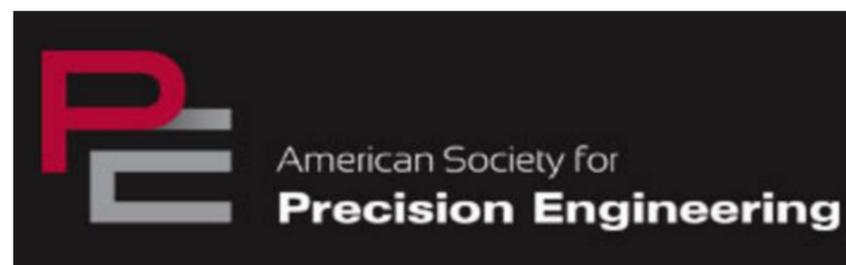


Feedback Based Technique for Improving Dynamic Performance of a Small Size Machine Tool

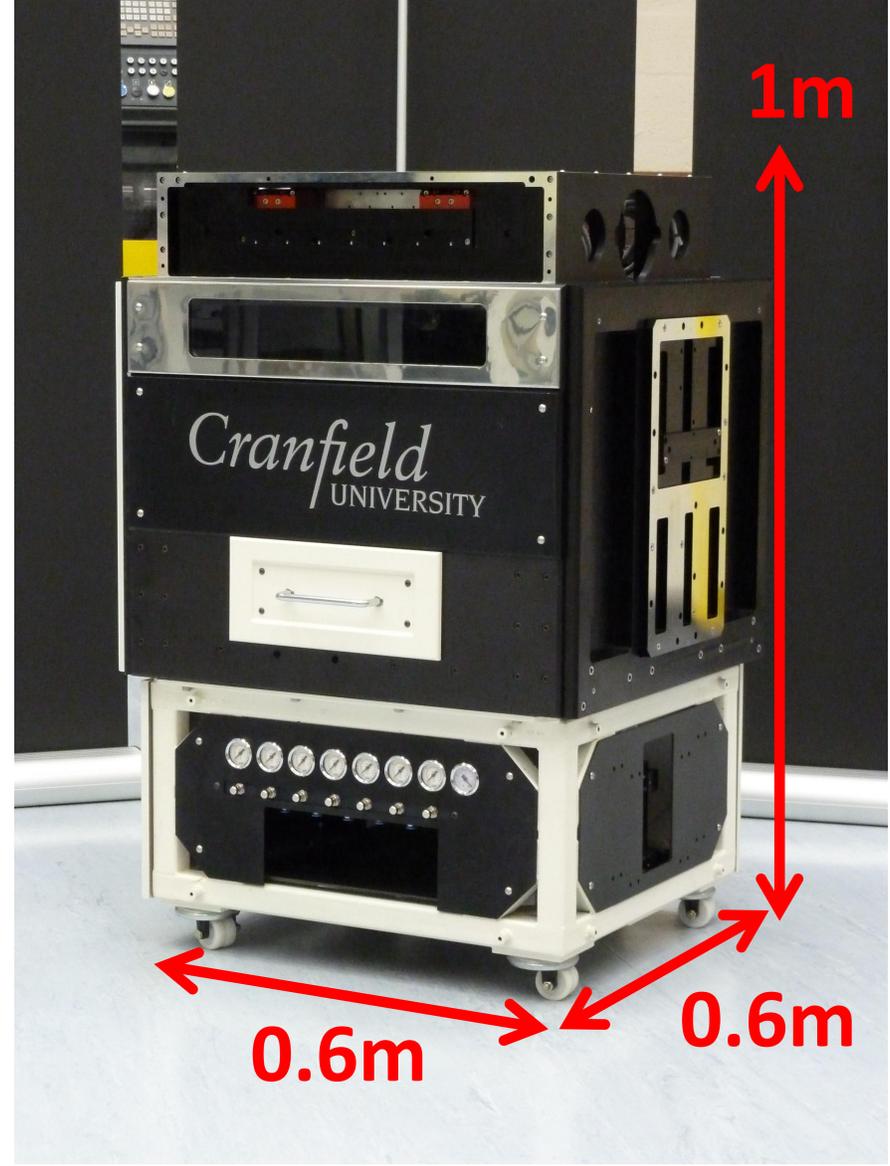
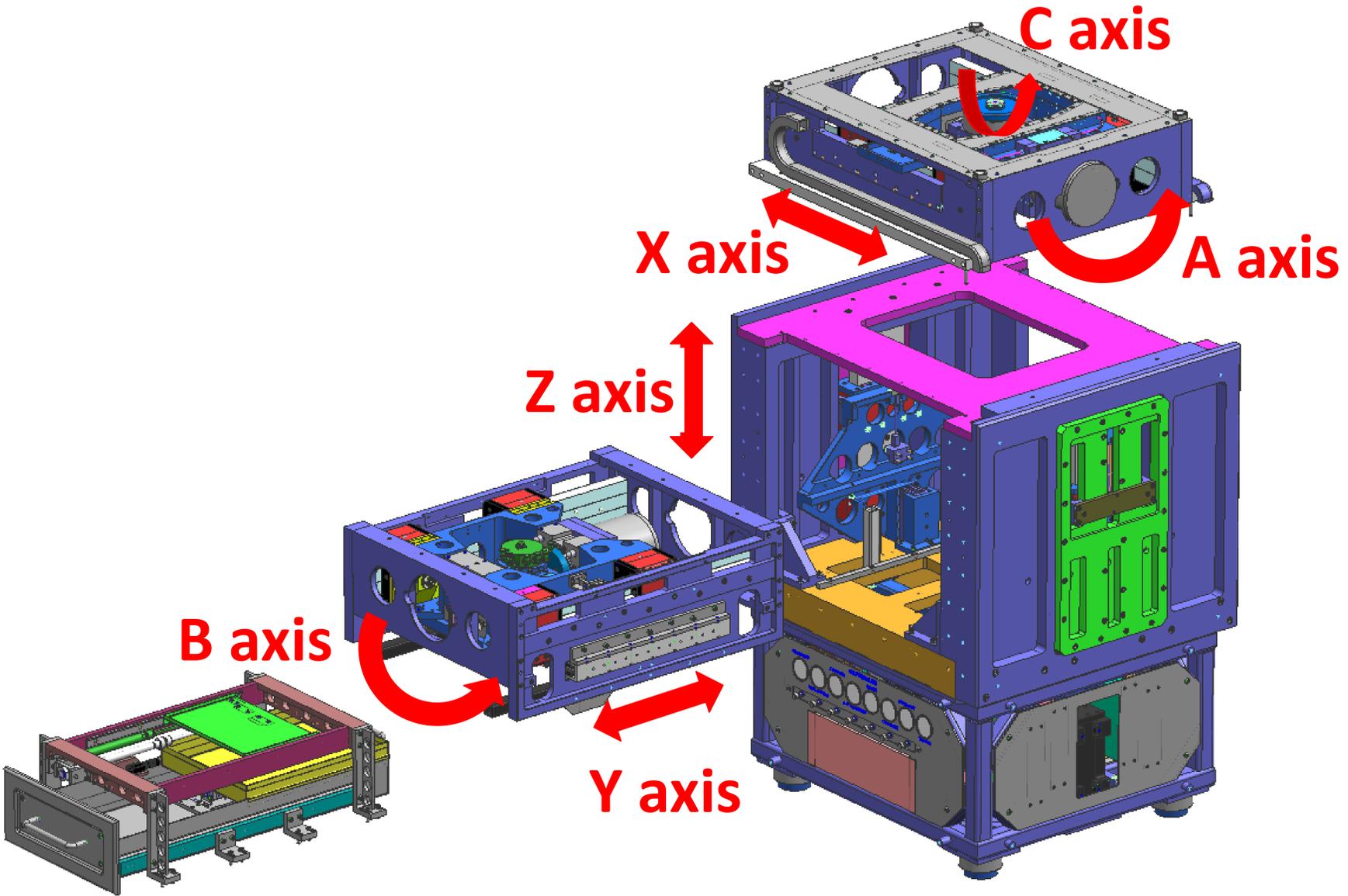
Jonathan Abir, Stefano Longo, Paul Morantz, Paul Shore

Precision Mechatronic System Design and Control - Spring Topical Meeting - 2016



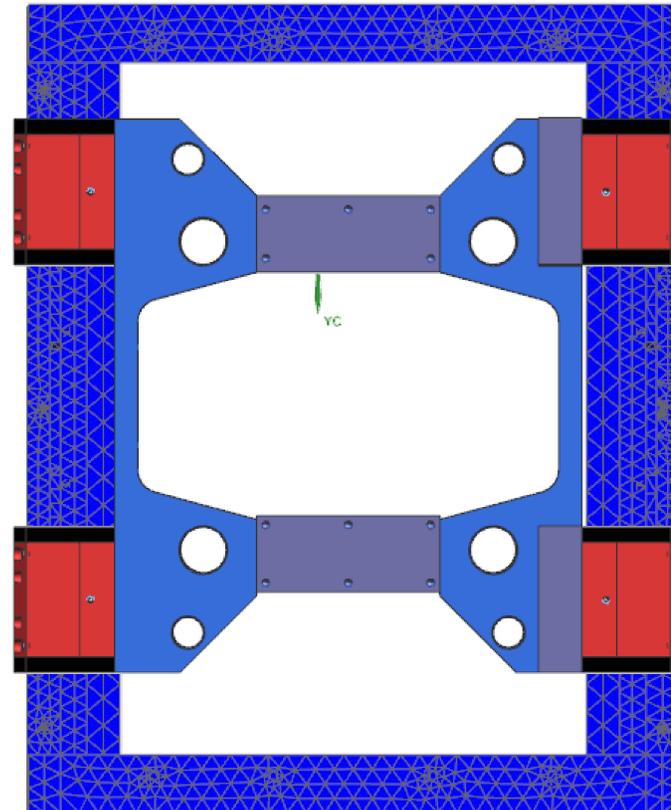
Research aim

- Improve the dynamic performance of a compact size CNC machine

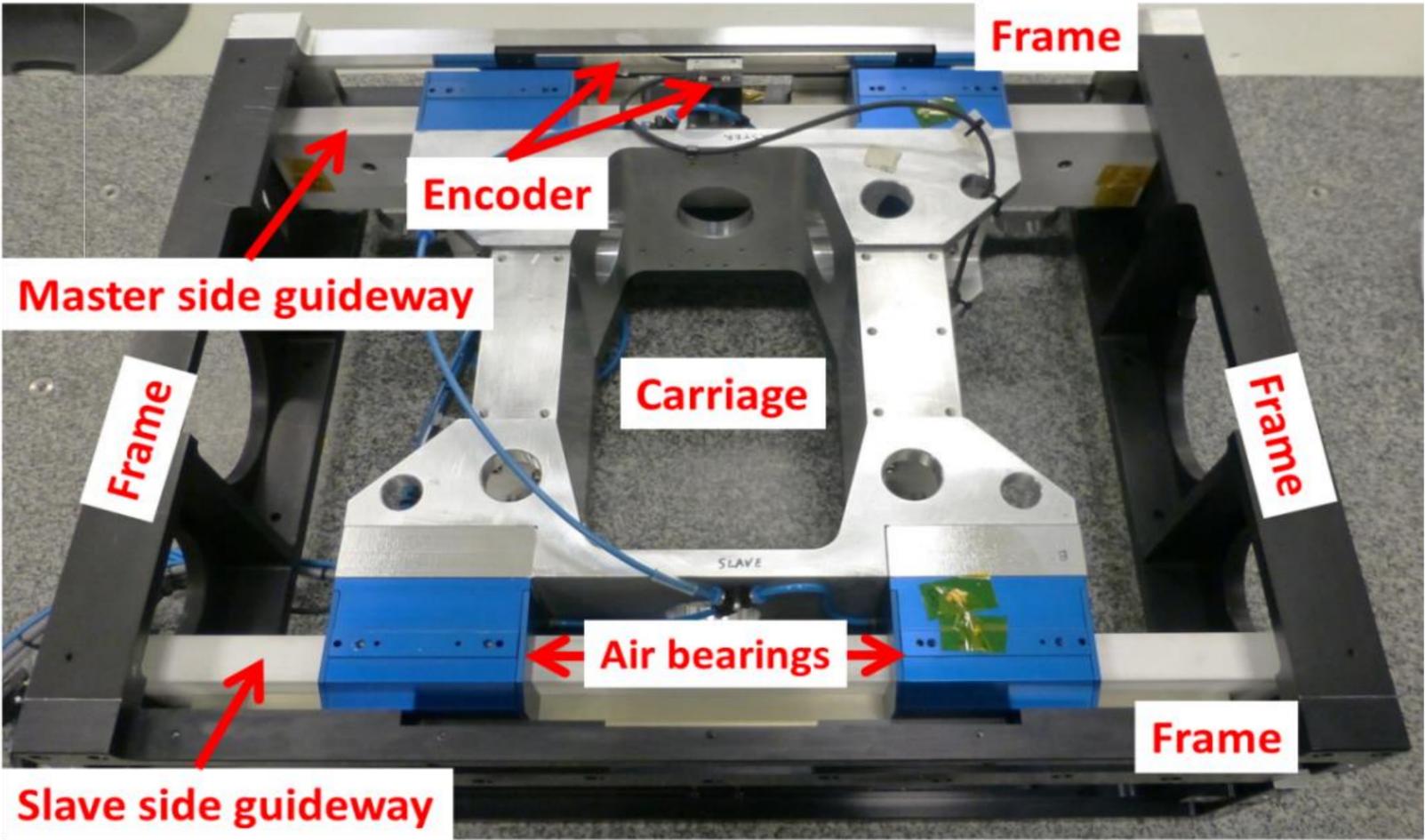
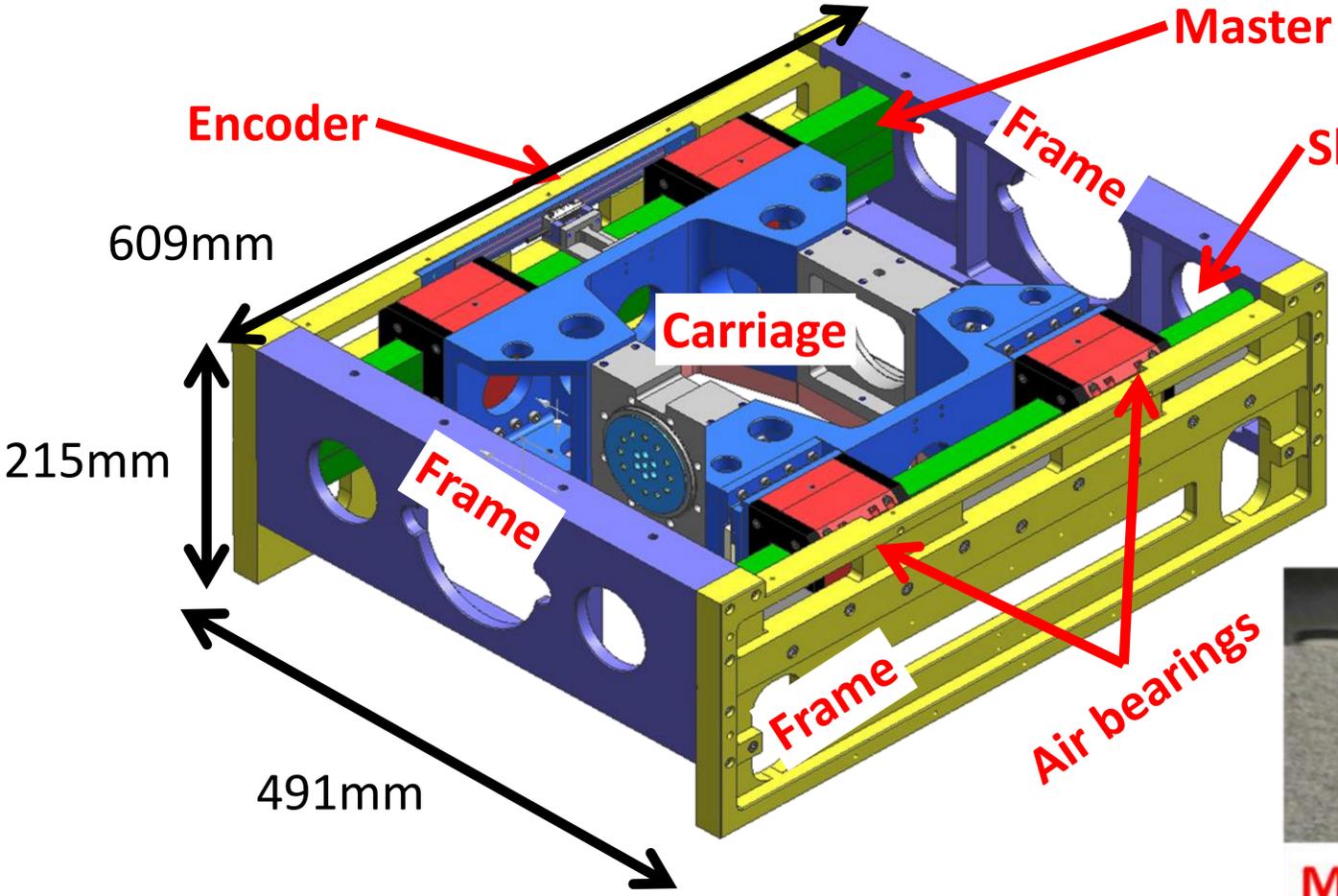


