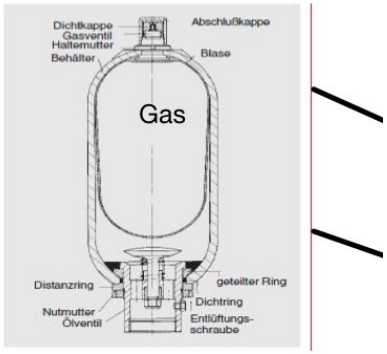
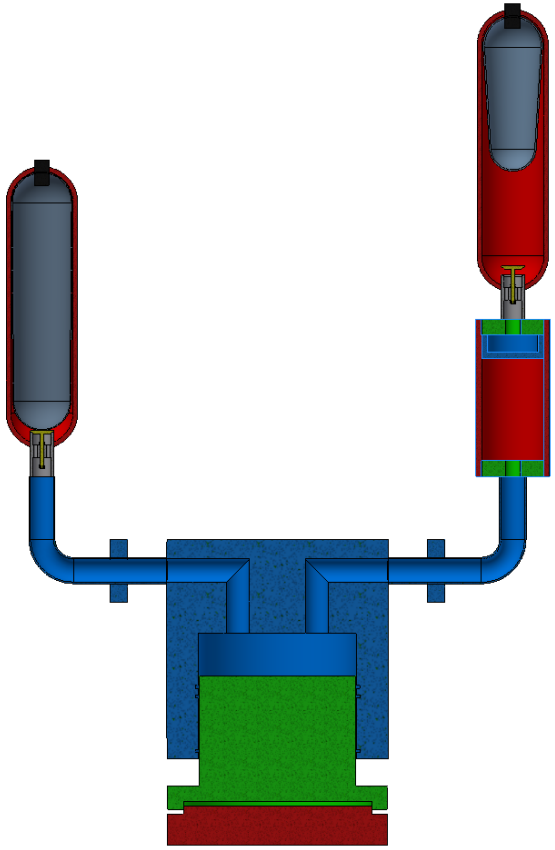
ELT Main Structure earthquake protection system concept: analysis and simulations

Concept

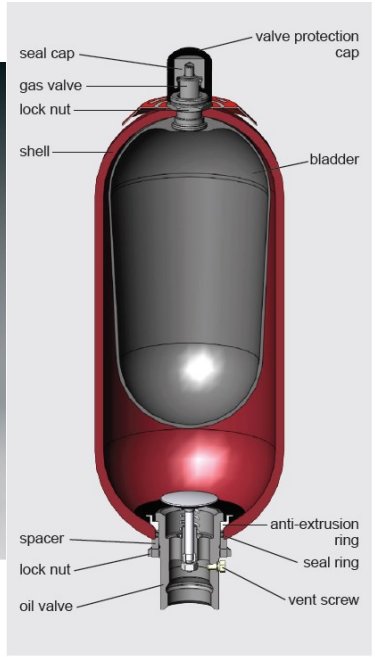
- Hydraulic system based on oil cylinders connected to accumulators



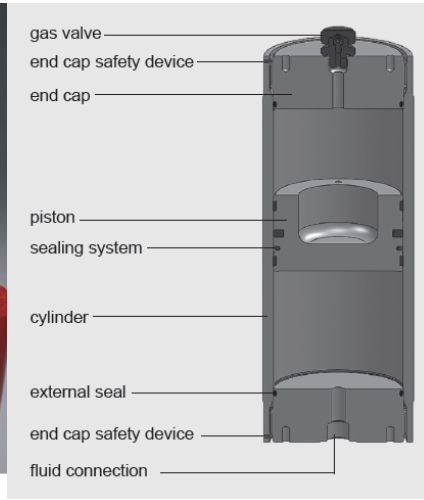


Concept: Accumulators

- Accumulators configuration A and B



Bladder



Piston

Modelling

- modelled and simulated using Matlab/Simulink
- The model is composed of two main elements:
  1) The model of hydraulics including pad cylinders, pipes, accumulator and throttle-check valves.
  2) The telescope structure is modelled:

  - a lumped mas/spring representing the equivalent mass seen by one of the supporting pads, i.e. 1/80th of telescope mass and representing the first eigenmode of the telescope
  - complete FEM representing all modes and mirror unit 6DOF motions.

Model: Hydraulic System

- **Cylinder** representing the oil volume: uses the oil flow, the position and velocity of the piston (cylinder) to compute the resulting force transmitted to the interface of the telescope model. The compressibility of the oil is used to represent the physical phenomenon.
- **Pipes** models represent three effects of i) the compressibility of the oil, ii) the friction of the pipe to limit the flow or to generate a pressure drop, iii) the dynamic effect of the varying flow using the inertial properties of the oil volume.
- Two configurations of **Accumulators**: Configuration A and B
- The inlet and outlet flow characteristics of the **valves**, i.e. flow as a function of differential pressure, are defined based on same lookup tables. The tables are used from the data sheet of some manufacturers (here Boch Rexroth).

Mechanical system

- Two mechanical models are used to study the effect of the protection system:

1) telescope structure is represented by a lumped mass spring system
   - to simplify the problem, reduce the computations and potential numerical issues and to focus on the principle of the hydraulic concept itself

2) assumes the complete FEM of the telescope structure representing the dummy mirrors and their 6DOF motions
   - level of the motions/accelerations at sensitive unit locations, e.g. M1, M2, during earthquake before and after the protection system activated

