HUMANOIDS AND HUMAN CENTERED MECHATRONICS

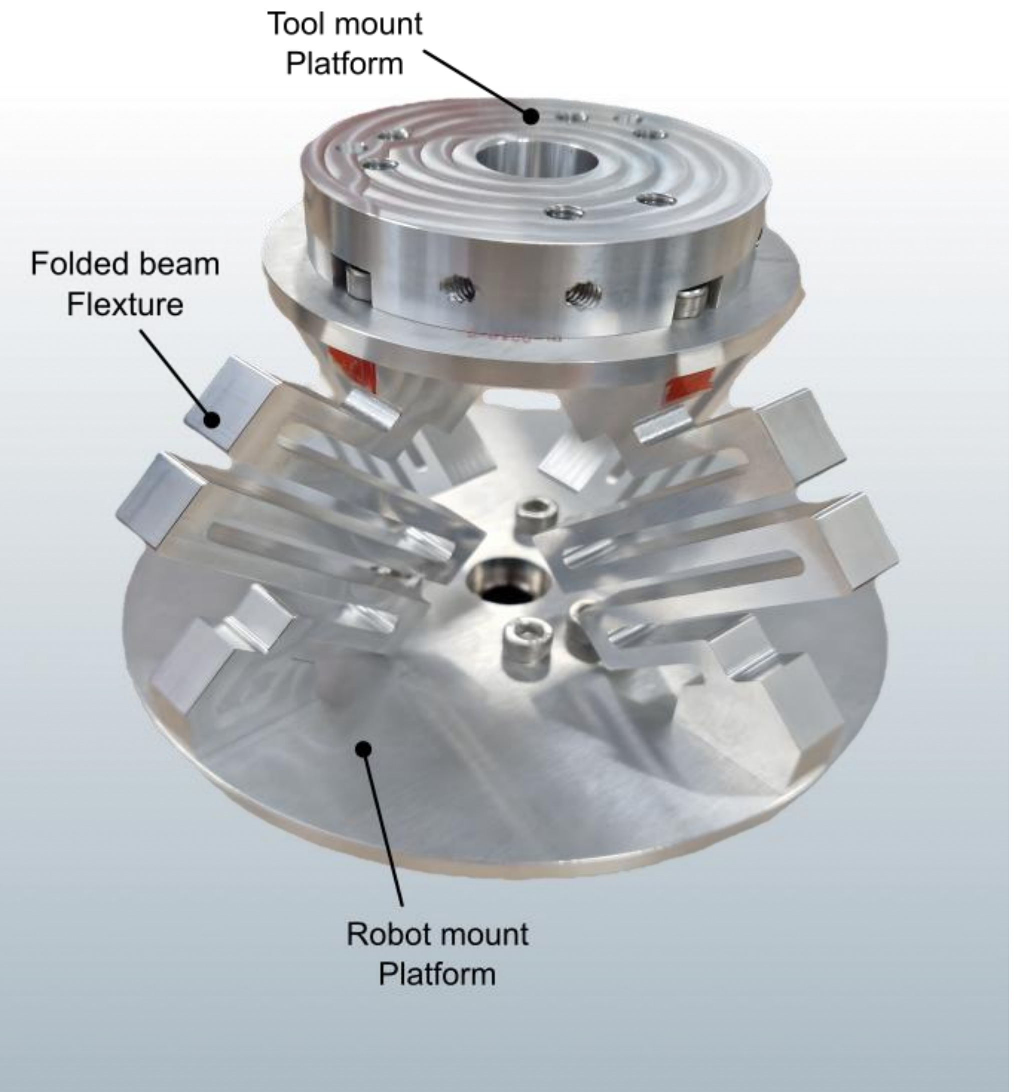
MAGICIAN
AUTONOMOUS DEFECTS DETECTION AND REPAIR IN MANUFACTURING

Project: Magician

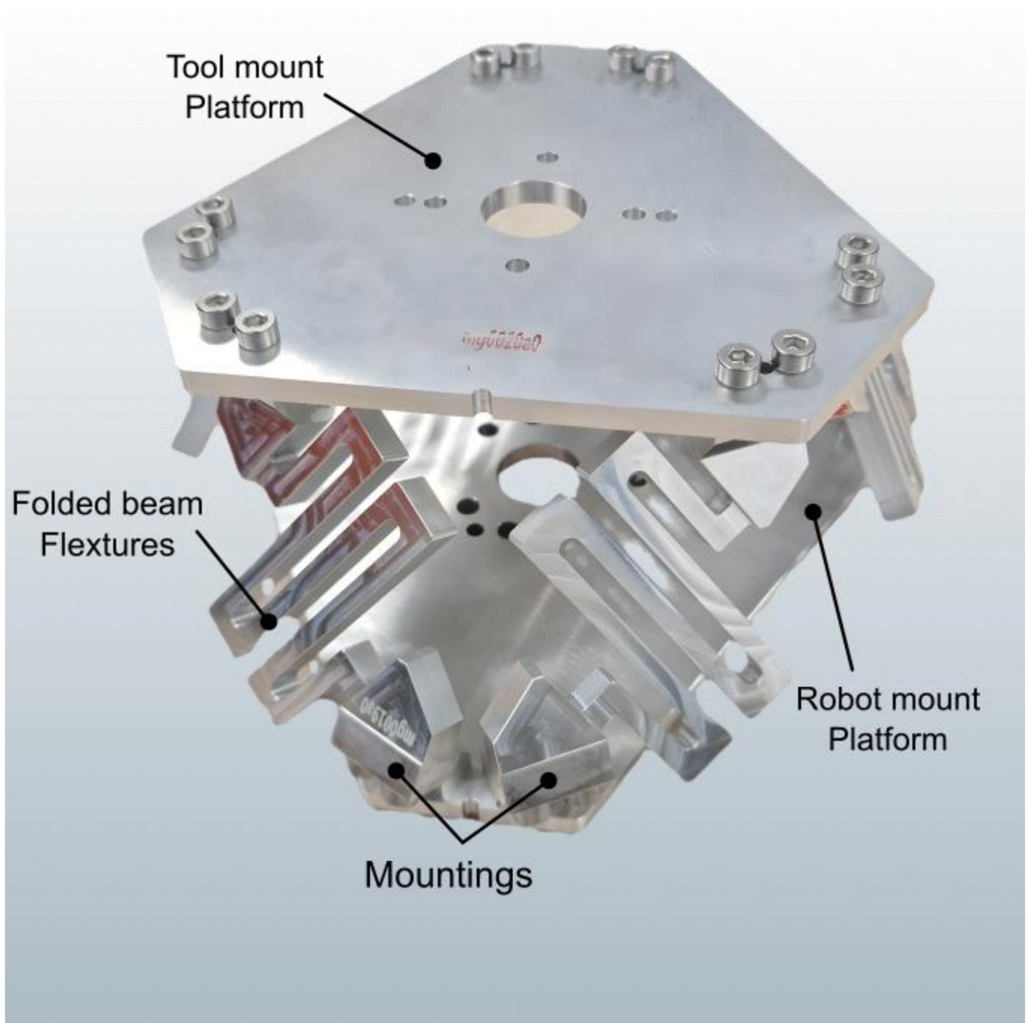
Isolator Prototype with Experimental Results

