FGS-TF GROUND TESTING PRIOR TO LONG-TERM OPERATION IN ORBIT ABOUT L2

Johanne C. Heald[1] and Mark O'Grady[2]

[1]Canadian Space Agency, Space Technologies Directorate, 6767 route de l'Aeroport, St-Hubert, Quebec, Canada J3Y 8Y9, Email: Johanne.Heald@asc-csa.gc.ca
[2]Canadian Space Agency, David Florida Laboratory, 3701 Carling Avenue, Ottawa, Ontario, Canada K2H 8S, Email: Mark.OGrady@asc-csa.gc.ca

ABSTRACT

The upcoming James Webb Space Telescope mission presents a significant challenge to the instrument designers, who must guarantee the operation of their instruments in the cryogenic environment (32 K) of space about the Earth-Sun L2 Lagrangian point for a period of at least 5 years after launch. A general overview of the FGS design will be presented in this paper, detailing both the Fine Guidance Sensor and the Tuneable Filter sides of the instrument. But more specifically in this paper, the facility in which the FGS is being ground tested, the David Florida laboratory (DFL), which has been updated to support cryogenic testing, will be described.

1. BACKGROUND ON THE FGS-TF INSTRUMENT

The James Webb Space Telescope (JWST) has been designed as an observatory for surveying the universe in the near- and mid-infrared wavelengths. As such, it has stringent temperature requirements, requiring operation at temperatures lower than 40 degrees Kelvin. The observatory is planned for launch in 2014, and will begin operations as soon as its commissioning phase and transfer to a halo orbit about the L2 Langrangian point in the Earth-Sun system is complete.

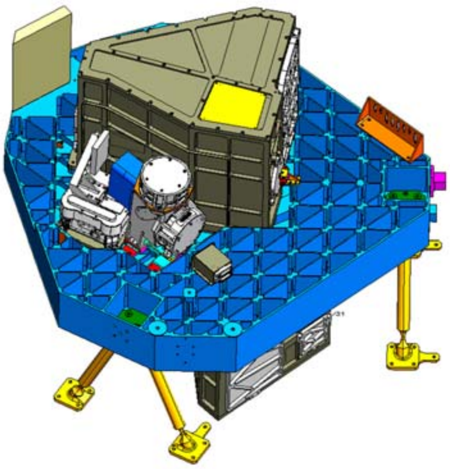

Figure 1. Fine Guidance Sensor Side of FGS-TF

JWST is an observatory that hosts four instruments, one of which is the FGS-TF.

The FGS (Fine Guidance Sensor) – TF (Tuneable Filter) instrument for the James Webb Space Telescope has been designed by the Canadian team, and is now in the midst of testing at the David Florida Laboratory (DFL) in Ottawa, Canada. See figures 1. and 2. for the design of the two sides of the FGS-TF. The FGS side of the instrument will be used to maintain the pointing stability of the telescope observatory during its scientific observations; the TF side of the instrument, meanwhile, will be actually executing some of those observations in narrow wavelengths of light, as dictated by pass-band filters. While the FGS side of the instrument is necessary for the successful use of the observatory, the TF side of the instrument is essential for the observatory to execute its mission. It is true that each of these two parts of the instrument have differing optical requirements, but they maintain a certain commonality in terms of the materials that are used to maintain a common coefficient of thermal expansion (CTE) and the mechanisms that are employed in this demanding thermal environment.

In order to meet the demands of the instrument tests, particularly its low thermal threshold, the current testing equipment at DFL required major upgrades. One of the mid-sized chambers in the laboratory,

