Design of a Low Micro vibration High Precision CubeSat Reaction Wheel

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Zyra Reaction Wheel

General

Torque = 1,5mNm
Momentum = 27,5mNms
Mass = 160g

Interface

Operating Voltage = 5 – 12V
RS485

Electronics & Control

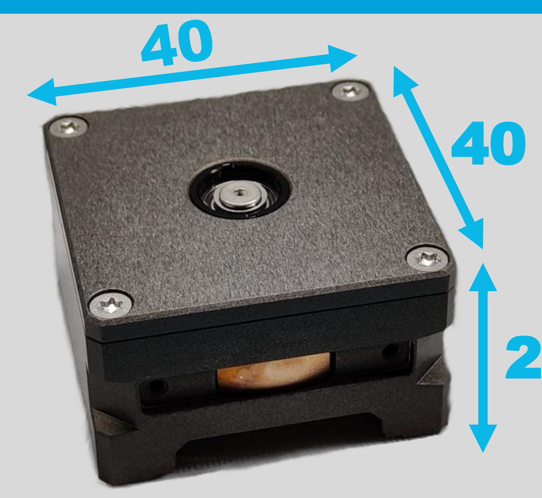
Integrated electronics
Four quadrant operation
Friction estimation and compensation
Customized control loops
Sensors and brake resistor