Machined Prototype Isolator platform

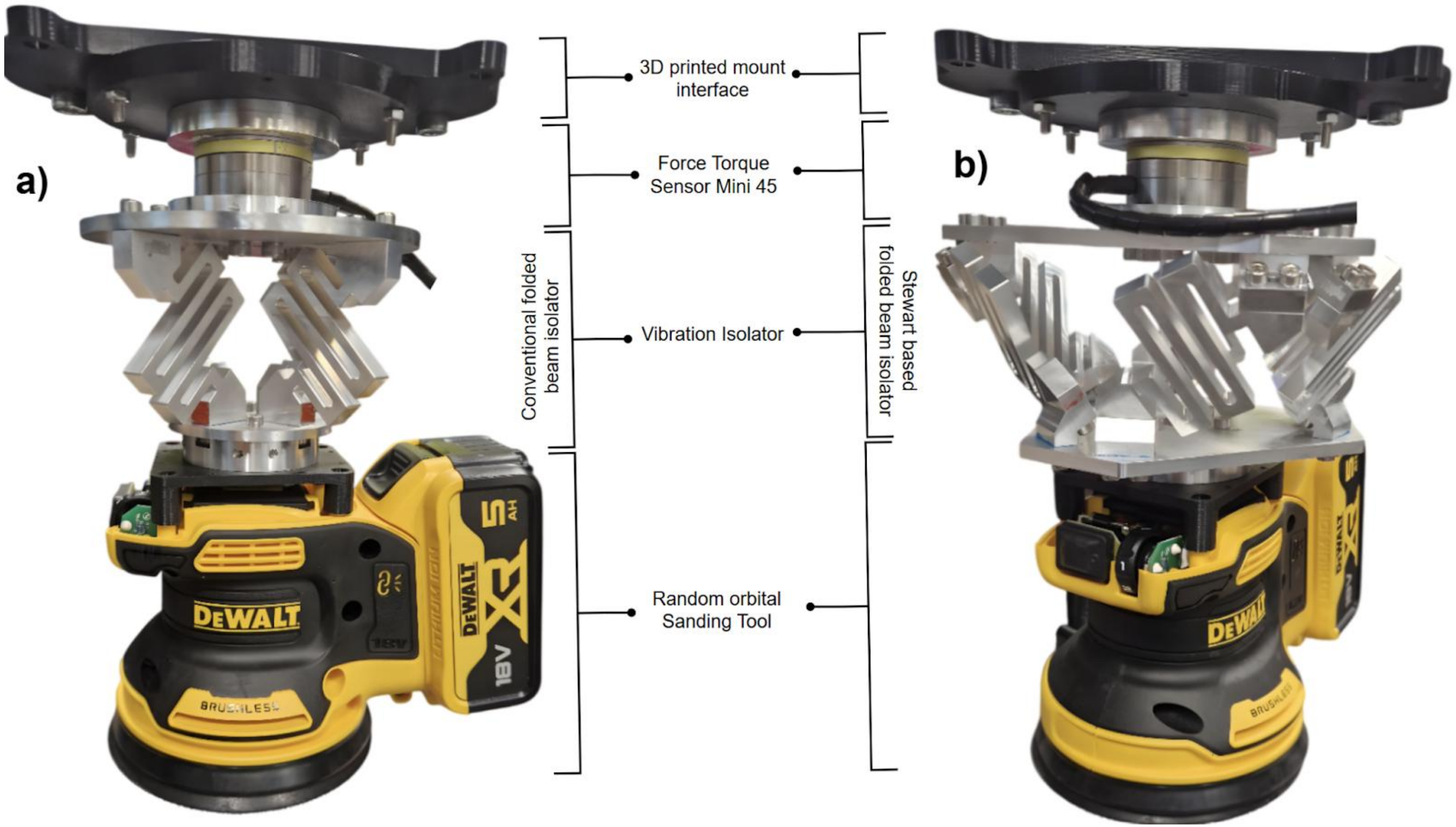
Conventional Isolator Platform



Stewart based Isolator Platform



Assembled Prototype End Effectors



a) Tool end effector interface with conventional isolator

b) Tool end effector interface with Stewart based isolator platform

Experimental Setup

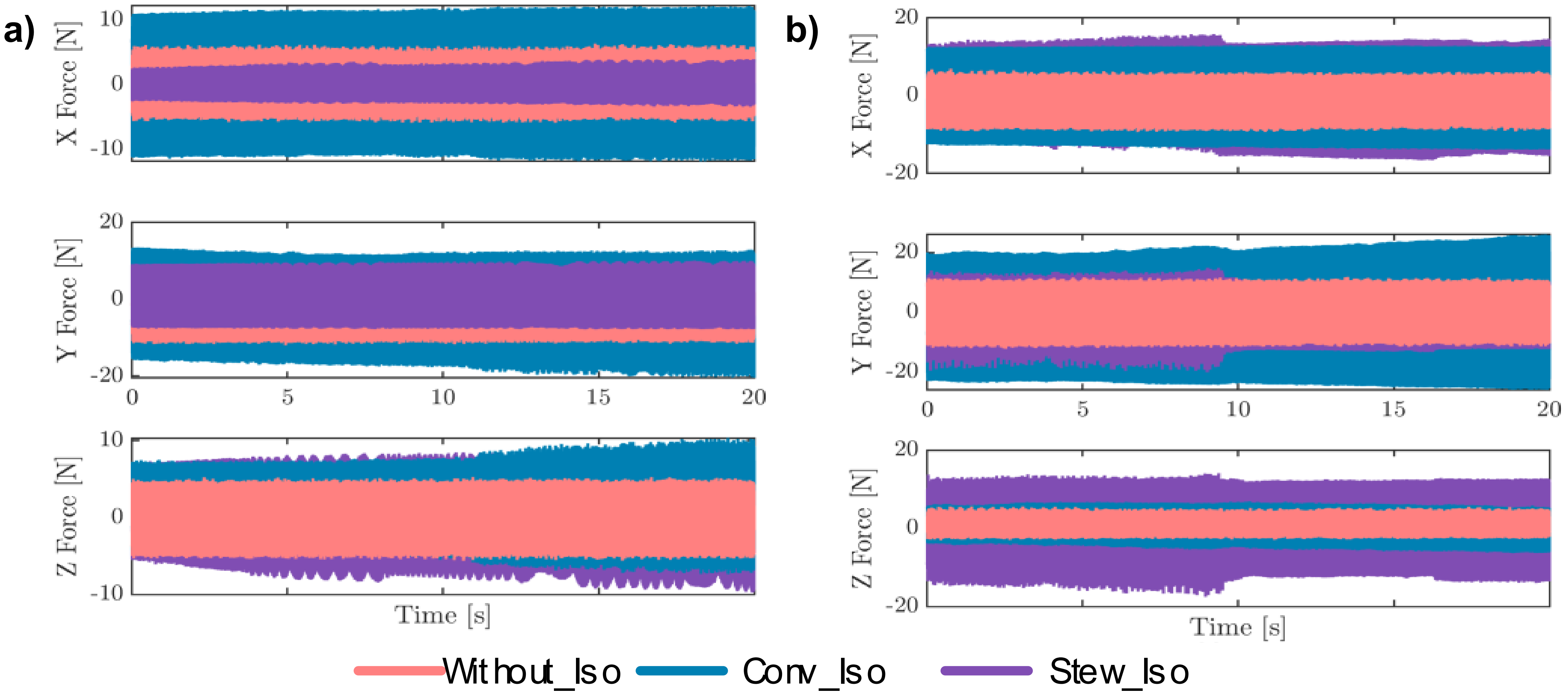
Free - Fixed zero degree orientation Experiment

- Initial testing to analyse the performance of the isolator platform
- Each test lasted for 20 seconds for the entire speed ranges of the tool
- Sensor used: FT Mini 45 which a sample rate of 1000 Hz
- With this setting we performed the test on both the isolator platforms and recorded the data in all principal direction forces

