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TESTING OF A CRYOGENIC HEAT TRANSFER JOINT FOR OMEGA

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ABSTRACT

Keeping cryogenic targets cold until immediately before a laser shot is essential for OMEGA (University of Rochester) cryogenic experiments. This is accomplished by use of a rapidly removed cryogenic shroud. To remove this shroud, a cryogenic heat transfer joint is required that can conduct significant amounts of heat and be easily engaged and disengaged while producing minimal vibration. A prototype of a Cryogenic Parting Joint that can perform this function was designed, built, and tested. Tests were performed using this device at liquid nitrogen (LN_2) and liquid helium (LHe) temperatures. The test results showed that, under both sets of conditions, the design concept is suitable for use in the final system design. This paper describes the test apparatus and presents the test results.

I. INTRODUCTION

The Cryogenic Target Positioning System, currently being designed for OMEGA, uses a Moving Cryostat to transport targets from the equipment that fills them with deuterium-tritium (DT) to the laser focus point. The Moving Cryostat must maintain each target at approximately 18 K during transport. Also, it must provide very stable temperatures for sustained periods to allow layering of the DT ice to occur inside the target. This is accomplished by surrounding the target in a cryogenic shroud assembly. Heat is conducted from the shroud assembly's inner components to a cryocooler located below the target mount area. This assembly must be removable so that targets can be loaded into the cryostat while they are at approximately 18 K. The shroud must be removed immediately before the laser shot without imparting a significant vibrational disturbance to the target area. The Cryogenic Parting Joint was designed to perform this function.

The Parting Joint consists of concentric rings of meshing “fingers” which provide a large surface area for heat transfer. The fingers are pressed together, providing a heat transfer path between the shroud assembly and the cryocooler. A helium actuated, annular stainless steel bellows provides a simple, fast, reversible actuation method for applying large forces to the heat transfer surfaces. Figure 1 shows a photograph of the Parting Joint prototype and the components that comprise it.

Figure 2 is a diagram of a complete Moving Cryostat shroud assembly showing the calculated heat loads and temperature gradients. The full shroud assembly consists of three concentric individual shrouds separated by insulating standoffs. The inner shroud will operate at about 18 K, and maintains the target temperature. The intermediate shroud serves as a heat shield for the inner shroud, and will operate at about 50 K. The outer shroud will remain at nearly ambient temperature. The inner and intermediate shrouds each have a parting joint to conduct heat from them to the cryocooler's two cold heads, which operate at 8 and 40 K, respectively. During the early stage of the shroud assembly design, the heat loads shown on Fig. 2 were calculated. These heat loads are due to thermal radiation and conduction from the outer shroud. The heat load due to tritium decay in the target is insignificant at 7 μW. This data was combined with the known temperature gradient between the target and the cryocooler heads to determine the performance criteria for the two parting joints. For this assembly to function, the inner shroud's parting joint must transmit at least 0.4 W of heat with no more than a 4.3 K temperature differential. The outer shroud's joint must transmit at least 3 W with less than 13.2 K temperature differential. Verification of the heat transfer rates that could be achieved across the

