EXPERIENCE WITH A ZERO IMPEDANCE VACUUM FLANGE AT He SUPER-LEAK TEMPERATURES FOR THE ILC

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Abstract

A new zero impedance vacuum flange has been developed for the accelerators in the ILC. We choose a unisex type with a 90-degree sharp edge forming the vacuum seal and giving a continuous smooth connection providing zero impedance as seen from the bunched beam and rf power. The variation in flatness between the flange and gasket along the inside wall is less than 50-µm. An He super-fluid leak rate of below 10^{-12} [atm/cm3/sec] was measured using the "build up method", i.e. the test measured the pressure built up over a three hour period while held at below 2-ºK. We tested the several potential gasket materials: OFC (Oxygen Free Copper) alone, Nb (niobium) plated with 10-µm of OFC, and bulk Nb, all at temperatures below 2-ºK. The same unisex type flange has also been used for the input power coupler for coaxial waveguide and for a cold side demountable type rf window. A long test run was carried out at an rf power of 1-MW, and a 1.5-msec pulse width, 5-pps repetition rate. Further, suitability was confirmed by operation at a maximum power of up to 2-MW, and a 1.5-msec pulse width, 3-pps repetition rate for 6 hours.

INTRODUCTION

To build an e+e- superconducting linear collider with center of mass energies from 0.5- to 1-TeV, the total number of components required is extremely large and no laboratory has ever experienced operation of so many accelerator devices. Further, although experience with high gradient super-conducting accelerators is still comparatively limited, it is clear that the reliability of the super-conducting cavity still lags behind that of existing normal-conducting accelerating structures both in terms of fabrication and operation. Thus, for the ILC, Reliability, Availability and Maintainability (RAM) are extremely important considerations. Furthermore, secondarily but still key considerations are to make the system simple, with higher efficiency and lower cost.

R&D for the hardware components just started in April 2005 at KEK. We began with the R&D for a vacuum flange (of the so-called MO type), which provides zero-impedance at the junction between flange and gasket. The idea for this flange concept comes originally from the S-band accelerator design at DESY [1]. It is going to be used for input power couplers, and in the beam pipe for the superconducting cavities.

This paper will describe the design details and experimental results of leak tests at He super-fluid temperatures and the high power operation in the input power coupler.

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UNISEX VACUUM FLANGE

For this project, one of the important goals was to design a standardized vacuum flange. This component has to serve in two roles as both an rf seal and a vacuum seal, even while working at below at 2-ºK for super-fluid liquid He. Further, the most commonly occurring problems such as discharge breakdowns and vacuum leaks often happen near flange gaskets. The new unisex type flange has been developed to increase reliability and reduce cost.

Flange Structure

Prototype flanges of two different sizes, 78-mm and 130-mm diameters were made. See the photograph shown in Fig. 1.

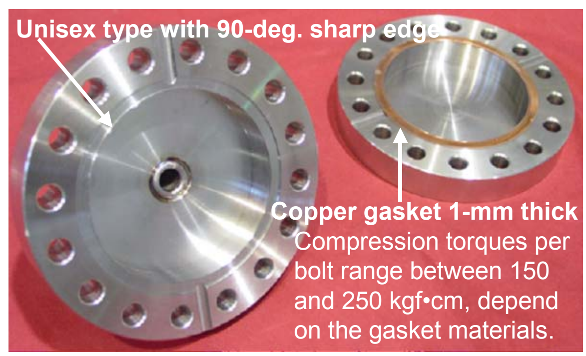

Figure 1: A photograph of a 130-mm diameter prototype flange (MO-unisex flange).