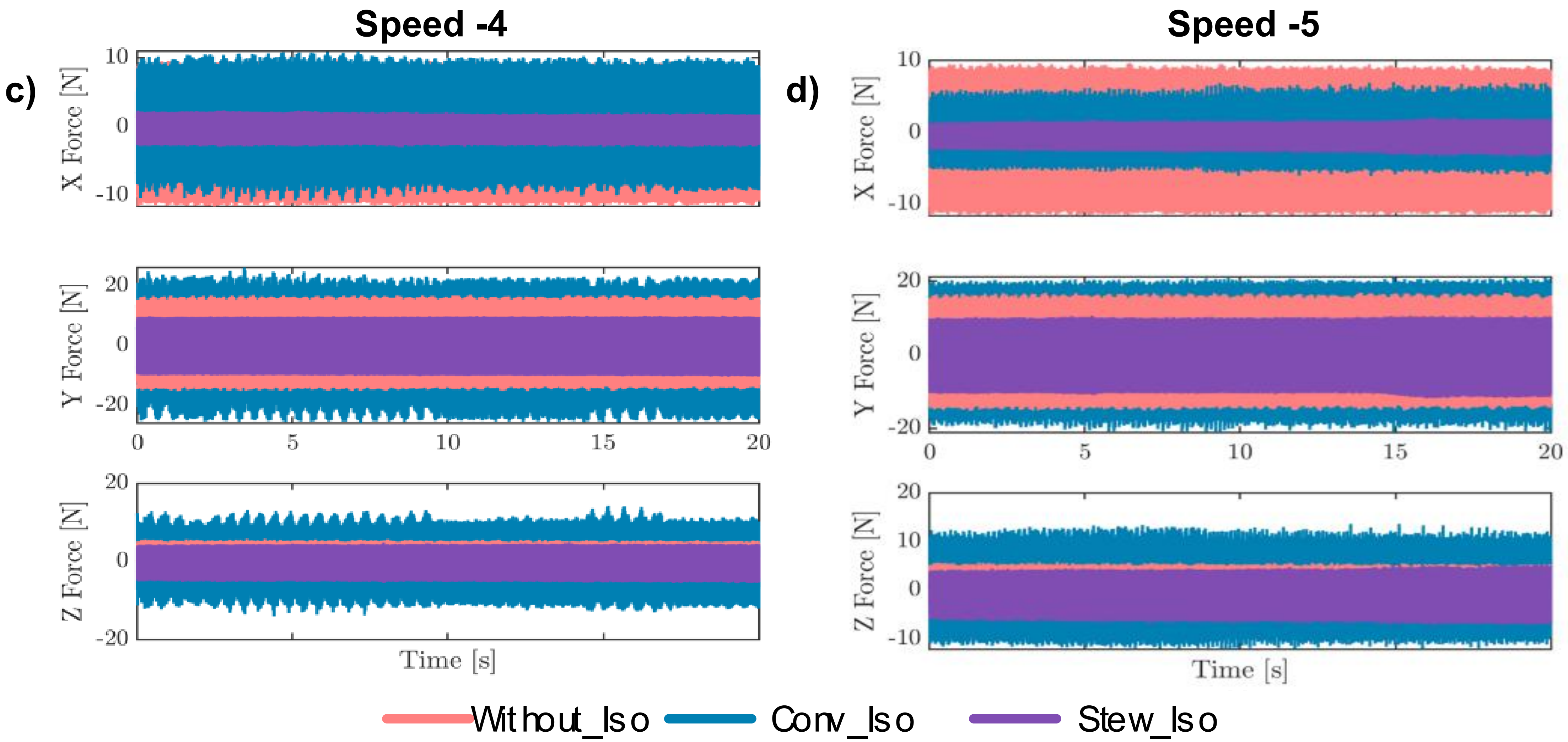
Results and Observations

At Low Tool Speeds

Speed -1 | Speed -2



At Medium Tool Speeds

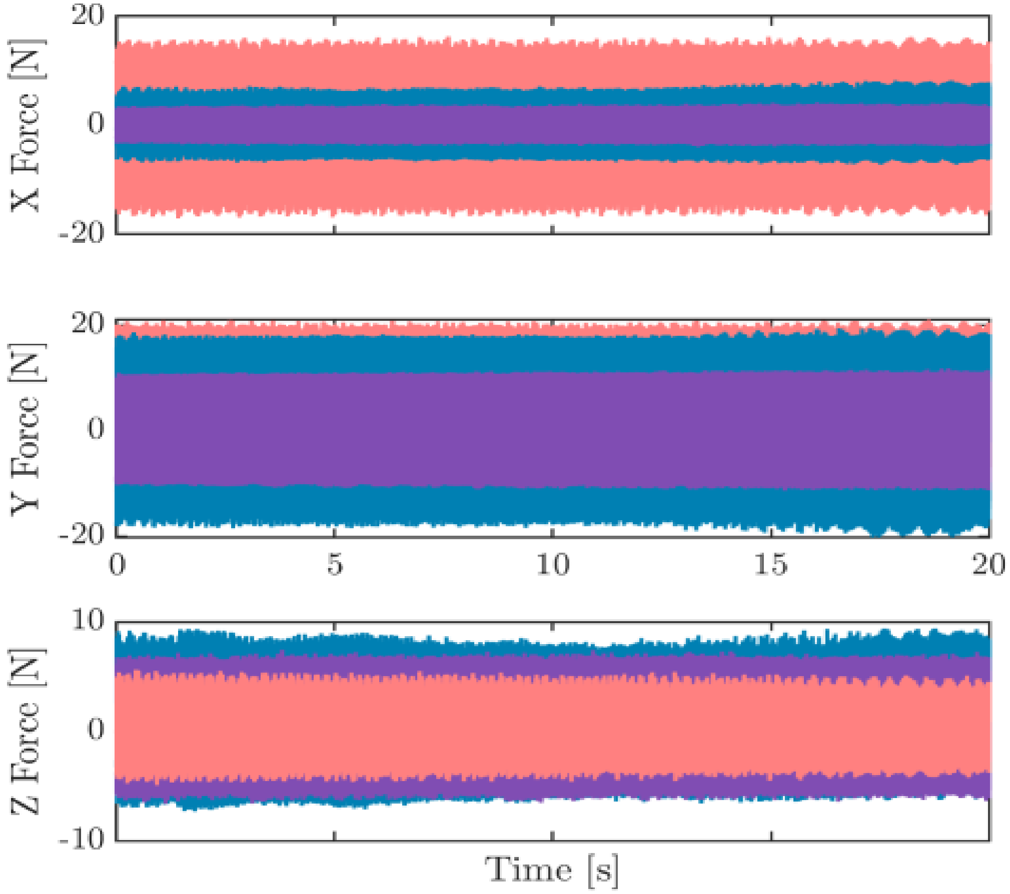


Results and Observations

At High Tool Speeds

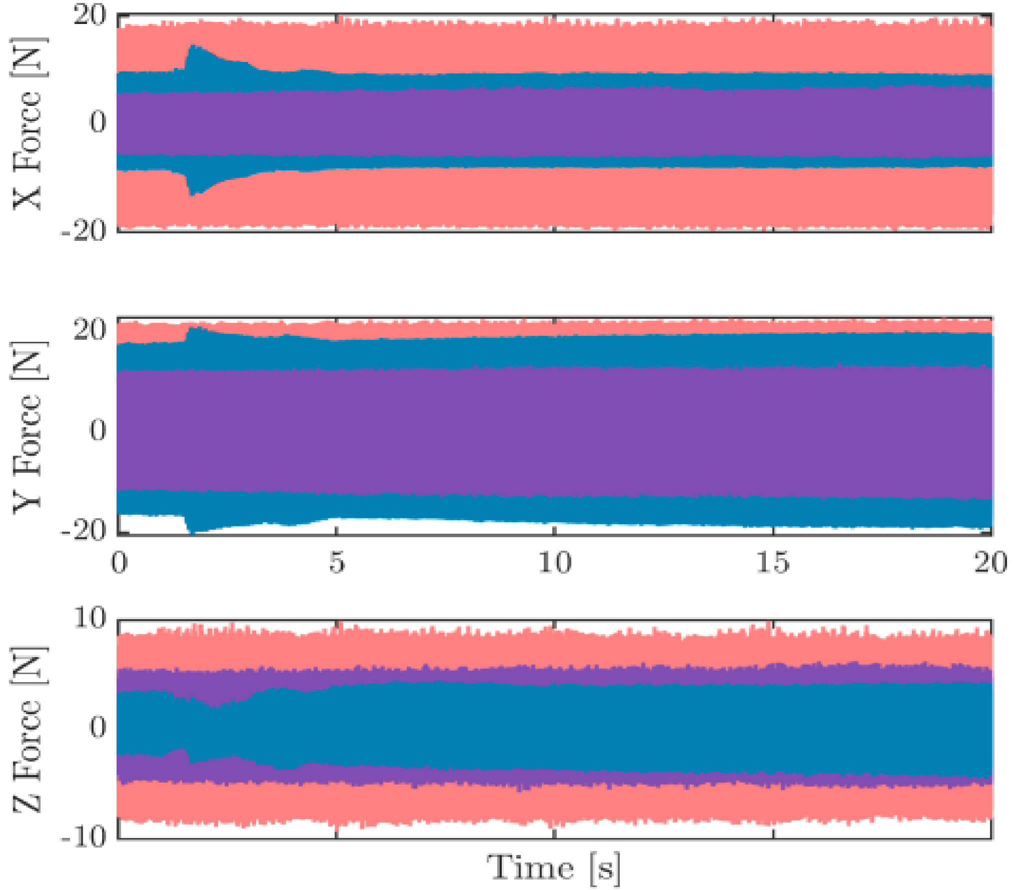
Speed -6

e)



Speed -7

f)



Without_Iso Conv_Iso Stew_Iso

Above force graphs Observations

At Low Speeds

- With out isolator performance is best compared with isolator case.
- Followed by Stewart platform isolator performance is the next best .
- Notably at Speed 1 in transverse x-direction the magnitude of force is even lower than the normal case.
- And conventional platform performance is poor compare to all because of its geometrical shape causing anisotropic condition with unequal force distribution.

