EVALUATION OF VATSEAL TECHNOLOGY TO SEAL WAVEGUIDE SERVING HIGH-FIELD SUPERCONDUCTING RF CAVITIES*

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Abstract

A waveguide flange seal serving a high-field, superconducting, radio-frequency (SRF) cavity ideally possesses several characteristics. Seals must generally be ultrahigh-vacuum leak tight. Seals must also bridge the inner surfaces of connecting flanges for optimum transmission and minimal heating due to trapped modes. In addition, if seal contact areas are minimized, flange seals may serve as convenient thermal impedances. Finally, seals must be easily cleanable and not be prone to generate particulate matter during assembly and disassembly. A unique sealing technology known as VATSEAL may neatly address all of the above requirements. In this paper, we describe our evaluation of VATSEAL technology for use in SRF cavity assemblies.

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. The product simply consists of an all-metal gasket with a raised, contiguous strip on both sides. The cross section of the raised strip is highly precise and designed so as to form a vacuum seal reliable for pressures as low as 10^{-13} mbar with proper flanges and sealing forces. The design is readily adaptable to user-defined geometries from 10 mm in diameter to 500 mm by 600 mm in extent [1]. Furthermore, because the seals are conductive and may be positioned as close as 1 mm from flange apertures, a minimal electrical disturbance is presented to traveling currents and fields. Indeed, VATSEAL gaskets have been used successfully at accelerator facilities relative to these qualities [2].

Table 1: Key VATSEAL Parameters [1]

Minimum Sealing Force	2000 N / cm
Thickness Before / After Assembly	0.60 mm / 0.45 mm
Required Flange Flatness	20 µm over 50 mm 200 µm over length
Minimum Depth of Gap at Seal	1 mm
Length of Gaps Between Flanges and Gasket	70 µm

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However, use of VATSEAL gaskets also presents many additional advantages for SRF systems. In particular, they are easily cleaned, involve no rubbing of metal surfaces during assembly, can be used in a highly compact flange configuration, and may act as an effective thermal impedance. Key parameters provided by the vendor are listed in Table 1.

FLANGE DESIGN FOR RELIABLE ULTRAHIGH-VACUUM SEAL

The vacuum tightness and reliability of a VATSEAL is a direct consequence of flange design. Critical issues are surface finish and flatness of the flange sealing faces under assembly. While the former is a trivial matter of applying correct processes during fabrication, the latter requires consideration of the forces required to adequately compress the seal. In addition, because the seal protrudes only 70 µm on either side of the gasket body, flanges with insufficient rigidity will interfere with the seal gasket or opposing flange face during tightening before sufficient sealing forces are achieved. Furthermore, an optimum seal design for waveguide requires that the sealing surfaces be as close as possible to the waveguide aperture, which exacerbates the moment loading on the flanges due to the distance between flange bolts and the seal.

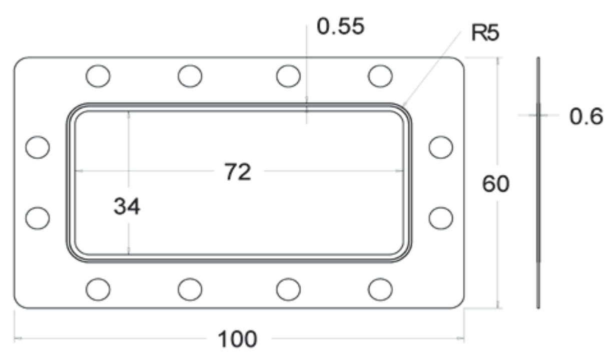

Figure 1: Geometry of WR-284 VATSEAL gasket.

An example of a copper VATSEAL gasket specified by the authors for use with WR-284 waveguide is depicted in Figure 1. A finite element study was conducted using ANSYS Mechanical software to determine if a typical stainless steel flange construction would be suitable for use with the VATSEAL gaskets. The flange was made to be 100 mm by 60 mm by 10 mm thick with a 3 mm deep recess for the waveguide connection. The distortion of the flange under loading at the bolt holes with an elastic reaction force along the sealing area is given in Figure 2. One can see in this figure that the sealing area (green and yellow band) remains flat within 1 µm and adjacent areas are in the same plane to a tolerance of 15 µm.

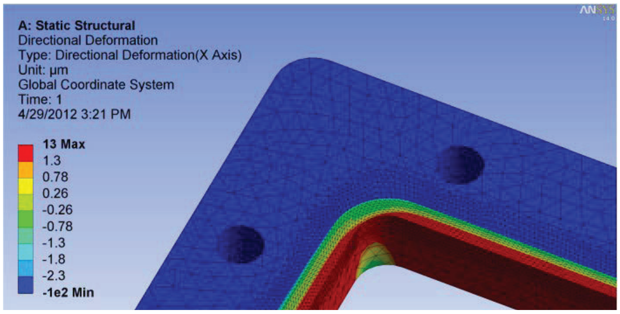

Figure 2: Deformation of a WR-284 flange under loading for use with a VATSEAL gasket.