Research objectives

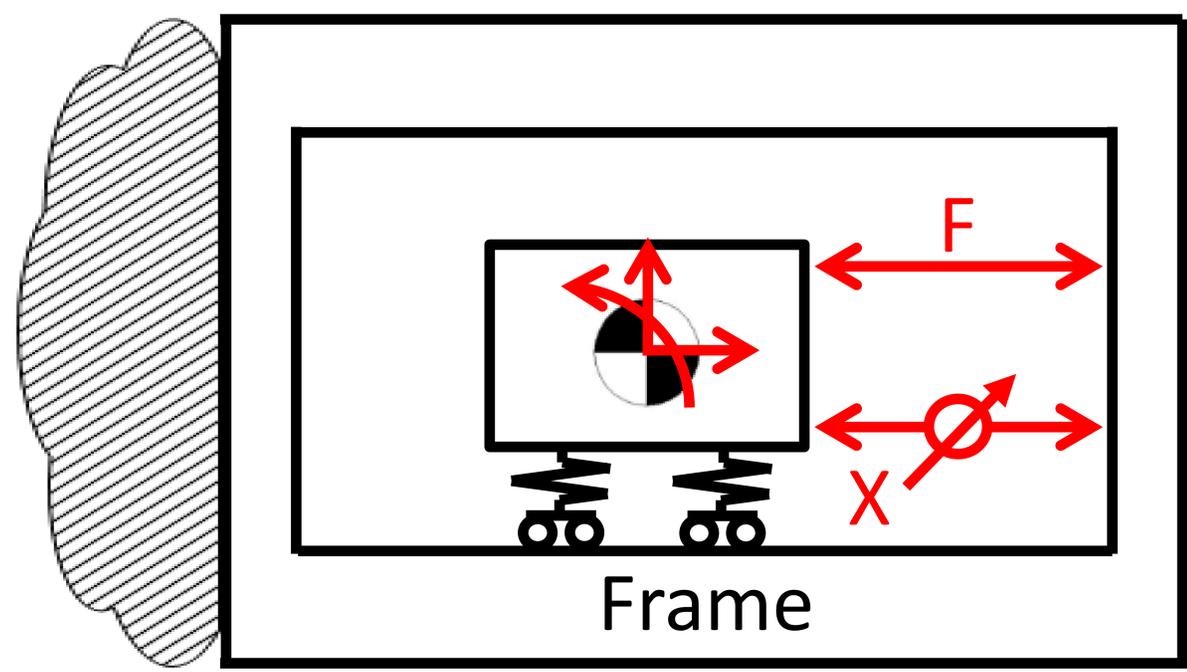
- Reduce the effect of machine **frame resonances**
- Improve the servo bandwidth (improve machining)



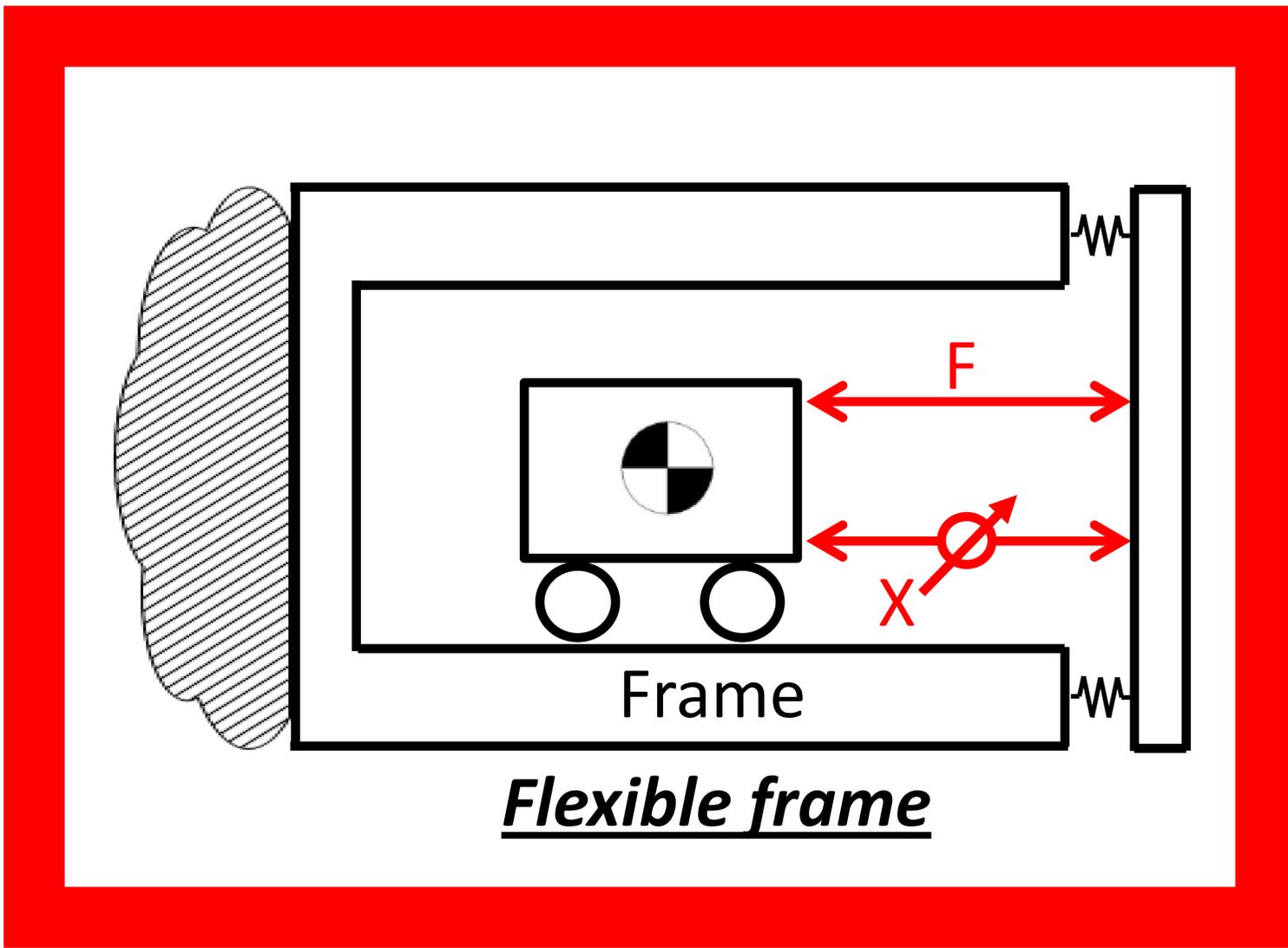
Simplified linear motion system of the $\mu 4$



