary in order to achieve a good overall VSWR. However, this matching causes the storing of energy in standing waves between the windows and the matching posts. If the walls of the waveguide were perfectly conducting, this standing wave would not pose a problem. However, because the walls are not perfect conductors (copper plated stainless steel) the standing wave from the matching elements deposits a non-insignificant amount of heat into the walls. There is no substitute for a window geometry which is inherently well-matched to the waveguide. The use of matching elements increases the storage of energy and thus heating. A possible candidate for a window geometry is a single round disc of beryllium oxide or aluminum oxide about 10 in. in diameter. Scale models have been fabricated which show excellent VSWR characteristics.

If it is necessary to have matching elements then it is best, from a wall heating standpoint, to maintain the largest waveguide size possible. This is illustrated by the data given in Table 1. This table shows the power dissipated in the finitely conducting walls of standard height (9 in.) and reduced height (5.5 in.) WR-1800 waveguide as a percent of the power flowing in a TE_{10} mode at 500 MHz. (One wavelength of waveguide was used to calculate the power dissipated.) Note that using reduced height waveguide results in about 1.5 times as much power dissipation. The reduction in height reduces the cross-sectional area of the guide which carries the power more quickly than it reduces the perimeter of the cross-section which determines the power dissipation. This results in increased wall losses for the same amount of power flowing in the guide.

Table 1 Percent of the power flowing in a WR-1800 waveguide at 500 MHz which is dissipated in the walls for different heights and wall materials.

Wall Material	Height (inches)	P_{diss} / P_{flow}
Stainless Steel	5.5	0.21%
Stainless Steel	9	0.15%
Copper	5.5	0.030%
Copper	9	0.021%

V. CONCLUSIONS

A window has been designed and fabricated which is close to meeting the design goals of the B-Factory requirements. Both high and low power tests of the window have been performed. Several areas have been identified which should aid in achieving an acceptable window in the next design sequence.

VI. REFERENCES

[1] J. Kirchgessner, et al., "Prototype 500 MHz Planar RF Input Window for a B-Factory Accelerating Cavity," Conference Record of the 1991 Particle Accelerator Conference, Vol. 2, pp. 678-680