Testing Results for Low Exported Force and Torque Cryocooler Mounts

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ABSTRACT

Increasingly, exported forces and torques (EFT) from cryocoolers are a system level concern with lower levels becoming the norm for instruments with cryocoolers. Typical capabilities in the 0-500 Hz range are ≤ 50 mN force and ≤ 25 mN-m torque. In anticipation of these lower levels, Ball Aerospace & Technologies Corp. (Ball Aerospace) developed a low EFT cryocooler mount design with passive isolators for both a single-stage Northrop Grumman Aerospace Systems (NGAS) High Efficiency Cryocooler (HEC) and a two-stage Ball SB235E cryocooler for the TIRS instrument on the LandSat Data Continuity Mission (LDCM). Together with the design and testing program, a modeling program was undertaken to allow model correlation from testing for future design maturity. Test results show the mount design successfully reduces EFT within the desired limits.

INTRODUCTION

One consequence of using mechanical cryocoolers is the exported force and torque (EFT) that can compromise the performance of any instrument incorporating them. To first order, EFT increases with cryocooler power; as cryocooler heat lift capacities have increased so has the EFT imparted to the system. These disturbances lead to line of sight noise (jitter) as well as structural modes that reduce the overall performance of a system. Cryocooler vendors have designed cryocoolers to minimize the EFT levels by using opposing motors as well as vibration cancellation algorithms within control software. However, instrument systems have become more sensitive to EFT, leading to the necessity of further methods of EFT reduction. In addition, in the past, cryocooler vibration requirements were exclusively force requirements with no specifications on the torque. Now it is also important to minimize the torque contribution to instrument level jitter.

In 2010, Ball Aerospace began an Independent Research and Development (IRAD) program to develop cryocooler mounts that reduce exported force and torque (EFT). The program focused on two cryocoolers: the single-stage Northrop Grumman Aerospace Systems (NGAS) High Efficiency Cryocooler (HEC) and the two-stage Ball SB235E cryocooler for the TIRS instrument on LDCM. All paths of EFT from the cryocooler were studied including the mount structure, MLI, loop heat pipes, cables, and thermal links. Thermal links are the widely used S-shape multi-foil stack with mounting blocks on each end. Both modeling and test were the focus of the IRAD. The integrated system was designed, developed and characterized with flight-like

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hardware over a full range of operating conditions. This high fidelity testbed can be used for systems with either low capacity or high capacity cryocoolers. EFT levels have been reduced at least 10 times over the inherent cryocooler disturbance levels.

HARDWARE TEST AND MODELING DESCRIPTION

Cryocooler EFT can transmit through the cryocooler mount, heat pipes, thermal links and cryocooler cables. In order to separate the contributions to the total EFT of each component, the testing was completed incrementally as shown in Figure 1. The cryocooler assembly (CCA) consists of the cryocooler, mounting plate, passive isolators and supports to the instrument mount. In this case, the hardware was not mounted to an instrument but instead it was mounted to a dynamometer. The CCA design changes with selected cryocooler to optimize the EFT performance for unique operating conditions such as the cooler frequency and mass. The design is optimized for each cryocooler. First, each component is tested per its specification. The dynamometer is characterized to understand its behavior. The EFT for the cooler without vibration cancellation algorithms is determined. This is the system baseline EFT without any software force cancellation and without isolators. The CCA is then characterized by itself. Finally, thermal links, cables, multi-layer insulation (MLI) and heat pipe simulators are added. In this case, the thermal links from the cryocooler's cold tip are a typical thermal s-link foil design. A simulator is used to emulate the heat pipe, which provides cryocooler heat rejection. Cables include those that to run the cryocooler and any required temperature sensors and heaters.

In parallel with the testing effort, a modeling effort was undertaken as in Figure 2. Detailed dynamic models of the CCA were constructed. With each level of testing, models and test results are correlated. At a program level, this modeling is too detailed for manageable dynamic models so reduced models based on the correlation are created. These reduced models then can be used by a program to show the dynamic behavior of an instrument using an isolated cryocooler.

