A NEW DESIGN FOR A SUPER-CONDUCTING CAVITY INPUT COUPLER

H. Matsumoto, S. Kazakov[#], K. Saito, KEK, Tsukuba, 305, Japan

Abstract

An attractive structure using capacitive coupling has been found for the input coupler for the 45 MV/m versions of the International Linear Collider (ILC) project. The coupler supports an electrical field gradient of ~1 kV/m around the rf window ceramic with 500 kW through power, a VSWR of 1.1 and a frequency bandwidth of 460 MHz. No unwanted resonances were found in the rf window near the first and second harmonics of the operation frequency.

INTRODUCTION

The aim of the ILC project is to build a new high-energy electron-positron linear collider for the 0.5-1 TeV C.M. energy regions. Even though it will not be easy, because of limited the site length available in Japan, our first goal will be to realize a 45 MV/m accelerating gradient with a 9-cell super-structure.

There will be an order of ten thousand accelerating cavities and input couplers in the completed ILC project. In truth, this will be such a large-scale machine, with huge total component counts the likes of which no laboratory has ever had the experience of fabricating or operating. While experience with the high gradient super-conducting accelerators is still comparatively limited, it is clear that the reliability of the super-conducting cavity is still behind its existing normal-conducting accelerating structures in both fabrication and operation. Looking at the KEKB injector linac for example, the difference in performance repeatability shows a gap. Thus, Reliability, Availability and Maintainability (RAM) are very important considerations for the ILC.

R&D for hardware for an input coupler just started in April 2005 at KEK. The target was to satisfy the needs of various applications, not only for the 45 MV/m ILC version, but also for other scientific applications, such as a single pass X-FEL and also for an energy recovery linac for future light sources.

In this paper, we report the detailed design of a new cold side input coupler using a capacitive coupling coaxial line.

CONCEPT

We began the R&D for an input coupler based on the following considerations:

1) A simple structure and reduced cost are important considerations for the input coupler. 2) The electrical field gradient around the rf window on the air side should be lower than 1 kV/mm with 500 kW through rf power. 3) Very low dielectric loss ($3x10^{-5}$) high purity ceramic should be used for the rf window. 4) Au-Cu brazing material for brazing between the ceramic and metals such as copper and stainless-steel should be used. 5) Finally, possible coating techniques such as "Diamond-Like Carbon Coating (DLCC)" for the ceramic window will be investigated.

From previous experience with the operation of various accelerators, we know that the practical upper limit for dielectric breakdown voltage is around 1 kV/mm in the air at one atmosphere, even though it might be as high as 3 kV/mm under ideal conditions. For example, the electrical field gradient of model EIA650 rectangular waveguide (82.6 mm x 165.1 mm) is 0.9 kV/mm with 5 MW through power. This should be under the 1 kV/mm limit and yet we have experienced breakdowns in it while testing klystrons. Thus, we would like to have an alternate vacuum type high power waveguide system for a fall back.

CERAMIC MATERIAL

As can be seen in Table 1, the rf loss of alumina ceramic is affected mainly by the content of Mg which is a typical binder used to keep the aluminium grain size to around 10 to 20 μm while the sintering.

Table 1: RF loss of various ceramics after sintering.

MgO content (%)	0.19	0.06	0
Loss tanδ ($x10^{-4}$) (at 2853 MHz)	13	3.0	0.3 (1)

NOTE: (1) measured at 10 GHz.

To reduce the rf loss in the input coupler, we will use a high purity ceramic with a loss tanδ on the order of 10^{-5} for the rf window. Such ceramic materials are available commercially; we choose one, model HA997 from NGK/NTK Co. of Japan, the specifications of which are listed in Table 2. Fig. 1 shows an electron microscope photograph of the alumina ceramic, composed of fine grain (Ø0.1- Ø0.5 μm) and high purity (>99.7%) material, this was originally developed for high Q ceramic filters for cellular phone applications.

Table 2: Major characteristics of HA997 Ceramic.

Alumina contents	99.7 %
Specific gravity	3.95
Dielectric loss tanδ (at 8 GHz)	3×10^{-5}
Dielectric constant (ε) (at 8 GHz)	9.8~9.9
Temperature coefficient of ε	+90~110 ppm/°C

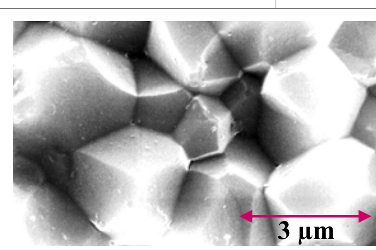

Figure 1: Electron microscope photograph of alumina ceramic material.

[#]sergey.kazakov@kek.jp

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NEW TYPE OF COLD SIDE WINDOW

We have been developing a capacitive coupling type coaxial line input coupler, with an inner conductor separated into two parts by a thin ceramic disk as shown in Fig. 2. Conceptually, the rf window consists of a simple ceramic disk flanked by two coaxial inner conductors mounted symmetrically with close spacing but no mechanical contact between the parts. The rf characteristics of the structure are the same as those of a conventional coaxial line. This realizes several advantages: as a klystron rf window, the ceramic window has a simple shape, easy to braze. Also there is very small thermal contact with the room temperature side. Further, it is not necessary to provide good mechanical or electrical contact between the inner conductors during assembly.