Balancing

G0,4
Static and Dynamic
Filed-balanced
Laser ablation

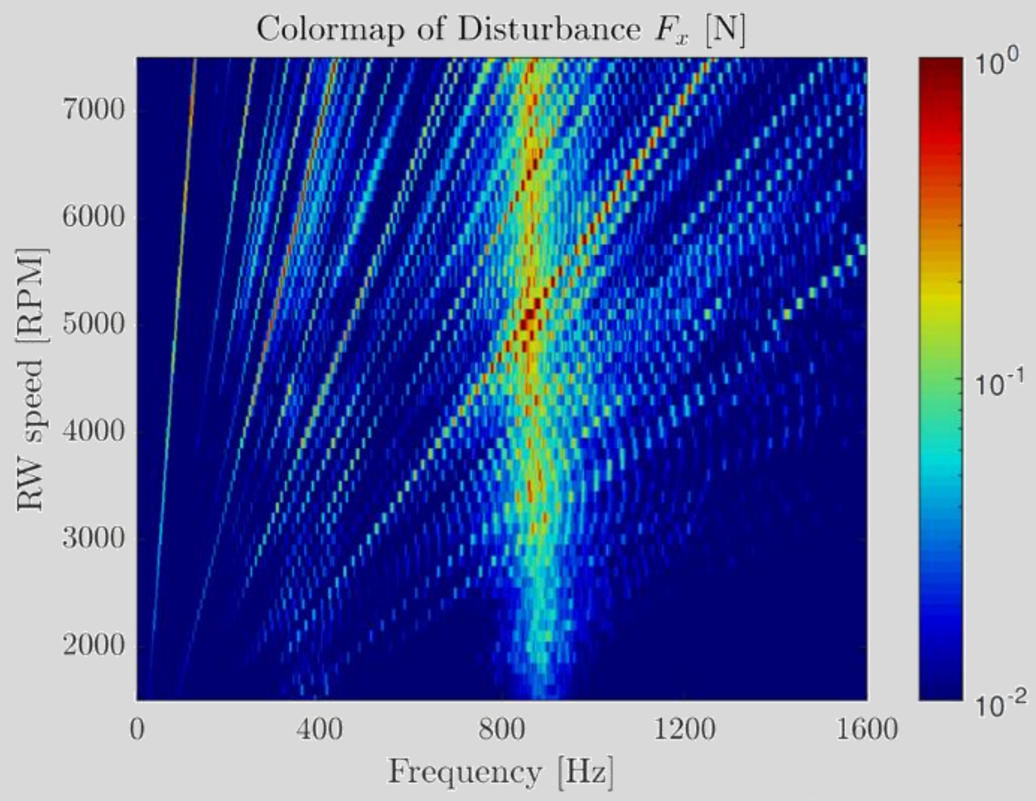
Preload

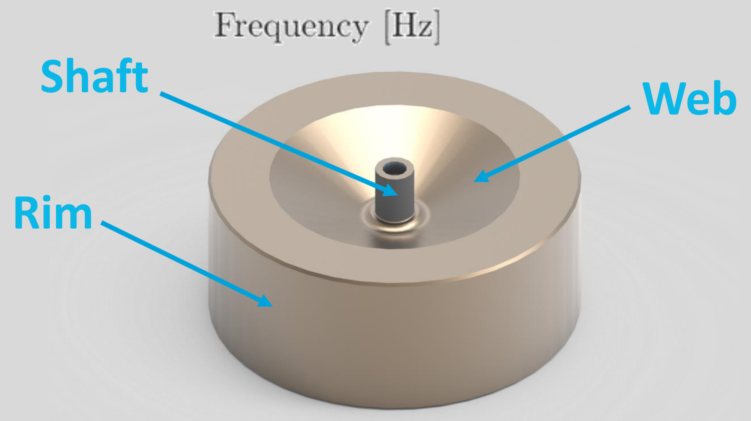
Soft preload suspension
Compensation for tolerances and thermal expansion
Avoid rattling and hammering
Ensure bearing life



Constrained Layer Damping - Rationale

Rolling element bearings are known to generate higher order harmonics. These harmonics can reach up to the 10th or higher engine order [1]. When wheels are used in a wide speed range, these higher order harmonics can pass and excite rotor eigenfrequencies and rotor modes, severely increasing the exported µ-vibrations at these frequencies. The amplification of these frequencies will then be governed by the quality factor (Q-factor) of the rotor. Single piece rotors have several advantages such as affordable tight tolerances, uniform mass and elimination of assembly errors, but such monolithic metallic structure feature high Q-factors. Material choice is a first way to address this [2], but damping will stay limited. To further increase the internal damping and reduce the Q-factor, Constrained layer damping is employed.

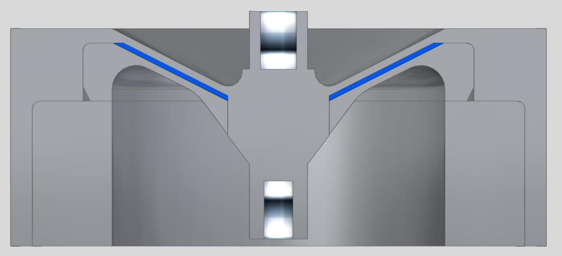




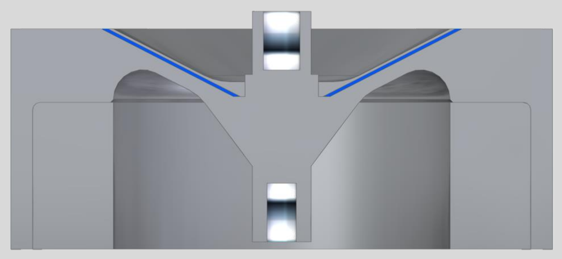
[1] S. J. Lacey, An Overview of Bearing Vibration Analysis, Schaeffler Group
[2] J. Zhang, R. J. Perez and E. J. Lavernia, "Documentation of damping capacity of metallic, ceramic and metal-matrix composite materials," JOURNAL OF MATERIALS SCIENCE, vol. 28, pp. 2395-2404, 1993.

Constraint Layer Damping - Design & Testing

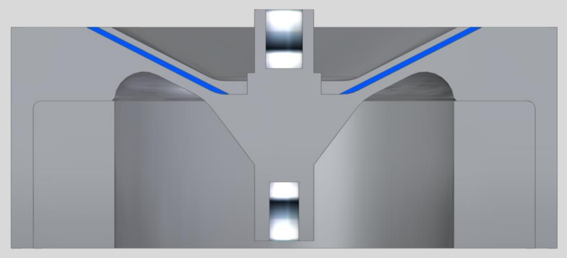
The principle behind CLD consists in adding a thin layer of viscoelastic (VE) material on top of the base structure and constraining it by adding a thin stiff sheet on the other side of the VE material, to force the entire VE layer into shear deformation when the base structure is bend [3]. This results in large VE material deformation and E-dissipation for relatively small base structure deformations. This principle was incorporated into the rotor of Zyra in 3 different ways, shown on the left.
These 3 rotor constructions were then tested against an undampened, solid rotor of the same dimensions, material and weight. The responses of all 4 rotors were measured with resonance searches between 5 and 2560Hz.



