Very Compact Integration of an Ultra-Low Vibration Platform for Space Cryocoolers Using Miniature High Frequency Actuators

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ABSTRACT

Air Liquide advanced Technologies in collaboration with Cedrat Technologies and SMAC has performed a study of a compact vibration control platform for mechanical cryocoolers. This solution has been proposed as an alternative approach to cryocooler integration with respect to suspended systems that must be mechanically locked during the launch phase. This system allows significant reduction of the platform's physical size and mass.

The platform filters vibrations generated by the cryocoolers above 150 Hz using passive dissipation in metallic or elastomeric mounting blocks. Vibration generated by the cryocoolers below 150 Hz is suppressed through a vibration cancellation algorithm that balances the opposed piston compressor (piston axis) and by miniature high frequency actuators for the other axes.

An overview of the system is presented together with results of initial tests

INTRODUCTION

Over the last 12 years, Air Liquide Advanced Technologies (AL.AT) has developed and matured pulse tube cryocoolers for both Earth Observation and Space Science programs.[1-5] The developments began with the 80K Miniature Pulse Tube Cryocooler (MPTC) before moving to the 40 - 50 K range with the large pulse tube cooler (LPTC), and now reach the 10 - 20 K temperature range.

The LPTC cooler has been selected for flight on two space programs with more than a dozen flight coolers scheduled to be delivered in the next few years. The LPTC is currently in the process of final qualification in the framework of a national program and will also provide cooling for the European Meteosat Third Generation (MTG) program.

A significant part of this development effort has been dedicated to performance refinement, system level optimization, and integration improvements with respect to induced micro-vibrations. The MTG project has been a challenging milestone in order to achieve the lowest induced vibration level possible, for which a dedicated integration platform has been studied, and proposed as an alternative approach to existing suspended systems with launch locking devices. As part of the final proposition for the MTG project, an ultralow induced vibration integration platform has been studied and partially tested, which combines the use of passive isolation dampers above 150 Hz and

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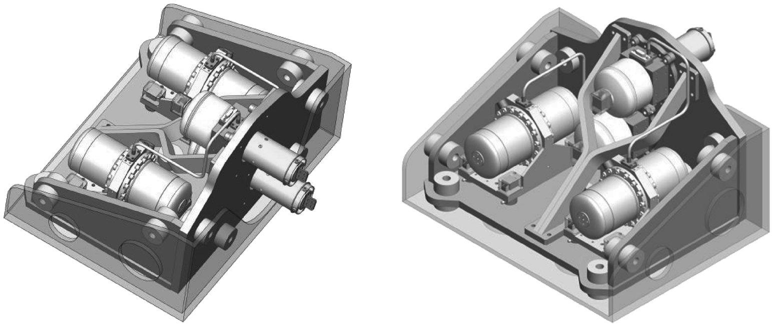

Figure 1. Proposed MTG ultra-low vibration integration platform

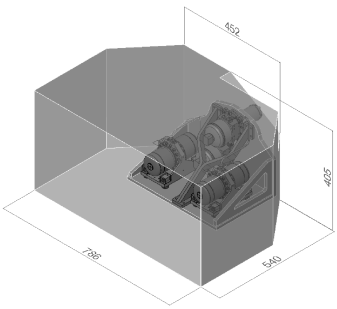

Figure 2. Compact integration of the platform compared to classical integration

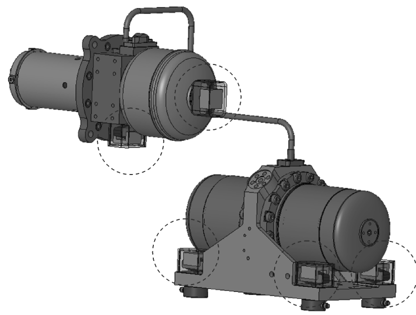

Figure 3. LPTC Cooler equipped with miniature actuators

active miniature piezoelectric actuators for low frequencies. This new approach allows a fully multi axis control to reduce the vibrations, with a control effort reduced to low frequencies only, and with very little additional power consumption. The platform is composed exclusively of flight proven components and materials, for the actuators, and elastomeric materials, which gives a high level of maturity to the proposed solution. The implementation of the actuator's drivers inside the electronic has been studied and assessed in terms of electrical consumption and reliability inside the MTG CDE.

This approach uses active balancing of the compressor moving masses along the piston axis, described previously,[1,2] and piezoelectric actuators for the other two compressor axes and the cold head.

PROPOSED MTG PLATFORM DESIGN

The achieved final plate form design, proposed for MTG weighs around 40 kg including two redundant LPTC coolers, and associated drive electronics, without any additional launch locking device required (Figures 1 & 2).