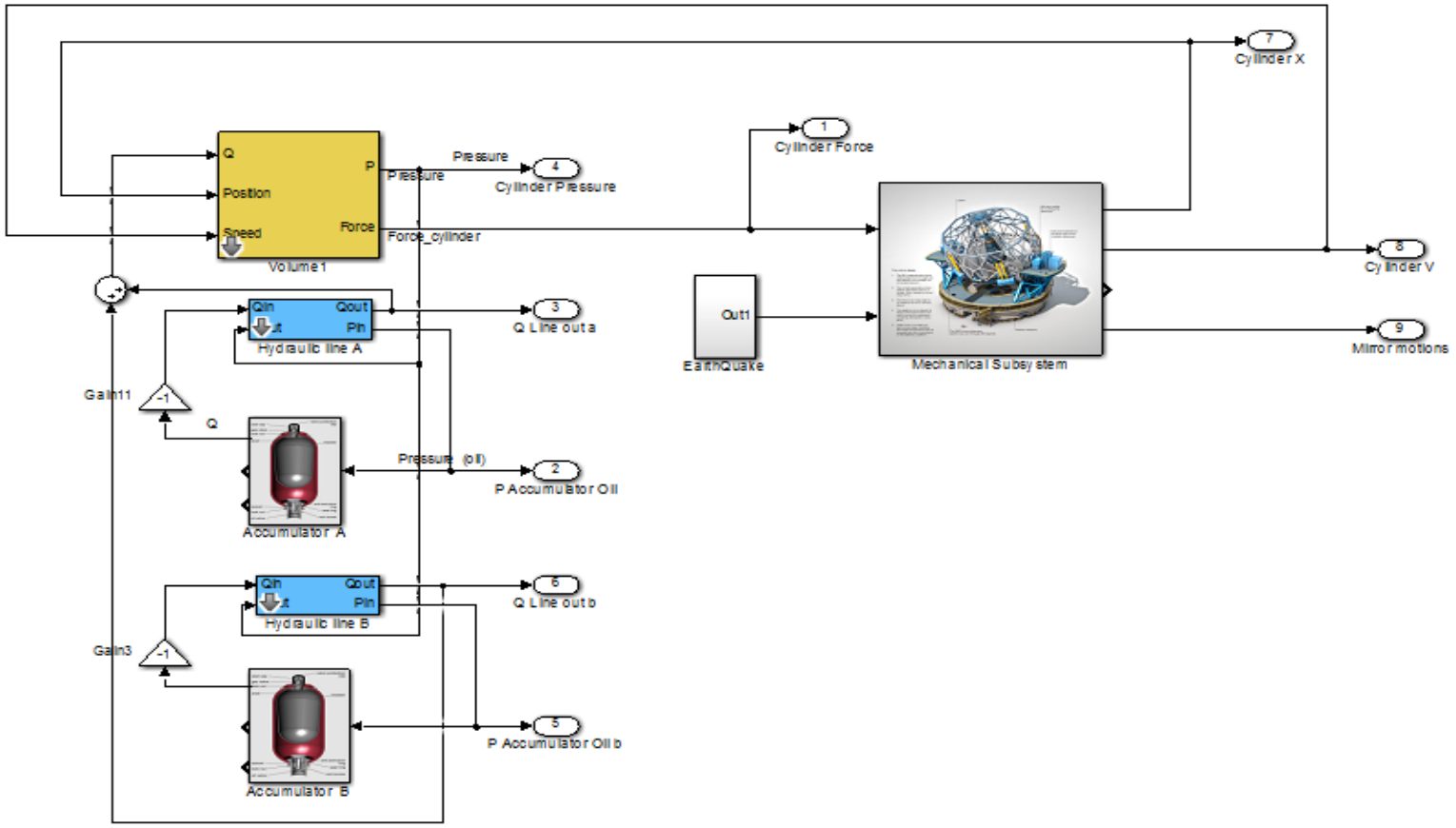
Proof of concept

- Two lumped mass and a spring system
  - The model assumes only one pad or protection system, consequently it is assumed to act on 1/80th of the telescope mass
  - A parametric model is constructed where the values of two mass, one representing the base and the second the telescope structure, and the spring can be tuned such to vary the principle oscillation mode of the telescope, e.g. 3 or 4Hz.
- The mass/spring system receives the force from the hydraulic cylinder as input (force to the base mass) and provides the difference motion of the ground and the base (as well as the speed) to the cylinder.

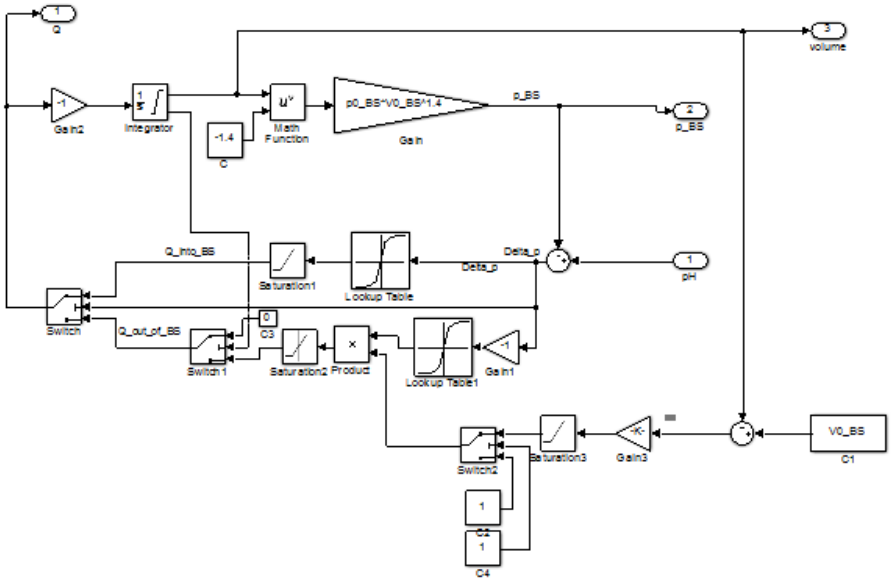
Complete system

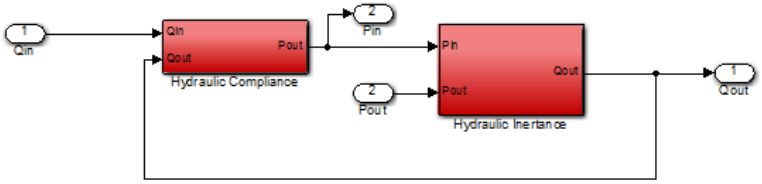
- FEM model of the telescope expressed in state-space format with appropriate inputs and outputs
- The model represents 200 modes (400 states) of the structure up to 20Hz.
- The main outputs of the model are the differential motion of the cylinders at location of the 80 pads, and motions of the telescope mirrors.
- The inputs to the model are the forces at the telescope interface to the pier (80 forces at pad locations), and the ground motion in three x, y and z directions.