TEST PROGRAM

The test goal is not only to obtain EFT data but also to understand it. The EFT is recorded by a fully characterized dynamometer. Stinger and tap tests provide further insight into the system dynamic performance. The test plan was to start as simply as possible to understand the results fully before adding successive complexity. Model correlation occurred simultaneously. At EFT levels of ≤ 50 mN force and ≤ 25 mN-m torque, a background disturbance characterization is necessary to understand its contribution to future EFT measurements. Figure 3 shows the characterization of the testbed.

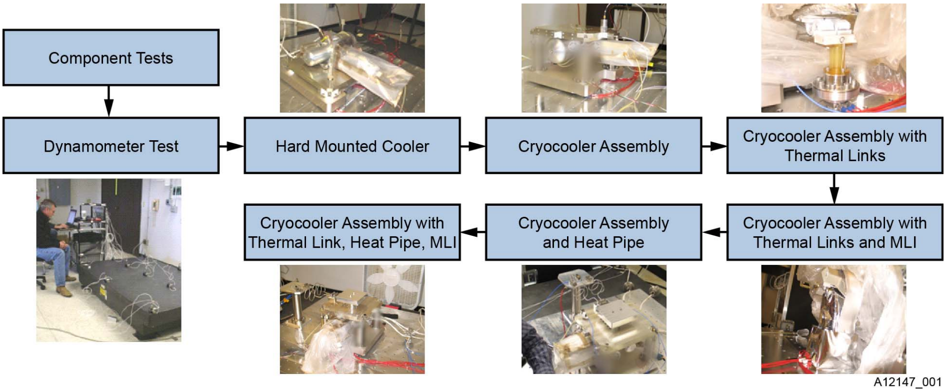


Figure 1. Incremental testing was used to characterize and understand each component and its contribution to EFT.

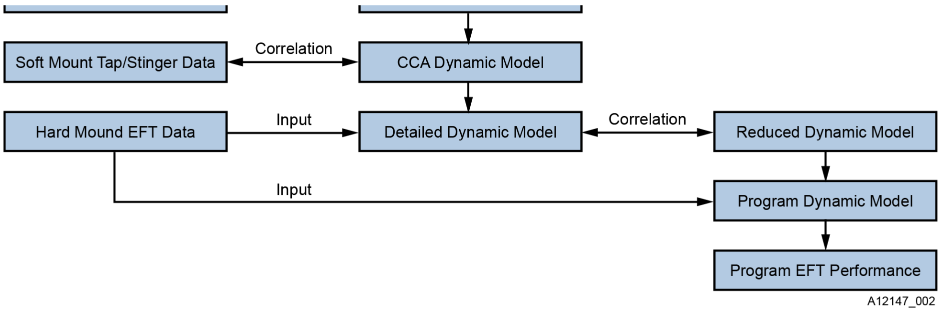


Figure 2. The modeling and correlation process is shown for the IRAD program.

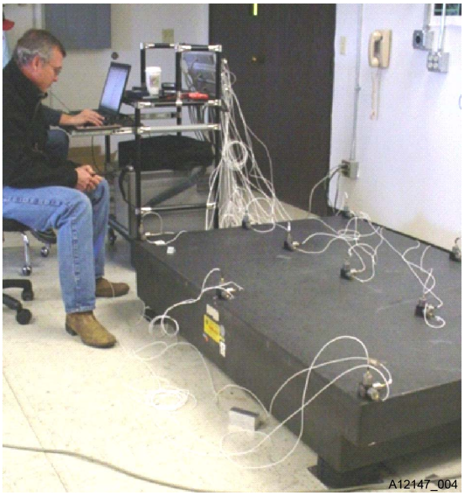


Figure 3. Dynamometer characterization starts the process to determine the inherent background levels of EFT.

