Characterization and reduction of LPTC exported microvibrations

Advanced Technologies

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Summary

LPTC description

Compressor induced vibrations

- Mechanical origin
- Design and MAIT
- CCE force measurement
- CCE vibration control loop

Coldfinger induced vibrations

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- Data processing
- Validation

Vibration measurements on MVB

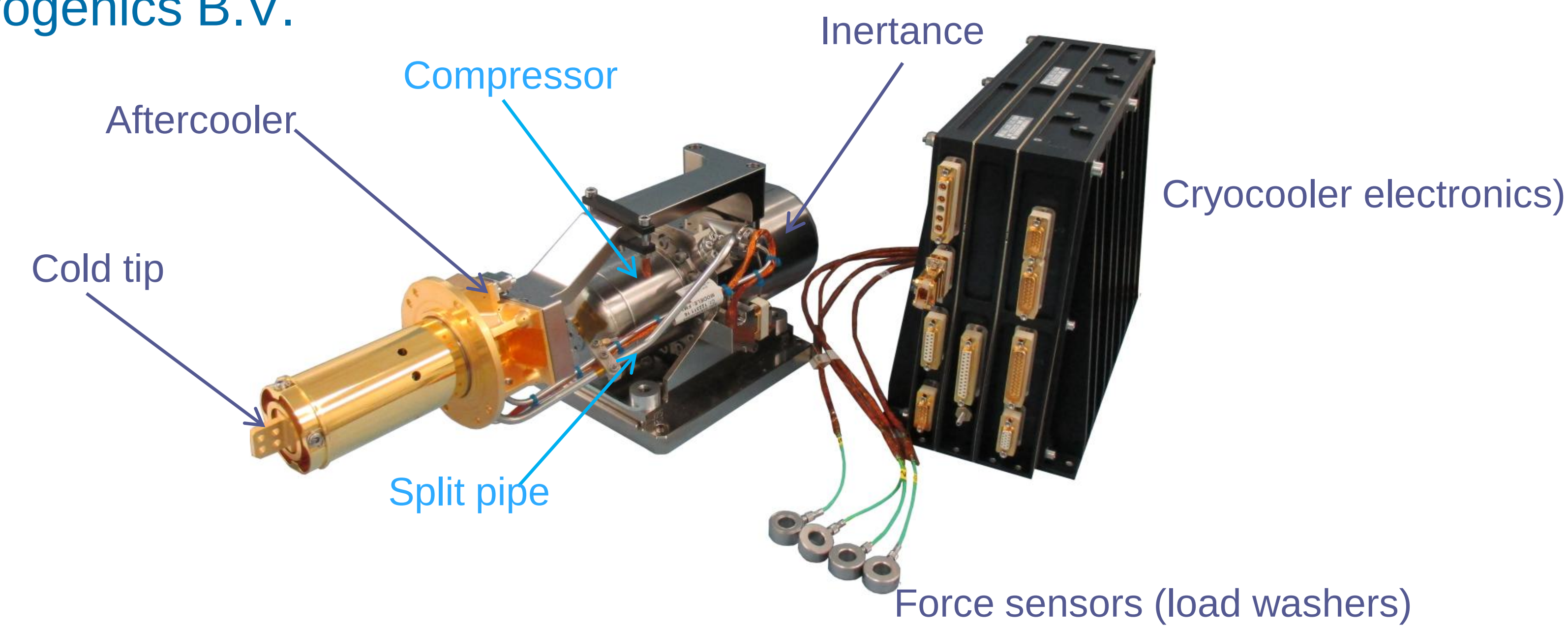
- Compressor
- Coldfinger

Conclusion

LPTC description

Large Pulse Tube Cooler (LPTC) is a Stirling-type pulse tube,

It is driven by a two piston linear compressor, supplied by Thales Cryogenics B.V.



Phase shift is obtained with inertance compactly mounted around the compressor part.

Compressor induced vibrations - mechanical origin

Main source of vibrations is the compressor part.

- The highest force is often observed at the compressor driving frequency (**H0 - fundamental**) parallel to the piston axis and is linked to an imperfect balance of the two pistons

- Secondary forces may appear on other axes due to residual piston misalignment (torques may also be induced, instead of forces)

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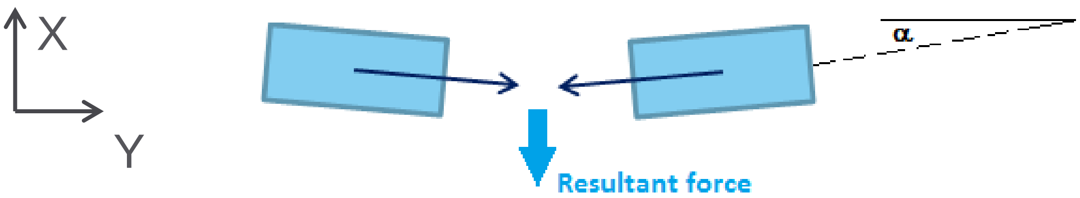
  exported at other harmonics (H2, H3,...H7).
- When these harmonics fall on a compressor structural eigenmode, the effort may be amplified