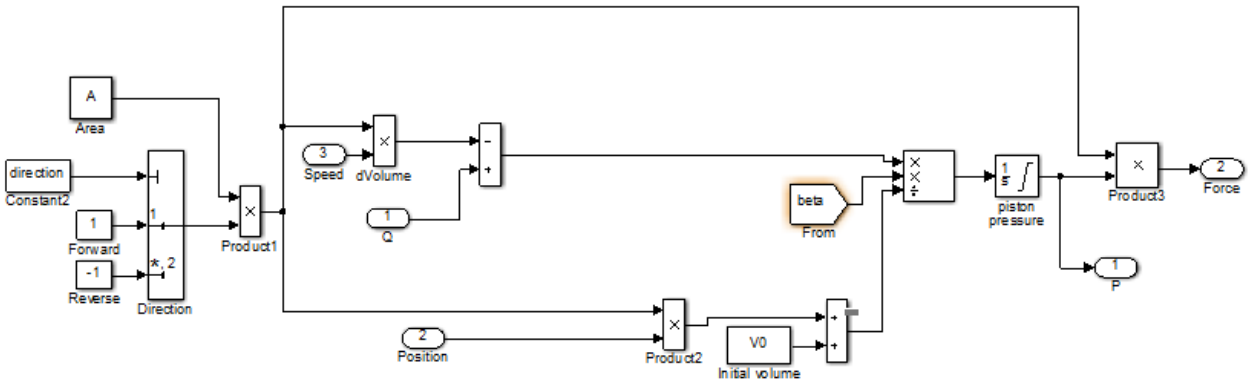
Combined model diagrams



Model diagrams







Parameters

Design and simulation parameters of the hydraulics system

Initial oil pressure of each cylinder:	**120 [bar]**
Ambient temperature (for oil characteristics)	9 [deg]
Cylinder area and diameter: * beta	0.028[m^2], 0.19 [m]
Initial volume of Cylinder (oil): area * 0.2	0.0056 [m^3]
Pipes lengths	1 [m]
Pipes diameter	0.0762 [m] (3 inch)
Initial nitrogen pressure of accumulator A (compressed accumulator)	125 [bar]
Initial nitrogen pressure of accumulator B (decompressed accumulator)	115 [bar]
Initial Cylinder (oil) pressure	120 [bar]
Initial Volume of accumulator A and B	18.4 e-3 [m^3]
Characteristic of None Reversible Valve (NRV) for accumulator A (inlet) and B (outlet)	See Table 3
Characteristic of Throttle valve for accumulator A (outlet) and B (inlet)	See Table 2

Parameters: valves

Characteristics of the throttle valves (accumulator A and B) LUT

Pressure [P]	0.1e5	0.5e5	1e5	2e5	3e5	4e5	5e5
Flow [m^3/min]	13e-3	35e-3	52e-3	77e-3	95e-3	110e-3	125e-3

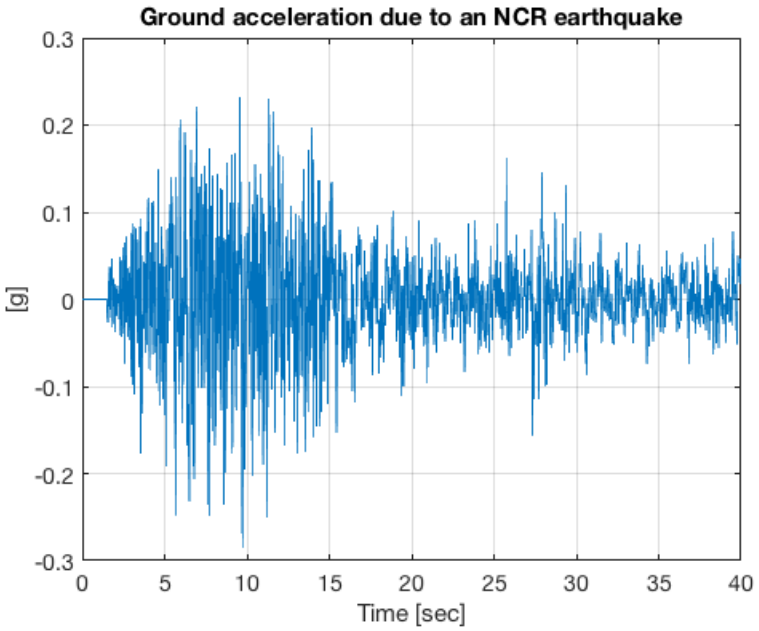
Characteristics of the NRV valves (accumulator A and B) LUT

Pressure [P]	0.25e5	0.5e5	0.9e5	1.2e5	2e5	3e5
Flow [m^3/min]	30e-3	75e-3	150e-3	225e-3	300e-3	375e-3

Assumptions

Telescope mechanical system parameters for lumped mass spring assumption

Total moving mass (Telescope mass/80 = Mt) [kg]	Base mass Mt_1 [kg]	Flexible mass Mt_2 [kg]	Telescope main resonant frequency [Hz]	Damping factor
3.45e6 /80 = 43125	0.2* Mt = 8625	0.8*Mt = 34500	4	0.01

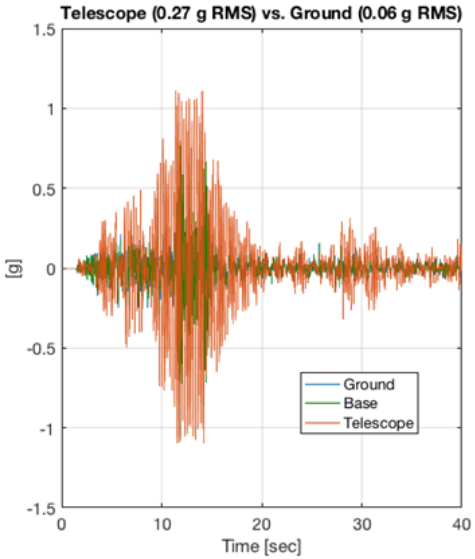


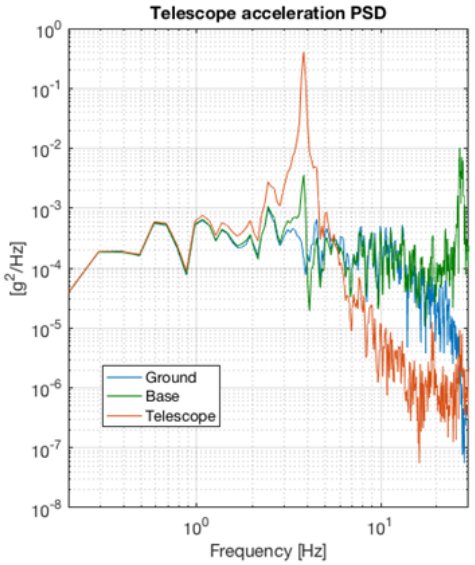
Ground acceleration in Z direction due to a NCR earthquake