We choose a unisex type with a 90-degree sharp edge forming the vacuum seal and providing zero impedance for the bunched beam and accelerating rf power. As can be seen in Fig. 2, the vacuum seal edge has a simple shape for easy machining and at the optimum compression forces there is no gap at the outside of the flange. We choose 1-mm thick metal for the gasket stock, the materials tried were bulk copper, Nb thin coated (~10-µm) copper, bulk Nb and bulk aluminium. The gasket was compressed down to 0.5-mm at the seal area by tightening the bolts. To provide for a good vacuum seal and rf contact, there are two technical key points: the surface roughness of the seal edge should be better than an R_{max} of 0.8-µm, and the physical hardness of the gasket material should be controlled to be almost the same as pure Aluminium. The typical test hardness of the sample gaskets was in the range of 45-55 when measured with a 100-g load. The typical surface roughness of the tested gasket was around 6-µm for R_{max}, which is same order of the usual metal gaskets such as used for the ICF type vacuum flanges.

Helium leak rates at liquid N_2 (77-ºK) and super-fluid liquid He (<2-ºK) temperatures were measured with a setup as shown in Fig. 3 and 4. A helium leak test was carried out between 3 and 5 times on each flange at each temperature.

For the first step, the test flange was given a He leak check at room temperature, with a go/no-go cut at $1x10^{-10}$ atm/cm^3/sec. Next, flanges passing that were rapidly thrown into the liquid N2 to give them a thermal shock, and kept in the bath until the bubbles from the boiling liquid N2 disappears. The flange under test was then quickly warmed back up to room temperature by a hot air-blower, and then another He leak rate measurement was taken.

For the second step, a flange under test would be mounted in a vertical cryo-module which was pumped down to below something on the order of 10^{-5} Pa, which made it possible to use the He leak detector to detect influx from surrounding liquid He. The helium leak rate was measured continuously while the temperature was cooled down to below the super-fluid He temperature. We used the so called pressure build up method to measure the He leak rate at below 2-ºK. A gate valve inserted in the vacuum line to flange under test was closed after the temperature was cooled below 2-ºK. The cryo-module was then held for 3 hours at that temperature. During this time, some number of super-fluid He molecules would get through the test flange but be trapped by the gate valve.

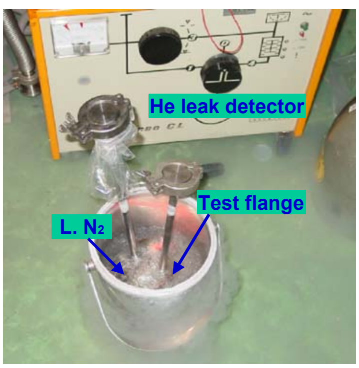

Figure 3: Thermal shock test at liquid N_2 temperature.

For the third step, the He cryo-module was warmed up to room temperature, and the gate valve opened to measure the pressure and thus the amount of He molecules accumulated. Fig. 4 show the experimental set up for the He leak rate measurement; which is comprised of a He cryo-module, a Q-mass analyzer, a He leak detector, an ion gage, a rough pumping system, a gate valve, three metal valves and a PC data acquisition system. The Q-mass analyzer system was used to identify the He molecules among the other various residual gases in the test volume. The helium leak detector used to measure to the usual He leak rate while cooling down to liquid He temperature and before closing the gate valve on going below 2-ºK. The gate valve was used to isolate the vacuum pipeline between the pumping system and the test flange and create a test volume. A typical experimental result for one of the copper gaskets is shown in Fig. 5 and an expanded view of the He build up part is shown in Fig. 6. The helium leak rate [atm/cm^3/sec] can be integrated from the build up area in Fig. 6.

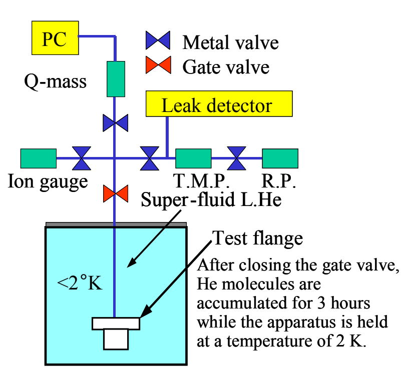

Figure 4: Experimental set up for the super-fluid He leak rate measurement using a pressure build-up method.