Dynamic mechanisms limiting servo control

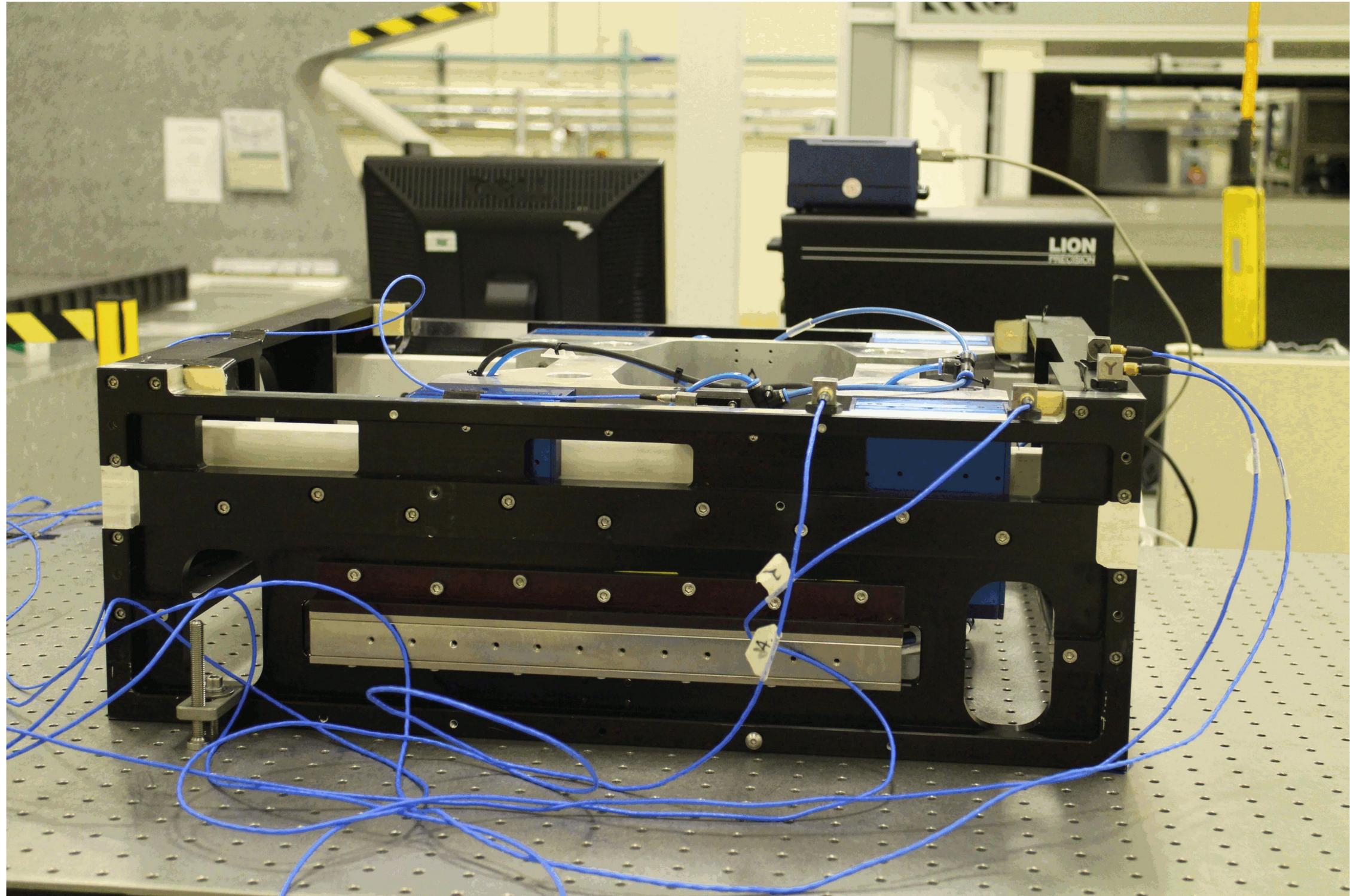


Flexible guidance

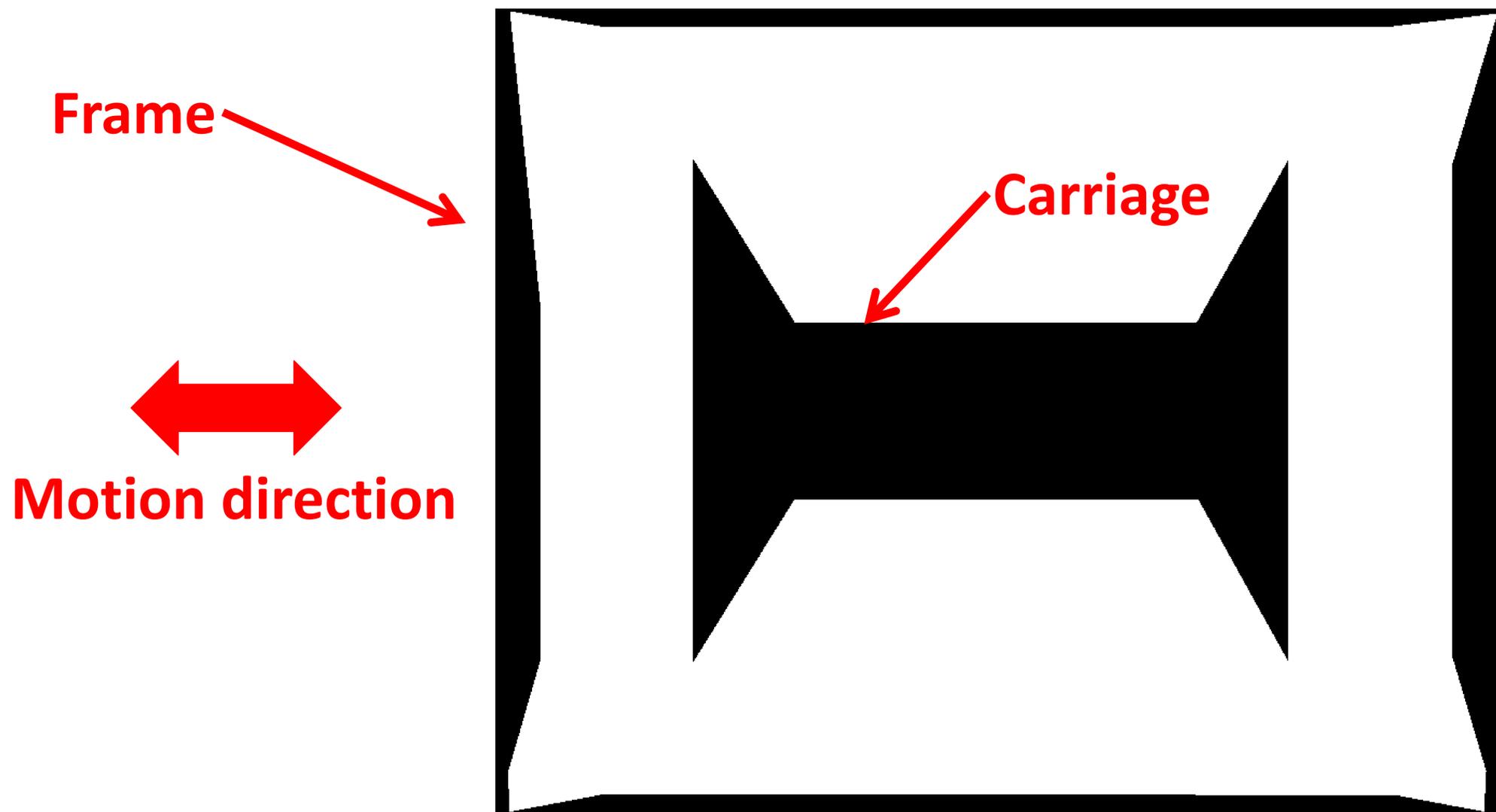


Flexible frame

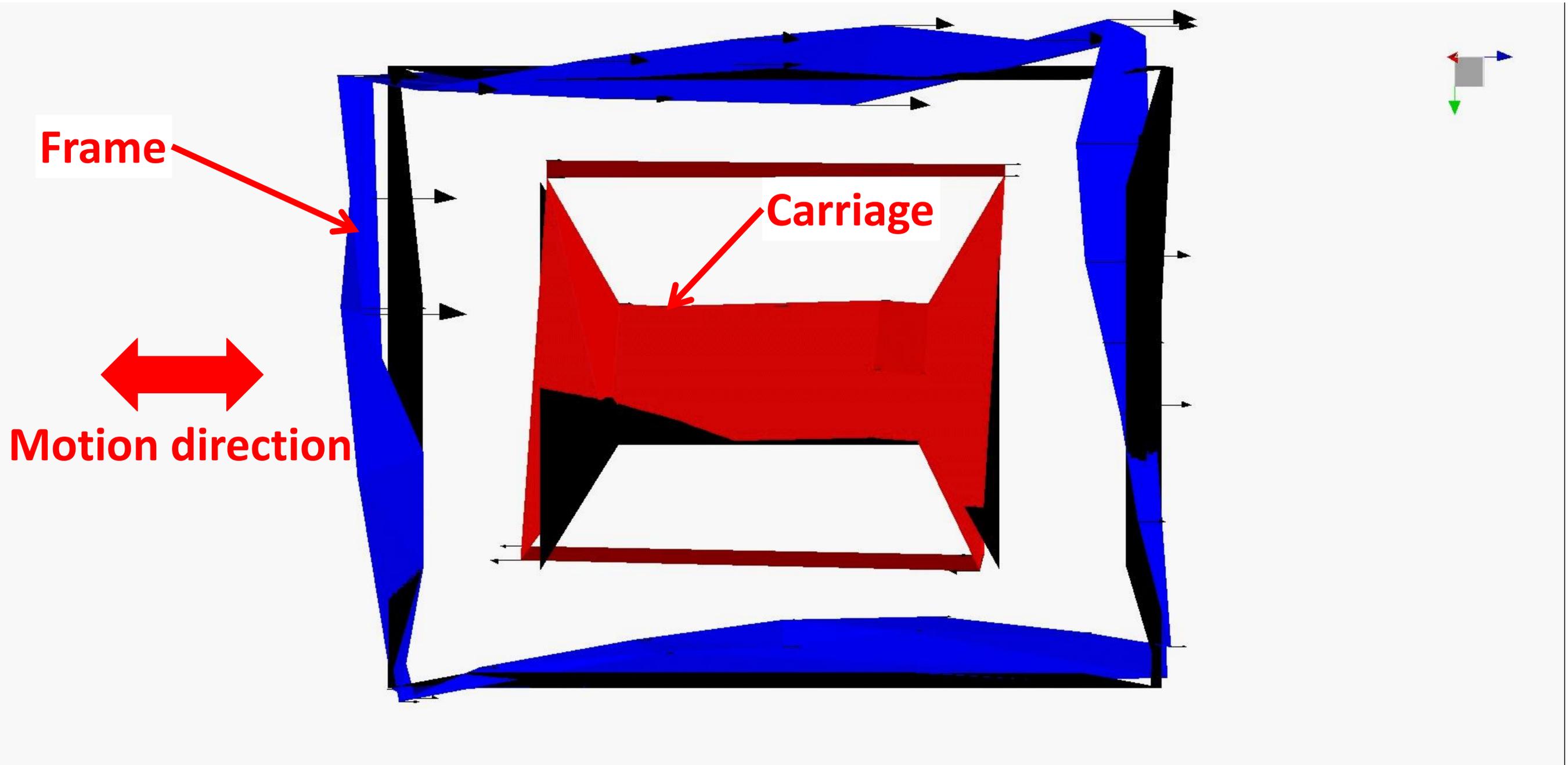
System identification – frame resonance (1) experimental modal analysis



System identification – frame resonance (2) experimental modal analysis

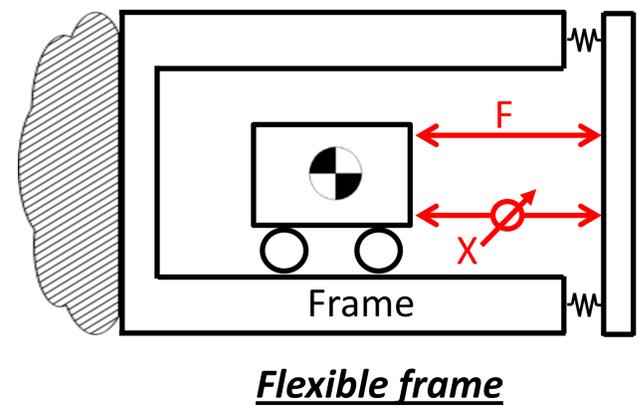
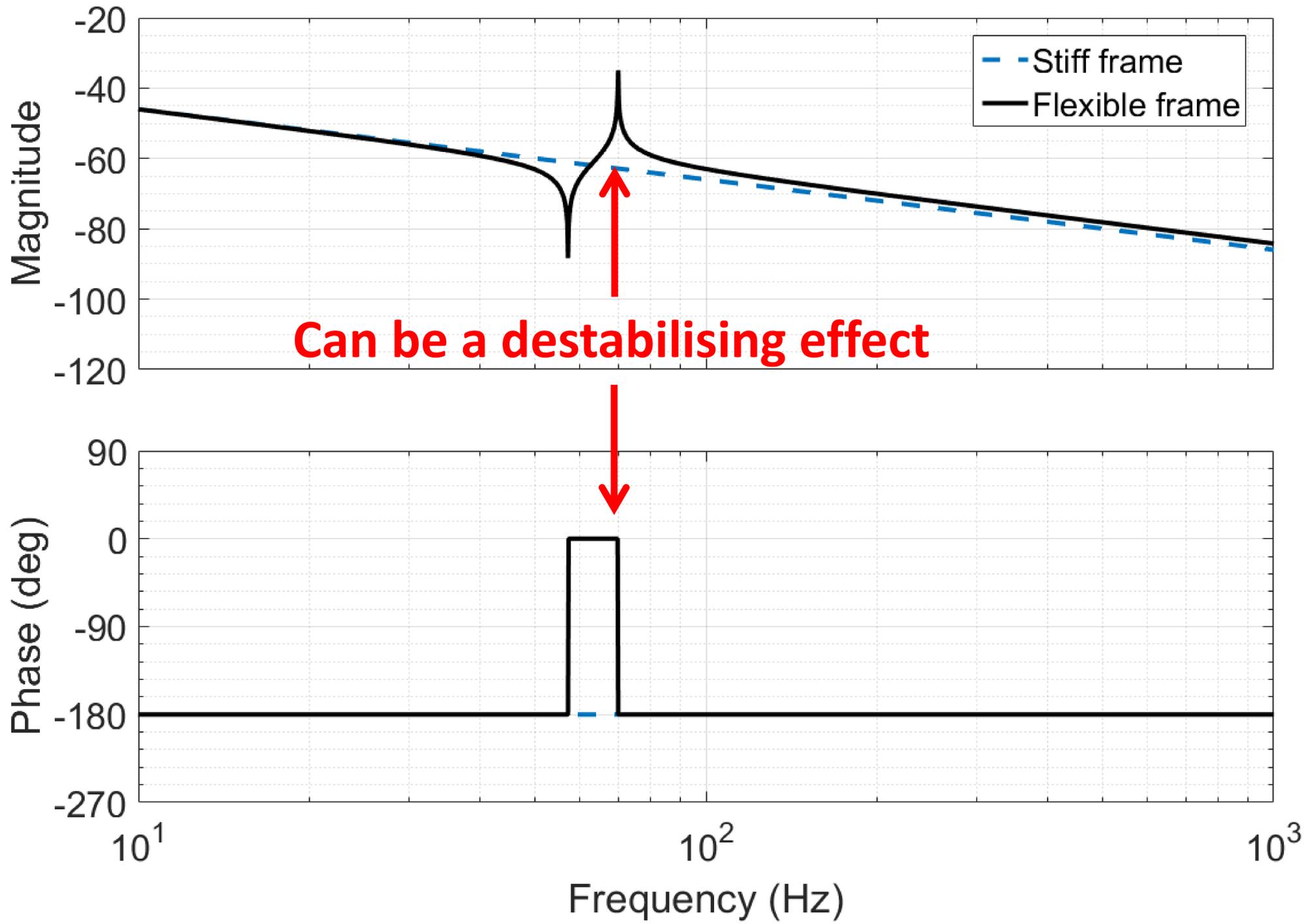