Compressor induced vibrations mechanical origin

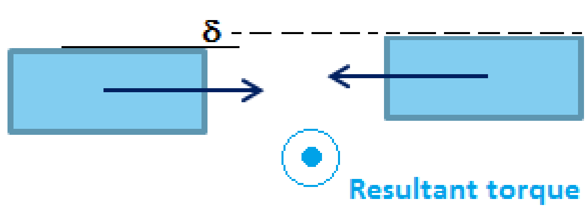
Force along X axis (due to a parallelism issue):

- Even if pistons had a perfectly synchronous, phase opposition movement, a net force would appear along X (forces cancel out in Y direction)



Torque along Z axis (due to eccentricity):

- d d torque.



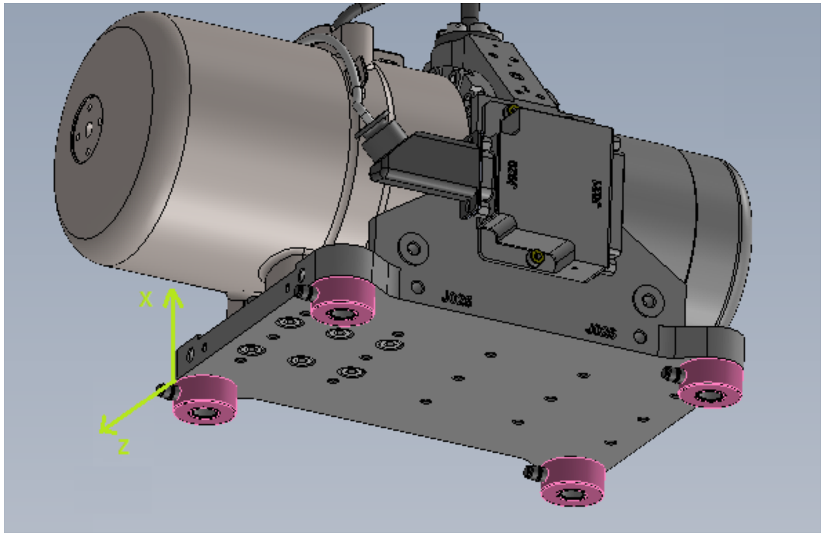
Compressor induced vibrations   design and MAIT

Besides a two opposite piston design, great effort is deployed during compressor MAIT process in order to ensure the lowest exported vibrations:

- Extended run-in in various orientations to eliminate all dry-friction phenomena
- Piston alignment procedure
- Intermediate vibration measurements along assembly, allowing to rule out bad motor pairings earlier
- Mass balancing to compensate for small electrical differences between motors

Compressor induced vibrations   CCE force measurement

LPTC features four 1-axis load washers acquired by the cryocooler electronics (CCE)



They are mounted between the compressor and the system interface, with a specific pre-stress.

CCE can thus measure the exported forces perpendicular to the plane (X axis in figure)

By making some assumptions, it can also estimate the forces caused by the piston axis (Y)

Compressor induced vibrations - CCE force measurement

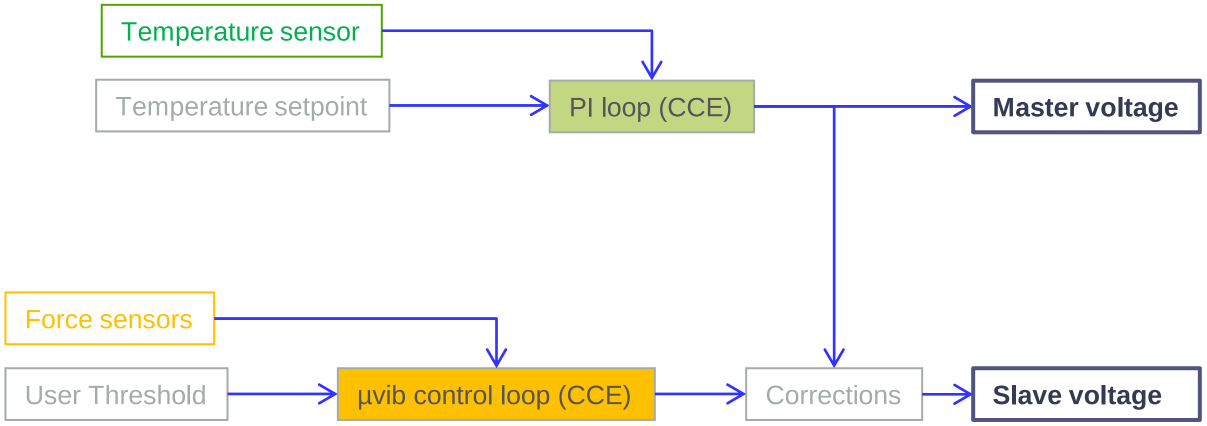
Natural axis of load washers is the **X** axis => CCE gets accurate measurements along this axis

Forces that can be mastered (caused by pistons, **Y** axis) can be estimated:

- □□ a b
  force acting on **Y**
- There may be small, pure torques around Z that get mistaken for a Y force.

