DEVELOPMENT OF C-BAND (5712 MHz) HIGH POWER WAVEGUIDE COMPONENTS

H. Matsumoto, T. Shintake, N. Akasaka, KEK High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki, 305, Japan and H. Baba, A. Miura, Nihon Koshuha Co., Ltd., 1119 Nakayama, Midori-ku, Nakayama, Kanagawa, 226, Japan

Abstract

High Power waveguide components at C-band (5712 MHz) frequencies have been developed for a main linac of e^+e^- linear collider range of 300-500 GeV C.M. energy. 350 MW of maximum rf power has to be transmitted through the waveguide components. An EIA-WR187 (W: 44.55 mm, H: 22.15 mm and t: 4 mm) type sized conventional rectangular waveguide was chosen to reduce transmission loss to about the same order of magnitude as with existing S-band waveguide. The thickness of the wave guide was fixed to make for easy machining, and assembling for the brazing process.

A vacuum waveguide flange of unisex type with a simple shape was successfully developed. A Beth-hole type coaxial coupler, E- and H-corner, directional coupler, vacuum pumping port, 3-stub tuner, viewing port and phase shifter were successfully developed all with input VSWRs of less than the 1:1.1.

1 INTRODUCTION

For an e^+e^- linear collider with a center of mass energy of 300 to 500 GeV, the main linac will use some 2040 rf acceleration units [1]. Each unit is comprised of two 50 MW klystrons, two modulator power supplies, one rf compression system of a new design, the waveguide system, four choke-mode type damped accelerating structures and their supporting girder. The total component count is extremely large and no laboratories have any experience yet in the operation of so many accelerator devices. Thus, it is very clear that the preeminent considerations are to make the system simple, highly reliable, of higher efficiency and lower cost.

In the C-band main linac, a maximum rf power of 350 MW has to be transmitted through the waveguide system to drive the accelerating structures with 32 MV/m. The high voltage break-down is dominated by the total rf voltage between metallic surfaces in the waveguide. The waveguide impedance at C-band takes on similar values at S-band. Therefore, the gap voltages in C-band waveguide need not take higher value than the S-band. According to some experience at S-band frequency, power levels of 350 MW should not cause any difficulty for stable operation. At the C-band frequency of 5712 MHz, there are two choices for waveguide size: one is EIA-WR187 (3.93-5.85 GHz), the other is EIA-WR159 (4.9-7.05 GHz). EIA-WR187 which has an inner cross section of 44.55 mm wide and 22.15 mm high was chosen over the larger waveguide because it can have an rf power transmission loss close to that of existing S-band waveguide. The theoretical rf transmission losses in rectangular waveguides of EIA-WR187 (at 5.712 GHz) and EIA-WR284 (at 3 GHz, 72.1 × 34.0 mm) are –0.032 dB and –0.021 dB, respectively. Fortunately the C-band main linac can use conventional rectangular type waveguide pipe. Further, the C-band high power rf system does not require any special components. Thus, it should be producible at the same reliability and cost as S-band.

However, there is no standard for C-band high power waveguide components, especially as high a peak rf power as 350 MW in vacuum. Thus, many components will have to be developed, but most of the design work will be straightforward without any particular limitations. Figure 1 shows a photograph of the directional coupler.

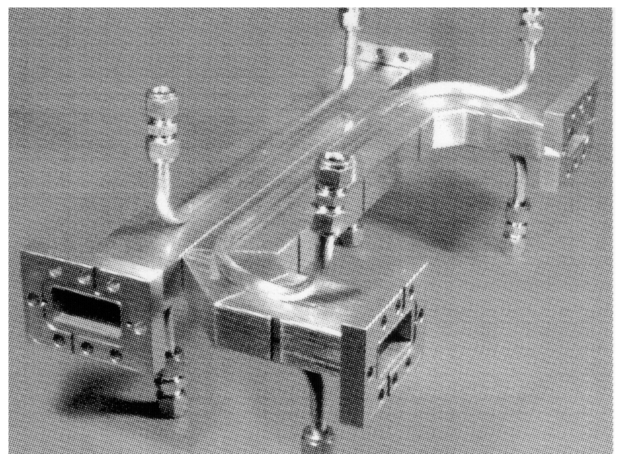

Figure 1: Photograph of a directional coupler for C-band frequencies.