System identification – frame resonance (3) experimental modal analysis



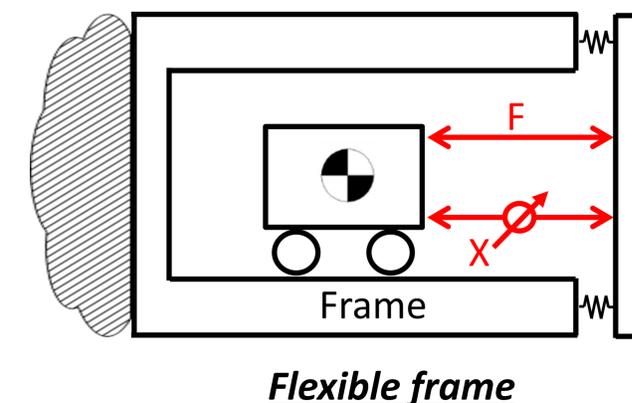
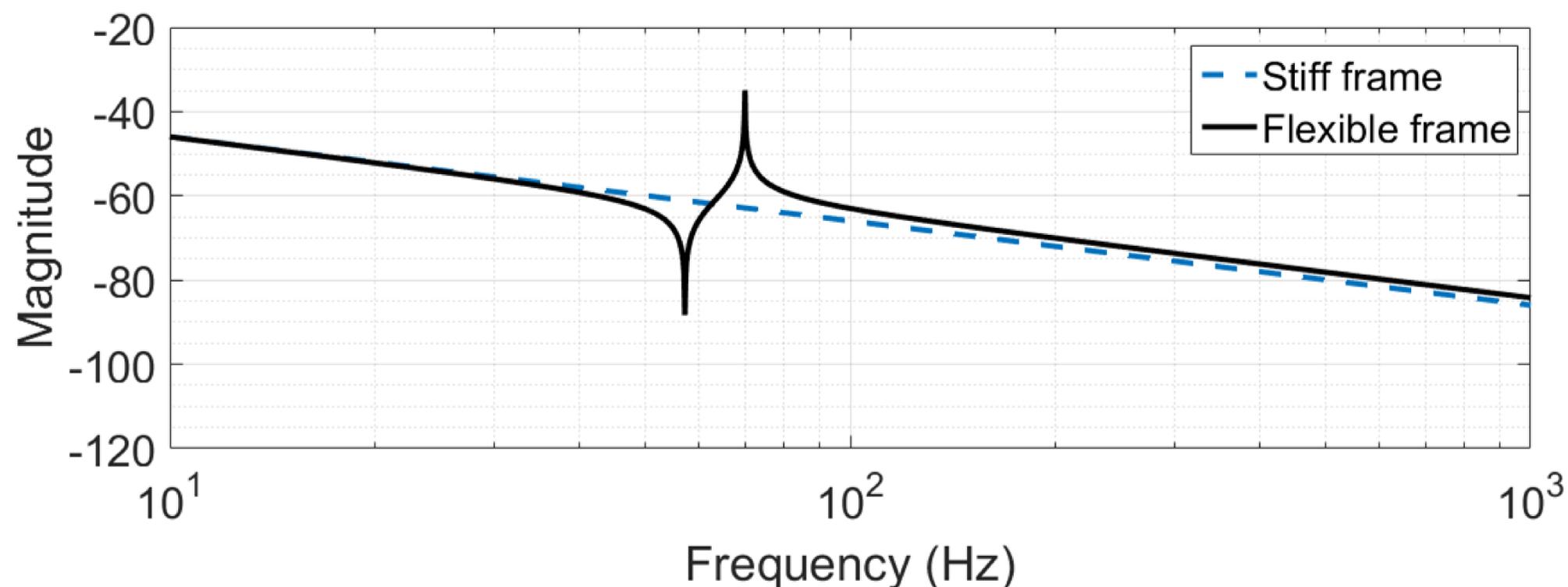
Frame is distorted – reference point is distorted