Simulation results: proof of concept

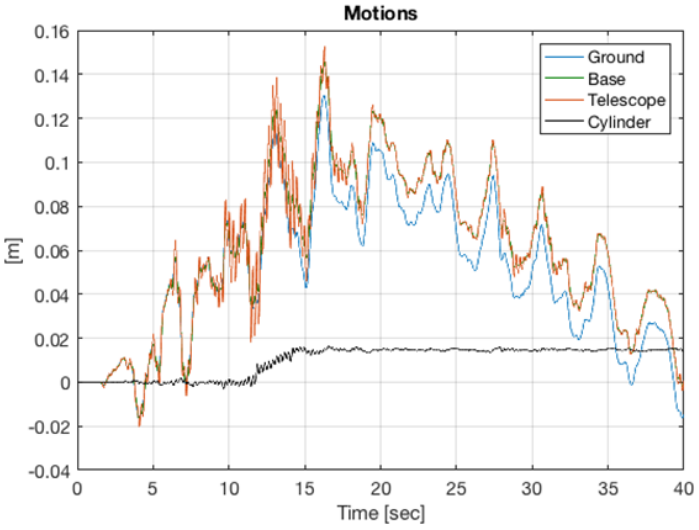
Lumped mass/spring model

Device ‘off’





Accelerations

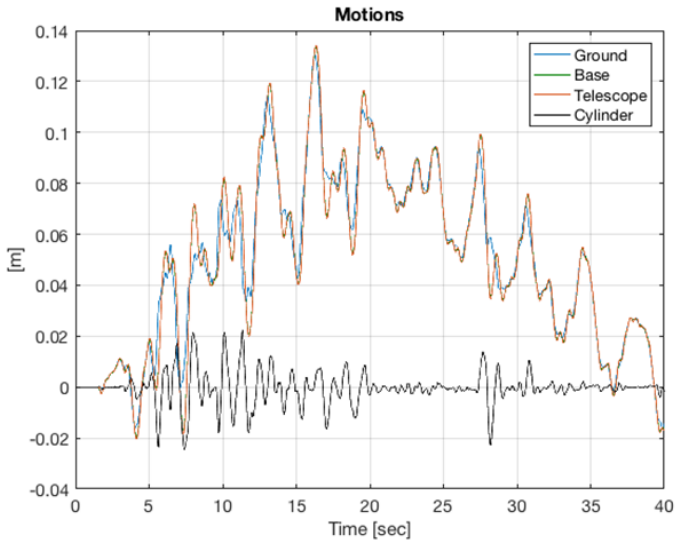


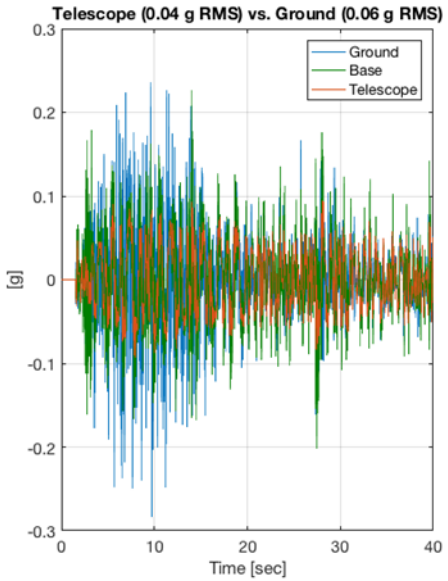
Motions

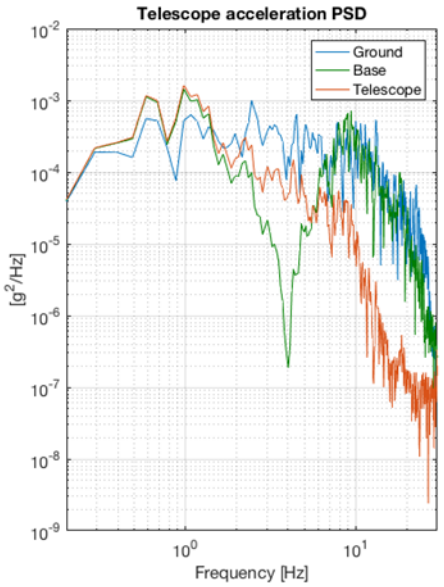
Simulation results: proof of concept

Lumped mass/spring model

Device ‘On’