This paper will describe the design concept and performances of wave guide components.

2 WAVEGUIDE COMPONENTS

2.1 Rectangular waveguide pipe

The raw materials of the waveguide use high quality OFHC (Oxide-Free High Conductivity) copper with a purity of > 99.96%, because one of the main reasons for rf breakdown is poor quality inner surfaces – insufficient purity of the raw copper material and it cleanness. Table 1 lists the chemical compositions of the copper material.

The rectangular waveguide is made by a cyclic extrusion process the first step to make a thick circular pipe from a copper bar, which is then gradually formed to shape by 7 more cycles of the pulling processes.

Table 1: Chemical compositions of copper. (%)

Pb	Zn	Bi	Cd	Hg
<0.005	<0.0001	<0.001	<0.0001	<0.0001
O_2	P	S	Se	Te
<0.001	<0.0003	<0.01	<0.001	0.001

A 3 m length was chosen as the unit length of the waveguide so that dimensional accuracy could be maintained. Also a 4 mm waveguide thickness was chosen to allow using a common jig to join each element in the brazing process. Typically a dimensional accuracy of <±0.1 mm and a surface roughness in the range of ~0.13-0.23 μm (rms.) at the center cross section of the waveguide is obtained. From the results of some experiments at S-band, it is clear that there will be no problem in actual operations at high peak rf power.

2.2 Waveguide vacuum flange

In this work, one of the important goals was to make a standardized waveguide vacuum flange. This important component has to serve in two roles as both an rf seal and a vacuum seal. Further, the most commonly occurring problems such as discharge breakdown and vacuum leak often happen near the flange gasket. A new type unisex waveguide flange has been developed to increase reliability and reduce cost; it comes from a modified DESY type S-band flange as shown in figure 2 [3]. As can be seen in the figure, the gasket edge has a simple shape for easy machining and the optimum compression forces produces zero gap at the outside of the flange. The loss in flatness between the flange and gasket along the inside wall is within 50 μm when there is zero gap in the outer wall between the flanges.

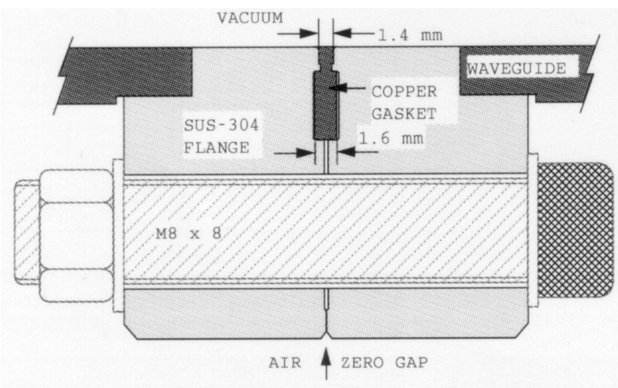

Figure 2: Unisex type waveguide vacuum flange. An expanded view of part of the gasket edge.

2.3 RF Window

The lifetimes of existing high peak power klystrons are typically at most around 4×10^4 hours on average; failures are caused mostly by broken rf window ceramics and insulation breakdown of the electron guns. In the C-band linear collider, more than 4000 klystrons will be used for the two main linacs. Thus, klystron replacement work has to be done without interrupting accelerator operation. It should be also noted that the aging process of an accelerating structure takes roughly one day, once the vacuum is broken. In order not to compromise the operational efficiency, a need arises for rf-windows that allow replacing klystrons without opening the accelerator vacuum system.