Flexible frame resonance in a servo plant

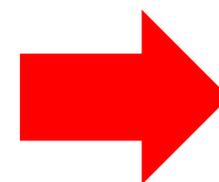


$$P(s) = \frac{X(s)}{F(s)}$$

Servo plant compensation techniques

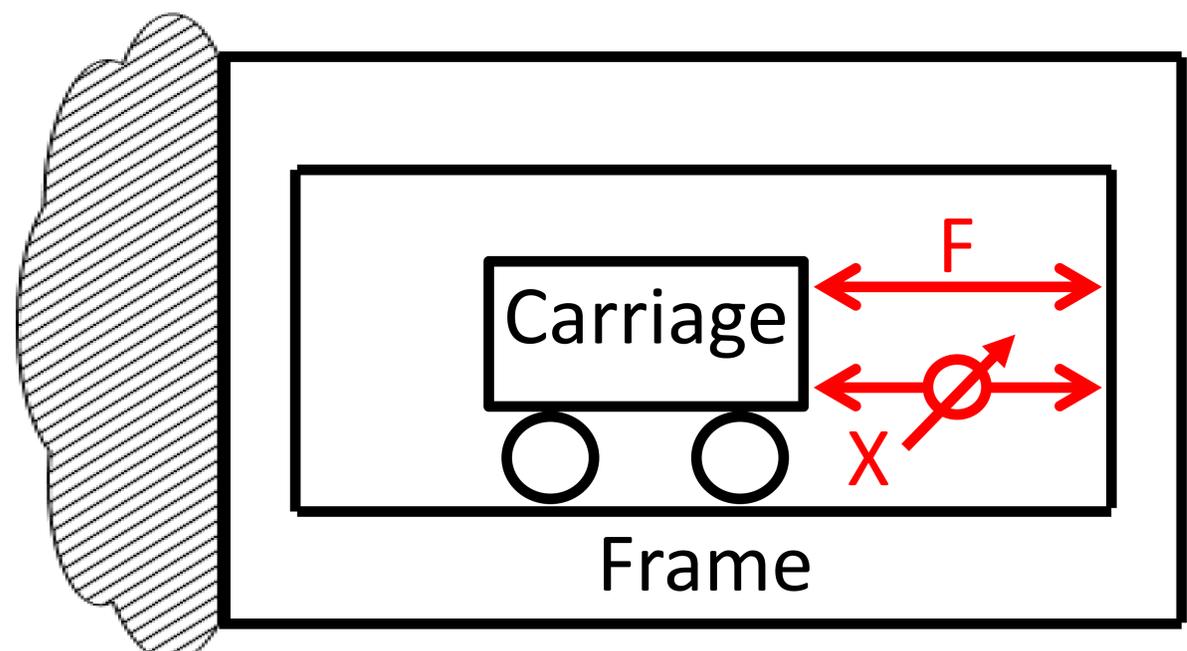


- **Filtering : Notch filter, Bi-quad filter, and Low pass filter**

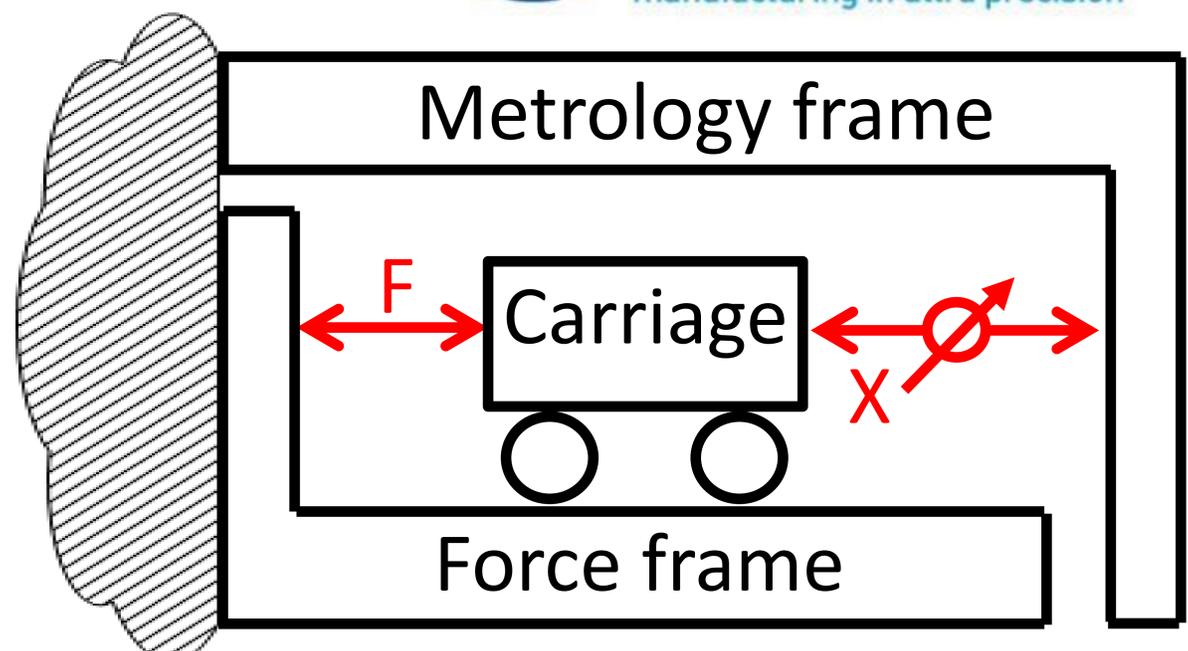


- **Phase lag**
- **Not robust for changes**

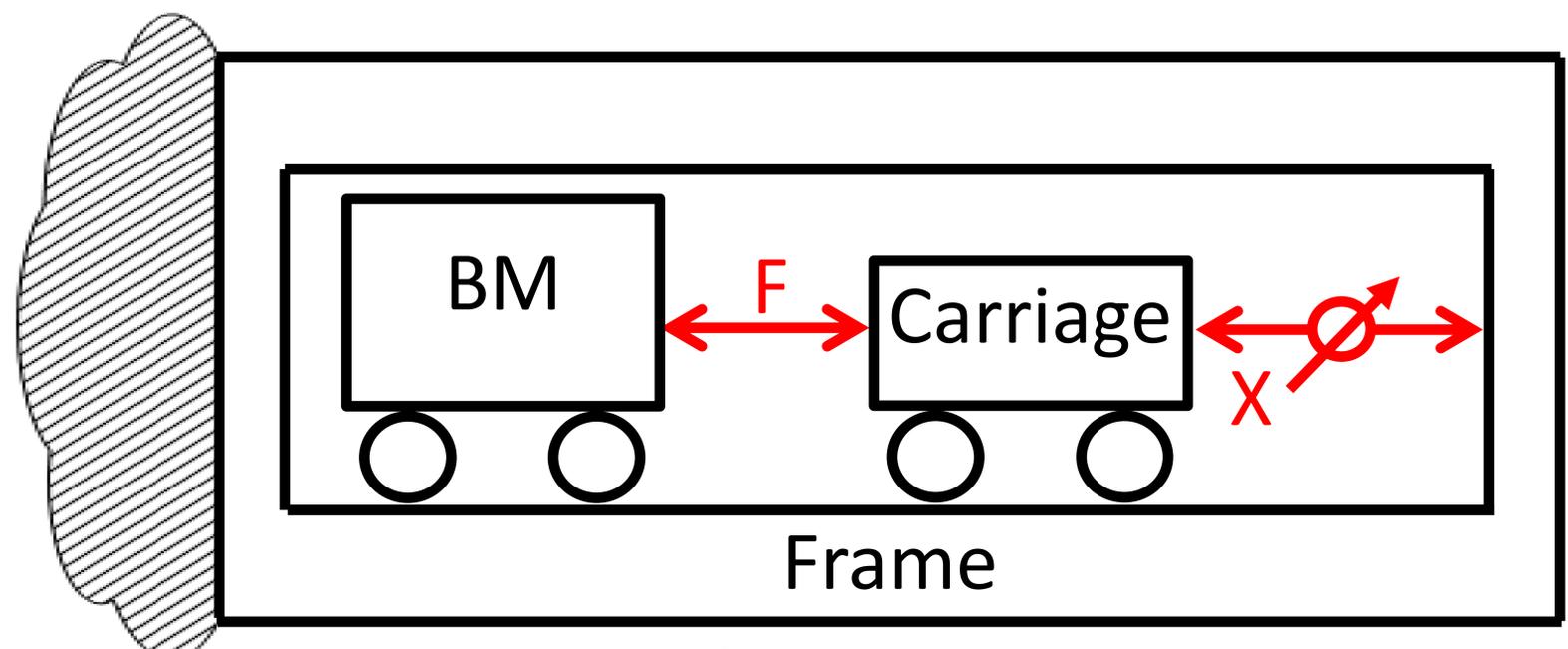
Machine frame concepts



Conventional

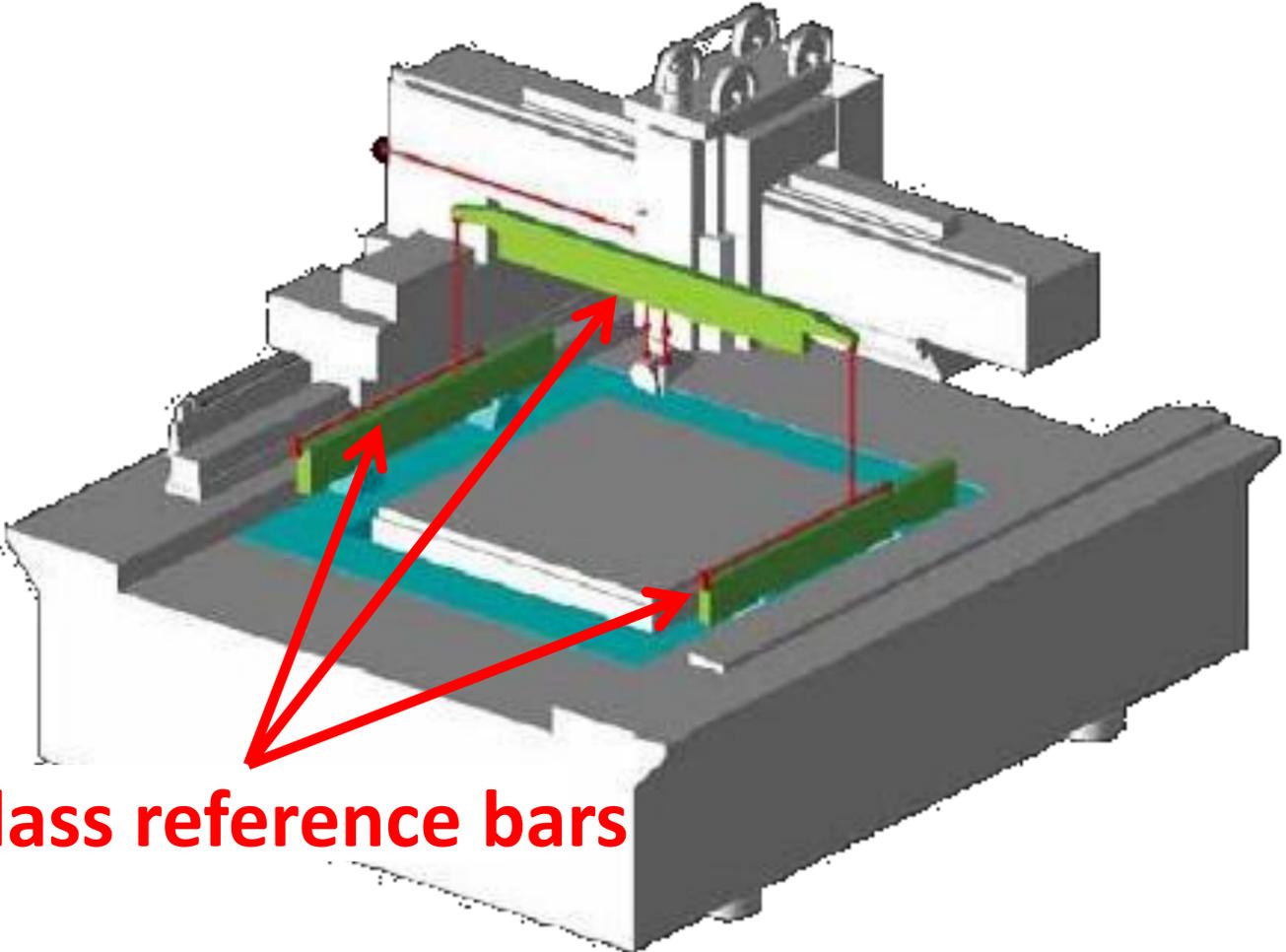
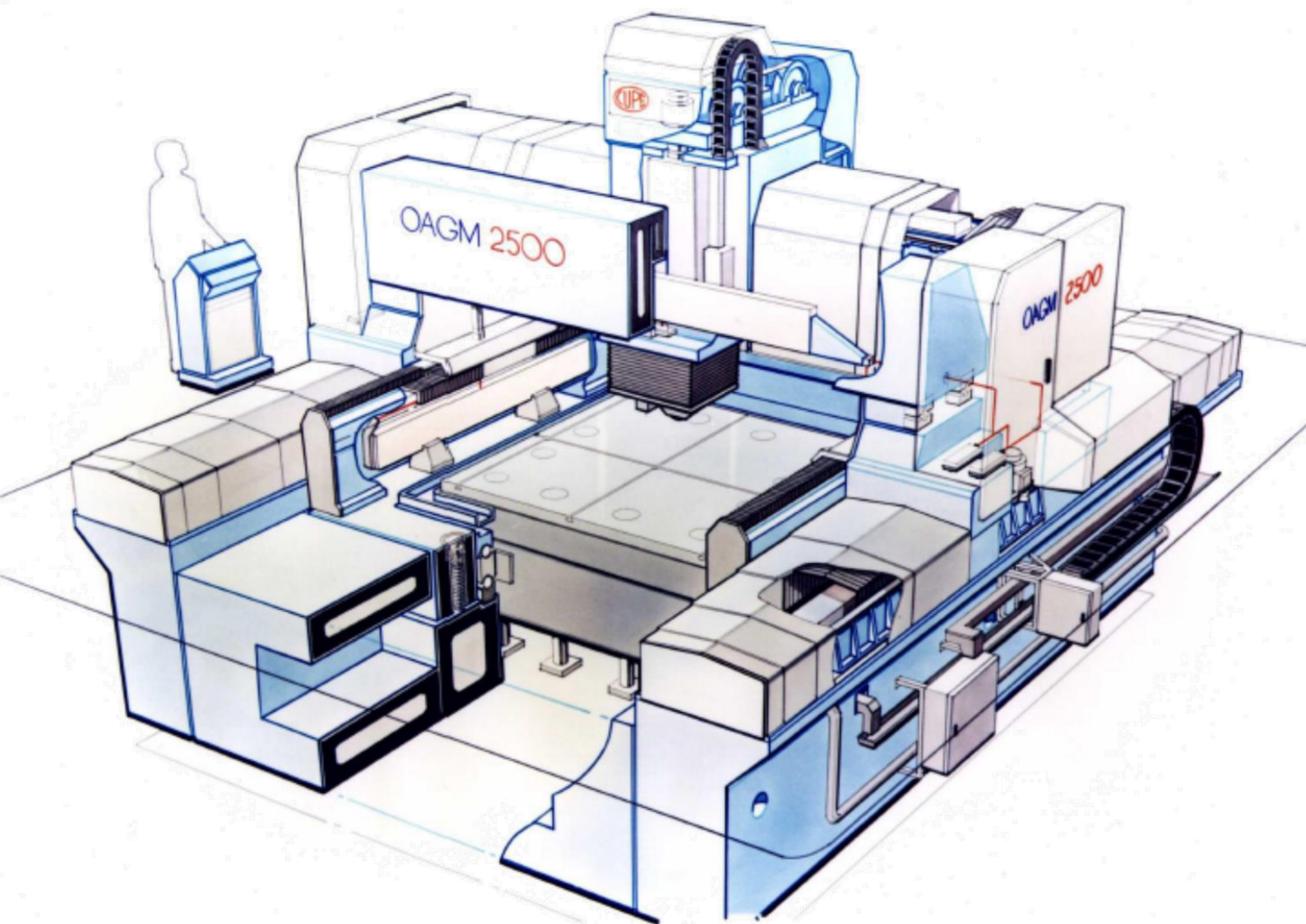


Metrology frame



Balancing Mass

Metrology frame in a machine tool



Glass reference bars

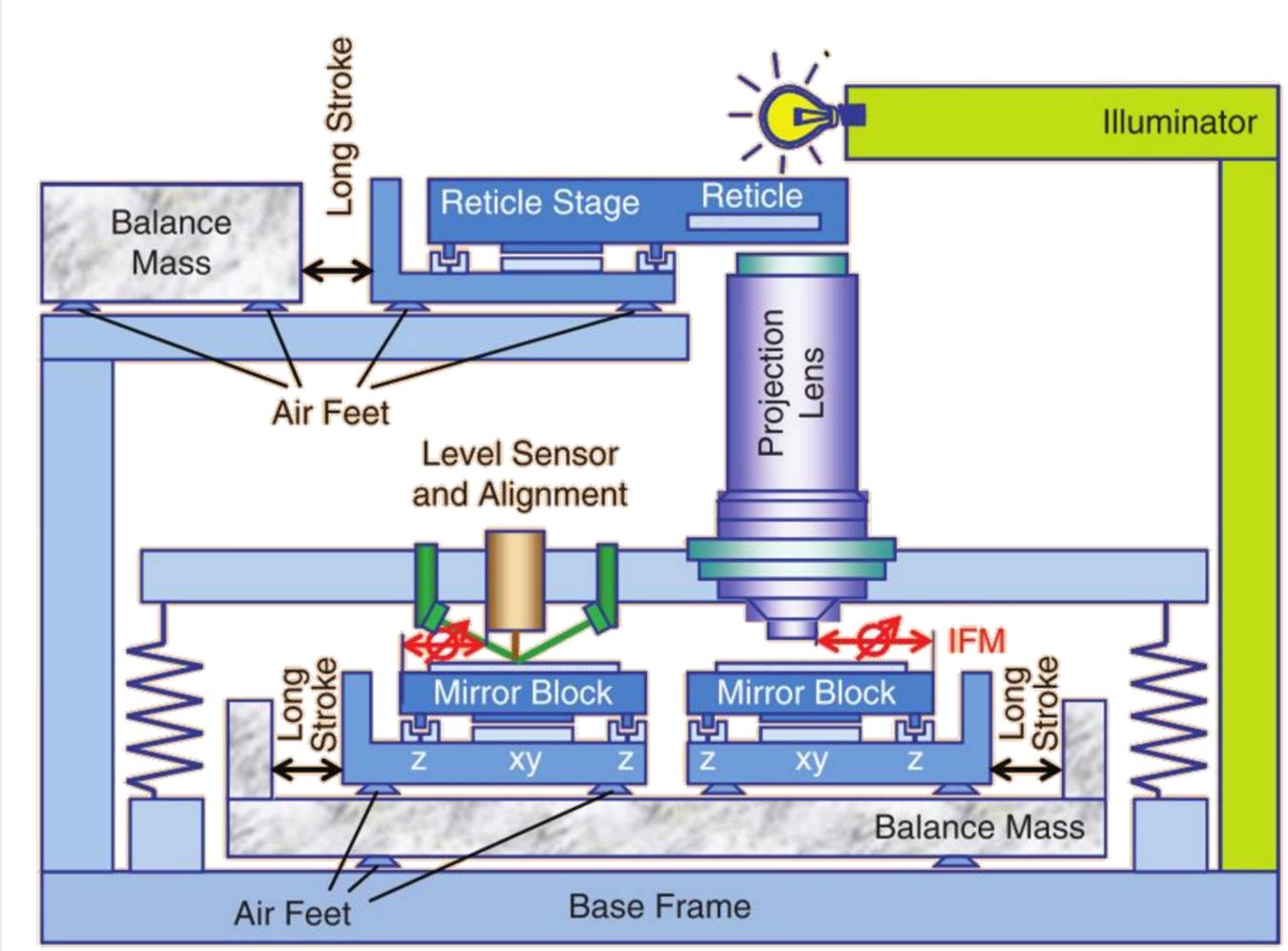
Shore P. et al. *Big OptiX ultra precision grinding/measuring system*. Proc. SPIE. 2005 www.cranfieldprecision.com

OAGM 2500 - Off Axis Grinding Machine

Balancing mass & metrology frame in a machine tool



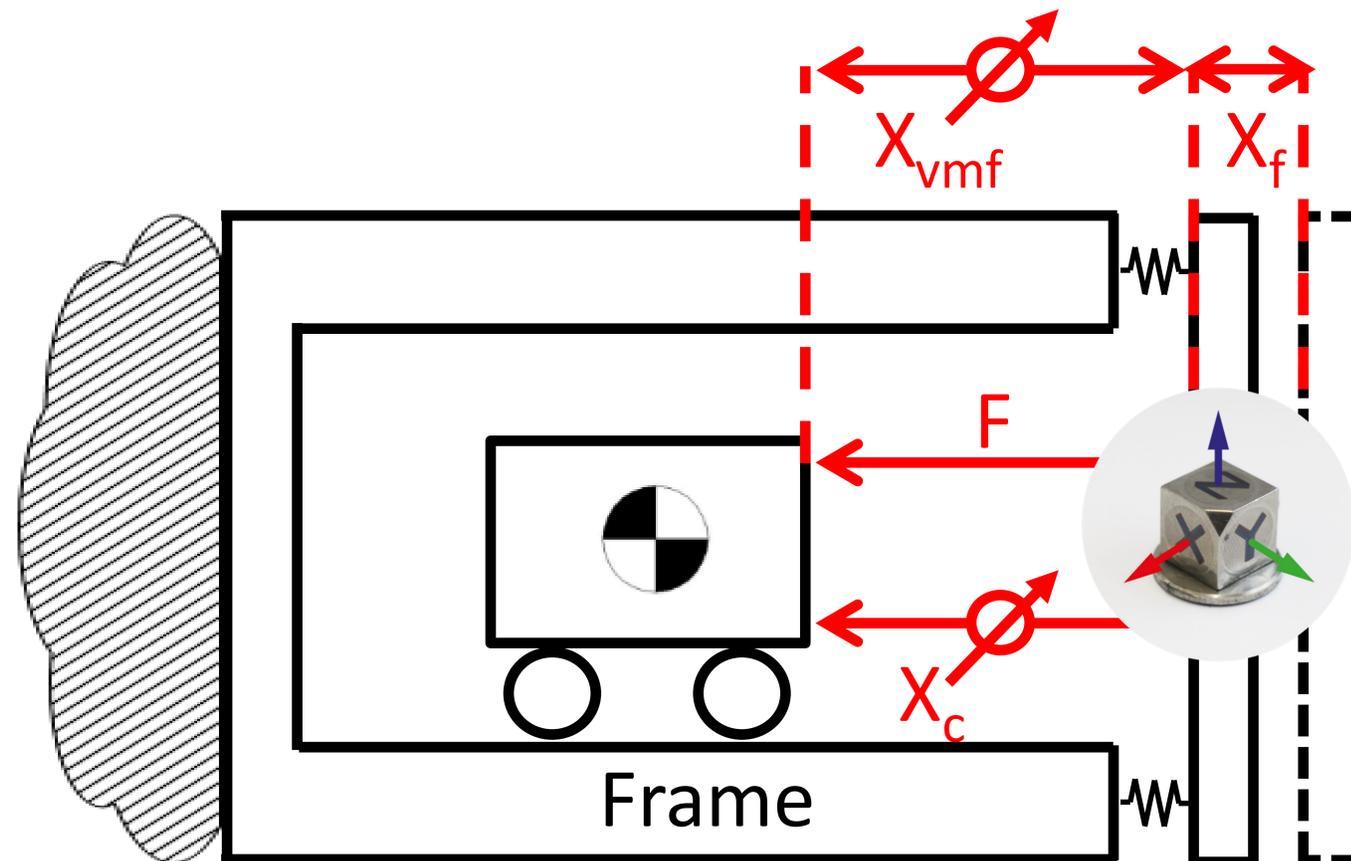
www.asml.com



Butler H. *Position control in lithographic equipment*. IEEE control magazine. 2011.