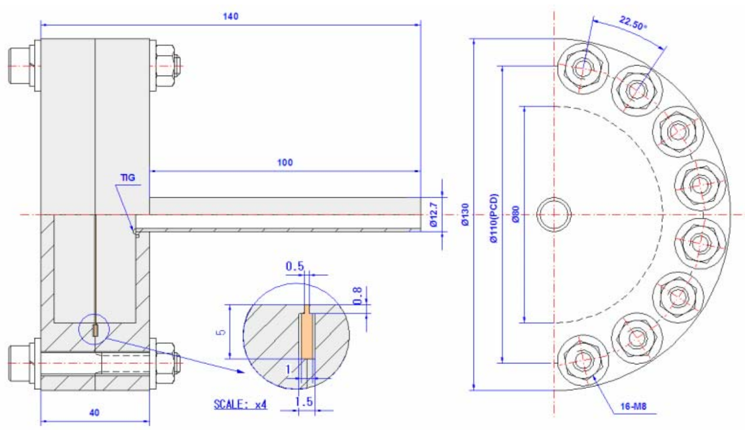

Figure 2: A cut away view of the MO-type unisex flange.

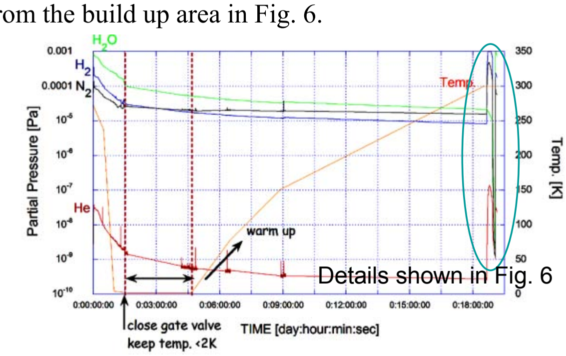

Figure 5: Q-mass measurements of the partial vacuum pressure as a function of time for He, H_2O, H_2 and N_2 in the over all vacuum system.

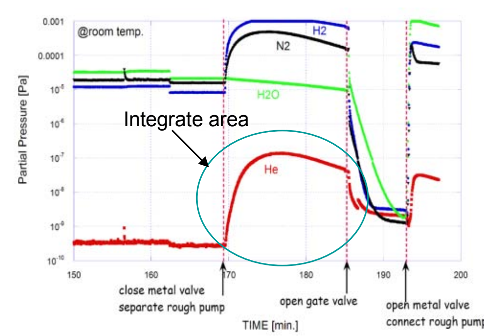

Figure 6: Q-mass measurements for the build up area of the He, H_2O, N_2 and H_2 in the flange test volume. The area is integrated for 3 hours while the vacuum pump system is isolated by the gate valve.

The same test stand and procedure was used for the various test gasket materials. The helium leak rate results using the build up method are as shown in Fig. 7. Our target for a He leak rate at super-fluid He temperature was that it should be below $1x10^{-12}$ atm/cm3/sec. As can be seen in Fig. 7, we easily obtained leak rates below $1x10^{-12}$

atm/cm3/sec, except in the case of the Nb plated copper gasket.

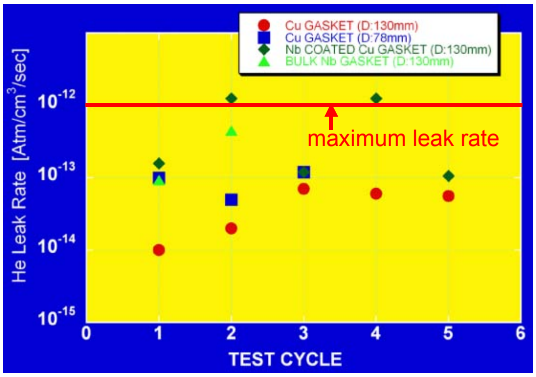

Figure 7: He leak rate using the pressure build up method at super-fluid He temperatures (below 2-°K) for various gasket materials.