Compressor induced vibrations CCE vibration control loop

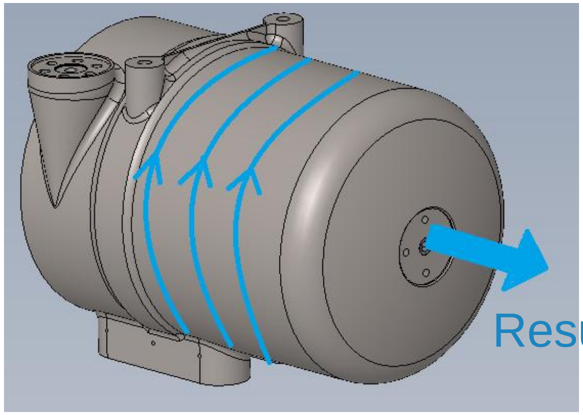
CCE continuously monitors the force and, by adjusting the difference in voltage between the motors, tries to decrease as much as possible the force exported on the piston axis (for the first 7 harmonics)

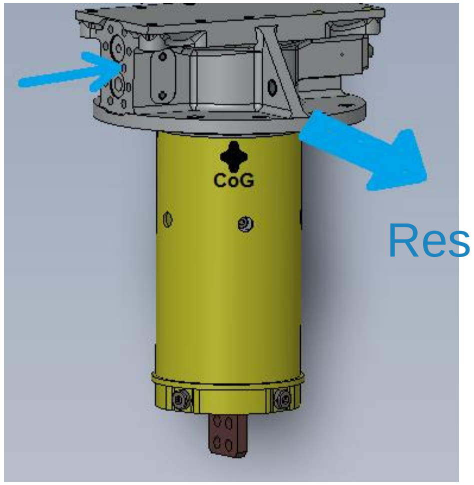


Coldfinger induced vibrations

Coldfinger and inertance can also generate forces and torques:

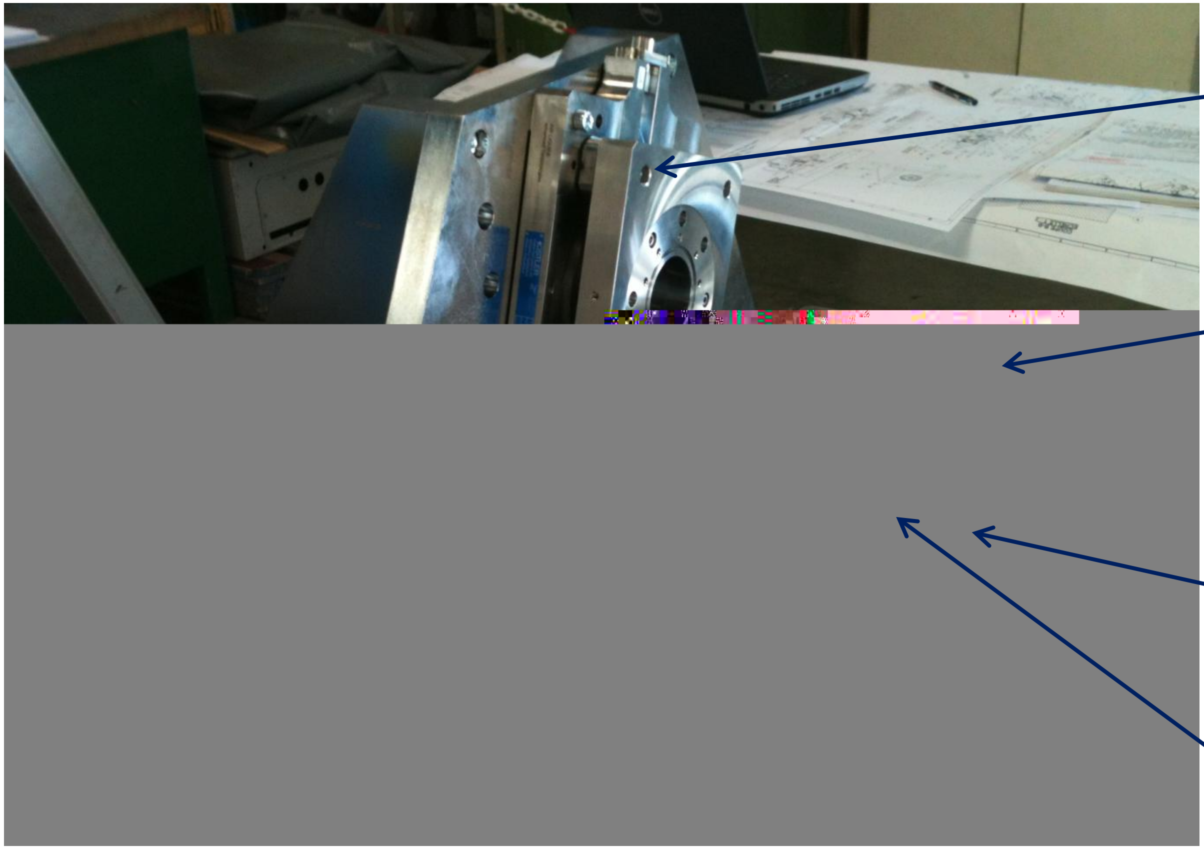
- Forces are caused by friction and changes in the direction of the flow (change in gas momentum)
- Torques can appear when gas inlet/outlet is not aligned with the barycentre of the coldfinger or in the inertance.