At Medium Speeds

- Here onwards the isolators did show their attenuation of vibrations especially Stewart based isolator , tracing a path close to the reference force i.e., 0 N in our current experiment.
- But when coming to the conventional isolator case having a similar performance as before with no signs of attenuation.

At High Speeds

- This is the most deserving and favourable speed domain where both of the isolator had a better attenuation characteristics.
- Particularly conventional isolator is also displaying Amplification characteristics

Results and Observations

No isolator vs Conventional Isolator – key Observations

- Amplification at Low Speeds (1–3): Strong negative isolation values (−167%, −92%, −67%) → transmissibility ≫ 1, isolator in stiffness-controlled regime, **amplifying instead of attenuating.**
- Outliers / Instabilities (Speeds 2–3): Extreme amplification in Y/Z (−223%, −194%) flagged as outliers → resonance crossings causing unstable force transmission.
- Onset of Isolation (≥4): Isolation begins to appear, mainly in the X-axis, marking transition towards inertia-controlled behaviour.
- Effective Isolation at Mid–High Speeds (5–6): X-axis shows ~60% isolation (≈ −8 dB), demonstrating **mass-dominated inertia-controlled isolation**.
- Anisotropy at Highest Speed (7): **Performance becomes axis-dependent**: strong isolation in X (51%) and Z (62%), but poor along Y (−5%), highlighting design-geometry limitations.

Table 9: Mean, RMS, Max and Isolation (No Isolator vs. Conventional Isolator). Isolation is amplitude reduction: Isolation $= 100(1-T)$. Color applies only to the Isolation column; values $< -100\%$ are flagged as {outlier}.

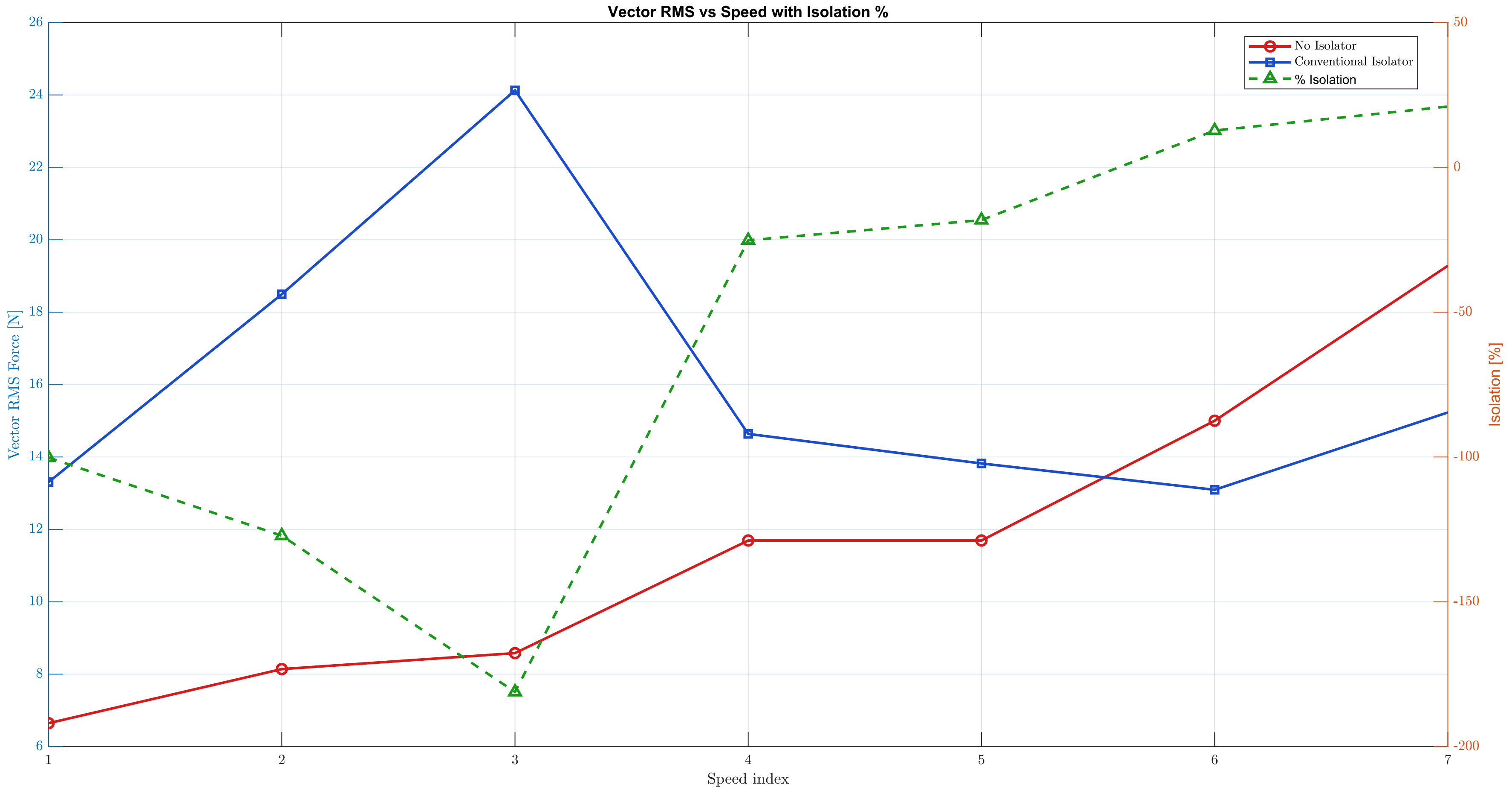
Speed	Axis	No Iso			Conventional Iso			T_{conv}	IL [dB]	Isolation [%]
		Mean [N]	RMS [N]	Max [N]	Mean [N]	RMS [N]	Max [N]	(linear)		
1	X	-0.034	2.966	6.384	0.027	7.937	12.204	2.676	8.55	-167.57$^{\{outlier\}}$
1	Y	0.001	5.413	11.911	0.049	10.393	20.427	1.920	5.67	-92.00
1	Z	0.060	2.465	5.628	0.098	4.106	10.295	1.666	4.43	-66.58
2	X	-0.022	4.646	9.427	0.052	9.229	13.980	1.987	5.96	-98.66
2	Y	0.022	6.427	12.222	0.017	15.641	26.070	2.434	7.73	-143.38$^{\{outlier\}}$
2	Z	0.045	1.841	5.649	0.109	3.503	6.848	1.903	5.59	-90.31
3	X	-0.045	4.662	8.155	-0.010	6.805	12.258	1.460	3.28	-45.95
3	Y	0.037	6.937	12.938	-0.430	22.424	34.749	3.232	10.19	-223.24$^{\{outlier\}}$
3	Z	0.071	1.947	4.263	0.189	5.741	11.064	2.949	9.39	-194.86$^{\{outlier\}}$
4	X	0.008	7.131	11.648	-0.092	5.708	11.040	0.801	-1.93	19.95
4	Y	0.099	8.946	16.912	0.067	12.162	26.031	1.360	2.67	-35.96
4	Z	0.074	2.417	5.744	-0.020	5.811	14.301	2.404	7.62	-140.40$^{\{outlier\}}$
5	X	0.008	7.131	11.648	0.019	2.794	7.012	0.392	-8.14	60.82
5	Y	0.099	8.946	16.912	0.276	12.309	21.117	1.376	2.77	-37.59
5	Z	0.074	2.417	5.744	-0.482	5.631	13.595	2.329	7.35	-132.94$^{\{outlier\}}$
6	X	0.018	9.685	17.073	-0.085	3.965	8.283	0.409	-7.76	59.06
6	Y	0.061	11.104	21.016	-0.102	11.722	20.171	1.056	0.47	-5.57
6	Z	0.102	2.819	5.624	0.196	4.280	9.397	1.518	3.63	-51.81
7	X	0.014	12.946	20.325	0.099	6.372	14.765	0.492	-6.16	50.78
7	Y	0.066	12.962	22.763	-0.041	13.645	20.956	1.053	0.45	-5.27
7	Z	0.084	6.015	9.942	0.025	2.273	4.512	0.378	-8.45	62.22