NGAS HEC Test Results

After the background disturbance level is determined, cryocooler data are taken without vibration cancellation software as the system baseline level (Figures 4 and 5). Individual harmonics are manually adjusted to achieve lower EFT. After getting baseline data, the first test includes the CCA by itself. The test verifies the highest EFT levels are generally at the fundamental frequency of the cooler. Although specific cooler structural modes can be excited and be large, in general, these higher frequencies are not an issue as the passive isolation system attenuates them. Figure 6 shows the EFT results at the fundamental frequency for various motor powers. Thermal links carry cryogenic cooling from the cryocooler to the object being cooled. Often MLI surrounds the hardware to lower radiation losses. The next step was to determine how the thermal link and MLI affect EFT performance. Similarly, heat pipes are used to provide heat rejection to the cryocooler and are another pathway for EFT from the cryocooler. Individually, these other EFT paths contribute smaller values than the primary mount. Finally, all EFT paths including mount, thermal links, cables and heat pipes are measured. Force is reduced from 400 mN maximum to less than 40 mN, or a 10x reduction. Torque is reduced from 70 mN-m to less than 15 mN-m, a reduction of more than 4x. An error analysis of the test set determined that the

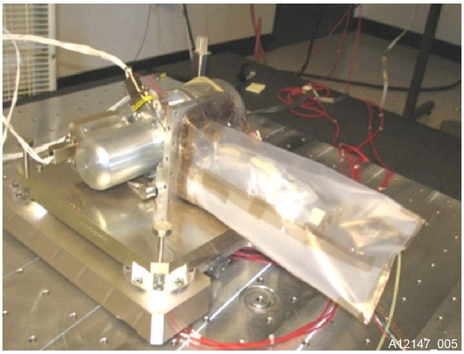
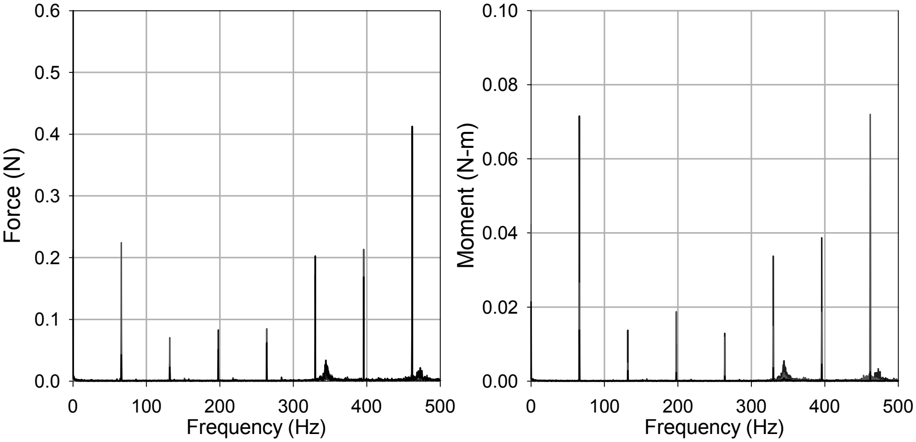


Figure 4. The NGAS HEC in baseline test configuration.



Figures 5. NGAS HEC baseline EFT data with the cooler operating at 82 K, 66 Hz at 170 W.