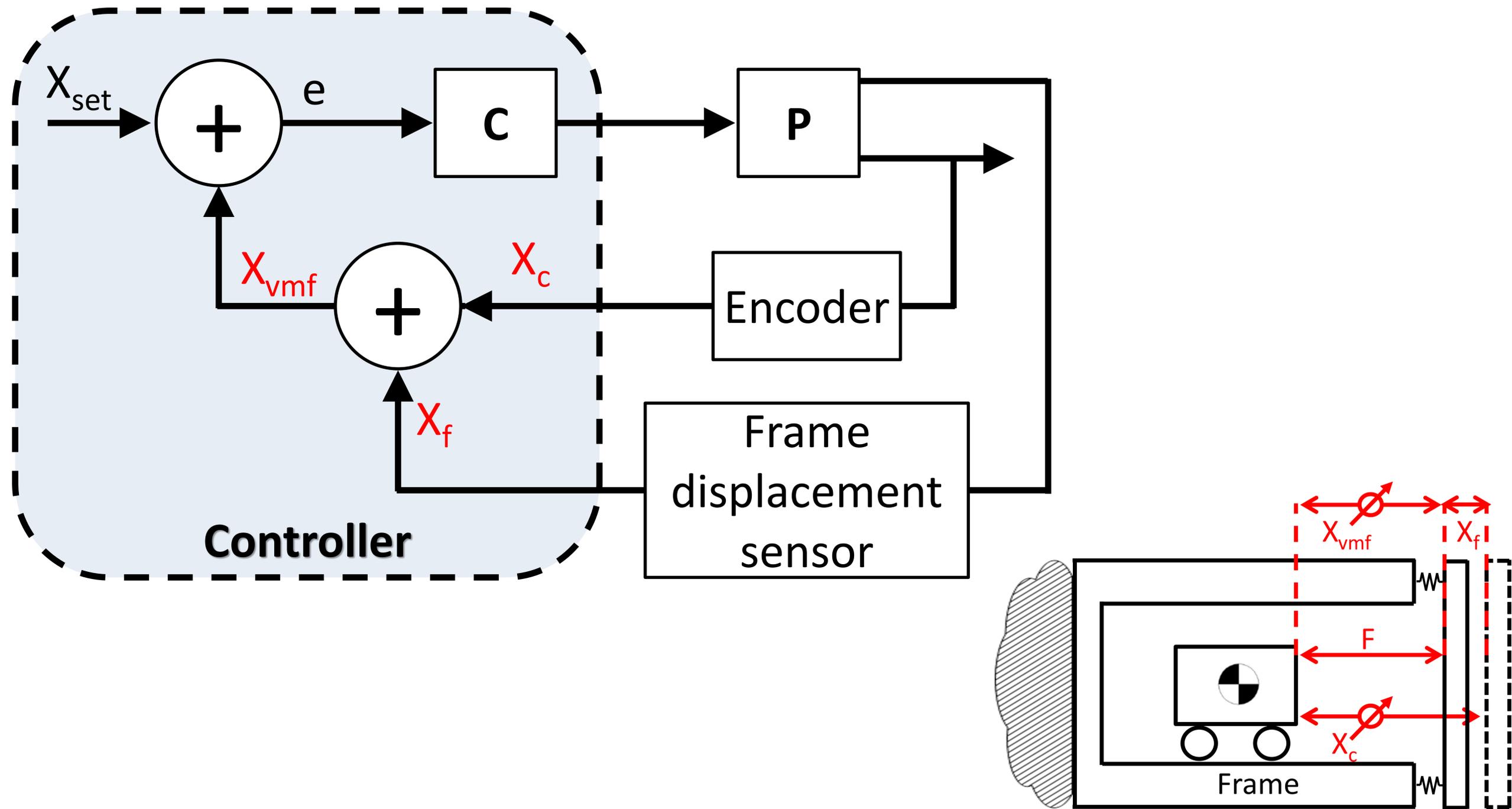
ASML TWINSKAN – Lithography platform

Virtual Metrology Frame concept



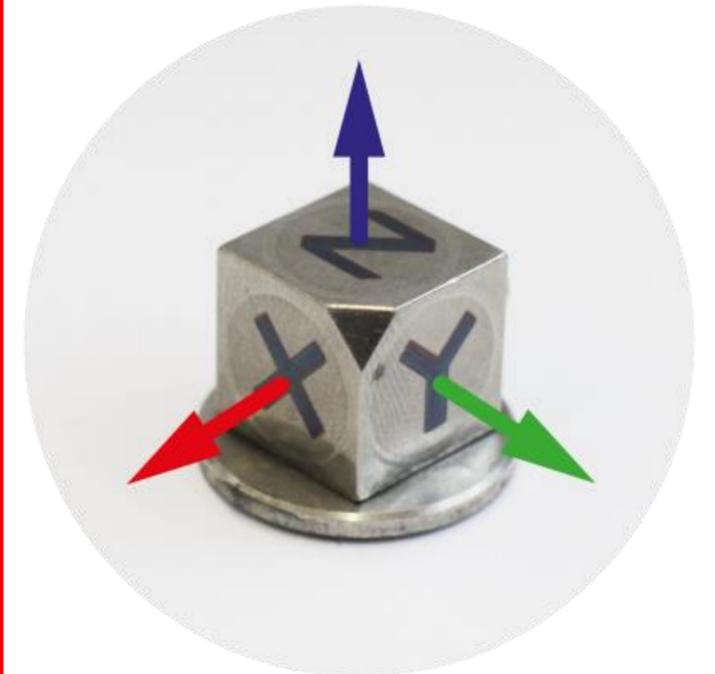
$$X_c - X_f = X_{vmf}$$

Virtual Metrology Frame concept – controller



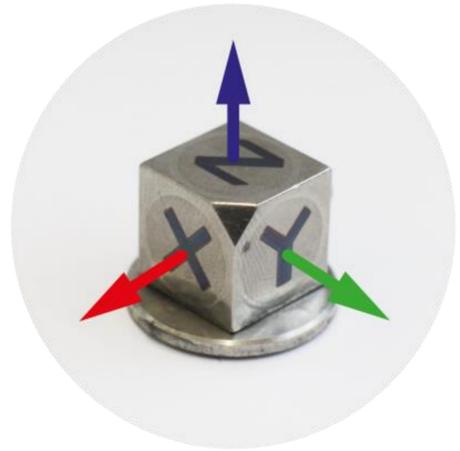
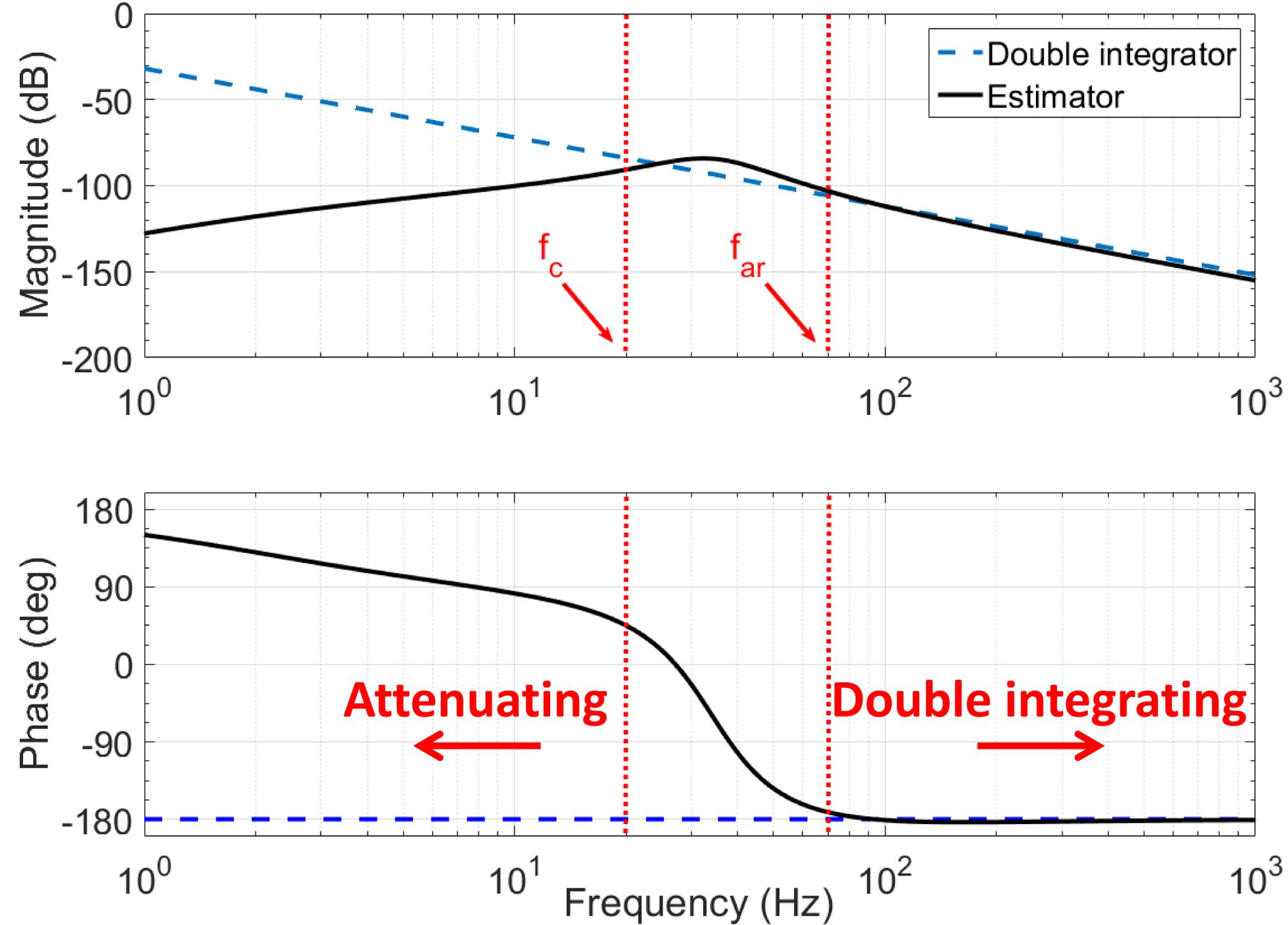
Requirements of frame displacement sensor

- No reference point – “virtual metrology frame”
- Low delay
- Low noise – compared to the encoder
- Measure dynamic displacement of machine frame