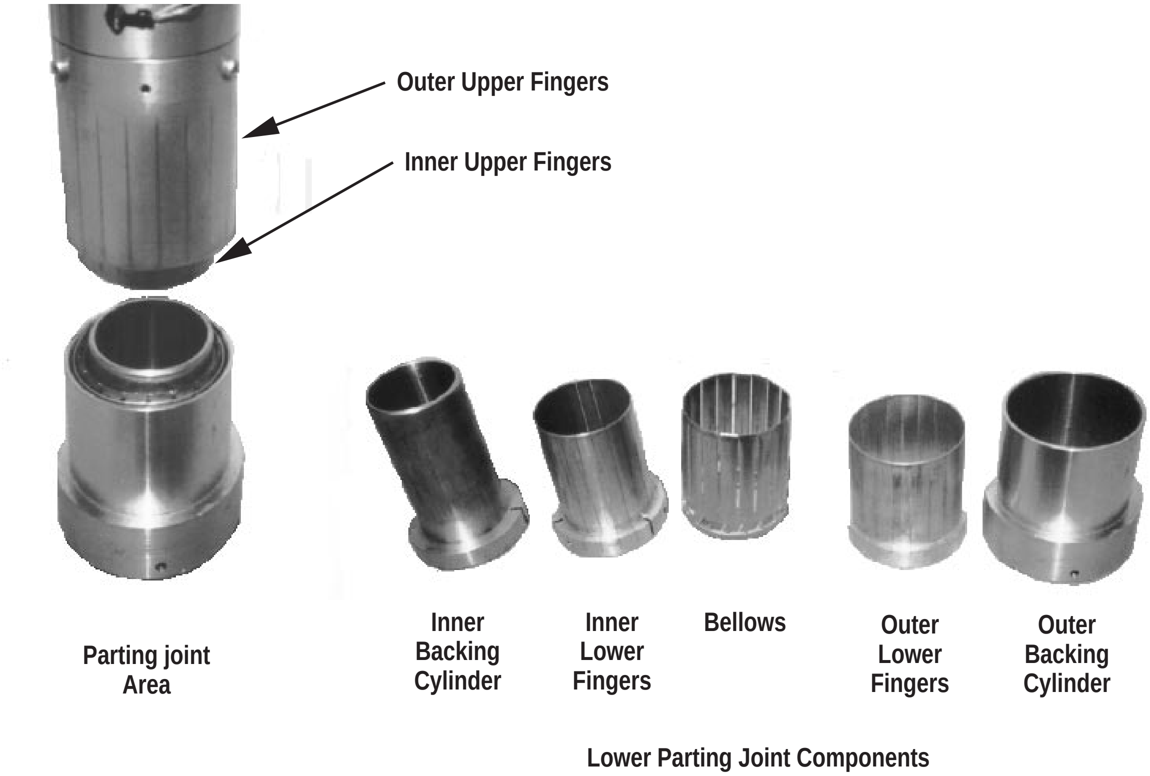

Fig. 1. Cryogenic parting joint prototype.

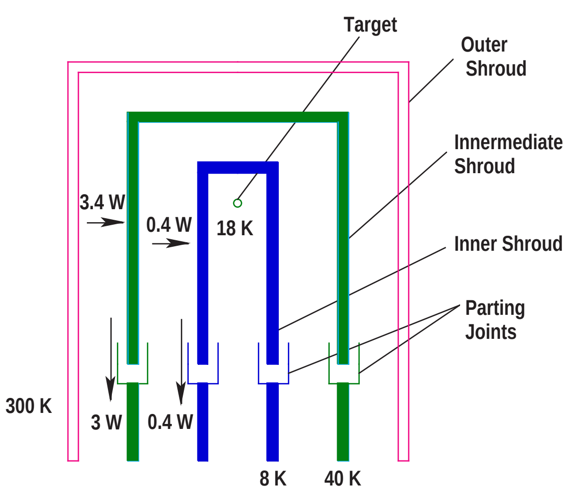

Fig. 2. Moving cryostat shroud assembly diagram.

Parting Joint's pressed metal surfaces was required before a decision could be made to incorporate it into the deliverable equipment.

A test fixture was designed which would both verify the critical heat transfer questions and evaluate the mechanical functions of the Parting Joint. The test fixture included one Parting Joint, which was the size of the unit that will be used in the intermediate shroud. The fixture used a liquid cryogen reservoir as a heat sink, permitting testing at both LN_2 and LHe temperatures. The performance criteria noted above were scaled to calculate representative pass-fail criteria for the inner shroud joint test. Mechanical function evaluations included the design and construction of the annular bellows, as well as the fit, tolerancing, surface finish sensitivity, and alignment of all the components.

II. EXPERIMENTAL APPARATUS

Figures 3 and 4 show a cross section diagram and a photograph of the test fixture, respectively. Control functions and data acquisition were performed via a personal computer. System operating parameters (time, temperature, pressure, and heater power) were logged at fixed intervals.

The test fixture components below the dewar lid were inserted into an LN_2 jacketed dewar during testing (see Fig. 3). The interior of the dewar was evacuated to about 10^{-6} Torr. Liquid cryogen (LN_2 or LHe) was fed into the cryogen reservoir via the cryogen fill line. The base of the heat transfer joint was immersed into the cryogen reservoir, providing a fixed temperature heat sink. Boil off from the cryogen reservoir was vented via a separate vent line.