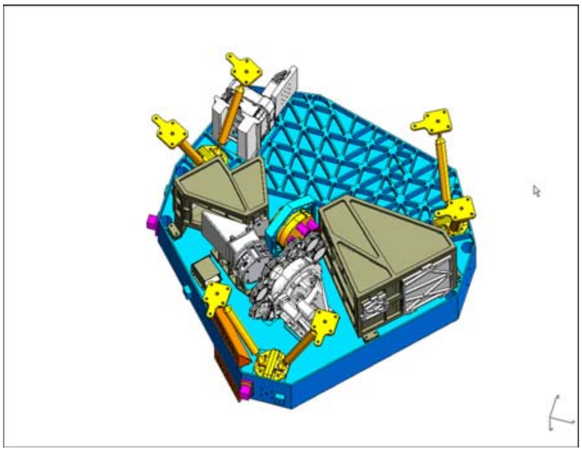

Figure 2. Tunable Filtre Side of the FGS-TF

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thermal vacuum chamber 3 (TV3) was therefore converted to one in which the new lower temperature range could be sustained. Prior testing in this chamber had only needed to achieve a temperature of approximately 80 K, the smallest temperature achievable using only liquid nitrogen cooling. Clearly, if lower test temperatures were required, a new cooling system was also necessary.

2. TV3 TEST FACILITY UPGRADE

Since its inception in 1972, the David Florida Laboratory has been used to verify a variety of spacecraft and instruments going into space, executing radio frequency, structural, and thermal qualification testing. Using the facility to support the testing of hardware for the JWST programme, however, required an upgrade of its facilities, as cryogenic testing at temperatures below 40 K had never been executed in the TV3 chamber at DFL before.

This new cooling system for the test chamber was designed to consist of manifold elements. First, a gaseous helium thermal shroud that would sustain an operating temperature of between 17 K (minimum) and 293 K (maximum) was necessary, with a bake-out temperature of 425 K. At its minimum temperature of 17 K, the shroud was designed to have a temperature precision of ± 4 K across its surface, with a uniformly distributed heat source with a thermal load of 400 Watts. Secondly, 4 actively cooled viewing ports were delivered with the shroud, consisting of rolling aluminium cover plate shutters. The shutters were to be driven through a linkage mechanism using a cryogenic stepper motor, with “dual-vee”-type dry-lubricated ball bearing wheels mounted to the shutter that are guided within a stainless steel track. Third, an actively cooled aluminium platen was designed to mount the hardware to be tested. The platen was expected to see the same range of temperatures as the shroud, and to maintain its temperature to within ± 4 K across its entire surface. To ensure meeting its thermal requirements, the platen included a “counter-flow” design, meaning that it contained two tube systems flowing in opposite directions to maintain thermal stability. The platen was designed to support a maximum test load of 8896.44 N (2000 lbs). Finally, a helium refrigerator and compressor system and its associated piping and feed-throughs were designed to support the chamber. The helium gas storage tank was mounted horizontally and had a volume of 964.3 litres (250 gallons). The refrigerator was designed with a thermal capacity of 560 Watts to manage parasitic heat losses from the shroud radiation, the structural conductivity, and piping losses. This cooling system was commissioned from the American company XL Technology Systems, Inc., in late 2006, installed in 2007, and performed system checks in 2008. Fig. 3 shows the TV3 chamber at DFL and its upgrades to support the cryogenic test environment.