ACTUAL FLANGE APPLICATION

For the ILC, mass producible, interchangeable unit "modularity" is a very important consideration in reducing the cost and keeping the structure simple. Thus, a de-mountable type input power coupler using the MO type unisex flange for the superconducting rf cavity was proposed for the ILC project [2].

Modular Structure

As shown in Fig. 8, the complete input coupler can be divided into four relatively simple parts to ease fabrication and assembly. Each part is jointed by the MO-type unisex flange with gaskets of copper and or aluminium material. A cold side rf coupler consist of a simple ceramic disk part and two enclosure flanges, using the MO type structure to seal the rf and vacuum. Our first target for input power coupler should be able to be handled rf power of up to 1-MW (1.5-msec pulse width and 5-pps repetition rate). We began the R&D for the input coupler based on the following considerations:
1) A simple structure and at reduced cost are important

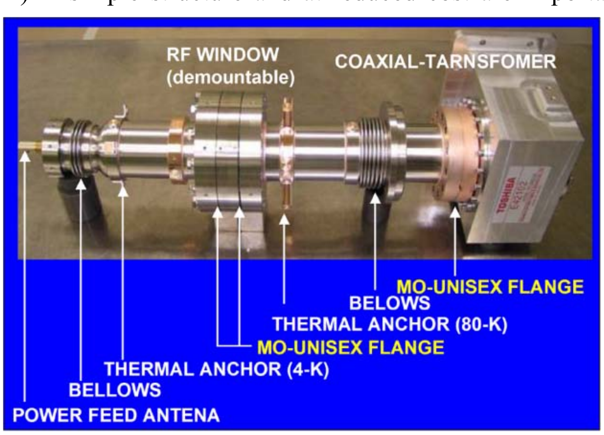

Figure 8: De-mountable type input power coupler using the MO type unisex flange. An input coupler consists of four parts, a coaxial waveguide transformer, a coaxial waveguide on the warm side, an rf window and a coaxial waveguide on the cold side.

considerations. 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 "TiN" for the ceramic window will be used.
Experimental Results

A high power test was carried out at KEK between May and July in this year. The test stand is comprised of two input couplers and a rectangular waveguide connected in series to form a travelling wave transmission line. Two ion pumps are used independently on the warm and cold sides. There are protective interlocks for the vacuum level and arcing inside the input coupler (using the optical photo detectors). Typical waveforms of the transmission rf power going through the two input couplers are shown in Fig. 9. Very stable waveforms at 2-MW peak power were obtained. No problems were found with the MO type unsex flanges while operating at various rf power levels. The vacuum pressure increases as a function of average input rf power. A typical temperature raise at 500-kW (nominal operational state) corresponding to a 3.75-kW average power is 38-ºC for the input waveguide and 45-ºC for the warm side rf window.

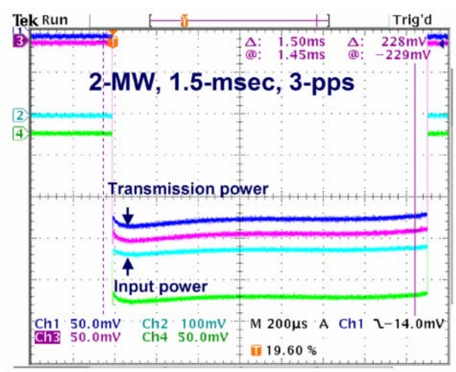

Figure 9: A typical rf waveforms at 2-MW of peak power, 1.5-msec of pulse width and 3-pps of repetition rate.

SUMMARY

An MO type unisex flange successfully demonstrated satisfactory rf and vacuum seal performance at various rf power levels. The helium leak rate at the super-fluid liquid He temperature is below $1x10^{-12}$ atm/cm^3/sec for various gasket materials such as bulk copper and Nb gaskets.

REFERENCES

[1] N. Holtkamp, Private discussion, DESY, 1998.
[2] H. Matsumoto, "A New Design for Super-Conducting Cavity Input Coupler", Linac Meeting 2005. (Domestic)