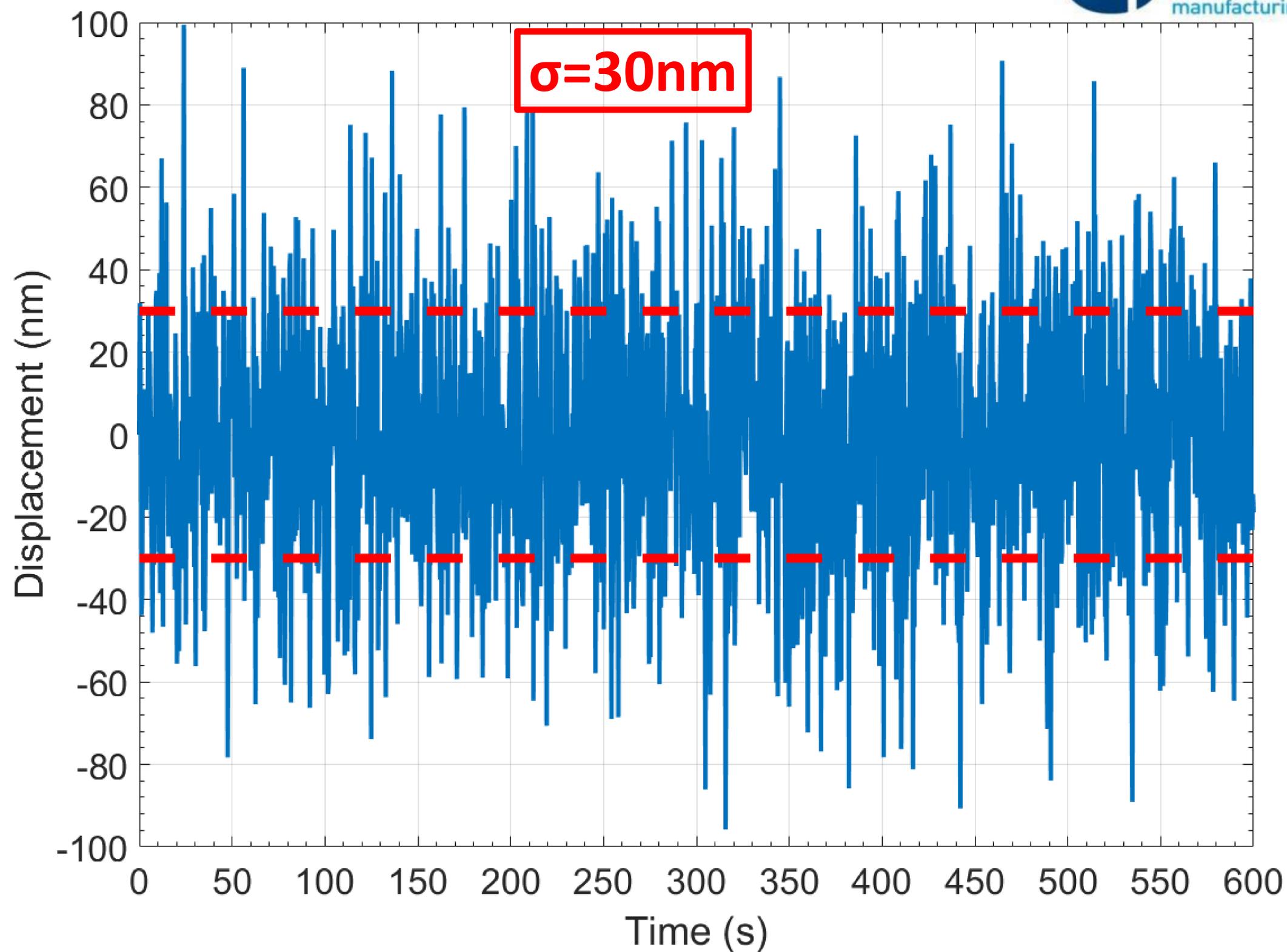


$$\iint a(t) dt^2 = d(t)$$

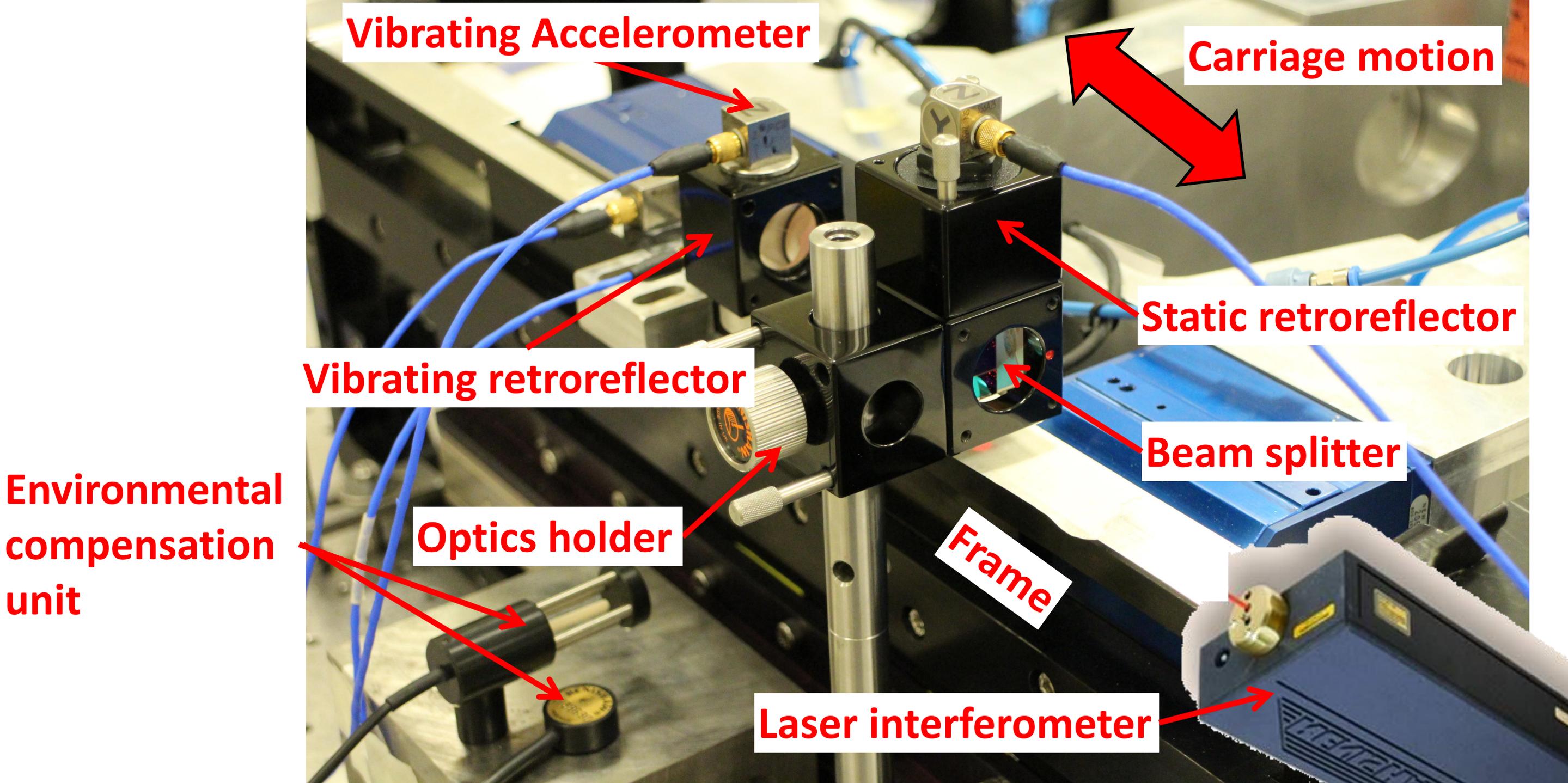
Frame displacement sensor - estimator (filter) design



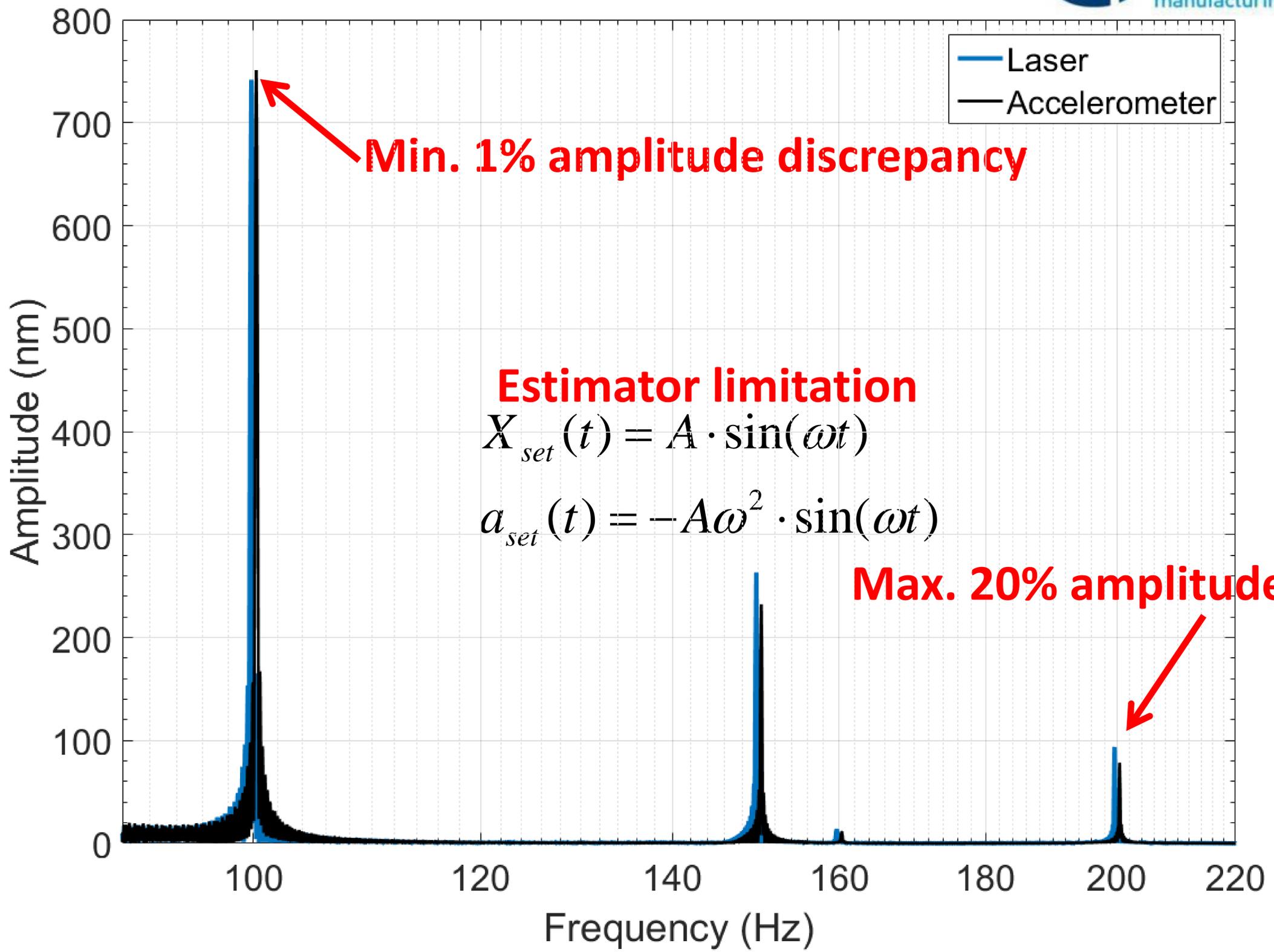
Validation of the estimator – long term



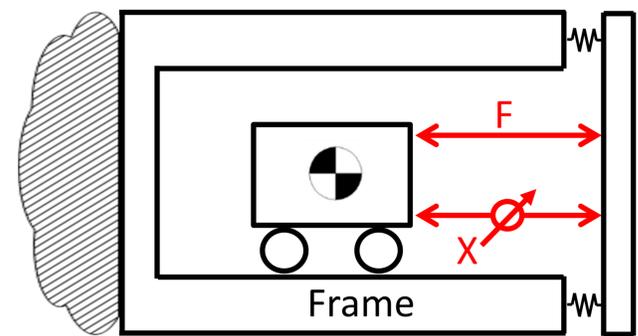
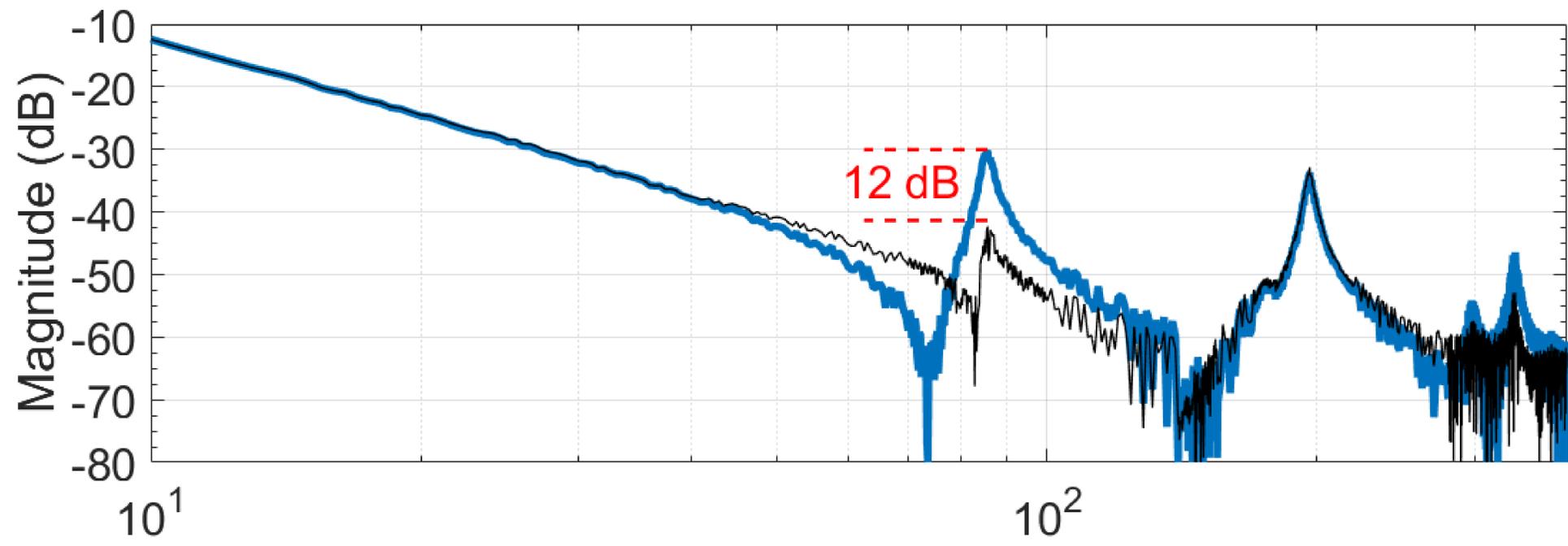
Validation of the estimator - setup