DR1
Base = 0,47mm
VE = 0,31mm
CL= 0,5mm



DR2
Base = 0,98mm
VE = 0,2mm
CL= 0,15mm

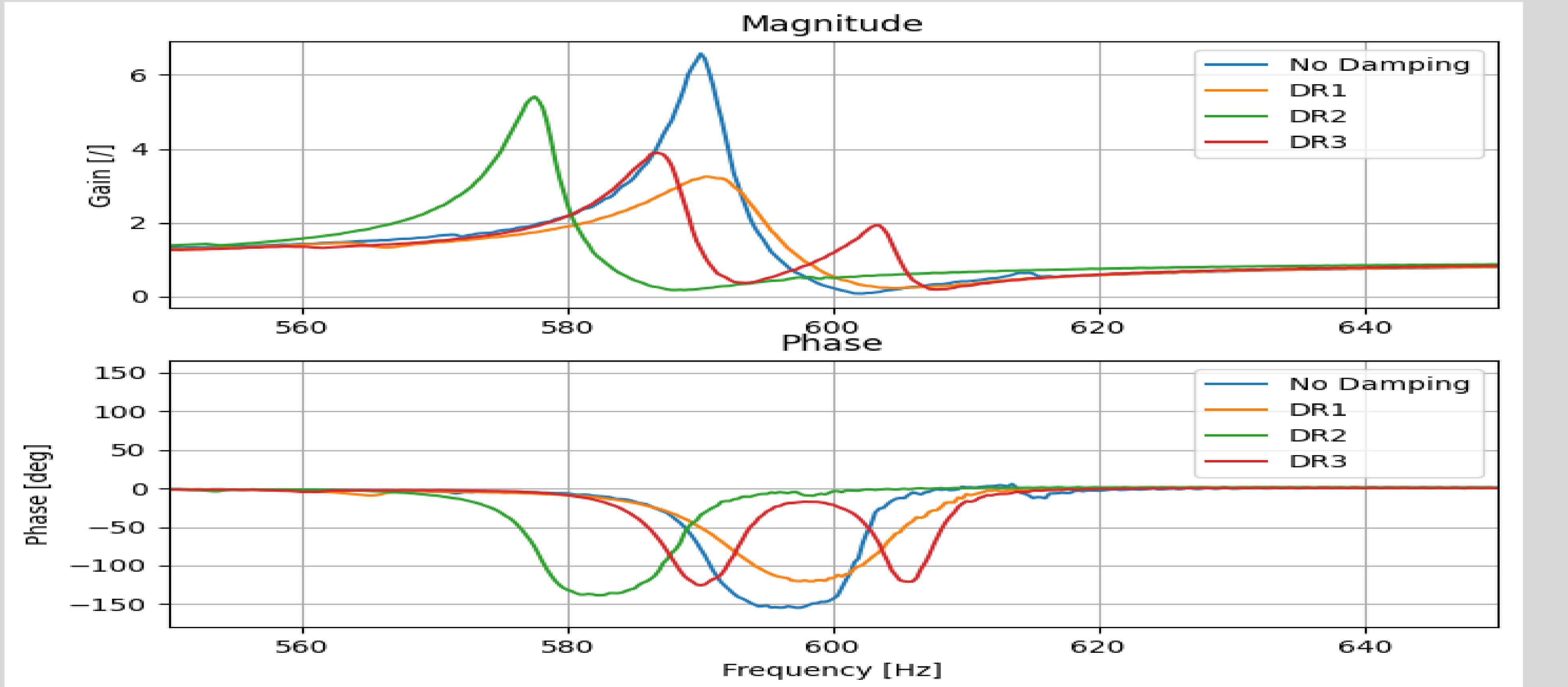


DR1
Base = 0,71mm
VE = 0,35mm
CL= 0,4mm

[3] J. de Vreugd, D. de Lange, J. Winters, J. Human, F. Kamphues and E. Tabak, "DAMPING IN SPACE CONSTRUCTIONS," in 13th European Conf. on Spacecraft Structures, Materials & Environmental Testing, Braunschweig, 2014.