Note: Rows marked with $^{\{outlier\}}$ indicate outlier operating points (Speed 2–3) with atypically large errors; interpret isolation metrics there with caution.

Results and Observations

Vector RMS Force vs Speed with Isolation % (Conventional Isolator)

- Low speeds (1–3): Clear amplification — RMS forces increase and isolation % is strongly negative.
- Mid speed (4): Onset of isolation, mainly in X-axis.
- Higher speeds (5–6): Partial isolation appears (~60%), but performance is inconsistent across axes.



Results and Observations

No isolator vs Conventional Isolator – key Observations

- Superior Low-Speed Stability: Unlike the conventional isolator, Stewart shows **less severe amplification at low speeds**; X and Y already provide partial attenuation at Speed 1, though Z still amplifies.
- Reduced Outlier Severity: While an extreme outlier exists at Speed 2 (Z axis, −352%, 13 dB), outlier occurrences are fewer and less widespread compared to the conventional isolator, indicating better damping and stiffness integration.
- Strong High-Speed Isolation: From Speed 4 onward, Stewart consistently achieves positive isolation; e.g., Speed 4 X-axis shows 77.9% (−13.1 dB), and Speed 5 X-axis peaks at 80.9% (−14.4 dB).
- Multi-Axis Robustness: Provides **more balanced attenuation across X, Y, Z** at higher speeds; residual negative isolation in Y at Speeds 6–7 (−5.8%, −13.9%) is much milder than the conventional case.
- Near-Isotropic Control: Stewart's geometric configuration provides a more uniform stiffness distribution and balanced vibration suppression across X, Y, and Z, **offering improved multi-directional performance.**

Table 10: Mean, RMS, Max and Isolation (No Isolator vs. Stewart Isolator). Isolation is amplitude reduction: Isolation $= 100(1 - T)$. Color applies only to the Isolation column; values $< -100\%$ are flagged as {outlier}.

