TE11/TM11 MIXED-MODE WAVEGUIDE VALVE AT X-BAND

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Abstract

A waveguide vacuum valve for WR90 waveguide was designed, fabricated and high-power tested. The valve consists of a modified commercial gate valve sandwitched with smooth tapers. The TE10 travelling wave in WR90 waveguide is transformed into TE11+TM11 mixed mode through the taper, going into the gate valve area and is transformed back to the nominal mode in WR90. The test has been successfully finished. The valve stably transmitted 40MW peak power with 500ns pulse width, which was limited by the available RF power source.

INTRODUCTION

A waveguide valve is one of the high power RF devices used for separation of some part of the system from others without purging the rest of the system. This feature can be realized with a window but we sometimes suffer from the puncture or cracking of the ceramic. In contrast, the waveguide valve can be more robust in a long period of operation, especially for the experimental setups where frequent configuration changes are needed.

A waveguide valve design for 30GHz was proposed by A. Grudiev [1] with using a commercial vacuum gate valve and transmitting the RF through the valve in the TE0n modes. The same type of valve but at X-band frequency was designed and tested and used at SLAC. These are compact in size and probably cheap because of using a commercial valve. However, a pair of mode converters from TE10 in rectangular waveguide to TE0n circular mode are needed. In the present paper, we propose another design based on the mixed-mode idea. Main motive force is the compactness of the mode converter with applying the TE11/TM11 mode instead of TE0n mode. This mixed-mode idea was originally proposed for the window design [2].

In the present paper, we review the design, fabrication issues and the high power test results.

DESIGN

Whole configuration is shown in the Fig 1 below.

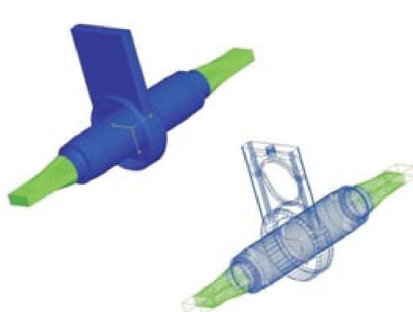

Fig. 1: Schematic of the whole assembly.

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Fig. 2: Schematic of mode converter.

Mode Converter

A schematic view of the mode converter is shown in Fig. 2. The cross section smoothly changes from rectangular to circular, which can be shaped with wire EDM machining. The circular pipe diameter is determined to be the same as the inner diameter of the vacuum gate valve.

Gate Valve

A mini UHV gate valve of VAT with CF070 was used [3]. In order to make this fit to the present RF high power transmission purpose, we made two main modifications, (1) rounding of 0.5mm radius at the opening edge from round pipe to valve volume and (2) extending the stroke of the seal with viton O-ring to escape farther away from axis.

Basic Electrical Design

The magnetic field which drives the longitudinal current at the valve may result in the excitation of the field in the valve volume. By taking TE11 and TM11 mixed mode configuration, we can design the magnetic field component which drives the longitudinal current component zero by choosing the proper longitudinal length. In practice, this choice minimizes the excitation of the valve inner volume due to the interruption of the current across the gap. As shown in the Fig. 3, the matching and transmission of this device is designed good enough for usual application.

In Fig. 4 are shown the E-field and H-field along the axis. It shows the reduction of H-field at the gate valve. It is also shown that not only the H-field but also the E-field at the gate valve is much reduced, comparing even to that at the nominal WR90 waveguide.

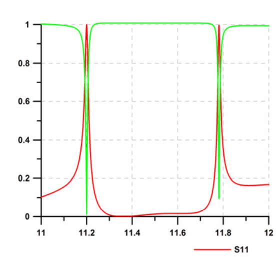

Fig. 3: S-parameters calculated by HFSS.

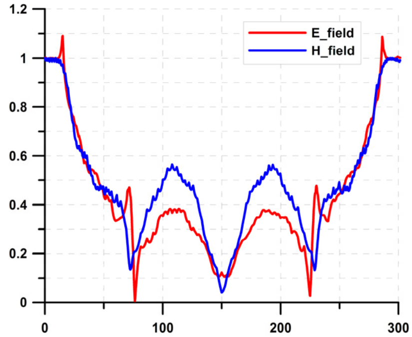

Fig. 4: E- and H-field along the axis.