- These efforts are only seen at the fundamental frequency (frequency of the pressure and flow waves)
- Generated levels are lower than those coming from compressor

MVB description   Overview



Coldfinger dynamometric table

Upper plate of compressor dynamometric table

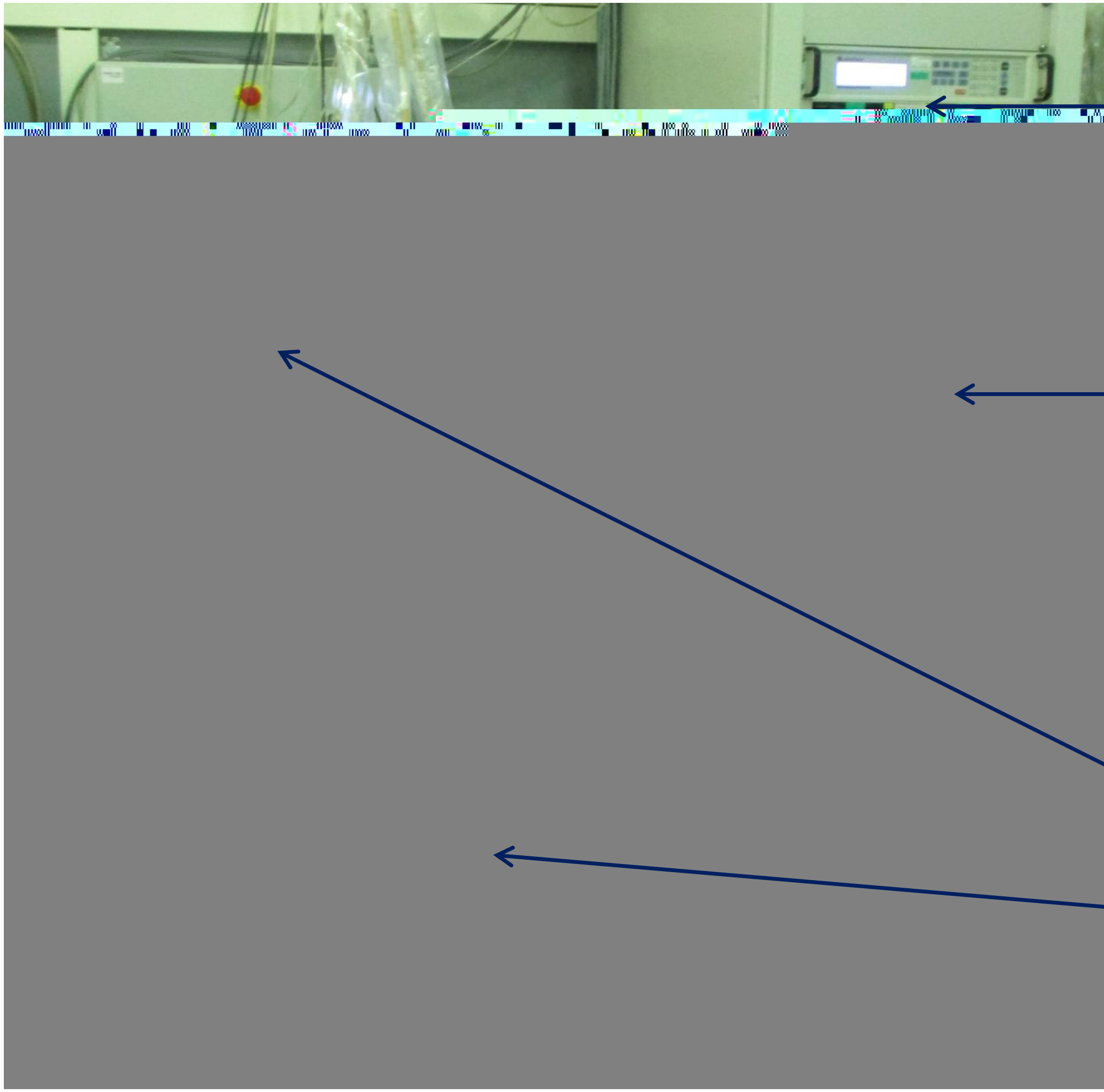
Lower plate of compressor dynamometric table