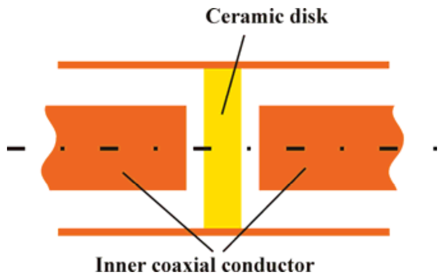

Figure 2: Conceptual sketch of the capacitive coupling for the rf window.

As shown in Fig. 3, the complete input coupler can be divided into four relatively simple parts to ease fabrication and assembly. If we assume that the inner conductors are not attached rigidly to the waveguide, we need only one bellows to absorb the movement of the coaxial line due to thermal contaction and expansion between cool down and warm up. To realize such a structure, we decided to use small metallic rods as spacers to hold the inner conductors on center. Each pair of rods is mounted in the gap between the inner- and outer-conductors, and are rotated 90 degrees from each other as shown in Fig. 3. Calculation results show that when the spacing rods are positioned optimally, a good enough frequency bandwidth can be realized.

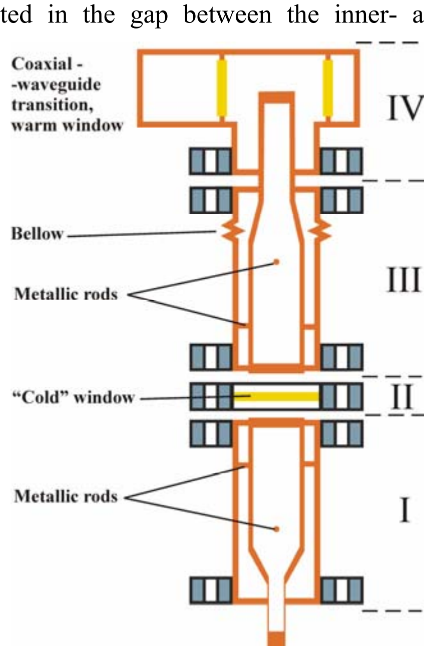

Figure 3: Overall conceptual drawing of the capacitive coupling type coupler.

Cold Side RF Window Simulation

The window is supposed to be used at the 500 kW power level. Thus, the maximum electrical field gradient on the ceramic surface and possible electron multipactoring around the rf window is an important consideration. This has been simulated with the ANSOFT HFSS code, in automatic regime. The physical geometries were optimised to get the maximum frequency pass-band while minimizing the electric field gradient on the ceramic surfaces. Fig. 4 shows the geometrical parameters, the design space was explored by random variations of each within their realistic physical ranges. The resulting optimum parameters for the cold side rf window are summalyzed in Table 3.

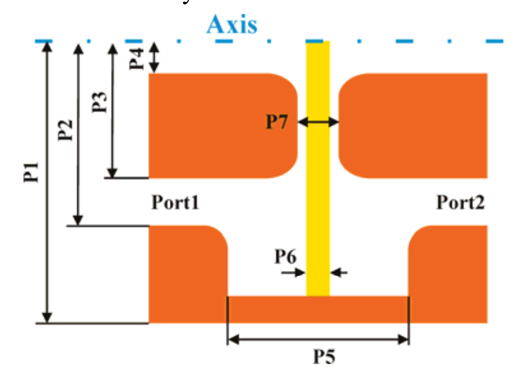

Figure 4: Window geometry parameters subject to optimisation.

Table 3: Optimised geometry parameters for the window.

P1	P2	P3	P4	P5	P6	P7
51	36	34	4	61.6	3.6	7.6

After analysis of the electron multipactoring situation, a 2 mm gap distance between the inner conductors and ceramic disk was chosen, this results in a 1.15 kV/mm electrical field gradient on the ceramic. For this case, multipactoring should occur when operating in a power zone ranging between 15 and 55 kW, so there should be no problem for the window at 500 kW. Figs. 5 and 6 show the frequency pass-band of the window and the electrical field distribution on the ceramic surface. From Fig 5, we see there is a good frequency bandwidth of 460 MHz at an input VSWR 1.1. Also, as can be seen in

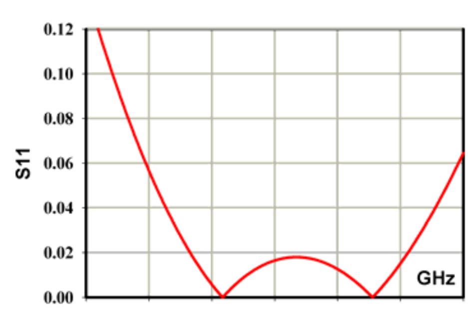

Figure: 5 Frequency pass-band of the rf window.