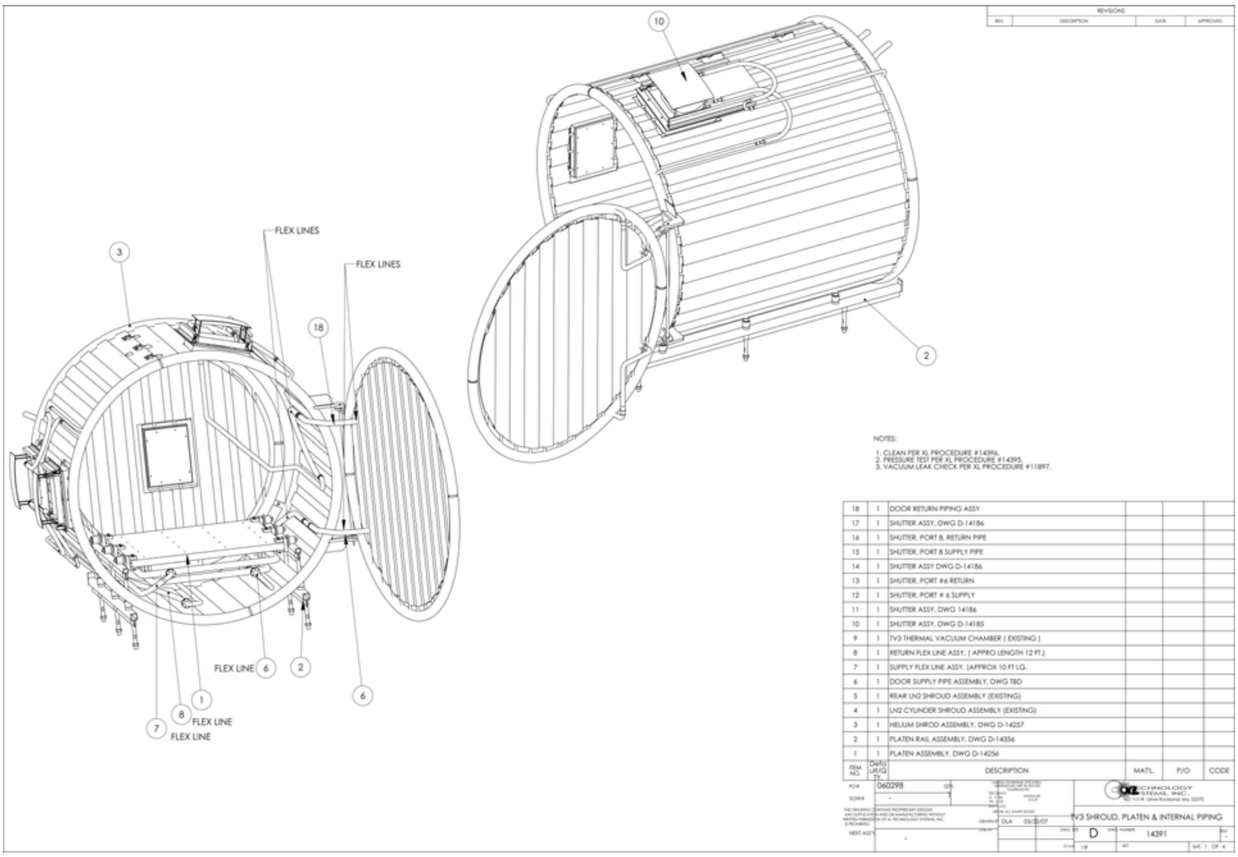

Figure 3. Cryogenic Updates to Thermal Vacuum Chamber TV3 at DFL

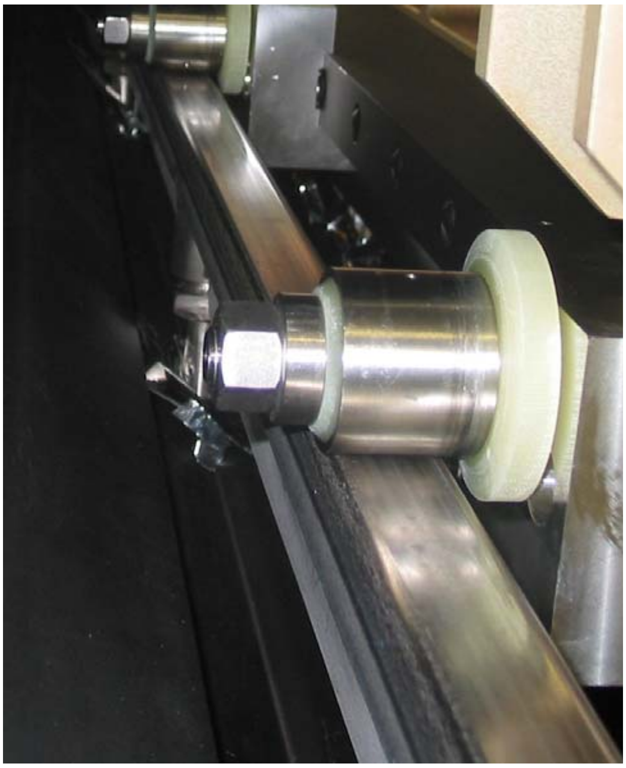

Figure 4. TV3 Platen Wheels on Chamber Rails

3. RESULTS OF TV3 SYSTEM CHECKS AND COMMISSIONING

3.1. TV3 Chamber Cleanliness

During system checks, the new cooling system experienced several challenges. Included among these was the cleanliness of the chamber. The FGS-TF instrument, being an optical space instrument, required the highest standard of cleanliness in its verification. Initial results from the commissioning of the new cryogenic test chamber, however, did not guarantee its cleanliness. The contract specified that any manufacturing for the TV3 chamber would be performed in a Class 100 000 (ISO 8) environment. It was thought that further cleanliness precautions that were put into practice in close proximity to the chamber would limit further contamination. In actuality, maintaining a clean environment has proven to be one of the most challenging elements of the TV3 chamber upgrade, requiring the addition of a class 1000 (ISO 6) environment adjacent to the testing chamber. One of the sensors to determine the temperature of the cooled chamber (the “cold finger”) was re-positioned so that it would not impact the tested hardware, and that hardware had to be carefully manoeuvred so that it would not bring contamination into the chamber.

3.2. Platen alignment

During initial testing of the TV3 chamber, it was discovered that the wheel axes of the platen were deformed and the rail alignment of that equipment was askew with respect its nominal alignment. The yield of one of the platen bolts was measured to be ≈ 0.2105° (measured to be 0.07 mm at 19.07 mm bolt length), which indicated that the contact angle between the platen wheels and the rails was non-Herzian since the slope of the profile within the contact area would cause a sharp discontinuity of pressure. The finite maximum value of the principal stress between the surfaces will find itself at the apex of the wedge, as calculated by:

$$(\tau_1)_{\max} = (E^* / \pi)\cot\alpha \qquad (1)$$