3-axes load washer (×4)

The bench includes two independent dynamometric tables that measure forces and torques up to 500 Hz

Compressor is mounted on one of the tables, the coldfinger on the other

MVB description   Overview



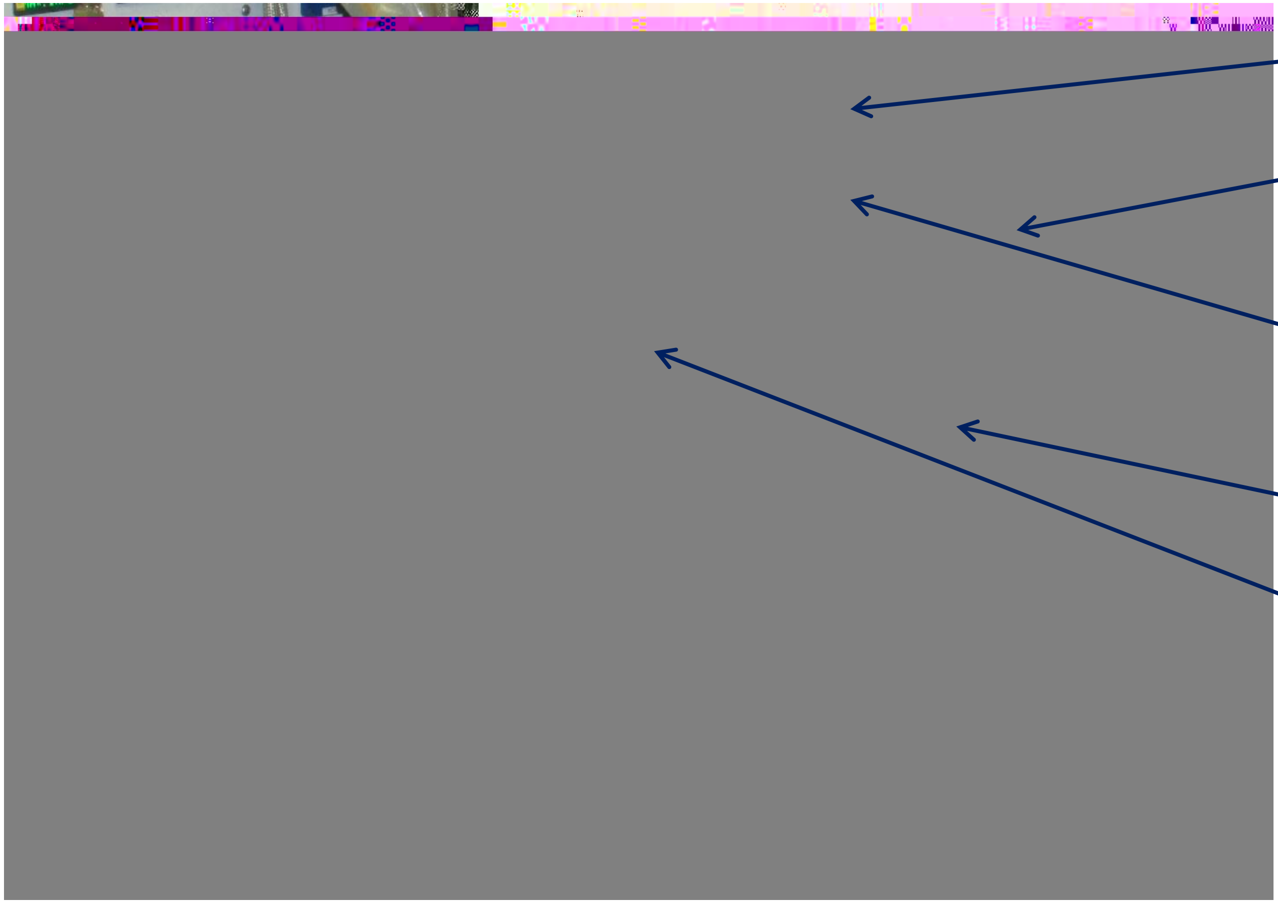
Cryogenic temperature controls

Force acquisition electronics

LPTC under test

Seismic mass (1.2 t)