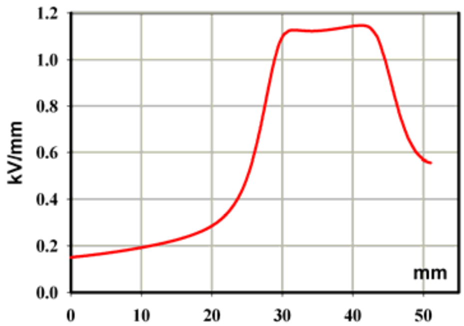

Figure 6: Electrical field distribution on the ceramic surface.

Fig. 6, the maximum electrical field gradient is only 1.15 kV/mm in the vacuum. This is very conservative as from previous experience we have found the vacuum breakdown voltage to range between 7 and 19 kV/mm for S-band frequency operation.

As a compromise between physical strength and rf frequency response, a 4 mm diameter was chosen for the inner conductor support rods. Fig. 7 sketches the 3-dim. layout showing the way the rods are inserted between inner and outer conductors. The spacing between rods was also chosen to provide maximum frequency pass-band.

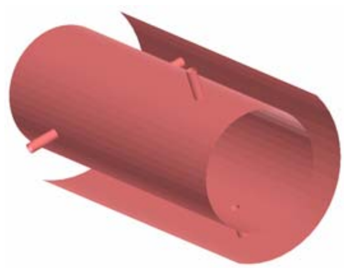

Figure 7: Layout of support rods for the inner conductors.

We fashion a smooth transition between the coaxial line and the accelerator structure with a minimum VSWR as shown in Fig. 8. It is also necessary to provide the connection with a cavity flange. Fig. 9 shows an overall frequency bandwidth obtained at the cold side to be 100 MHz at an input VSWR of 1.1. As can be seen in Fig.9, the new rf window has no resonances near the first and or second harmonics of the operating frequency.

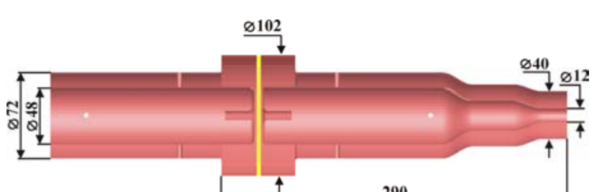

Figure 8: A cut away view of the cold window.

Thermal Loss

The relative ohmic loss of the over-all assembly in Fig. 8 is $3.5x10^{-3}$ for the copper material, and for the ceramic a much smaller $2.2x10^{-5}$, because of its very low dielectric loss (model HA-997). Fig. 10 shows the distribution of the square of the magnetic field strength on the surface of part of the coupler with 500 kW of through power. We

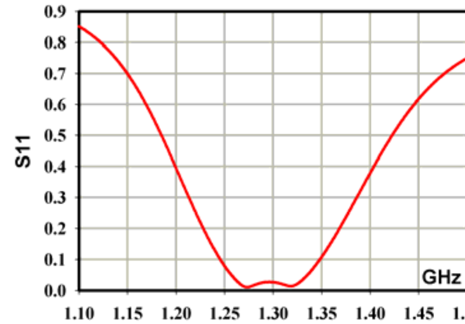

Figure 9: Frequency pass-band of cold window.

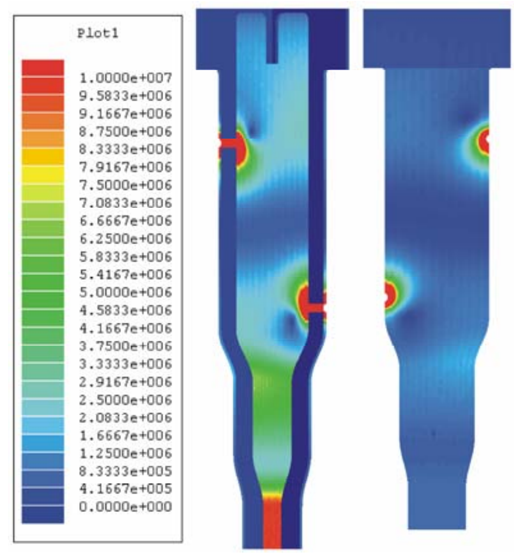

Figure 10: Distribution of magnetic field strength squared on the surface of part of the coupler.

will apply thermal anchors at 4 K and 90 K near the rods to reduced thermal energy flow into the cavity.

SUMMARY

We have successfully found a possible solution for fabrication and rf performance with a new cold side capacitive coupling type input coupler. The maximum electric field gradient on the window ceramic is only 1.15 kV/mm at 500 kW of through power. A frequency bandwidth of 460 MHz at an input VSWR of 1.1 was obtained for the rf window, and 100 MHz overall as seen from the cold side. It was confirmed that there are no unwanted resonances near the operation frequency both at the rf window and also overall from the cold side. Thermal losses are concentrated at the support rods and antenna probe. However, the relative ohmic loss is $3.5x10^{-3}$ for the copper material and only $2x10^{-5}$ for the ceramic disk.

REFERENCES

[1] R. Brinkman et al., "TESLA Technical Design Report", March 2003.

[2] M. Matsumoto, "High Power Coupler Issues in Normal Conducting and Super-conducting Accelerator Applications", PAC99, New York 1999, p536.

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