where α is the angle of the wedge and E^* is the elastic modulus of the contact surfaces dictated by:

$$\frac{1}{E^*} = \frac{1-\nu_1^{\ 2}}{E_1} + \frac{1-\nu_2^2}{E_2} \qquad (2)$$

which is 57.16 GPa in the case of aluminium platen wheel supports in contact with steel rails. Therefore, a maximum principal stress of 4956.075 GPa was applied at the apex of the wedge between the wheel and the rail, a stress which was beyond the yield stress of platen bolt.

In consequence, design changes were made to the wheel assemblages to make them considerably stiffer, and the test rails were aligned to much tighter tolerances. A test was then carried out to remove structural safety concerns: a mass of 1500 ± 50 pounds (680.4 ± 22.7 kg) was applied to the platen to verify that it could support the load it was designed for, within a factor of 1.5 of the design load.

COM DEV Canada, the Canadian FGS-TF instrument designer, is now using the updated facilities to verify all the FGS-TF instrument requirements, for both its Engineering Test Unit (ETU) and its space flight-ready Proto-Flight Unit (PFU). The ETU can be seen in the DFL TV3 facility in Fig. 6.

3.3. Vibration Environment

Since many of the tests involved in the FGS-TF qualification involve optical alignment and stability, it was judged important to determine the noise floor of the upgraded test chamber due to ambient noise exterior to the test chamber and the environmental noise (due to the new cryogenic compressor) of the test itself. In order to take this data, several sensors were installed on a test fixture during cryogenic testing for validation, including six low-temperature Kistler accelerometers arranged in two groups of three to take data in 3 orthogonal directions. See Fig. 5 for further details, where the pale green boxes represent the approximate placement of the two accelerometer groups on the test fixture.

3.3.1. Vibration Data Analysis

The vibration data that was gathered in the TV3 chamber during an operational alignment test of the

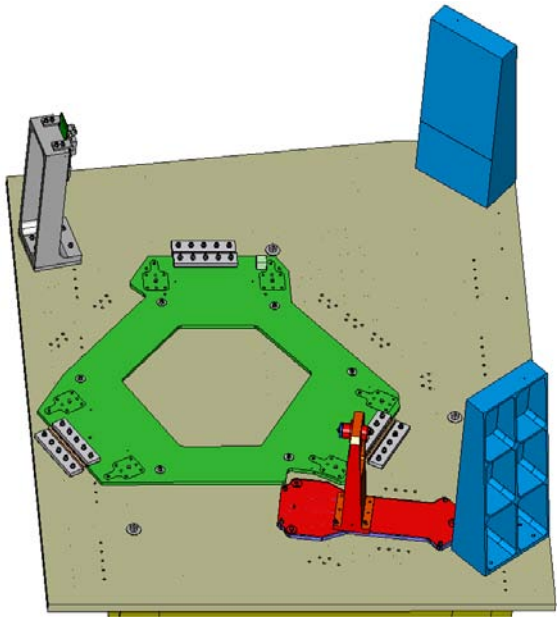

Figure 5. Test Configuration for TV3 Vibration Characterisation

fixtures, but without the FGS-TF in the test chamber.