MVB description   Overview



Split pipe

Inertance

Compressor

Compressor dynamometric table

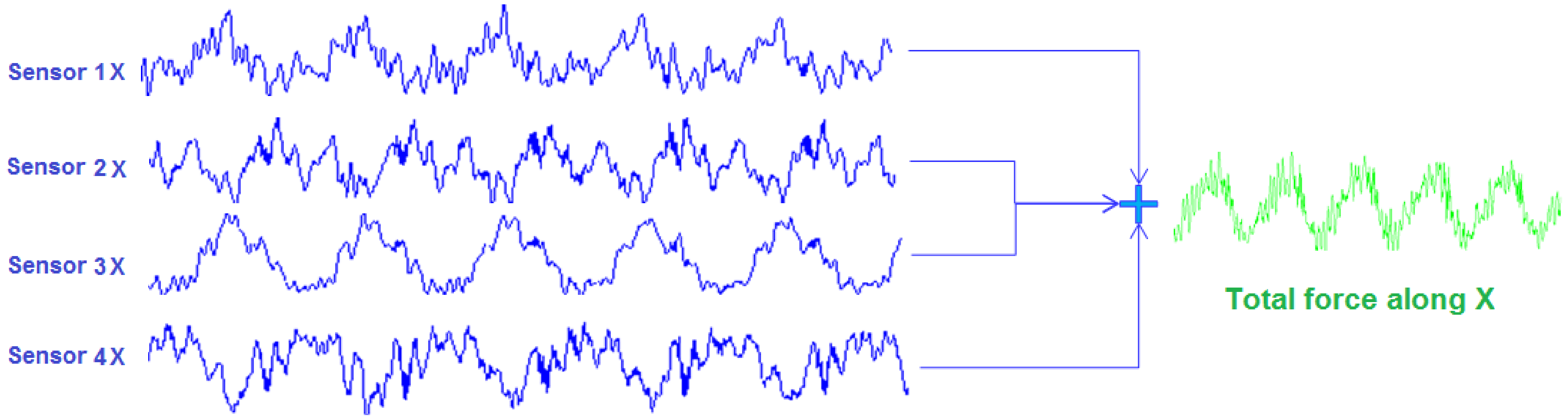
Coldfinger aftercooler

MVB provides adequate interfaces for compressor and coldfinger, taking into account the necessary heat exchangers, proper structure behaviour, and vacuum to achieve cryogenic temperatures.

MVB description Data processing

Piezoelectric sensors in the tables produce electric charges which are then converted to voltage by special amplifiers.

A set of DAQ, handled by a Labview program, acquire these voltages at a **10 kHz rate** and convert them into forces which are then treated to give the torques and forces exported by the coldfinger/compressor.



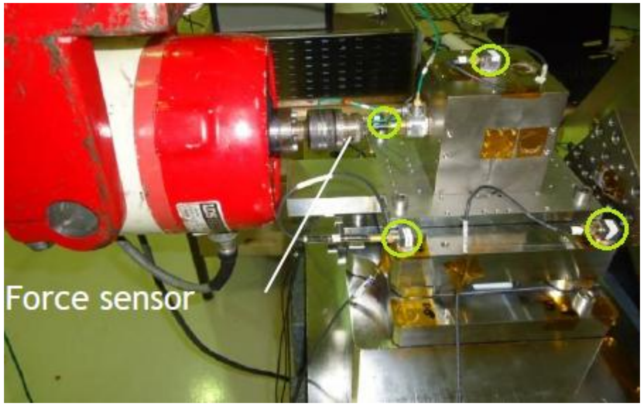
A total of 24 signals are acquired with a delay smaller than 10 µs, in order to have meaningful computations even for the highest harmonics.

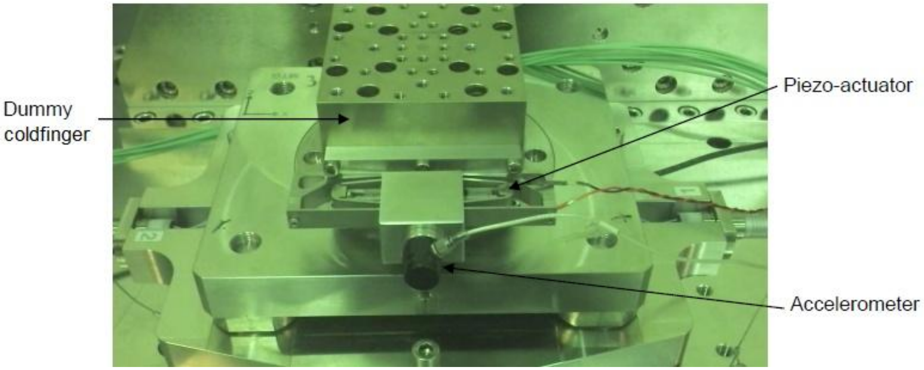
MVB description   Validation of test bench

Amplifiers are very sensitive -> typical 50 Hz noise levels are enough to saturate them

- Copper overshielding sleeves, grounded on both sides, are mandatory

To have trustworthy measurements between 50-500 Hz, the bench d eigenfrequencies within this interval.





This specification demands a very careful design of the MGSE and a validation of the structure response by testing.