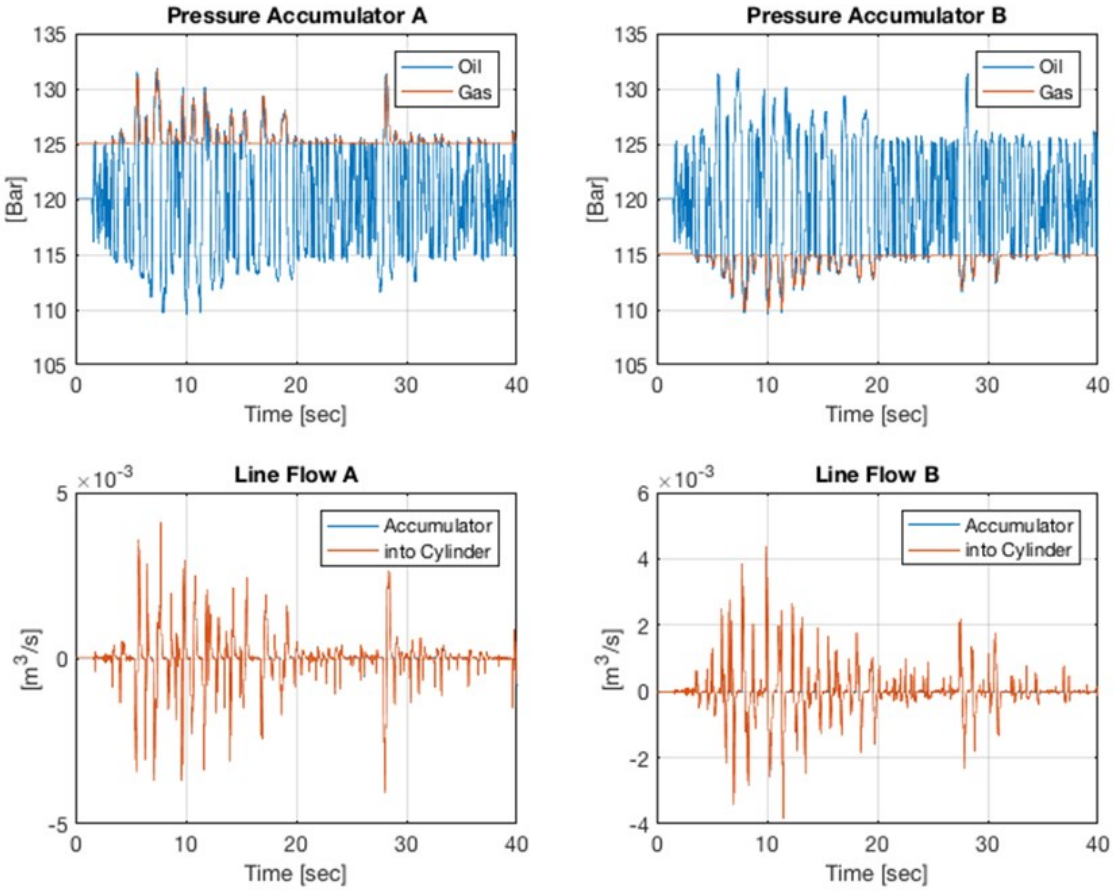




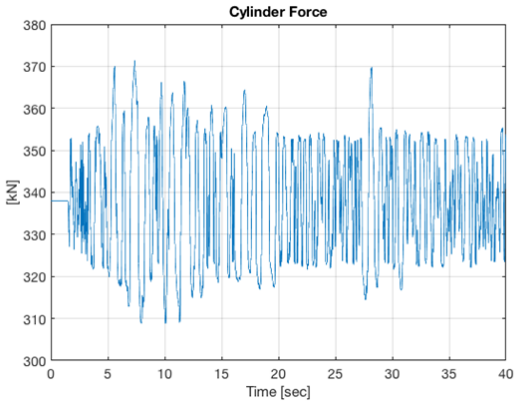
Accelerations

Motions

Simulation results

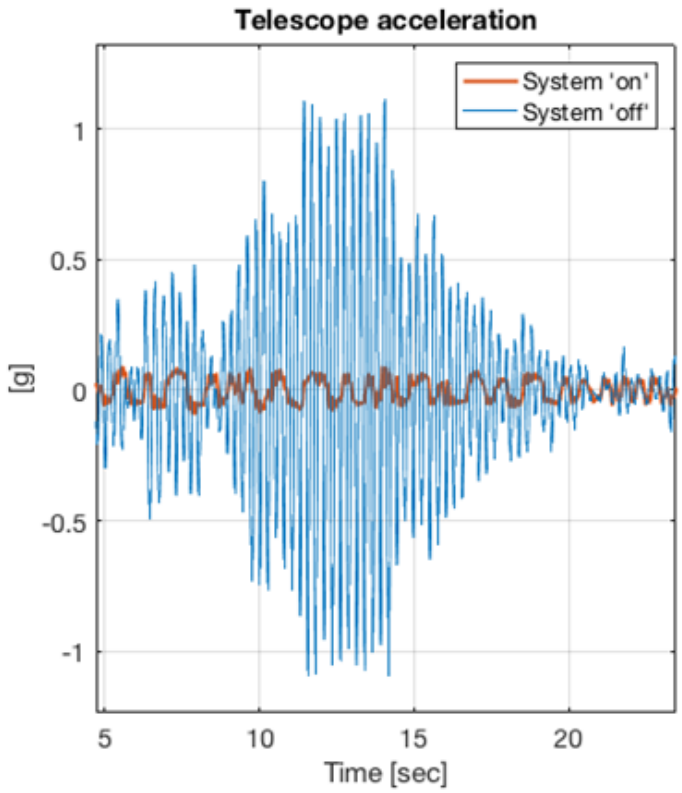


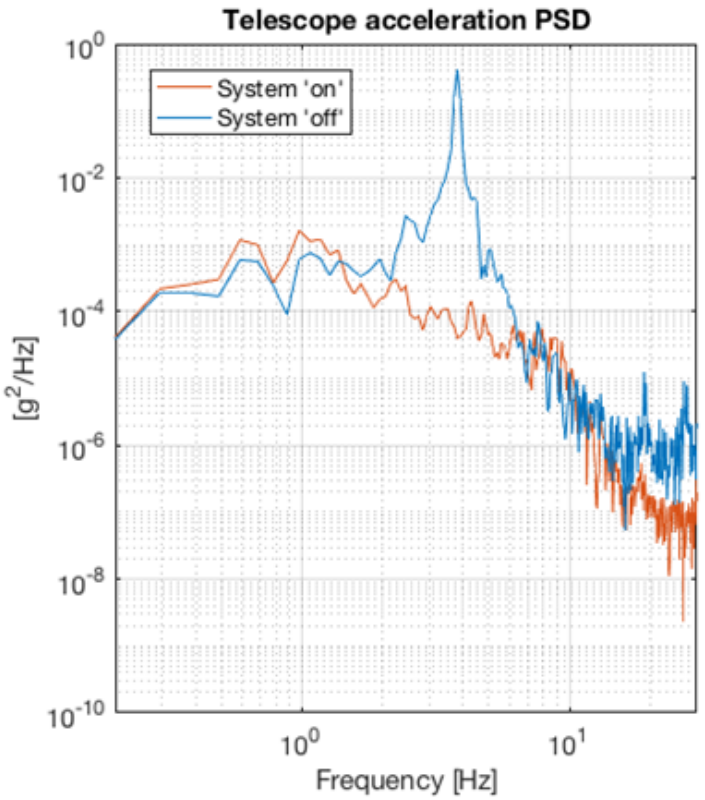
Pressure and Flow in accumulators



Cylinder Force

Simulation Results: proof of concept

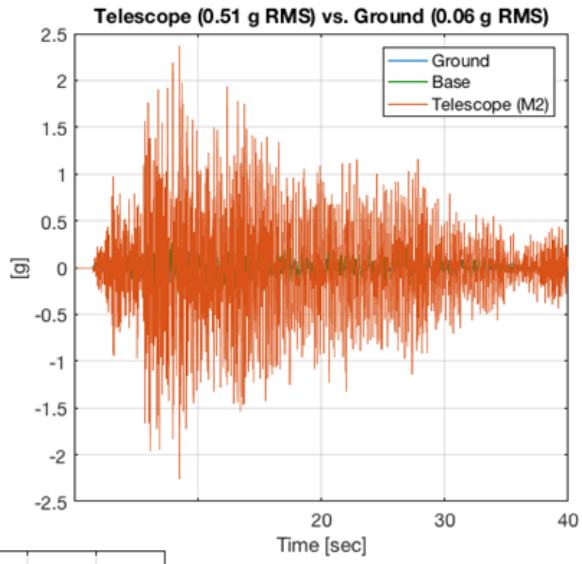