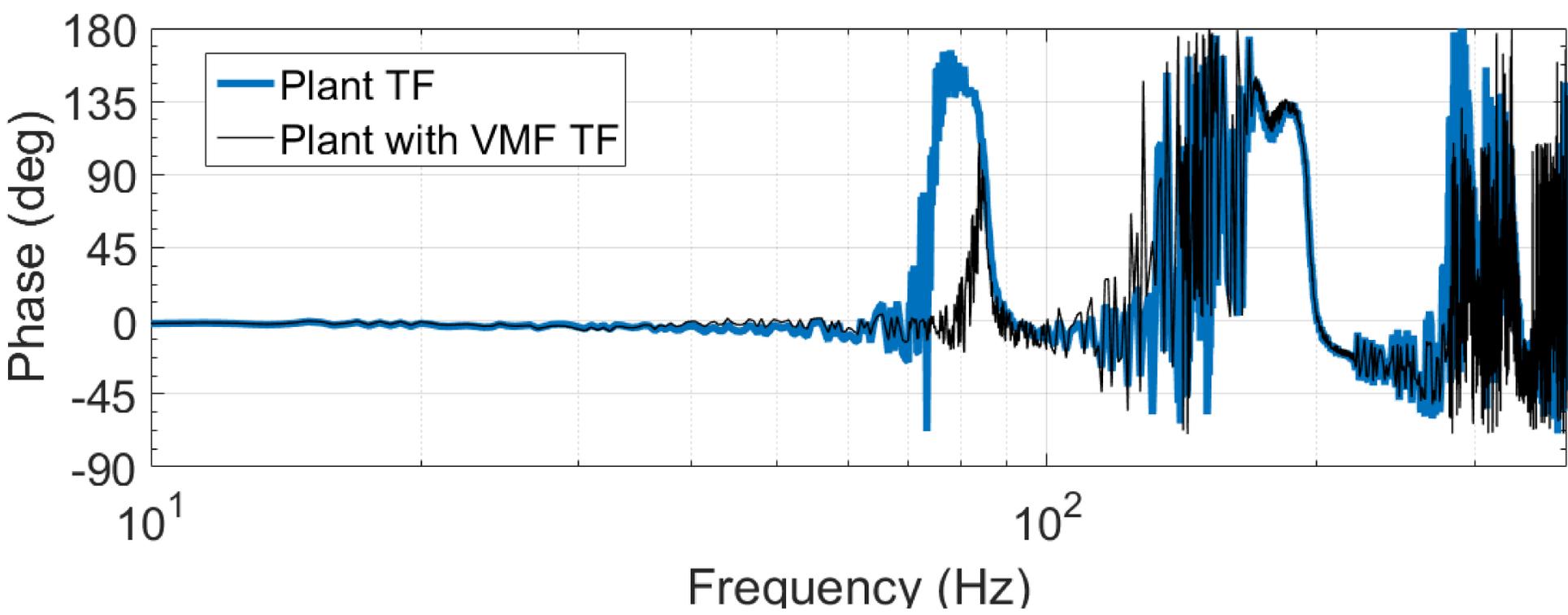
Validation of the estimator - results



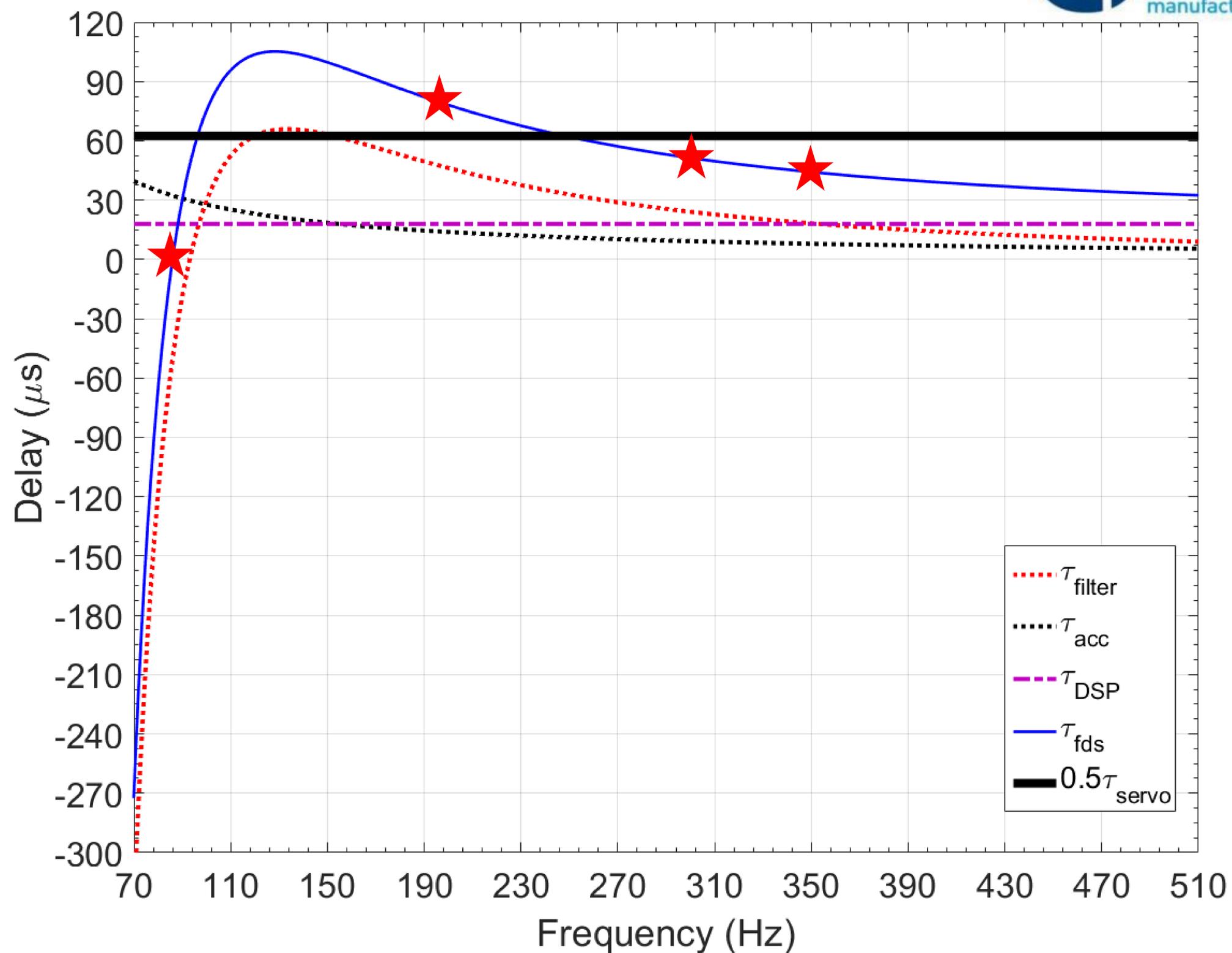
Results of plant transfer function



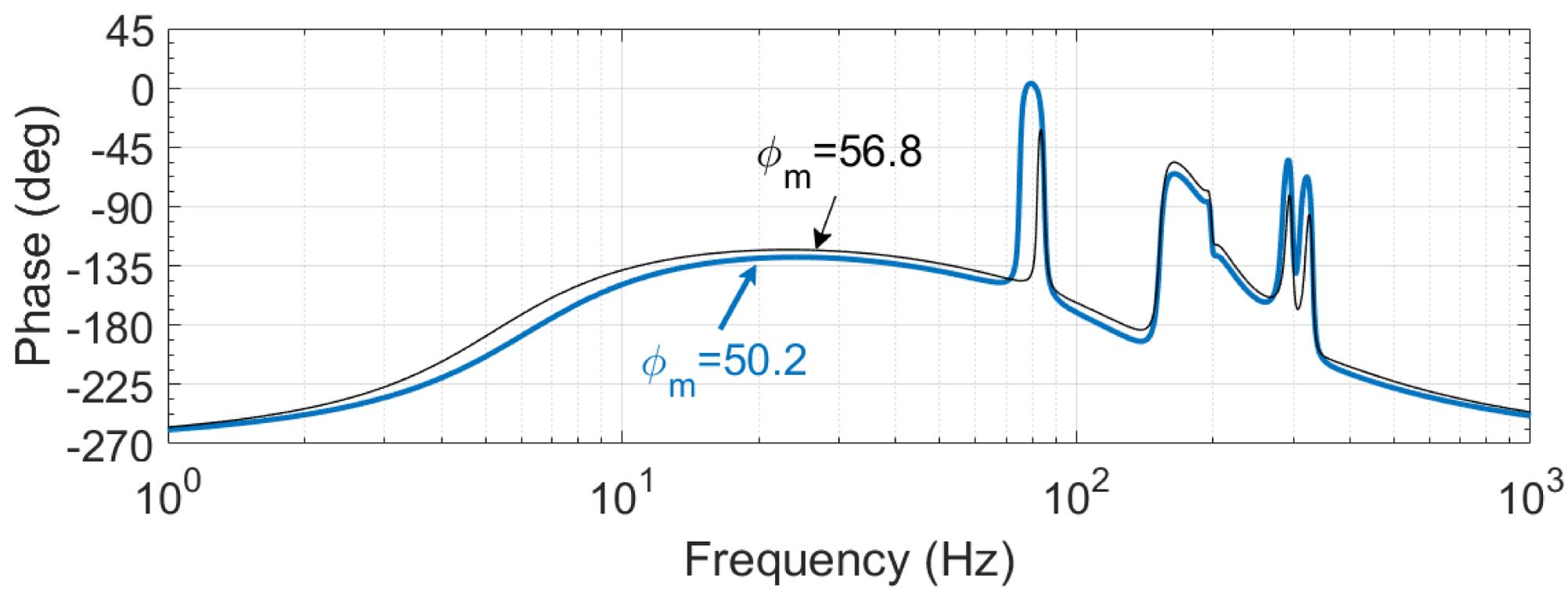
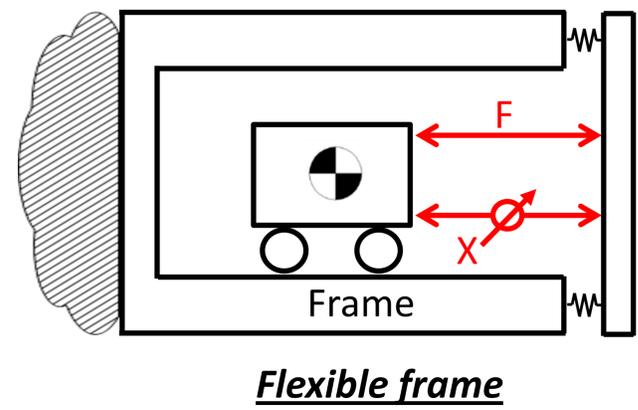
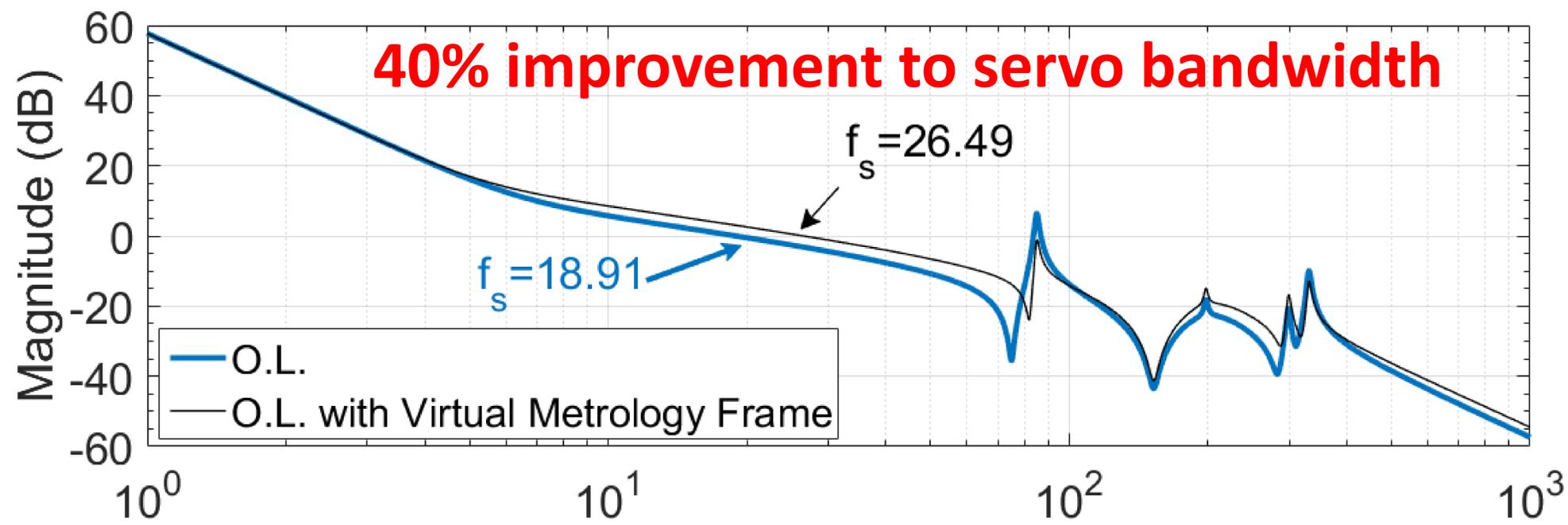
$$P(s) = \frac{X(s)}{F(s)}$$



Virtual Metrology Frame time delay



Open loop Bode graph



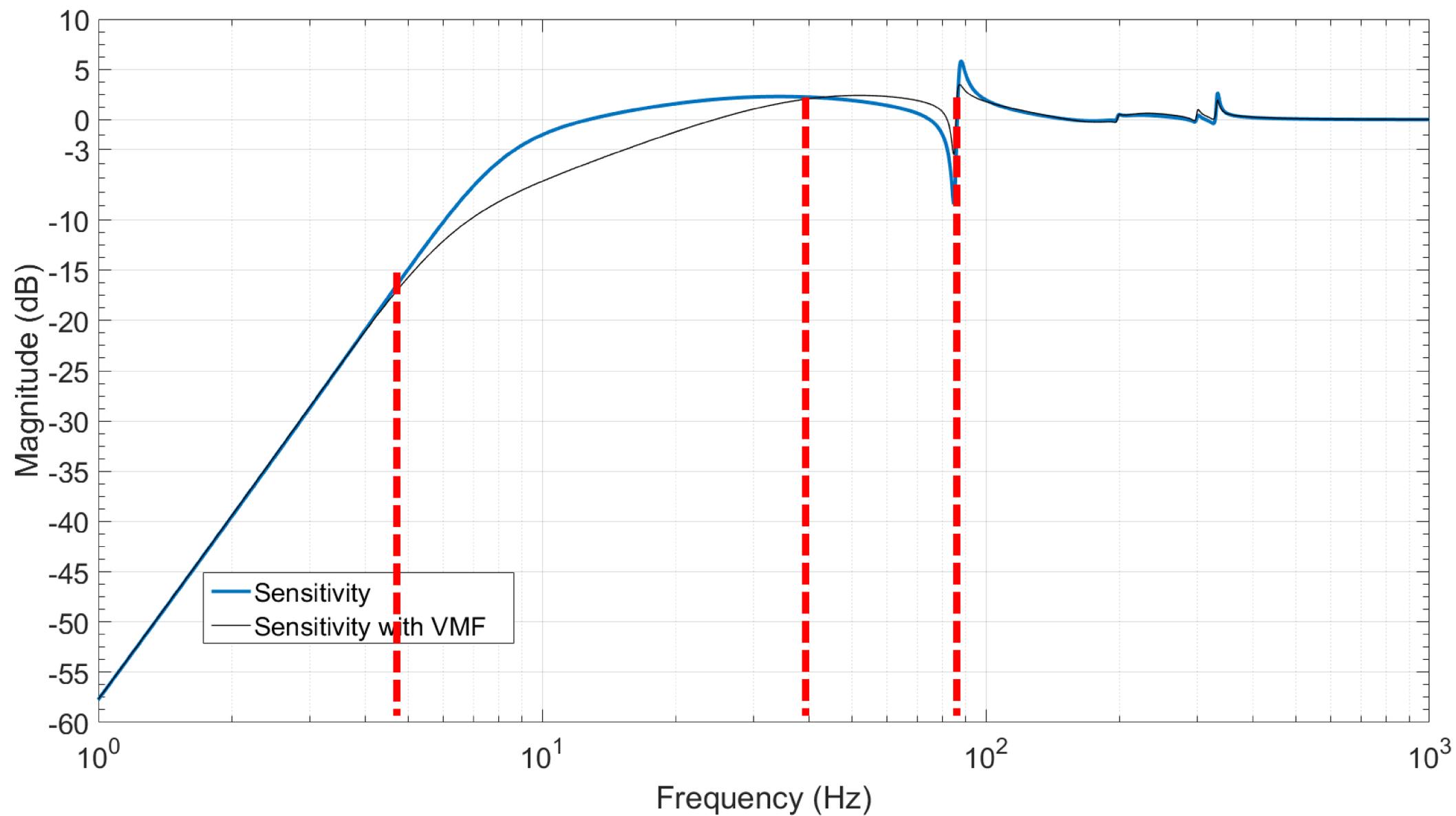
Notch filter @ 195Hz

G_m – Gain margin >6dB

ϕ_m – Phase margin >45°

f_s – Servo bandwidth

Sensitivity graph



Summary:

- **Dynamic displacement sensor using accelerometer**
 $\sigma=30\text{nm}$
- **Servo plant compensation technique :**
 - **Robust**
 - **No instability**
 - **No phase delay**
- **Improved the servo bandwidth by 40%**



Summary:

- **Dynamic displacement sensor using accelerometer**
 $\sigma=30\text{nm}$
- **Servo plant compensation technique :**
 - **Robust**
 - **No instability**
 - **No phase delay**
- **Improved the servo bandwidth by 40%**