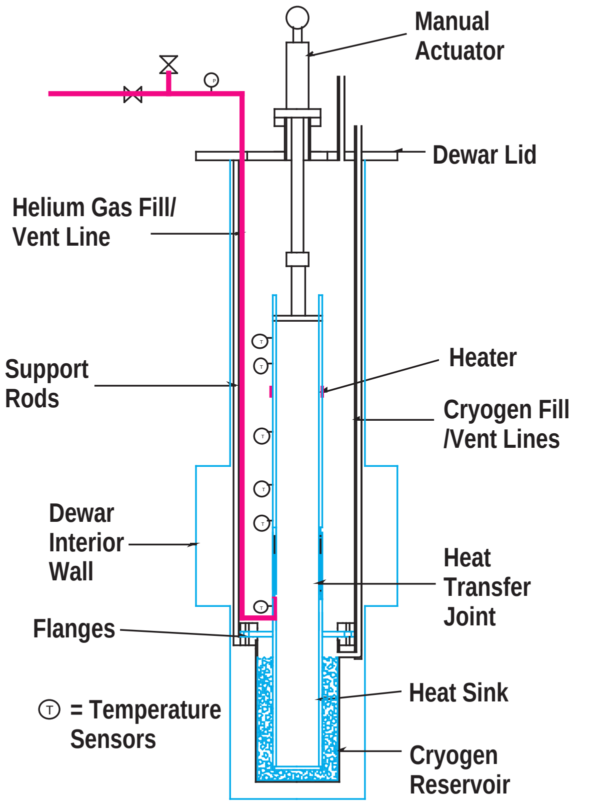

Fig. 3. Test fixture hardware (cross section view).

The test fixture was equipped with sensors and electronics that measured and controlled the test conditions. Temperature sensors were located as shown in Fig. 3 to measure the temperature gradients that existed during the tests. A heater was used to input known heat loads ranging from 0 to 12 W. A vacuum gauge measured the dewar's interior pressure to ensure that no leaks had occurred. A pressure gauge on the helium line measured the bellows inflation pressure, and thus the force applied to the pressed metal surfaces.

The upper Parting Joint heat transfer fingers were made in both copper and aluminum versions so that both materials could be evaluated. The Parting Joint components used in these tests had the following dimensions:

Outside diameter = 2.75 in.
Inside diameter = 1.75 in.
Heat transfer finger length = 2.6 in.
Area of pressed surfaces = 45 $in.^2$ (approx).

The manual actuator was used to evaluate how much effort is required to separate the components while they are at cryogenic temperatures.

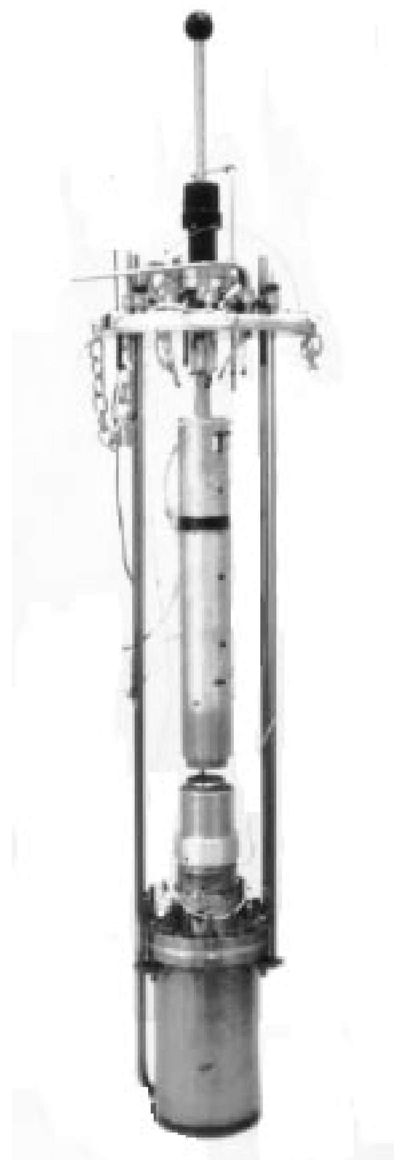

Fig. 4. Photo of test fixture.

III. EXPERIMENTS

Using the apparatus described above, experiments were performed to characterize the Parting Joint's thermal performance under various operating conditions.