Spurious Resonance

In practice, we may have some spurious resonance, which cannot be simulated accurately from the beginning due to the insufficient geometrical information of the gate valve and the errors due to the actual setup. One of the typical spurious resonances is shown in Fig. 5 below. The frequencies of such resonances are to be avoided from the operation frequency by carefully adjusting the length with varying the vacuum gasket thickness.

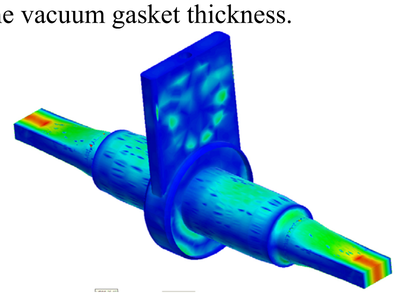
Fig. 5: Spurious resonance example.

FABRICATION

The mode convertors were made by milling and wire EDM. In order to remove the bad surface created by the wire EDM, we applied a 20-micron electropolishing (EP). Then, the parts were brazed in a vacuum furnace.

With assembling all the parts and varying the thickness of the CF070 gaskets, we tuned the spurious resonance points away from the operation frequency. The tuning is shown in Fig. 6. From this measurement, we chose the gasket thickness to be 4.6mm.

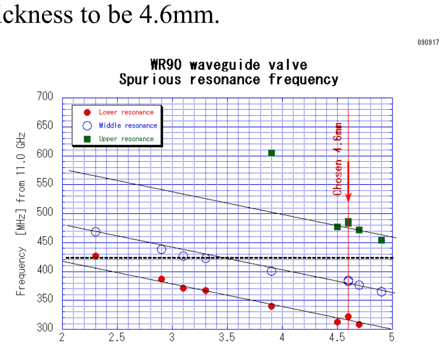

Fig. 6: Spurious resonance frequency vs gasket thickness.

HIGH POWER TEST

Test Procedure and Setup

The high power test of the waveguide valve was done at KEK KT-1 50MW X-band station [4]. The experimental setup is schematically shown in Fig. 7 and the actual setup is shown in Fig. 8. Two -60dB directional couplers (DC's) were located upstream and downstream of the waveguide valve, respectively, to monitor the RF power flow. We can identify the breakdown events at the valve by observing the reflection signals from these two DC's. (The RF load is another source of RF breakdown). Typical pulse shapes are shown in Fig. 9. We set an X-ray detector near the valve to confirm whether the breakdown event occurs at the valve itself. Two CCG's (cold cathode gauges) monitor the local vacuum pressure upstream and downstream of the waveguide valve.

The high power test has been done from Nov. 6 to Nov. 24, 2009. We started the normal conditioning process (1st phase) where we had some outgassing from various devices. After the outgassing was gone, the 2nd phase started, where we counted the faults due to the valve with keeping the peak power and pulse width. The repetition rate was always 50pps.

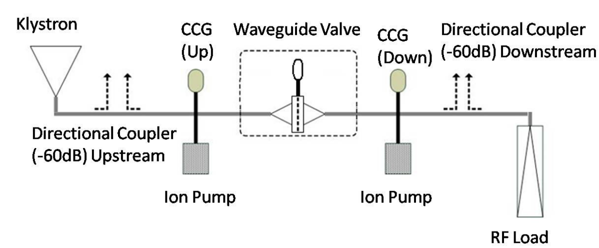

Fig. 7: High power test setup.

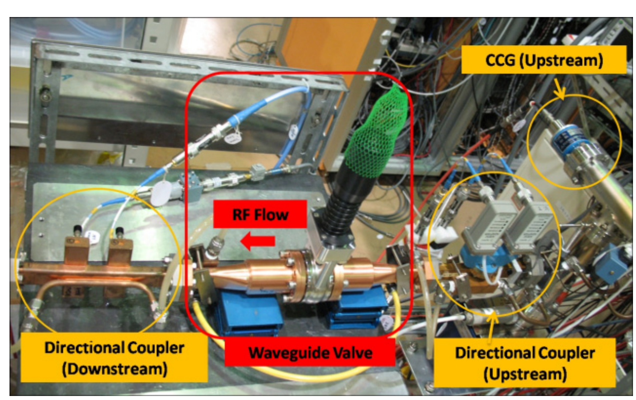

Fig. 8: The waveguide valve under test at KT-1, 50MW X-band station of KEK.