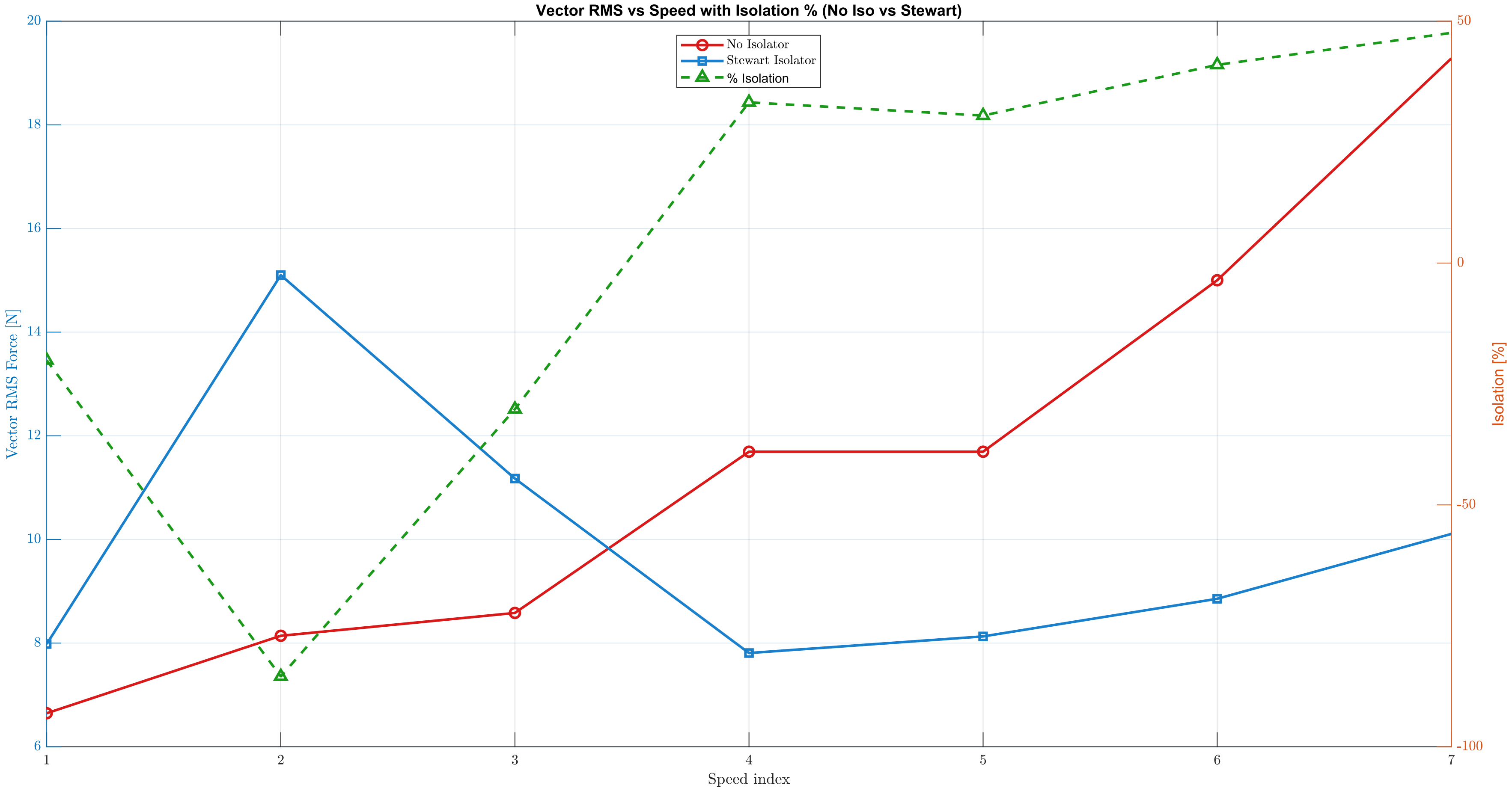
Speed	Axis	No Iso			Stewart Iso			T_{stew}	IL [dB]	Isolation [%]
		Mean [N]	RMS [N]	Max [N]	Mean [N]	RMS [N]	Max [N]	(linear)		
1	X	-0.034	2.966	6.384	-0.007	2.041	3.963	0.688	-3.25	31.18
1	Y	0.001	5.413	11.911	-0.004	6.061	10.077	1.120	0.98	-11.96
1	Z	0.060	2.465	5.628	0.060	4.776	9.762	1.938	5.75	-93.75
2	X	-0.022	4.646	9.427	-0.006	9.508	16.602	2.047	6.22	-104.67 {outlier}
2	Y	0.022	6.427	12.222	0.000	8.271	20.064	1.287	2.19	-28.71
2	Z	0.045	1.841	5.649	0.036	8.319	17.538	4.520	13.10	-351.95 {outlier}
3	X	-0.045	4.662	8.155	0.162	5.886	9.744	1.263	2.03	-26.26
3	Y	0.037	6.937	12.938	-0.117	7.648	11.602	1.102	0.85	-10.24
3	Z	0.071	1.947	4.263	-0.176	5.633	9.272	2.893	9.23	-189.30 {outlier}
4	X	0.008	7.131	11.648	0.032	1.577	3.011	0.221	-13.10	77.88
4	Y	0.099	8.946	16.912	-0.034	6.927	10.406	0.774	-2.22	22.57
4	Z	0.074	2.417	5.744	0.115	3.240	5.621	1.340	2.54	-34.03
5	X	0.008	7.131	11.648	0.010	1.363	3.455	0.191	-14.38	80.89
5	Y	0.099	8.946	16.912	-0.025	7.123	11.816	0.796	-1.98	20.38
5	Z	0.074	2.417	5.744	0.117	3.672	7.299	1.519	3.63	-51.90
6	X	0.018	9.685	17.073	0.007	2.354	4.180	0.243	-12.29	75.70
6	Y	0.061	11.104	21.016	-0.007	7.437	11.780	0.670	-3.48	33.02
6	Z	0.102	2.819	5.624	0.021	4.191	7.442	1.487	3.44	-48.65
7	X	0.014	12.946	20.325	0.006	4.113	7.429	0.318	-9.96	68.23
7	Y	0.066	12.962	22.763	-0.030	8.560	13.800	0.660	-3.60	33.96
7	Z	0.084	6.015	9.942	0.091	3.457	6.246	0.575	-4.81	42.52

Note: Rows marked with {outlier} indicate outlier operating points (Speed 2–3) with atypically large errors; interpret isolation metrics there with caution.

Results and Observations

Vector RMS Force vs Speed with Isolation % (Stewart Isolator)

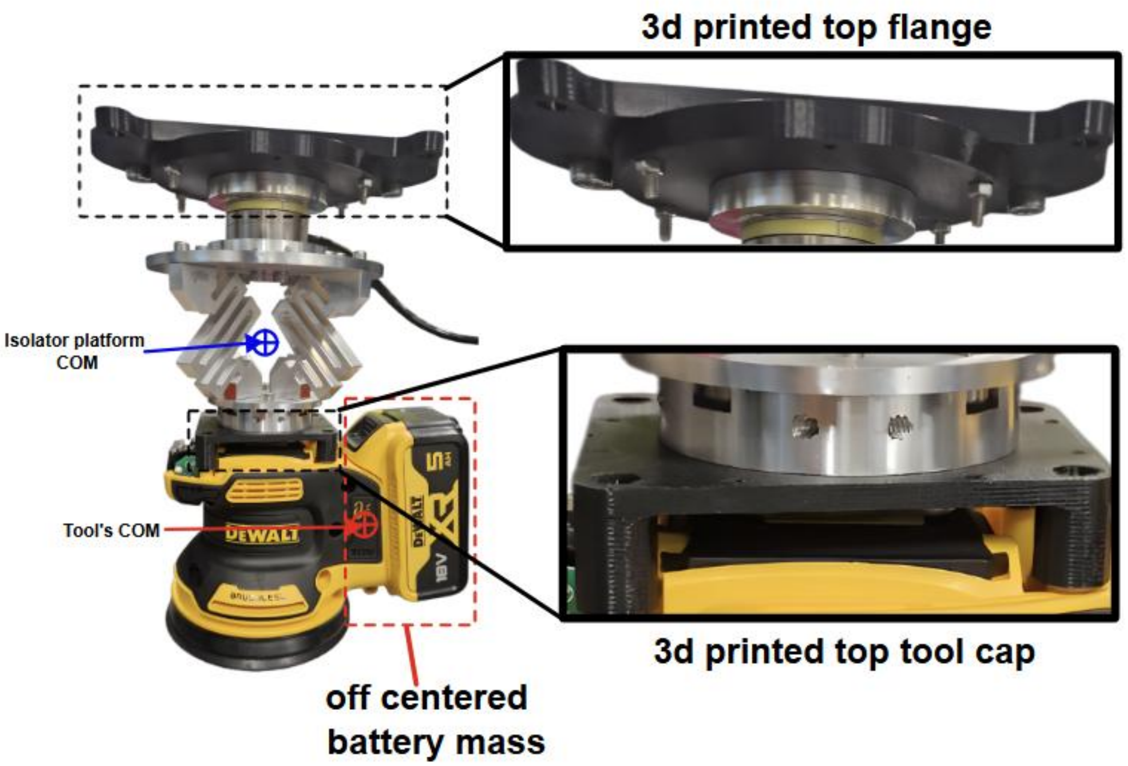
- Low speeds (1–3): Mixed results, some amplification (esp. Z), but less severe than conventional.
- From speed 4 onward: Isolation becomes effective, especially in X.
- Higher speeds (5–7): Consistent isolation across axes (up to ~80%), showing stable inertia-controlled behaviour.



