Active Damping of Rotating Platforms using Integral Force Feedback

ISMA-USD 2020, September 7-9, 2020

Thomas Dehaeze [1,3] Christophe Collette [1,2]

[1]Precision Mechatronics Laboratory, University of Liege, Belgium

[2]BEAMS Department, Free University of Brussels, Belgium

[3]European Synchrotron Radiation Facility, Grenoble, France

ESRF
The European Synchrotron

ISMA-USD
International Conferences on
Noise and Vibration Engineering
Uncertainty in Structural Dynamics

Outline

Outline

Dynamics of Rotating Platforms

Decentralized Integral Force Feedback

Integral Force Feedback with High Pass Filter

Integral Force Feedback with Parallel Springs

Comparison and Discussion

Model of a Rotating Positioning Platform

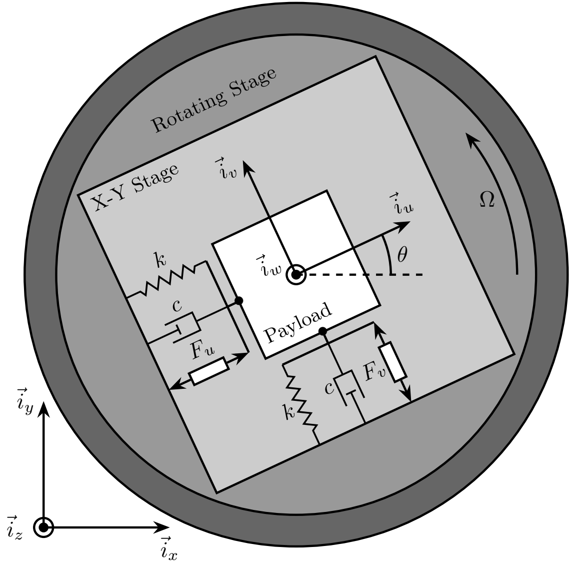


Fig.: Schematic of the studied System

Equations of Motion - Lagrangian Formalism

Lagrangian equations:

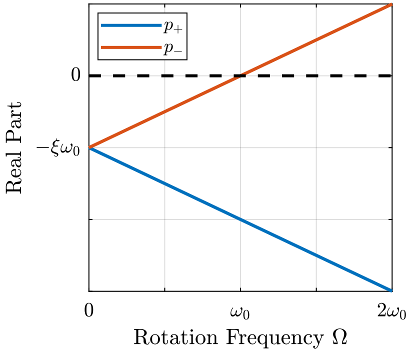
$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) + \frac{\partial D}{\partial \dot{q}_i} - \frac{\partial L}{\partial q_i} = Q_i$$

Equations of motion:

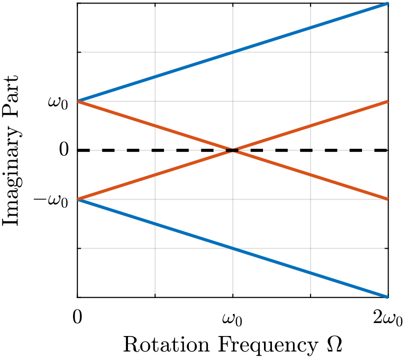
$$m\ddot{d}_u + c\dot{d}_u + (k - m\Omega^2)d_u = F_u + 2m\Omega\dot{d}_v$$
$$m\ddot{d}_v + c\dot{d}_v + (k \underbrace{- m\Omega^2}_{\text{Centrif.}})d_v = F_v \underbrace{- 2m\Omega\dot{d}_u}_{\text{Coriolis}}$$

Centrifugal forces $\Longleftrightarrow$ Negative Stiffness
Coriolis Forces $\Longleftrightarrow$ Coupling

Transfer Function Matrix the Laplace domain



(a) Real Part



(b) Imaginary Part

Fig.: Campbell Diagram : Evolution of the complex and real parts of the system's poles as a function of the rotational speed Ω

Outline

Force Sensors and Decentralized IFF Control Architecture

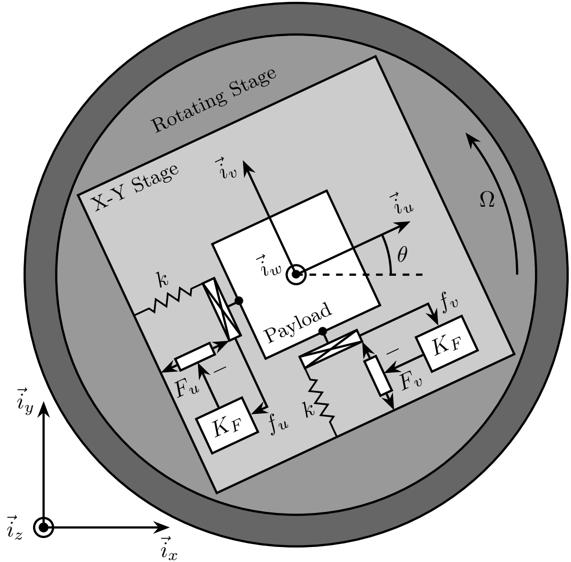


Fig.: System with added Force Sensor in series with the actuators, $K_F(s) = g \cdot \frac{1}{s}$