Constrained Layer Damping Results

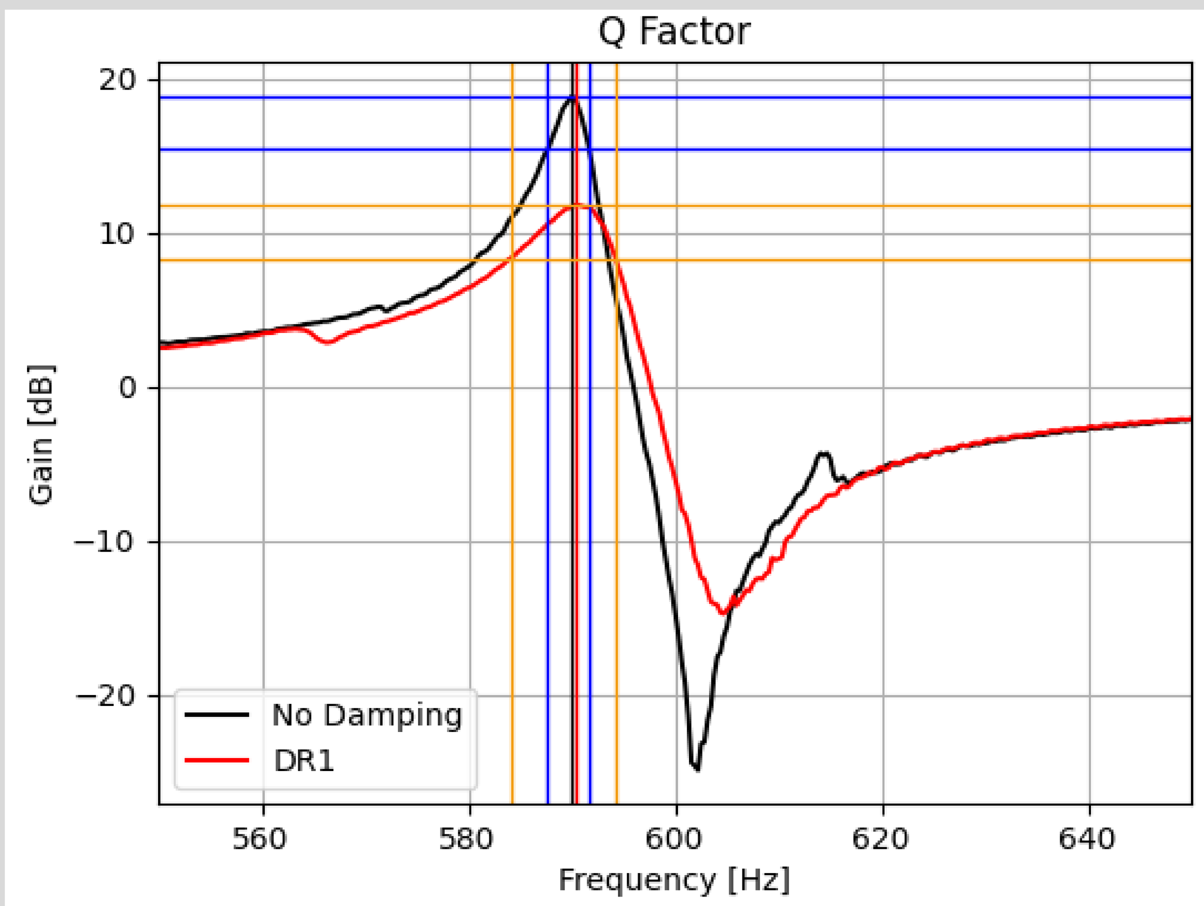
DR1 showed the best performance. While DR2 Had little effect and DR3 showed Tuned Mass Damper-like behavior [4], only DR1 showed the expected results for the CLD approach. The amplitude of the response at the resonance frequency is lowered without changing its location in the frequency domain of creating additional resonances by a THD would.



To quantify the improvement, the Q factors can be compared. Q-factor can be calculated and linked to the damping ratios by the formulas:

$$Q = \frac{f_c}{\Delta f_{-3dB}} \qquad \frac{1}{Q} = 2\xi$$

Where f_c is the location of the resonance frequency and Δfc is the 3dB bandwidth of the peak. These formulas represent a quantification for the aspect ratio of the peak and a measure for how underdamped a system is. This is visually represented in the figure below.



Applying these formulas to the responses of the undamped rotor and DR1 yields following values. Comparing the Q-factors, the CLD approach lowered the Q-factor by 59,2%. When comparing resonance frequencies, no significant shift is observed. This in combination with the fact that the material, shape and mass remained the same, allows us to conclude that CLD provided a way to increase the damping of the rotor while leaving its stiffness untouched.

Rotor	Q [/]	ζ [/]	f_n [HZ]
Undamped	146.04	0.0034	590.07
DR1	58.09	0.0086	590.39

[4] M. Gaspar, "The mechanism and applications of a Tuned Mss Damper (TMD)," BSB Group, 22 11 2017. [Online]. Available: https://bsbgroup.com/blog/the-mechanism-and-applications-oftuned-mass-dampertmd#:~:text=What%20is%20a%20Tuned%20Mass,earthquake%20or%20high%20winds%20h it.. [Accessed 23 11 2022].