2.3.1 Ceramic material

There are three important technologies to make robust alumina ceramic for the high peak power rf windows: (1) use high quality alumina powder which has a fine grain size of <0.8 μm with 99.99% of purity, (2) eliminate the voids inside the ceramic even those whose sizes are on the order of a few micro-meters, and (3) use low rf loss sintering binder materials. Micro-voids between the ceramic grain boundaries and large amounts of Magnesium (Mg) are the main reasons for the discharge breakdown problem in high peak power rf windows [3]. For our work, a Hot-Isostatic-Pressing process was used to eliminate the micro-voids resulting in a reduction from 3.8% to less than the 0.5% by volume weight. The Mg in the sintering binder was successfully reduced to 0.06% by volume weight.

2.3.2 Structure of the window

A pill-box shaped traveling-wave rf window was designed for the 50 MW C-band klystron; it will be used for the two rf windows connected at each output port. The window has a diameter of 57 mm, length of 72.85 mm and a 3.85 mm thick ceramic disk. The design was made to have no TE22 or TE51 resonance modes at 5.712 GHz. For this design, the most important considerations were in reducing the electrical field strength at the window ceramic disk by choosing a traveling-wave structure, and the use of very high quality ceramic disks. Figure 3 shows the electrical field distributions in steady state and the frequency response of the rf window.

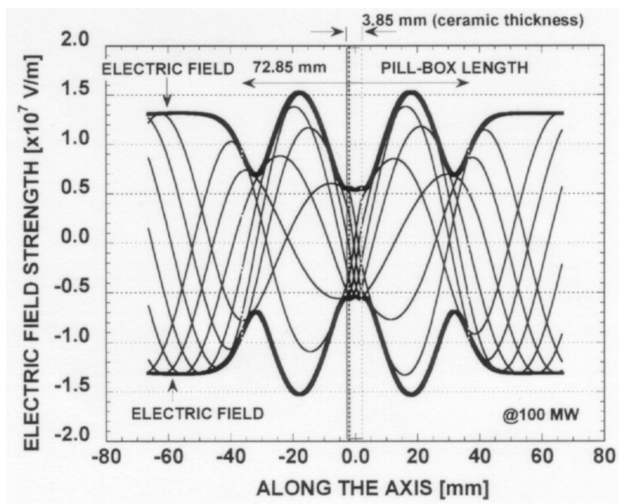

Figure 3: Electrical field strength. Two thick solid lines shows the electrical field strength along the axis.

As can be seen in the figure, the envelopes of the electrical field strength are reduced just at the ceramic disk. The frequency bandwidth where the reflection coefficient is 0.1 or less is 500 MHz as shown in figure 4. These characteristics will be good enough for the 50 MW klystron. Thus from the R&D results at S-band frequency, it will be good enough to apply 50 MW of peak rf power at C-band.

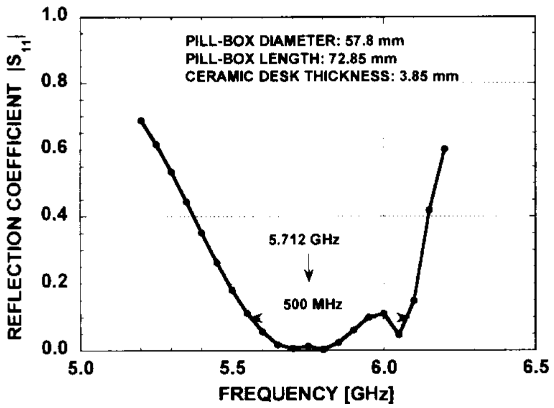

Figure 4: Frequency bandwidth of traveling-wave type pill-box window.

2.4 Traveling wave resonator

The design and fabrication of a Traveling Wave Resonator (TWR) is very useful in developing the key technologies for unknown, variable frequencies, because it is composed of several necessary high power waveguide components such as a directional coupler, a phase-shifter, a stub tuner, a pair of the Beth-hole couplers, two vacuum pumping ports, two viewing ports, E- and H-corners. The parameters of our TWR are shown in Table 2.