IFF Plant Dynamics

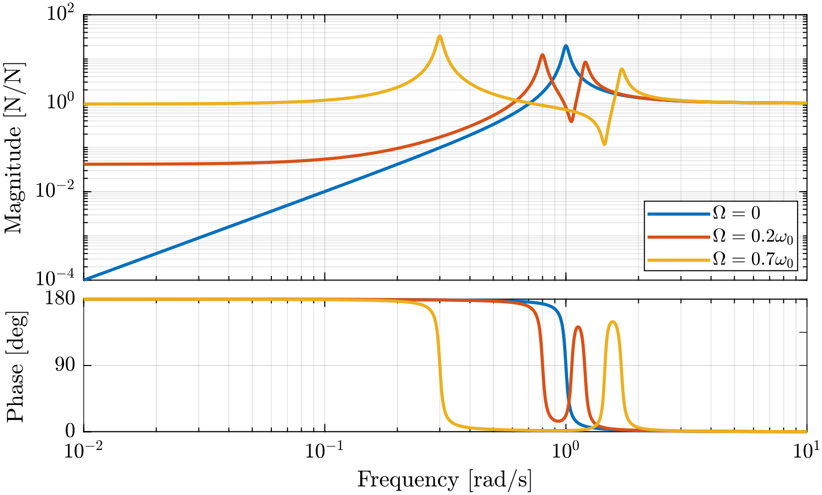


Fig.: Bode plot of the dynamics from force actuator to force sensor for several rotational speeds Ω

Decentralized IFF with Pure Integrators

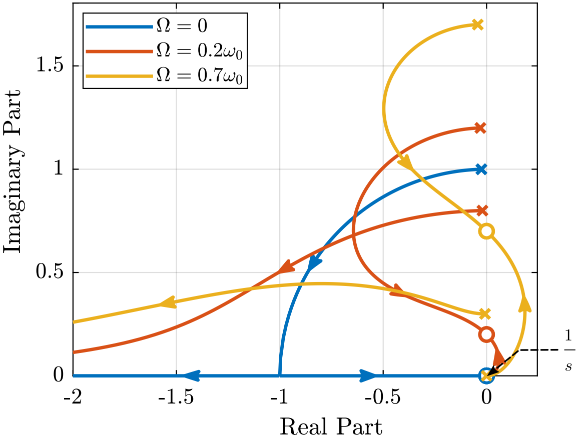


Fig.: Root Locus for Decentralized IFF for several rotating speeds Ω

For $\Omega > 0$, the closed loop system is unstable

Outline

Modification of the Control Law

$$K_F(s) = g \cdot \frac{1}{s} \cdot \underbrace{\frac{s/\omega_i}{1 + s/\omega_i}}_{\text{HPF}} = g \cdot \frac{1}{s + \omega_i}$$

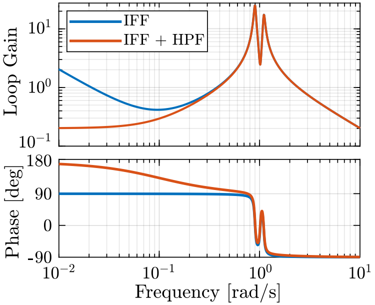


Fig.: Loop Gain

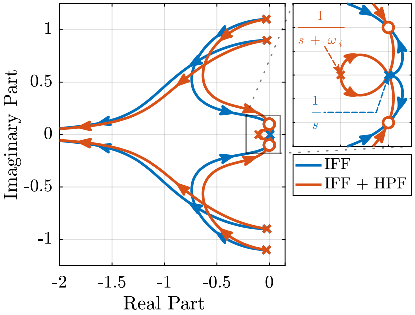


Fig.: Root Locus

Effect of ω_i on the attainable damping

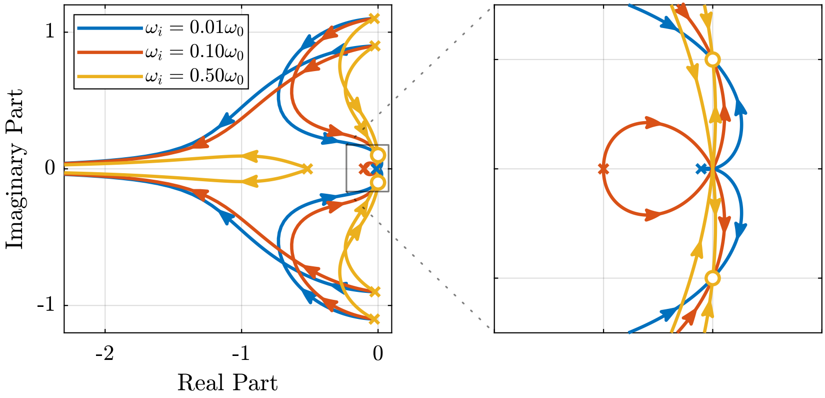


Fig.: Root Locus for several HPF cut-off frequencies ω_i, $\Omega = 0.1\omega_0$

$$g_{\mathsf{max}} = \omega_i \left(\frac{{\omega_0}^2}{\Omega^2} - 1 \right)$$

small $\omega_i \implies$ increase maximum damping
small $\omega_i \implies$ reduces maximum gain g_{max}