Four test apparatus configurations were evaluated. These were:

1. LN_2 heat sink, aluminum upper fingers
2. LHe heat sink, aluminum upper fingers
3. LN_2 heat sink, copper upper fingers
4. LHe heat sink, copper upper fingers
   (The lower Parting Joint components were aluminum in all cases.)

For each of these test apparatus configurations, tests were done to obtain sufficient data to plot sets of performance curves. These were:

1. Parting Joint Temperature Differential (ΔT) vs Bellows Pressure (with no Heater Power) (Baseline case)
2. Parting Joint ΔT vs Bellows Pressure (at fixed Heater Power)
3. Parting Joint ΔT vs Heater Power (at fixed Bellows Pressure)

By comparing the baseline case temperature gradients with the other cases, the net impact of the energy input via the heater was determined.

The annular bellows was operated to 300 psig at 5 K. In addition, it was cycled over 300 times from 0 to 200 psig at about 10 K during the test activity.

IV. TEST RESULTS

The test fixture worked very well in obtaining all of the required data. The data showed the Parting Joint to be a very effective design solution for meeting the Moving Cryostat's performance requirements.

Thermally, the Parting Joint performance exceeded the pass-fail criteria, which were $\leq$4.3 K joint ΔT at 1 W heat load for the LHe cooled case, and $\leq$13.2 K joint ΔT at 3 W heat load for the LN_2 cooled case. Figures 5 and 6 show plots of the results for the LHe cooled case (copper upper finger configuration). Figures 7 and 8 show plots of the results for the LN_2 cooled case (copper upper fingers). Bellows pressures above 200 psia did not improve heat transfer noticeably.

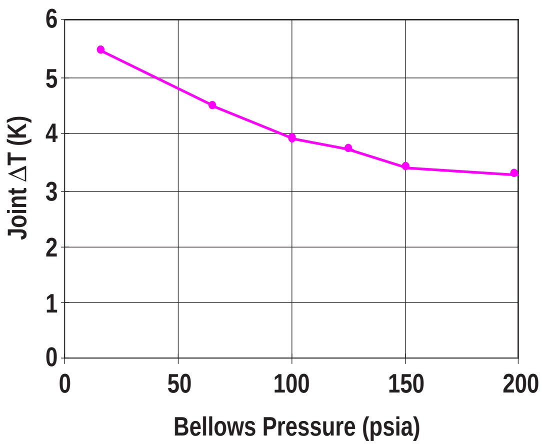

Fig. 5. Thermal performance of liquid nitrogen cooled parting joint as at 1 W conducted heat load.

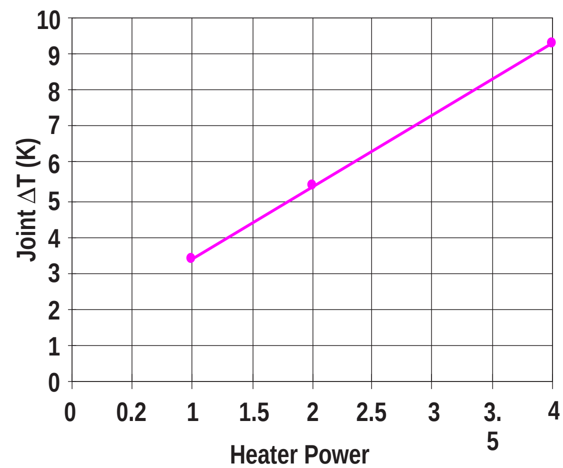

Fig. 6. Thermal performance of liquid helium cooled parting joint at 150 psia bellows pressure.

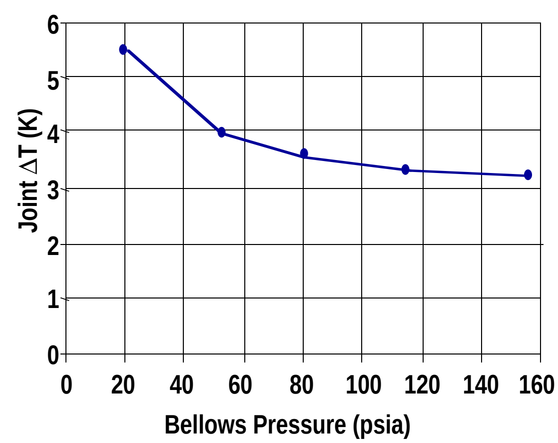

Fig. 7. Thermal performance of liquid nitrogen cooled parting joint at 3 W conducted heat load.