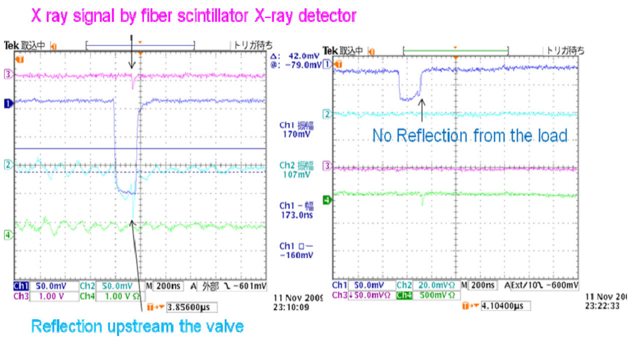

Fig. 9: Waveforms of breakdown events at the valve.

Processing Result

The first phase is the RF processing, where we increase both the peak power and pulse width. We started with short pulse width, 50ns, and increased it gradually. The goal of the processing was 50MW/ 400ns and this was accomplished by Nov.16.

The system was operated automatically most of the time. The operation system controls the RF power to make the vacuum pressure values, which are aleways monitored by the CCG's, below certain threshold values. When the pressure pops up and goes beyond the threshold, the system immediately reduces the power until the pressure comes down below the threshold.

During 1st phase we observed a few events with X-ray detector signal. These events may be the breakdowns due to the valve. In order to identify the breakdown location more accurately, one should use more X-ray detectors or other devices such as acoustic sensors. However, these X-ray events disappeared eventually and practically we do not need to worry any more.

Evaluation of Fault Rate

We started 2nd phase operation from Nov 17, where we kept the peak power and pulse width and observed how often the faults occurred (most of the cases, faults are due to breakdowns of some components). We chose three pararmeter sets in this phase: 60MW/200ns, 50MW/360ns and 40MW/500ns, which were limited by the available power and pulse of the power source. The trend is shown in Fig. 10. The breakdown was identified with the RF reflection signals and X-ray signal. The result of the fault rates is listed in Table 1. There were many trips as shown in the figure but we have not encountered any breakdown event attributed to the waveguide valve. The valve was very stable. We have tested the valve up to the maximum capacity of KT-1 station and the valve worked very stably within this range.

After this two-stage test, the valve has been staying at KT-1 station. Recently we tested a series of RF loads at the same station. (Three loads were tested successively during last several months.) In each of the setup of the load, we took the same procedure: we closed the valve, replaced the load and evacuated the system and opened the valve again. There has not been any indication of degradation of the valve performance so far.

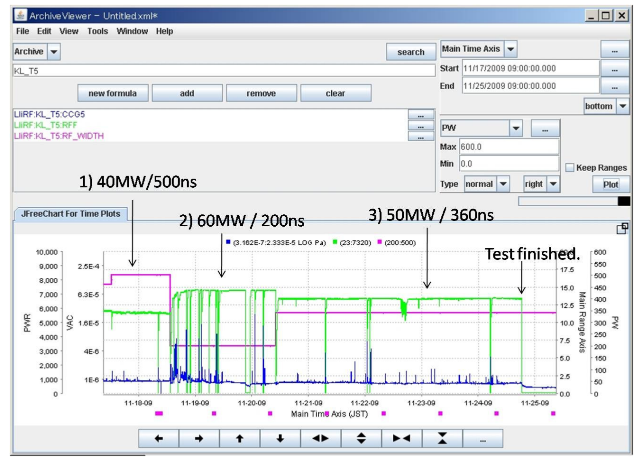

Fig. 10: Runs for fault rate evaluation.

Table 1: Observed Faults

Power/width	Run time	WG Valve	RF Load
60MW/200ns	42.3 Hr	0	8
50MW/360ns	104.5 Hr	0	4
40MW/500ns	24.9 Hr	0	0

DISCUSSION

It has been proved that the valve can hold good vacuum seal property when it is closed and it works fine when it is opened for the RF operation. For the usage at KT-1 station, this valve shows excellent performance.

REFERENCES

[1] A. Grudiev, "Development of a Novel RF Waveguide Vacuum Valve", TUPCH142, EPAC2006, Edinburgh, Scotland, 2006.

[2] S. Kazakov, "A New Travelling-Wave Mixed-Mode RF Window with a Low Electric Field in Ceramic Metal Brazing Area", KEK Preprint, 98-140, Aug. 1998.

[3] VAT Mini UHV gate valve, 01032-CE01-AQJ1

[4] S. Matsumoto, "High Power Test Areas: Nextef", CLIC08, CERN, 2008, http://project-clic08-workshop.web.cern.ch/project-clic08-workshop/