DESIGN AND TEST OF A CRYOGENIC SEAL FOR RECTANGULAR WAVEGUIDE USING VATSEAL TECHNOLOGY*

J. Fuerst†, J. Holzbauer, J. Kaluzny, C. Montiel, Y. Shiroyanagi, B. Stillwell
Argonne National Laboratory, Argonne, IL 60439, USA

Abstract

Vacuum sealing technology for superconducting rf applications must possess certain characteristics: reliability, cleanability, low-particulation, and ultra-high-vacuum-compatible seal quality. These requirements most often lead to the use of CF-type flanges with copper gaskets, aluminum-magnesium diamond seals, or formed indium wire. The use of superconducting rf technology in high-current accelerators and the associated high-power waveguides leads to an additional requirement: minimization of trapped field losses in the seal and beam impedance by minimizing the width and depth of the pocket created by the seal. CF-type flanges and diamond seals must be made circular and have a minimum stand-off distance from the inner diameter of the sealing flanges, making them especially unsuited for rectangular waveguides. Indium wire can be made in any shape, but the appropriate line loading must be established, and the spreading of the indium during sealing is challenging to control. Disassembly of the indium joint is also quite messy and risks contamination of any nearby niobium surfaces. A commercial sealing technology known as VATSEAL may neatly address all of the above requirements. Elsewhere, its feasibility was studied using finite element modeling. In this paper, we installed the VATSEAL to our mock-up flanges, measured vacuum leak rate in a pumped helium bath, and confirmed the seal is high vacuum tight even at 1.65 K.

INTRODUCTION

VATSEAL is a product of VAT Vacuum Valves of Switzerland and is offered by the company as a solution for vacuum, cryogenic, and high-temperature sealing applications for both circular and rectangular seal geometries. It consists of an all-metal gasket with a raised, contiguous strip on both sides, as shown in Figure 1, that serves as the sealing surface. Additionally, this seal geometry available from VAT is customizable, giving great flexibility in the exact shape of the sealing surface and making it theoretically customizable to any waveguide geometry.

The cross section of the raised strip is highly precise and designed to form a vacuum seal reliable for pressures as low as 1E-13 Torr with proper flanges and sealing forces. In the past, the seal was tested at 77 K by immersing the flanges/seal assembly into LN2 [1]. However, it had not been tested at lower temperatures. This paper reports the leak test results from 300 K to 2 K.

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† fuerst@aps.anl.gov

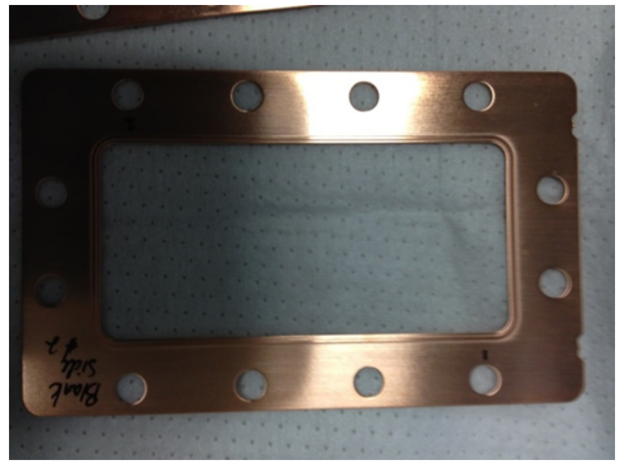

Figure 1: Photograph of a rectangular waveguide VATSEAL.

PRELIMINARY TESTING

The VATSEAL test assembly consists of a 2.75-inch (7.0-cm) CF-type flange, a 1-inch (2.54-cm)-diameter pipe, and two 1-cm-thick rectangular flanges. The VATSEAL sample is installed between the rectangular flanges, which were polished to an rms finish of 0.2 microns (8 microinches). The flatness of this flange was also within the manufacturer's specification of 20 microns over 50 mm [2]. The seal was made using 12 UNC #8-32 socket head cap screws made of high-strength A286 alloy with silicon-bronze hex nuts. The fasteners were tightened in a star pattern in increments of 23 N-cm (2 in-lb) to avoid distorting the seal. It was observed repeatedly that sealing was not achieved with a fastener torque of less than 565 N-cm (50 in-lb), which provides approximately 6800 N (1524 lbs) of compressive force on the seal per screw. The resulting average loading is 3386 N per cm of sealing line which is considerably larger than the minimum of 2000 N per cm of sealing line called for in the VATSEAL specification [2].

The leak rate was checked by a standard leak test procedure of spraying ultrapure helium gas around the entire sealing joint. No leak was detected down to the background of 2.3E-9 Torr·l/s at room temperature. The test assembly

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was then installed to the cryostat with instrumentation as shown in Figure 2. An extensive description of the testing cryostat and associated cryogenic systems has been published [3].