The multi-axis vibration control is achieved by a combination of passive isolation dampers that become effective for frequencies higher than 150 Hz, and active control using the existing compressor moving masses balancing method for the piston's axis, and external miniature actuators for the compressor and cold finger transverse axes (Figure 3).

The achievable induced vibration level (resultant of compressor plus cold finger) has been analyzed with finite element analyses based on the achieved control performance of the actuators, and the theoretical isolation performance of the dampers. The expected performance, shown in Figure 4, is a maximum level of 100 mN over the full frequency range up to 1000 Hz and lower than 50 mN in the frequency range of 50 Hz-460 Hz (8 harmonics of the LPTC drive frequency at 57.5 Hz).

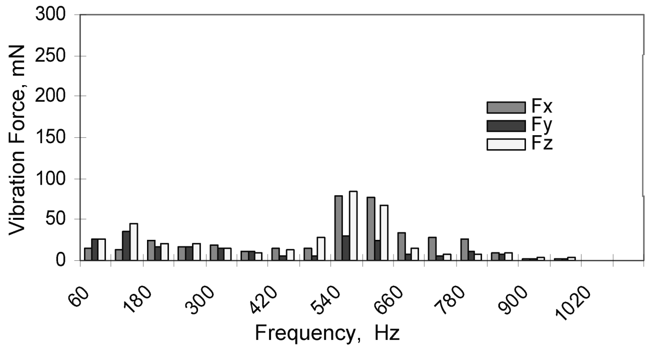

Figure 4. Theoretical achievable induced vibration performances (resultant)

The complete system performance could not be tested as the proposed platform assembly has not been retained by the MTG project. However, the complete system has been analyzed for launch loads to demonstrate the suppression of the launch locking device.

MINIATURE PIEZOELECTRICACTUATORS

The miniature actuators have been integrated onto the compressor and the cold finger as shown in Figures 5 to 7. On the compressor the actuators have been collocated with the interface load washers which provide the in flight force information by interpreting the moment measurement in the in-plane axes (FY and FX) and by a direct measurement in the out-of-plane axis (FZ). On the cold finger the actuators have been located onto the gas momentum geometrical sources, as no mechanical moving part generates vibration on pulse tube type cold fingers.

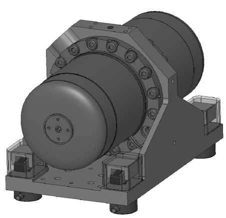

Figure 5. Collocated integration of the miniature actuators on the compressor interface load washers

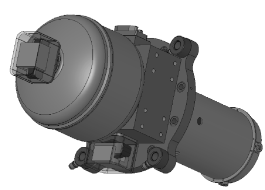

Figure 6. Integration of the miniature actuators on the cold finger resultant vibration sources