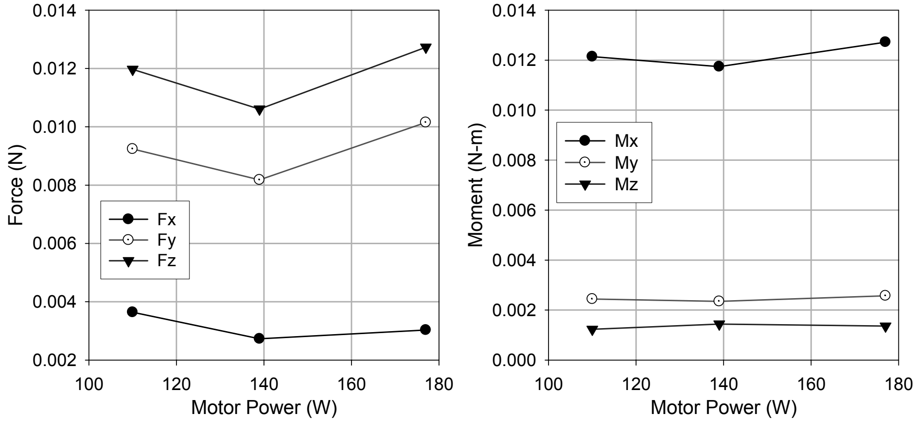


Figure 6. NGAS HEC CCA only EFT data at the fundamental frequency of 66 Hz at various motor powers.

overall accuracy of the EFT measurements is ±12% while repeatability is 1% to 2%. At each step of testing, modeling was correlated to test results leading to a correlated detailed structural model.

Ball SB235E Test Results

After concluding NGAS HEC tests, the Ball SB235E started in the same process to obtain similar data for a larger capacity two-stage cooler (Figure 7). Lessons learned from the NGAS HEC testing were incorporated into the design of the Ball SB235E testing. Baseline data were taken, but the test configuration was not optimized in the hopes of obtaining passive results quickly. Data for the passive CCA only show exported forces at less than 50 mN (Figure 8).

CONCLUSION

Ball has successfully demonstrated a novel EFT mitigation design on both a smaller capacity single-stage NGAS HEC and a larger capacity two-stage Ball SB235E cryocooler. Work continues this year to complete the two-stage cryocooler testing.

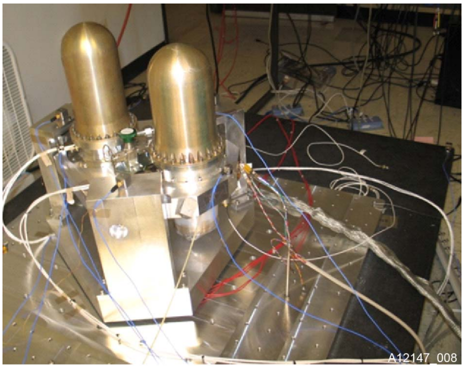


Figure 7. The Ball SB235E cryocooler in EFT test configuration.

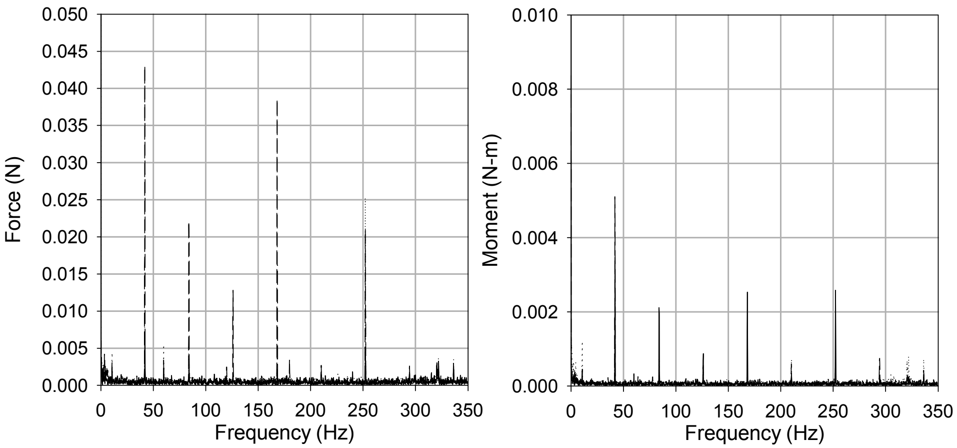


Figure 8. Ball SB235E CCA only exported force to 350 Hz.

ACKNOWLEDGMENT

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