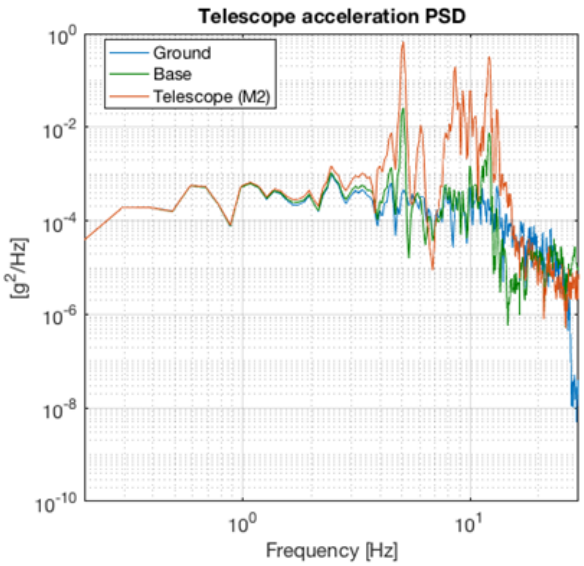


Simulation results: complete system

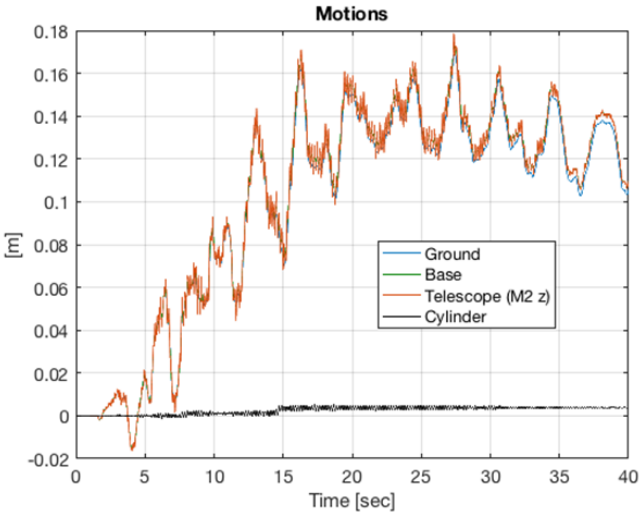
FEM model

Device ‘Off’





Accelerations

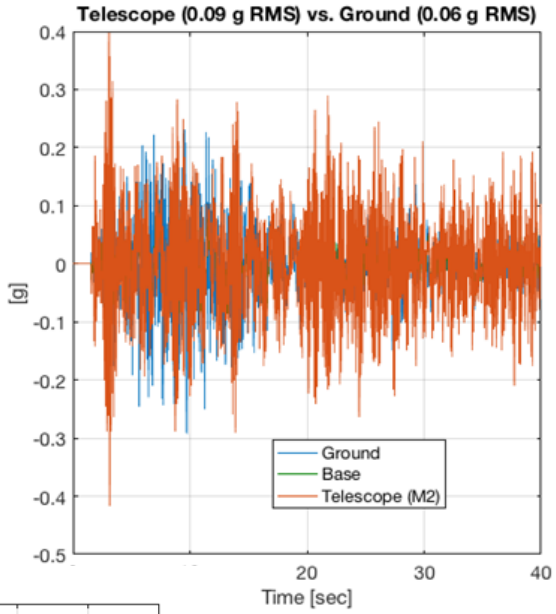


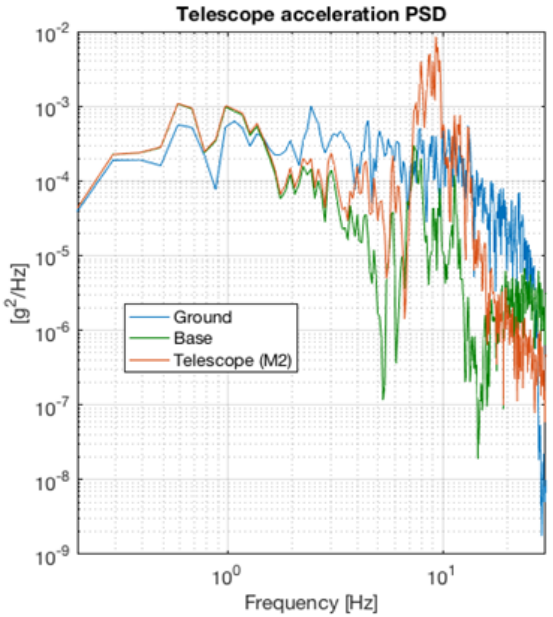
Motions

Simulation results: complete system

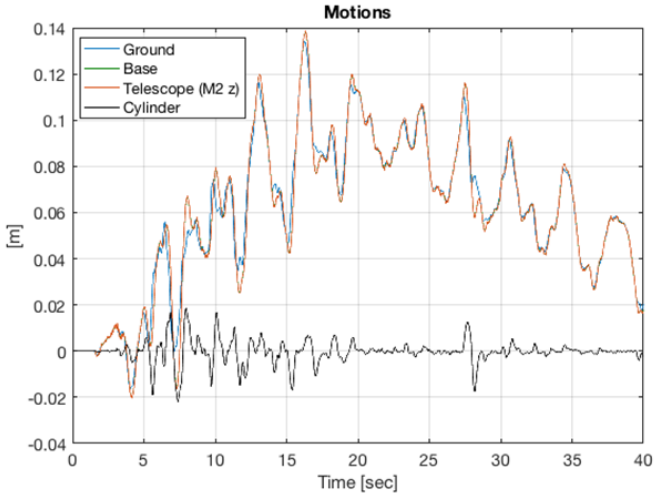
FEM model

Device ‘On’