THERMAL CONDUCTIVITY

The amount of heat transfer permitted by a VATSEAL connection follows from the gasket material, the area of the sealing surface, the position of the sealing surface on the flange, the thickness of the compressed seal, and the thermal conductivity of the space between the flanges and the gasket outside the sealing region. Figures 3 and 4 show the temperature profile in a cross section of the flange assembly and heat flux distribution in the VATSEAL gasket calculated using ANSYS Mechanical software for the flange design described above, given fixed waveguide temperatures of 80 K and 300 K on opposite sides of the connection. Radiative heat transfer is neglected in these analyses. Heat flow through the seal is calculated to be 266 W. Although the seal contact area is small, the limited thickness of the seal allows it to function as a fairly good conductor of heat. In addition, because the seal is placed so close to the waveguide aperture, the thermal path through the stainless steel flange is minimized. Therefore, the characteristics of the VATSEAL design that optimize its electrical performance also compromise its thermal performance. However, the thermal conductivity is nonetheless expected to be very good in comparison with popular designs that utilize wide, flat copper gaskets.

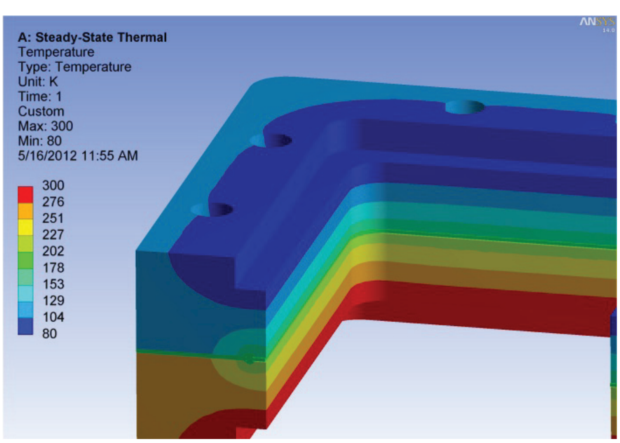

Figure 3: Temperature profile of an 80 K to 300 K WR-284 connection using a VATSEAL gasket.

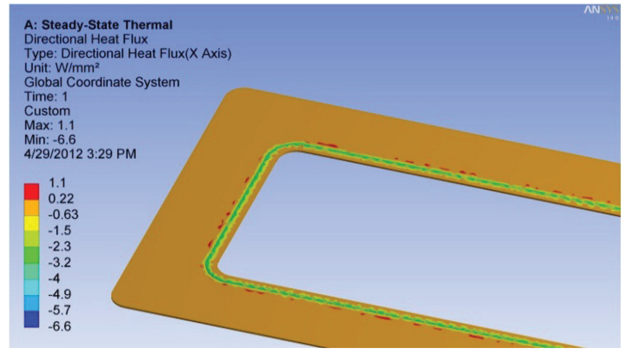

Figure 4: Heat flux through a VATSEAL gasket separating WR-284 flanges bonded to 80 K and 300 K waveguide.

RF LOSSES

ANSYS HFSS software was used to visualize energy losses in the VATSEAL connection relative to those in copper waveguide walls. Figure 5 depicts power density on the surfaces adjoining the interior vacuum space of a WR-284 copper waveguide interrupted by the VATSEAL gasket described above and provided with 1 kW of power at 2815 MHz. One can see that the losses on the VATSEAL gasket surfaces are similar to those on the broad wall of the waveguide. Only 0.0047 W of the 4.67 W/m of total calculated losses are deposited on the VATSEAL gasket. In addition, reflection due to the VATSEAL was determined to be much less than -30 dB at this frequency.

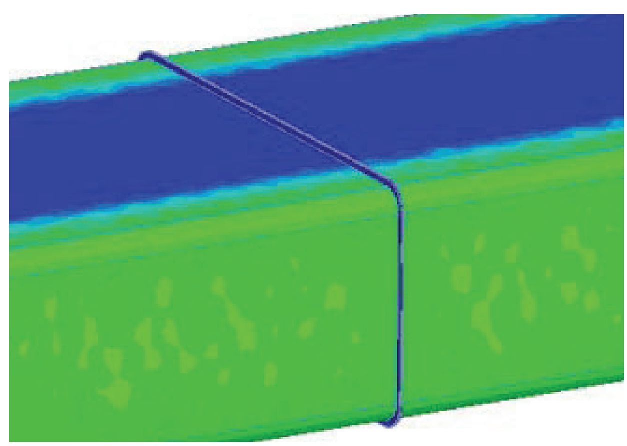

Figure 5: Power density indicating degree of energy loss in interior walls of waveguide and VATSEAL assembly.

ACKNOWLEDGMENT

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REFERENCES

[1] http://www.vatvalve.com
[2] H. Stechemesser, V. Vau, Vacuum 46, 867 (1996).