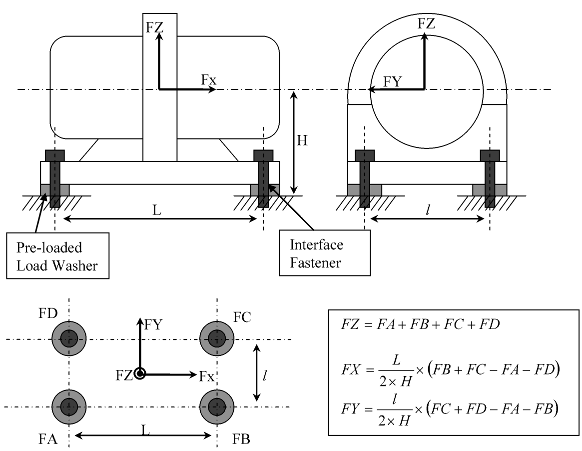

Figure 7. In flight interface force measurement with momentum interpretation

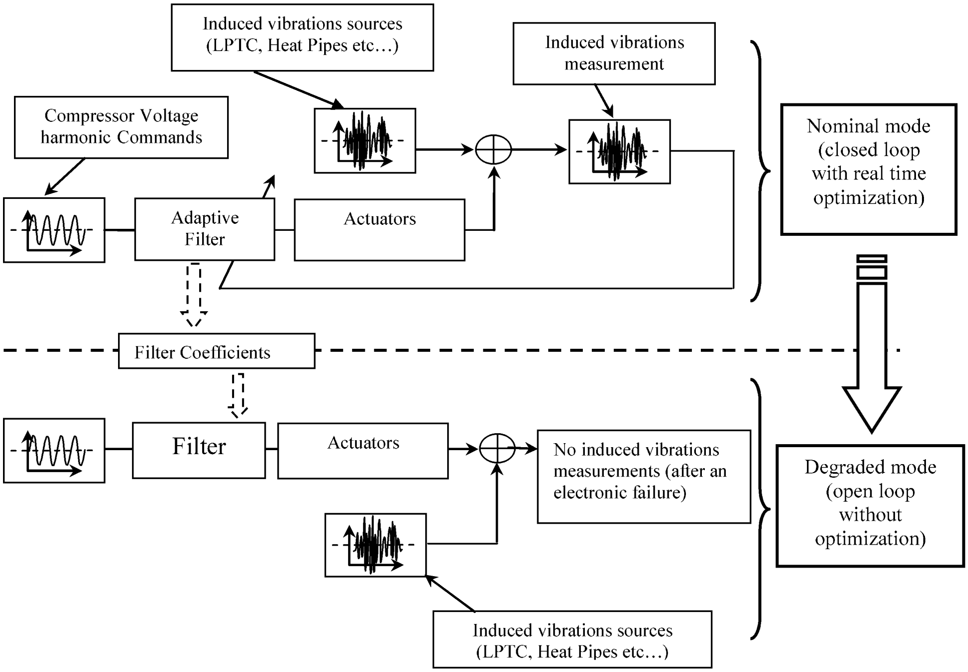

Figure 8. Proposed feed forward control scheme

The actuators selection and integration have been undertaken in partnership with CEDRAT which has developed piezoelectric actuators for space applications; these are flight proven on several missions. The inherent good balancing of the compressor and the inherent low vibration level of the pulse tube type cold finger has allowed selecting small size actuators providing a proof mass force up to 200 mN, with a few grams mass attached, with a very small electrical consumption, and a very compact design. The major advantage of miniature actuators is the very high resonance frequency above 1000 Hz which makes their use compatible with the launch sine and random vibration environment without any locking required.

The existing frequency domain control method currently applied onto the compressor moving masses has been successfully tested on the actuators, and has been considered as a backup method for MTG. A significant demonstration effort has been realized for the MTG project to demonstrate the performance and advantages of feed forward real time control methods which are not currently used for coolers on space applications compared to state of the art frequency domain optimization methods. Time domain tests have been realized to assess the achievable control performance and to propose the most appropriated control scheme. The final proposed control approach (shown in Figure 8) is based on a combination of time domain adaptive filtering and actuator differential phasing optimization. The advantage of adaptive filtering methods is the possibility to operate the control on a degraded mode without available vibration measurements once the filter coefficients have been defined.

Figure 9 illustrates the test setup, while Figure 10 shows the control performance achieved with a classical real time control approach (adaptive filtering not tested yet) on the test set up of Figure 9. The result noted as “without cancellation” means only with the compressor moving mass balancing control (resultant over all axes).

ACTUATOR DRIVERS IMPLEMENTATION INSIDE THE CDE

The actuator driver implementation inside the LPTC Cooler Drive Electronic (CDE) has been assessed in terms of electrical consumption cost and reliability. A dedicated design has been pro-

Figure 9. Real time control test set up with the LPTC compressor

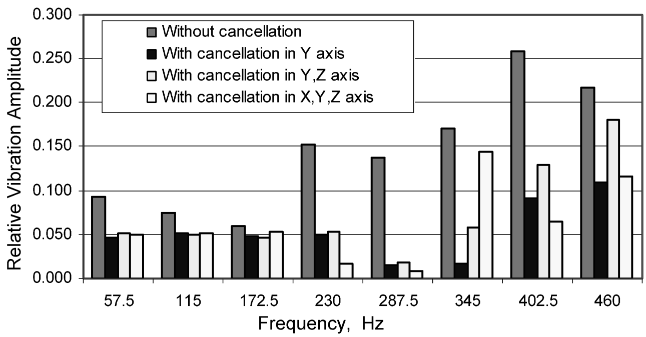

Figure 10. Resultant interface forces measured with and without real-time active cancellation

posed with an optimized architecture for the actuators differential phasing strategy which allows achievement of a high level of efficiency, a low electrical consumption, and a good reliability figure compared to the number of actuators. As a final design performance achieved, the reliability penalty committed for the MTG CDE was only 0.4%, with an additional electrical consumption of 12 W including the CDE efficiency.

DAMPER ASSEMBLY

The damper assembly, shown in Figure 11, has been designed for cut off frequencies in the range of 150 Hz to 180 Hz (six rigid body modes) and reduces the vibration for frequencies higher than 300 Hz. This suppresses the need for any launch locking device and reduces the control effort to only the four first harmonics (instead of eight), which are low frequencies.

The damper assembly design (Figure 13) has been realized in partnership with SMAC, which has developed and qualified elastomeric materials for cryogenic applications and space cryostats (situated very close to the detectors).