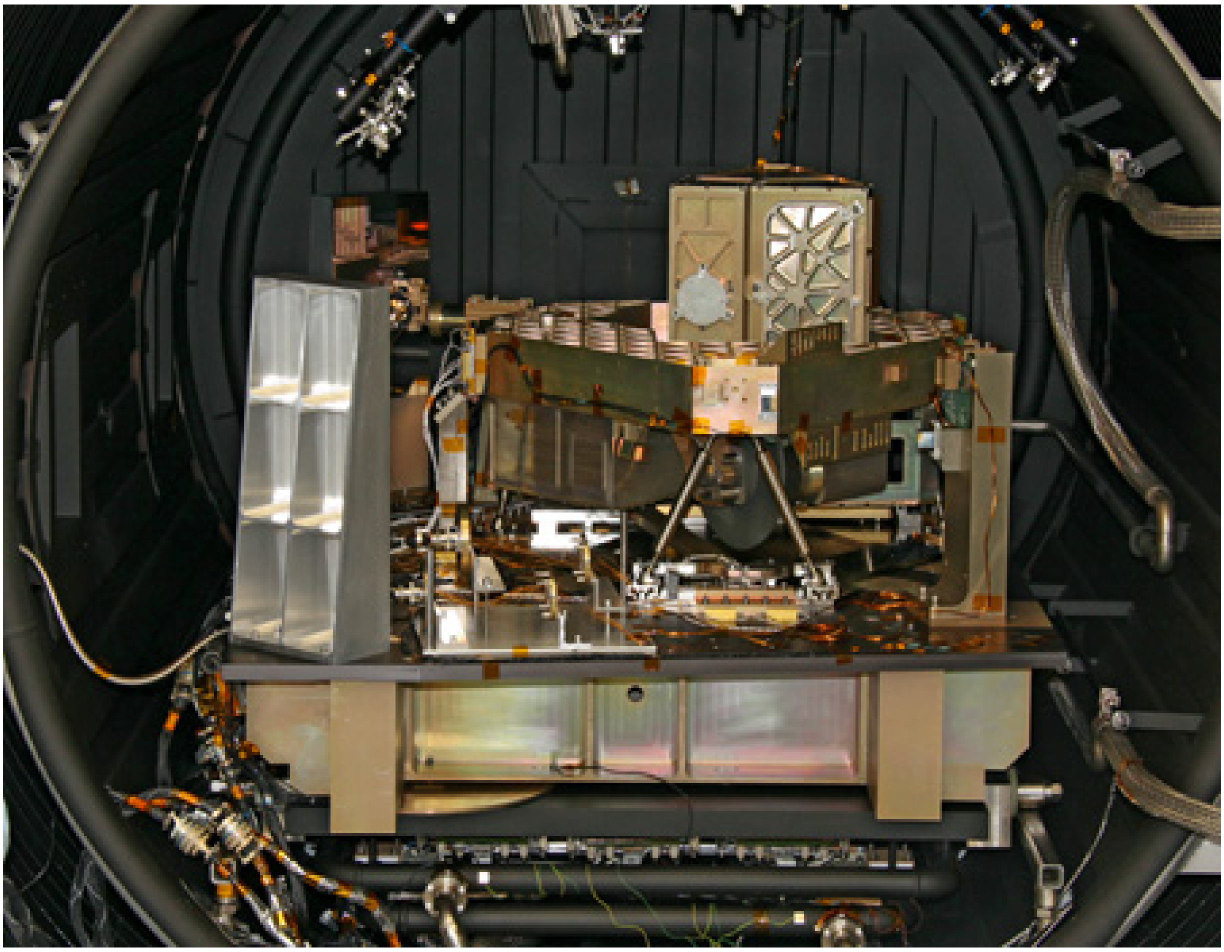

Figure 6. FGS-TF in TV3 chamber at David Florida Laboratory

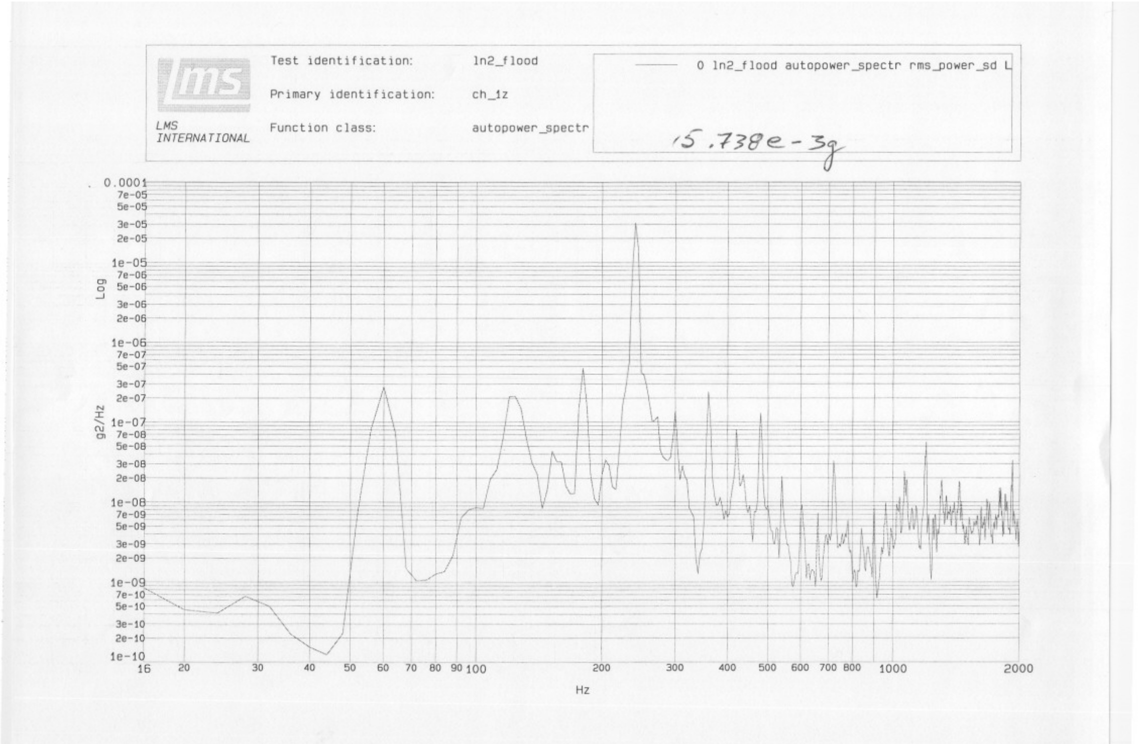

Figure 7. DFL TV3 Chamber Vibration Results Perpendicular to Ground at Ambient Temperature

An example of vibration data from TV3 can be found in Fig. 7, taken at ambient temperature two years before the upgrade of the chamber for cryogenic operation. In those previous test results, one of the most important things to note is the strong vibrations indicated at the 60 Hz point, as well as at 120 Hz and 180 Hz. Given previous experience testing in quiet test environments for optical equipment, it was speculated that these lines are due to electronic equipment "humming" in the room outside the TV3 chamber. These lines are followed by a surprisingly strong vibration at ~230 Hz, presumably associated with the ambient laboratory noise.

When those vibration results are compared to data that was taken in the chamber after the upgrades for cryogenic cooling were made, very few of the same vibration lines could be recognized. See Fig. 8 for comparable test results in the same chamber cooled to cryogenic temperature. Note the near-absence of the 60 Hz line seen in Fig. 7, while the 120 Hz and 180 Hz vibrations are still present. Once again, a strong vibration is seen at approximately 230 Hz, although in this case it is followed by an almost as strong vibration at ~275 Hz and another at ~390 Hz. The greatest surprise in this data is vibration that occurs in a distributed fashion between 830 and 895 Hz. This vibration is several orders of magnitude greater than the lower-frequency vibrations, and it is speculated that the vibration occurs as a result of the liquid helium cooling system. While optical alignment of the FGS-TF is expected to be measured in a static vibratory environment, this unexpectedly strong vibration at higher frequency could impact the test results if measurements are made that require high-frequency data. It is presumed that such reactions could be damped through the interface to the platen, were such measurements to be made.