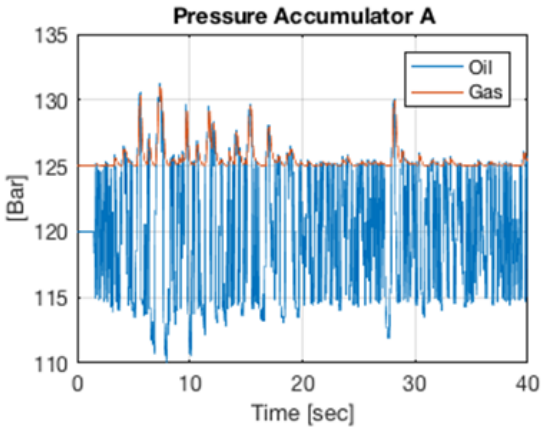


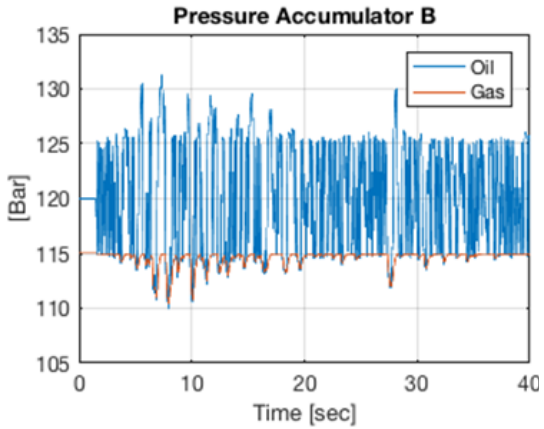
Accelerations at M2 unit

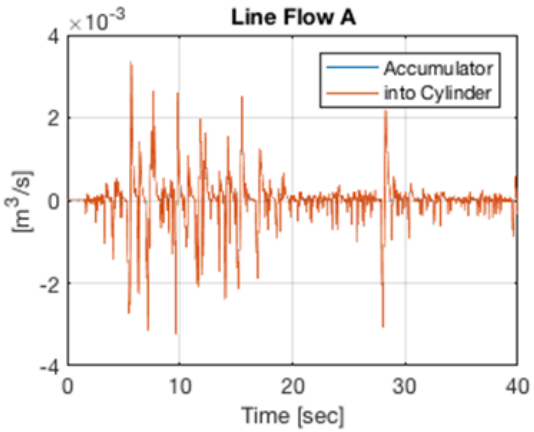


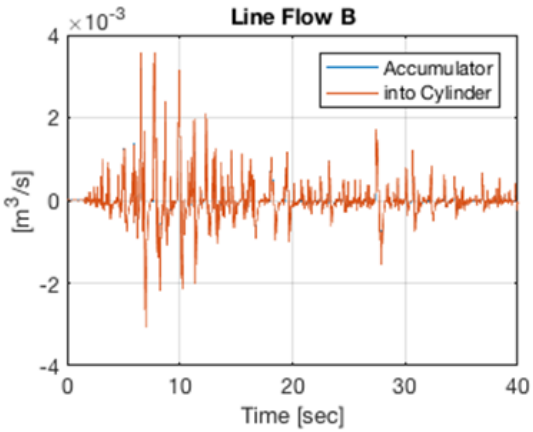
Motions

Simulation results: complete system

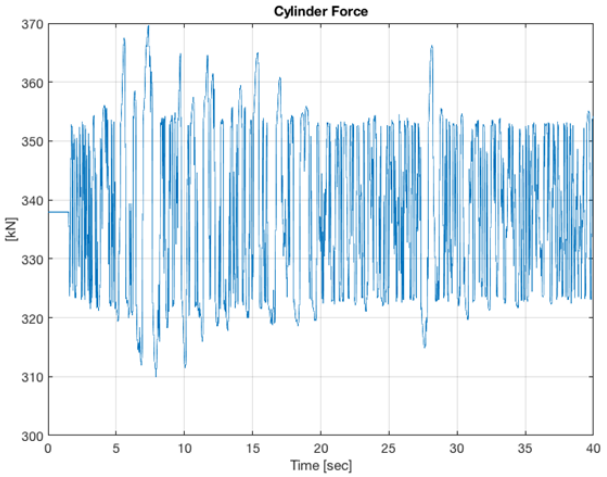






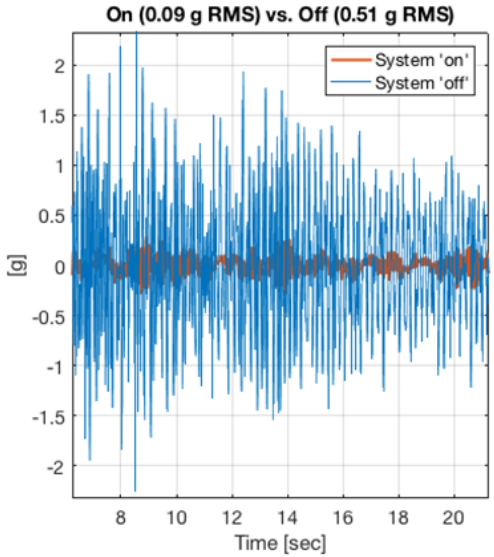


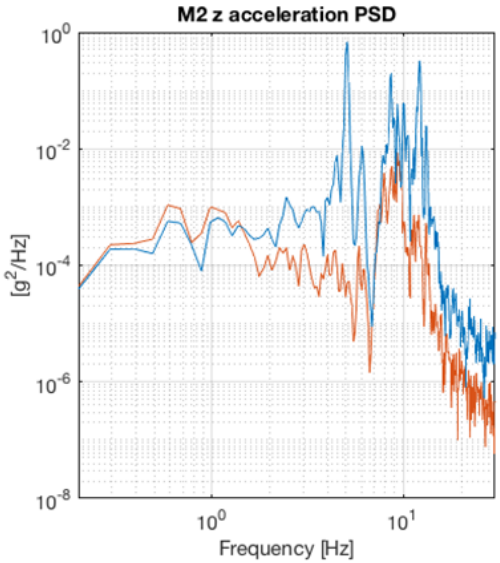
Pressure and Flow in accumulators