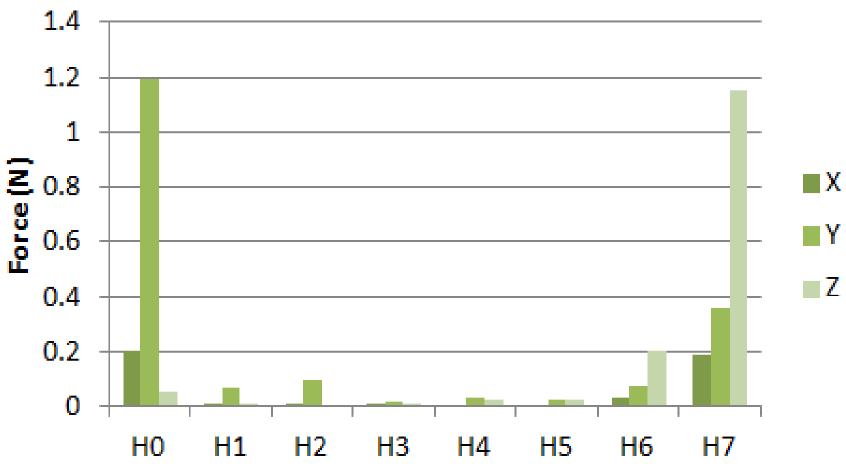
Exported vibration measurements on LPTC compressor

Once mounted on MVB, µvib measurements can be performed on a LPTC operating in nominal conditions

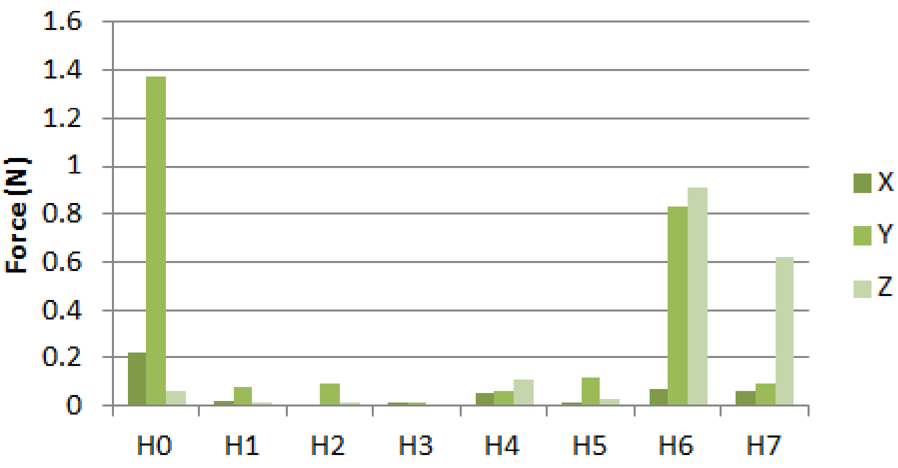
- Between 50 and 70 K, with electrical input power between 80-160 Wrms

Exported forces depend mainly of the input power, the driving frequency and the compressor temperature.

H0 = 56 Hz (100 Wrms)



H0 = 58 Hz (100 Wrms)