4. CONCLUSIONS

The TV3 chamber at the David Florida Laboratory has now been fully qualified for cryogenic testing of the FGS-TF instrument as required by the JWST programme. Its cleanliness has been confirmed by several runs-through of testing to 32 K, followed by chamber and test article inspection. The alignment of the test equipment in the chamber encountered an oversight of the contact mechanics of the platen wheels on the chamber rails. This situation was rectified by re-designing the stiffness of the system and requiring a tighter tolerance on the pieces installed. Finally, the vibratory environment at cryogenic temperatures was confirmed to be adequate for optical alignment tests. A new vibration at 830-895 Hz was noted in the cryogenic test, but given its high frequency it is not expected to negatively impact the tests.

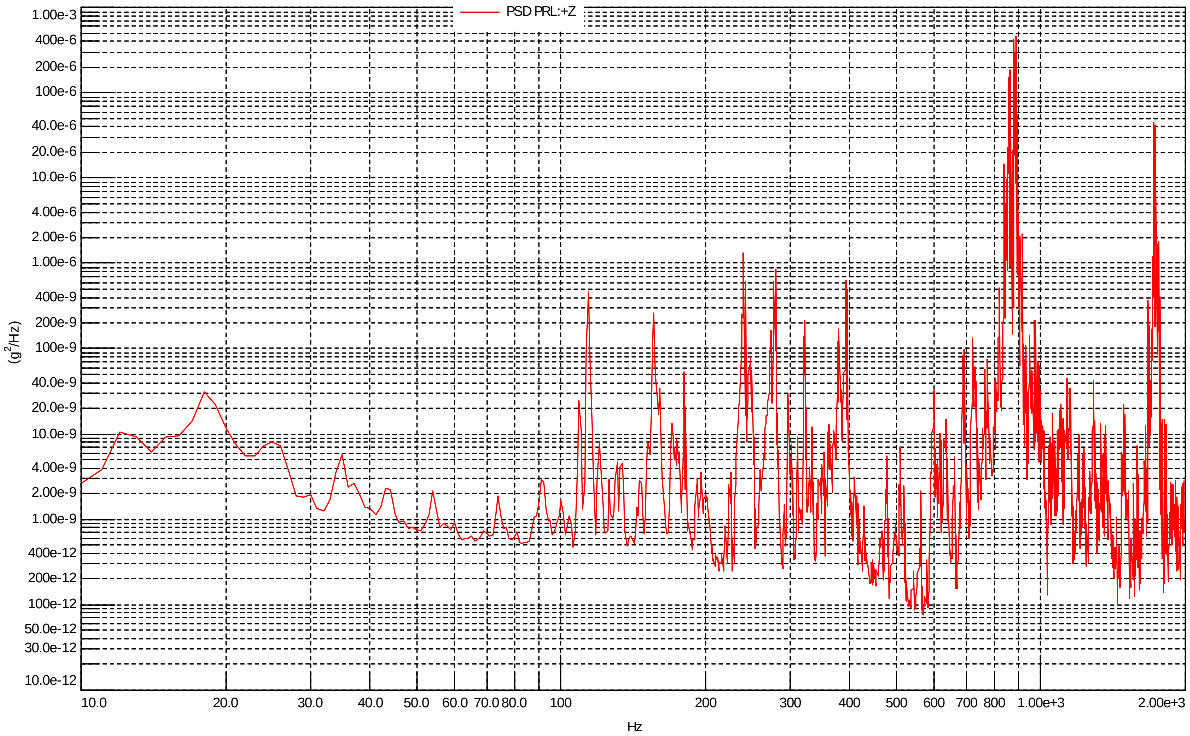

Figure 8. DFL TV3 Chamber Vibration Perpendicular to Ground at Cryogenic Temperature

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