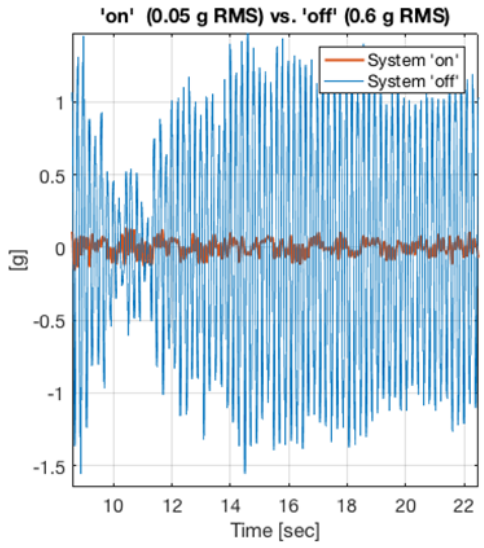
Cylinder Force

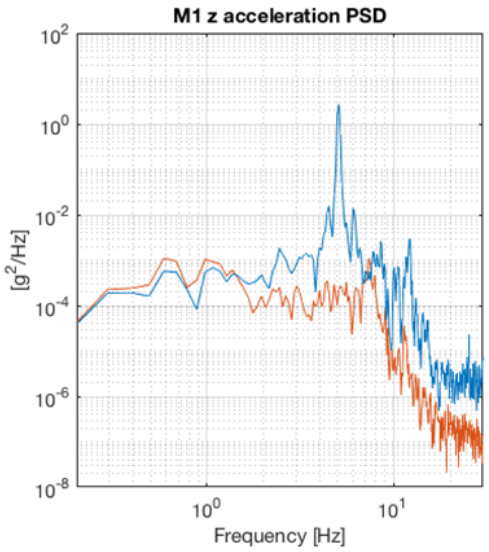
Simulation results: complete system





Accelerations M2 z: system 'off' and 'on'

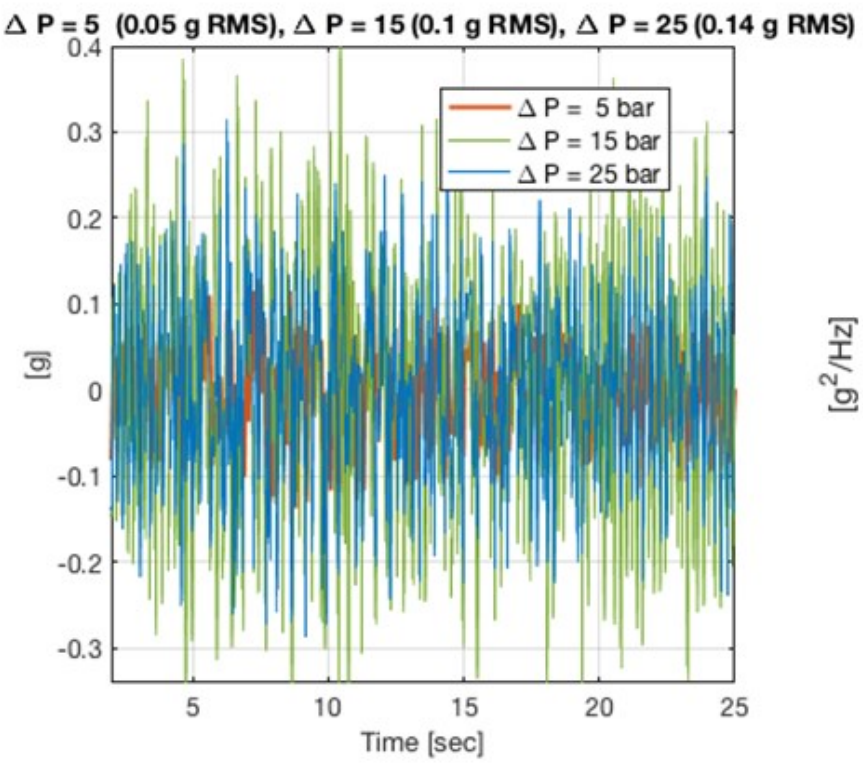


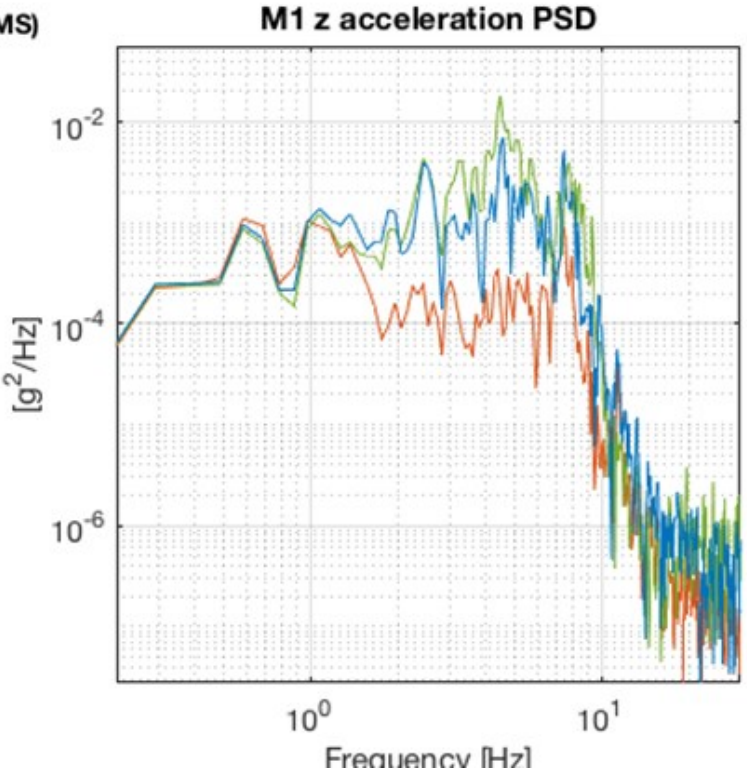


Accelerations M1 z: system 'off' and 'on'

Simulation results: complete system

Effect of pressure/force threshold parameter





Reminder: System ‘off’ ➔ M2 z acc 0.6 [g] rms