Results and Observations

Comparative Evaluation – Conventional vs Stewart Isolator

Aspect	Conventional Isolator	Stewart Isolator
Low-Speed Behavior (1–3)	Strong amplification (negative isolation, transmissibility ≫1); late onset of attenuation.	Amplifies at low speeds but **less severe**, with earlier onset of attenuation due to 6-DOF geometry.
Outlier Behavior	Frequent and severe amplification outliers (esp. Y/Z at speeds 2–3).	Outliers fewer and less severe; mainly limited to Z-axis at Speed 2.
Cause of Outliers	Flexible 3D-printed sandwich parts, COM misalignment with battery mass, and folded-beam design amplify coupling.	Better damping and stiffness integration reduce severity of outliers.
High-Speed Performance (≥4)	Mixed results: e.g., Speed 7 X-axis shows ~50% isolation (−6.2 dB) but Y simultaneously amplifies (−5%).	Consistent strong isolation (>60% across multiple axes at speeds 4–7).
Design Dependence	Unequal load sharing in folded beams → biased response to lateral forces.	More uniform stiffness distribution → balanced load handling.
Directional Dependence	Directionally biased; isolation varies significantly per axis.	Balanced attenuation across X, Y, Z; well-suited for multi-DOF robotic applications.
Overall Assessment	Limited isolation, prone to amplification and directional imbalance.	Superior stability, effective multi-axis control, and predictable high-frequency isolation.

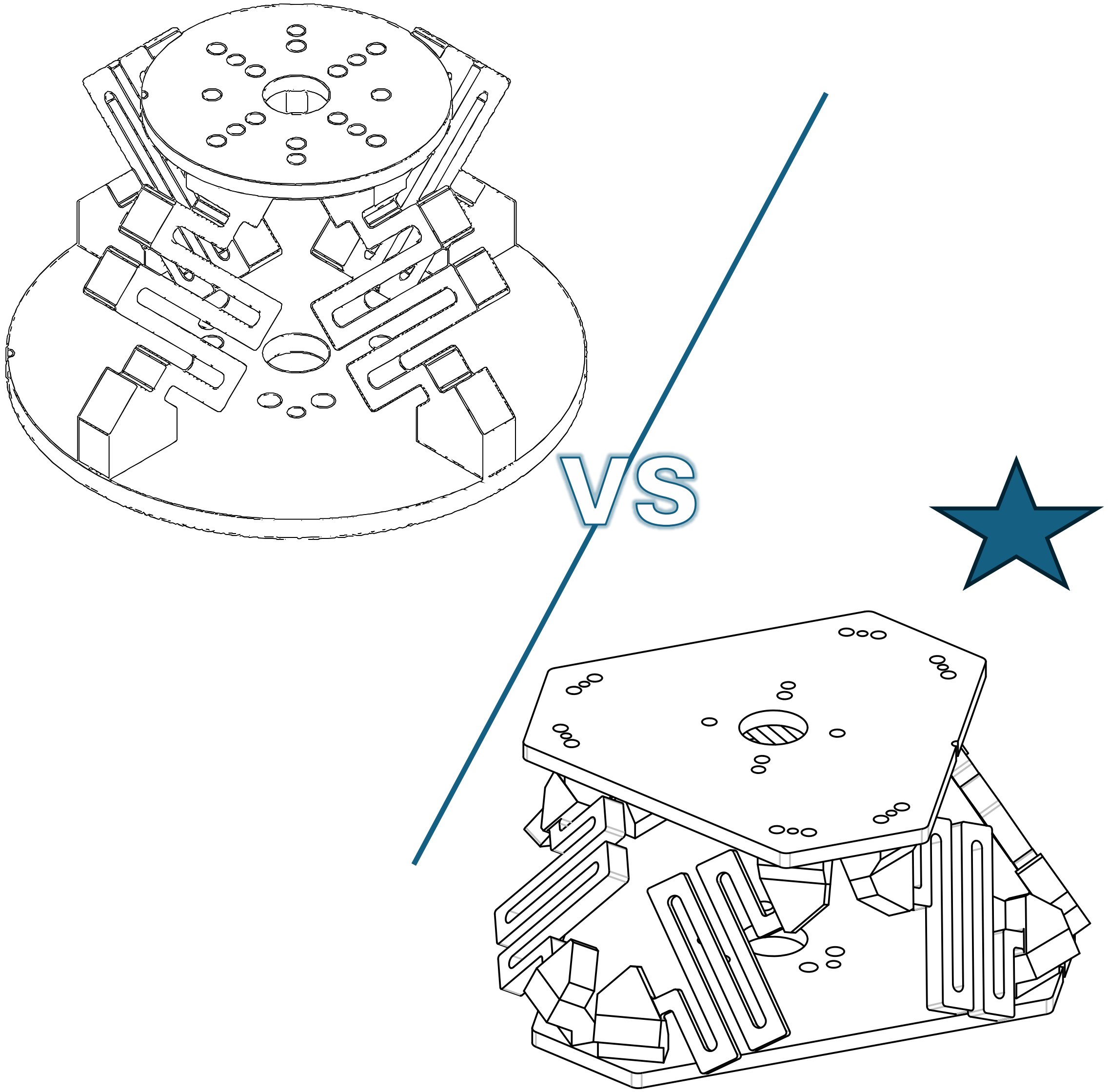


Final Experimental Summary

1.**Performance Regime:** Isolation effectiveness improves at higher tool speeds; Stewart shows stable, predictable attenuation across the operating band.

2.**Stewart Advantages:** Provides higher isolation percentages, balanced multi-axis control, compact design, and superior dynamic stability, making it more suitable as a passive end-effector interface.

3.**Conventional Drawbacks:** Exhibits resonance-driven amplification at low–mid frequencies and strong axis-dependent behavior, limiting robustness and applicability.



Thank you very much
for your attention...