Table 2: C-band TWR parameters

Physical size	166 cm × 75 cm
Resonant loop length	~300 cm
Number of wavelengths	48 at 5.712 GHz
Input coupler ratio	-12 dB
RF power gain	12.3 dB
One-way loss in loop	0.11 dB
Variable phase shifter range	±180° at 5.712 GHz
5 elements stub tuner range	$\Gamma < 0.13$ at any phase

This TWR was designed with no specific upper peak rf power handling capability, but it had to be operational at a minimum peak rf power of 150 MW. To guarantee the performance of the rf window in the TWR, the window has to operate even with an overload condition of three times higher than the actual operational output power from klystron. For the moment, 5 MW of rf power will be fed to the TWR from a 5 MW klystron that was received from SLAC. In this case, the rf window of the C-band klystron will test the rf power up to 85 MW, that will be good enough to check the performances of the rf windows for the 50 MW klystron.

In general, the upper limit of rf power handling capability of the TWR would be set by breakdown in one of the tunable components such as the phase-shifter, or the 5 elements of the sub-tuner or the gasket of the vacuum flange [4]. Most TWRs use a variable phase-shifter consisting of a pair of movable multistage choke short plungers with a 3 dB hybrid coupler which usually has rectangular cross section. Thus, the movable choke short plungers have to be aligned to the same gaps with less than a 1 mm error on both horizontal and vertical over the full stroke, that is very hard work even at the S-band frequency. Therefore, it was decided to try to use a circular waveguide (TE11 mode) for the pair of movable shorting plungers as shown in figure 5.

Using circular waveguide will reduce the difficulties in fabrication as well as increase the breakdown limit. The phase shifter has 360° of tuning range with an input VSWR within the 1:1.1. The rf pickup monitor used is based on the Beth-hole type directional coupler with a demountable structure. The vacuum seal between waveguide and coupler head used a ceramic disk (t: 1.5 mm and ϕ: 24 mm) with a metal o-ring gasket, it does not require any brazing process. The other components have already been done by this time. High power operation of the TWR will be started beginning in June 1997.

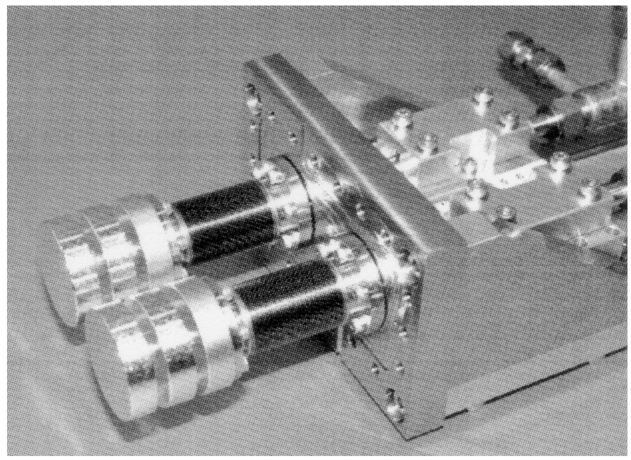

Figure 5: A photograph of the circular movable shorting plungers.

3 CONCLUSIONS

C-band high power waveguide components were successfully developed with a very conventional rectangular waveguide which further does not require any special structure. It was confirmed that the unisex waveguide vacuum flange is very useful to make the system simple as well as to reduce the cost. Thus, the total system cost would be reduced as compared with an existing S-band frequency accelerator with same reliability criterion.

4 REFERENCES

[1] T. Shintake, *et al.*, 'C-band main linac rf system for e^+e^- linear collider of 0.5 to 1.0 TeV C.M. energy', Linear Accelerator Conference 1996, p184-186

[2] N. Holtkamp, DESY, private comments at 1995

[3] A. Miura and H. Matsumoto, 'Development of an S-band rf window for linear colliders', NIM-A334(1993)341-352

[4] W.R. Fowkes, *et al.*, 'High power rf window and waveguide component development and testing above 100 MW at X-band', Linear Accelerator Conference 1992, p184-186