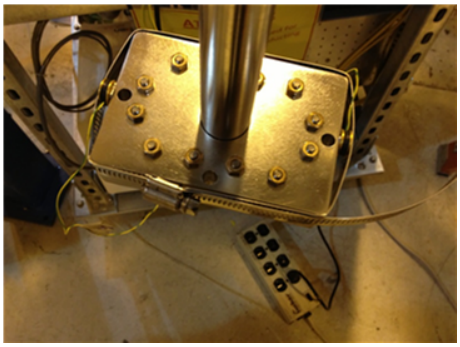

Figure 2: Photograph of VATSEAL test setup. The photo shows the bottom section of the VATSEAL assembly and temperature sensors Temp 1 and Temp 2. Temperature sensors not shown are Temp 3 at the 2.75-inch Conflat flange above and Temp 4 at the adapter plate.

The bottom of the rectangular flange is 14 cm above the bottom end of the level gauge with 15 cm of liquid level covering the seal itself. Four silicon diode temperature sensors are attached. Temp 1 and 2 are hose clamped to the perimeter of the top flange for redundancy, as shown in Figure 2. Before the cryostat is inserted into the dewar, leak was checked by a residual gas analyzer (RGA) (The leak detector was not available at that time.) The partial pressure of helium was 3.4E-10 Torr when helium gas was sprayed on the seals.

COOLDOWN PROCESS AND LEAK RATE MEASUREMENT

Figure 3 top shows temperature as a function of time for the entire cool-down and warm-up cycle which took two days. Figure 3 bottom shows the detail of the same cool-down for the three hours including the start of liquid helium flow. As a preparation for cool-down, the test cryostat is evacuated and then purged by helium gas up to 760 Torr five times. At the last purging, the cryostat was pressurized to 1 psi above atmosphere (812 Torr). The VATSEAL space was evacuated by the leak detector up to 6.9E-5 Torr. The leak rate was recorded continuously throughout the cool-down. No leak was detected at 2.2E-9 Torr·l/s in what was effectively a pure helium environment. The cool-down began with LN2 flow precooling of the cryostat thermal shield circuit. The next day, liquid helium flow was started. As shown in Figure 3 (bottom), the cooling rate when cooled by LHe flow was 260 K per hour. This is a reasonably fast rate that would be typical of or faster than an SRF test cryostat or cryomodule. Temp 1, 2, and 3 were in the same range. The Temp 4 cools slower than the other three locations since this is far away from the bottom of the cryostat. LHe transfer continued until the level gauge showed

Figure 3: Temperature vs Time (hr) for the test's thermal cycle (top) and specifically during the cool-down to 2 Kelvin (bottom).

14 inches (35.6 cm) from the bottom of the level gauge, well above the VATSEAL (15 cm). As can be seen in Figure 4, a slight fluctuation was seen in the leak rate when the seal became submerged in the liquid. Once the liquid level was stable, vacuum pumping of the helium space was started to achieve lower temperatures. The leak rate and helium vessel pressure were measured during the pumping process and especially at the lambda point 37.8 Torr. The leak rate remained between 1.5E-9 Torr·l/s and 2E-9 Torr·l/s during the entire cool-down from 220 K to 1.65 K. During the pump-down the liquid level dropped to 6.5 inches (16.5 cm), still above the level of the seal. The system was warmed up slowly as shown in Figure 3 (left). After the system reached room temperature for a few days, a second thermal cycle was performed. Since the cryogenic system used during the first test was not available at the second cool-down, we transferred LHe from a storage dewar. The cool-down rate was 6.3 K/hr for LN2 pre-cool and 55 K/hr for helium gas cool-down. The helium liquid level was not high enough to cover the VATSEAL at the second cool-down. The leak rate was continuously measured up to 4.3 K at the VATSEAL. No leak was observed, giving confidence that the seal was not damaged by the first thermal cycle.

The leak rate sensitivity in the second cool-down was not as good as during the first cool-down. It is suspected

Figure 4: Leak rate is plotted as a function of temperature (K) in log scale. No leak was detected between room temperature and 1.65 K.

Figure 5: Leak rate is plotted as a function of temperature (K) for second cool-down between room temperature and 4.3 K in log scale.

that this is due to the venting of helium into the atmosphere during the second test, which would then permeate though O-ring seals in our vacuum pumping system, poisoning the RGA sensitivity.

RESULTS AND DISCUSSIONS

Figures 4 and 5 summarize the leak rate measurements. Temperatures below 4.2 K in Figure 4 are calculated from measured pressure values using the helium vapor pressure curve. The leak rate remained between 1.5E-9 Torr·l/s and 2E-9 Torr·l/s during the entire first cool-down from 220 K to 1.65 K, and the liquid helium level was above the seal during this cool-down. After the thermal cycling to room temperature, a second cool-down result also showed no leak at 4.3 K. At this time the helium level was lower than the seal, so the VATSEAL was surrounded by 4 K helium gas. We concluded VATSEAL works well even below the lambda point. Since no leak developed during the second cool-down, the VATSEAL also endures thermal cycling.

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