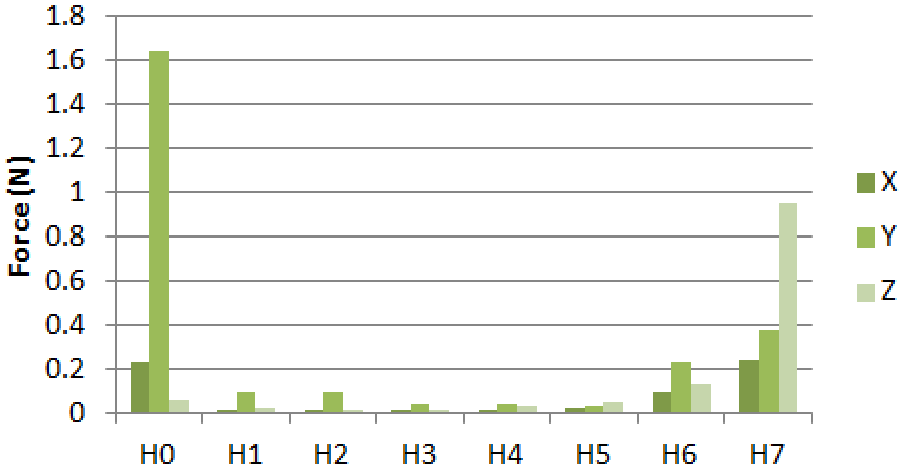


Without electronic correction

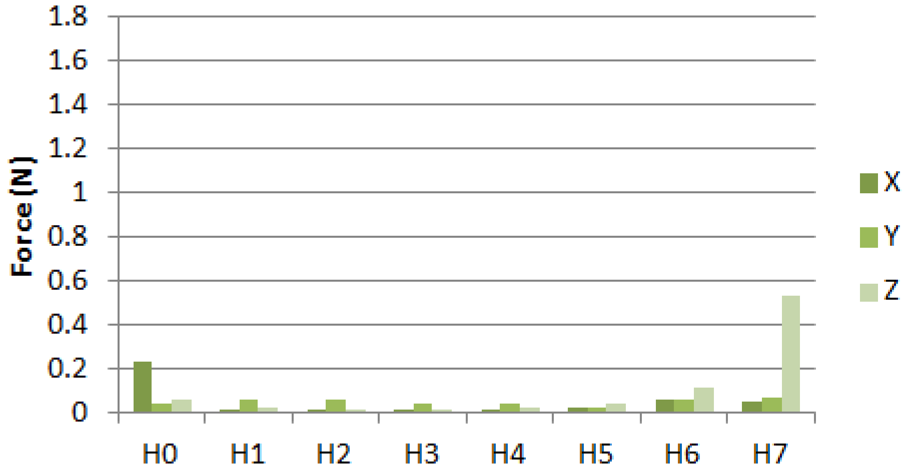
Exported vibration measurements on LPTC compressor

Although the vibration control loop (VCL) operates based on an estimated force, the effect on the true force along Y (measured by the table) is quite satisfactory

H0 = 56 Hz (140 W_{rms})



Before VCL

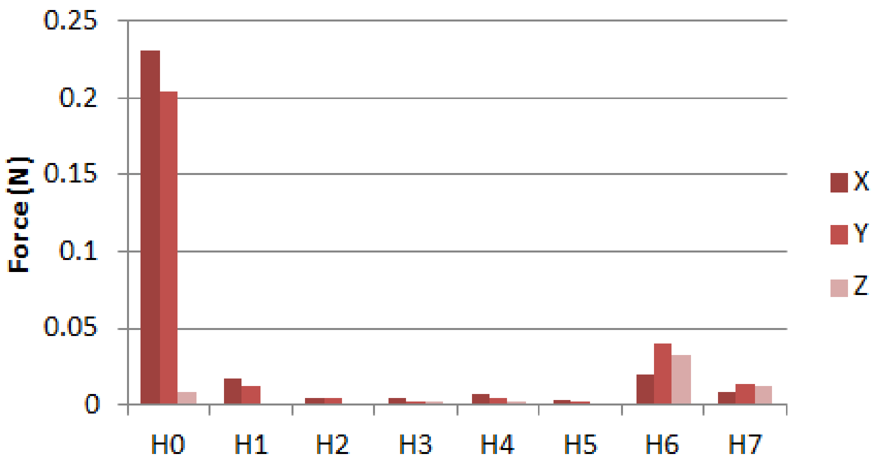


After VCL

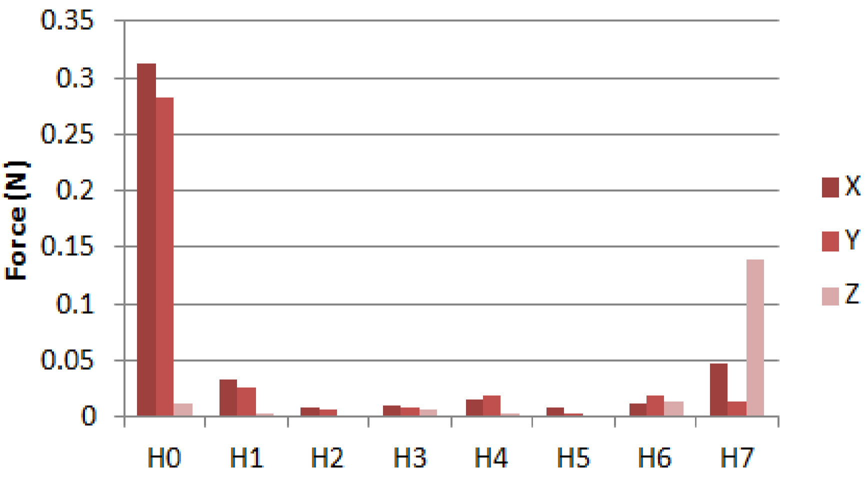
High levels at H7Z come from a compressor resonance

Exported vibration measurements on LPTC coldfinger

Coldfinger exported forces -> they increase with increasing input power (increased He flow)



H0 = 58 Hz (80 Wrms)



H0 = 58 Hz (160 Wrms)

□ d

Conclusion

Compressor is the main cause of LPTC exported vibrations, and significant efforts are done at manufacturing/assembly level to reduce them at the origin.

To further reduce those forces, cryocooler electronics includes a control loop working with the output from load washers installed under the compressor

To be able to properly characterize our system up to 500 Hz, while operating in nominal conditions, a test bench and its companion software were designed and developed at ALAT.

Test campaign confirms that in most cases the control loop, working simply on 1-axis sensors output, can successfully reduce the highest exported levels on piston axis by at least one order of magnitude.

End of presentation

Thank you for your attention