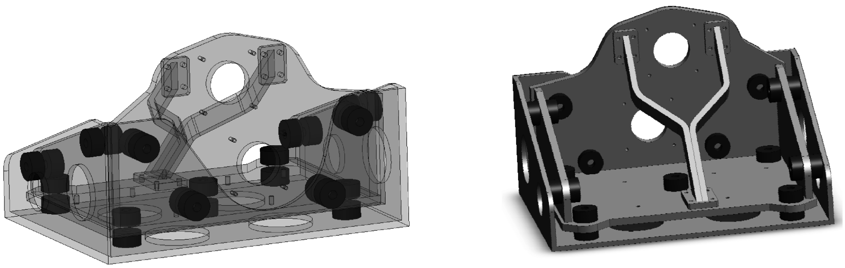

Figure 11. High frequency passive isolation assembly

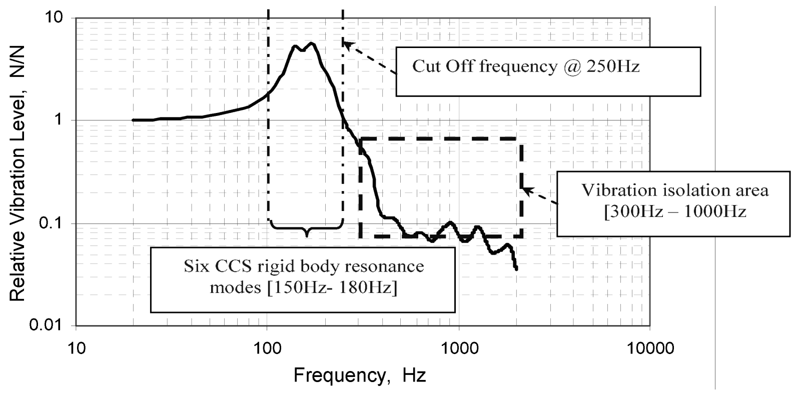

Figure 12. Theoretical dampers isolation performance (resultant)

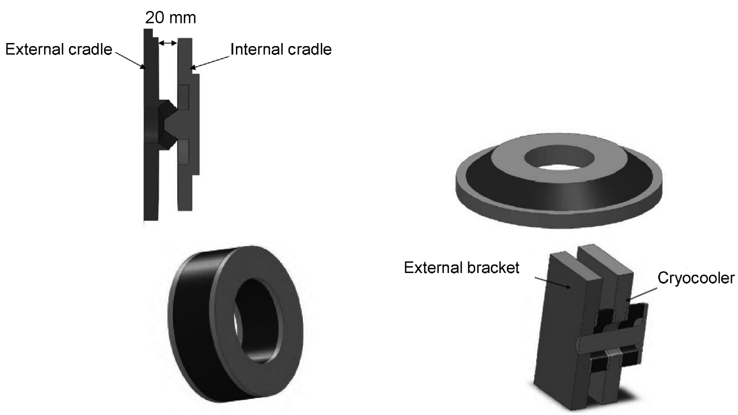

Figure 13. Elastomeric damper designs from SMAC with space qualified materials

The final design of the damping assembly frequency coverage from both active and passive vibration control systems is summarized in Figure 14.

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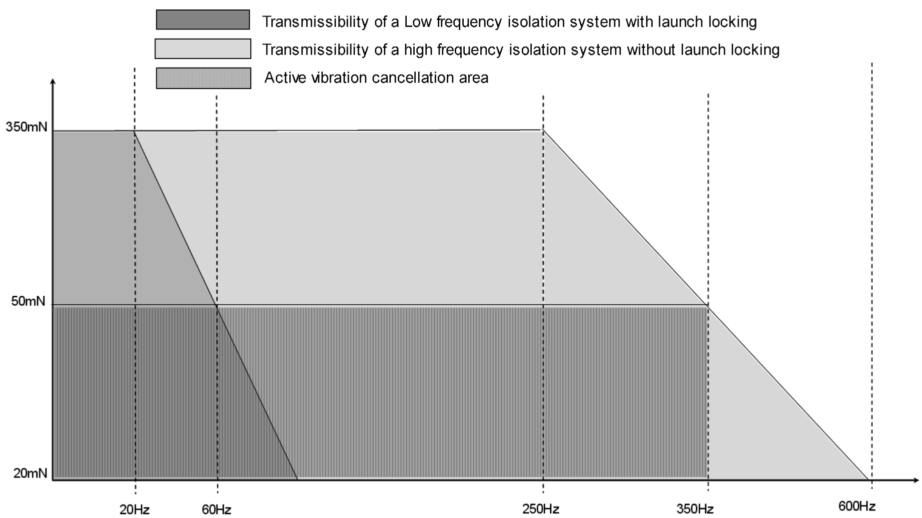

Figure 14. Frequency coverage of the platform

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