At LHe temperatures, the specific heats of the joint materials are very low, and the heat transfer rate across the joint is extremely responsive to a change in bellows pressure as Fig. 9 illustrates.

As expected, when the Parting Joint prototype was outfitted with aluminum upper heat transfer fingers, the results were similar to, but not as good as the copper cases, especially in the lower temperature range. For the LN_2 cooled case, the temperature gradient was about 25% greater than for comparable copper upper finger tests. For the LHe cooled case, it was about 50% greater. The conductivity of aluminum declines very rapidly with temperature below 20 K. The net result is aluminum is not a good material choice for this application at temperatures

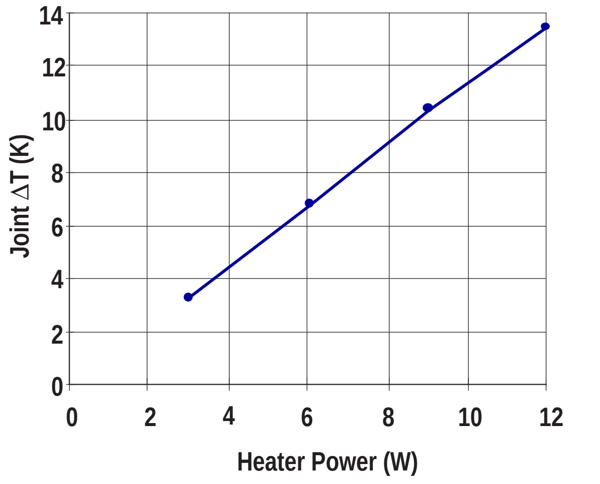

Fig. 8. Thermal performance of liquid nitrogen cooled parting joint at 150 psia bellows pressure.

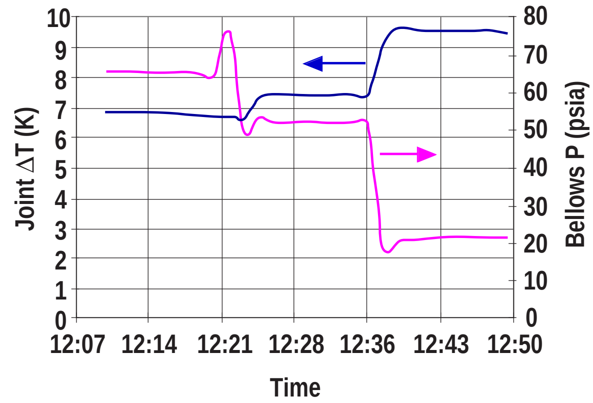

Fig. 9. Typical experimental trace obtained for step changes in bellows pressure while operating at liquid helium temperatures.

below approximately 20 K. In addition, copper is preferred to aluminum from a neutron activation standpoint.

The following observations and assessments were made regarding the Parting Joint's mechanical function:

1. The nominal clearances, tolerances, and fits selected for the components were suitable for use in the final design.
2. Separating the Parting Joint is easy at all temperatures. When the annular bellows was depressurized, no sticking of the parts was observed.
3. Applying only 15 psia to the annular bellows engages the Parting Joint hard enough that it cannot be separated manually.
4. No leaks were detected from the annular bellows.
5. The heat transfer surfaces are not sensitive to surface finish. After repeated engagements of the heat transfer surfaces, the parts had numerous small scratches in them, but there was not a noticeable deterioration in thermal performance.
6. When the shroud assembly is placed onto the lower half of the Parting Joint, the parts do not have to be precisely aligned. The shroud assembly's inner heat transfer fingers are 1/2" longer than the outer ones, and provide coarse alignment to get the engagement process started. A 0.020" chamfer was included on the ends of the mating parts, and was sufficient to guide them together.

V. CONCLUSIONS

The Cryogenic Parting Joint met the thermal performance requirements at the heat loads and at the temperatures of interest for the OMEGA Cryogenic Target Positioning System. Copper is preferred to aluminum as the material of construction. The mechanical performance of the components was as expected, and the suitability of this design for use in the Moving Cryostat was verified.

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