Optimal Control Parameters

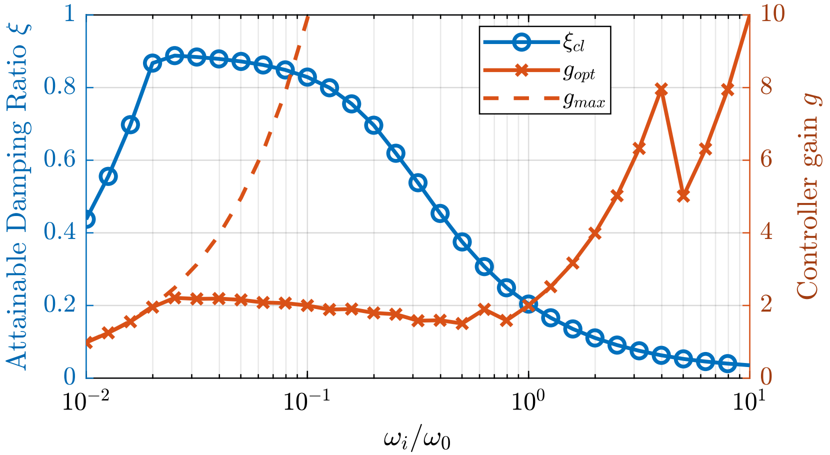


Fig.: Attainable damping ratio ξ_{cl} as a function of the ratio ω_i/ω_0. Corresponding control gain g_{opt} and g_{max} are also shown

Outline

Stiffness in Parallel with the Force Sensor

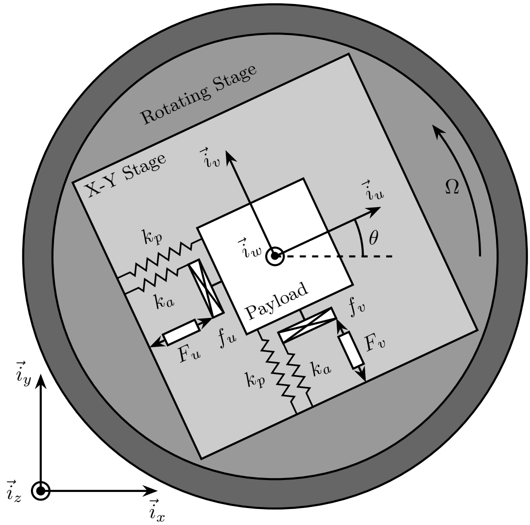


Fig.: System with additional springs in parallel with the actuators and force sensors

Effect of the Parallel Stiffness on the Plant Dynamics

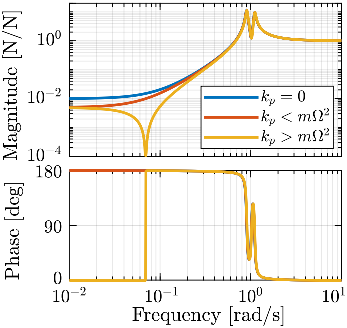


Fig.: Bode Plot of f_u/F_u

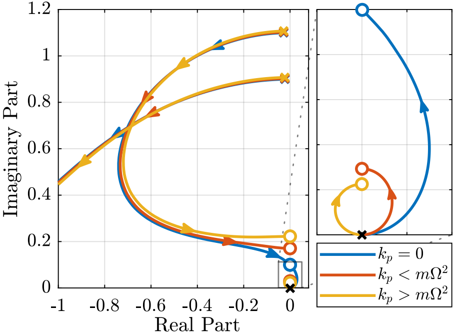


Fig.: Root Locus for IFF

If $k_p > m\Omega^2$, the poles of the closed-loop system stay in the (stable) right half-plane, and hence the **unconditional stability of IFF is recovered**.

Optimal Parallel Stiffness

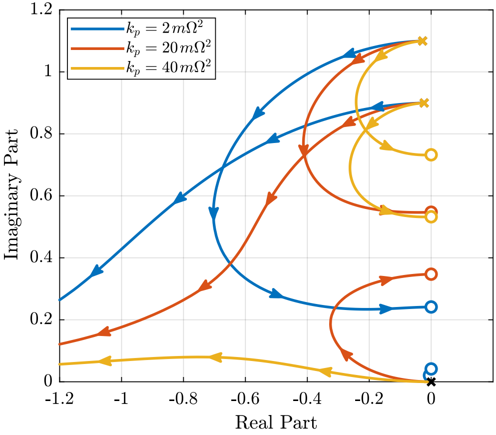


Fig.: Root Locus for three parallel stiffnesses k_p

Large parallel stiffness k_p reduces the attainable damping.

Outline

Dynamics of Rotating Platforms

Decentralized Integral Force Feedback

Integral Force Feedback with High Pass Filter

Integral Force Feedback with Parallel Springs

Comparison and Discussion

Comparison of the Attainable Damping

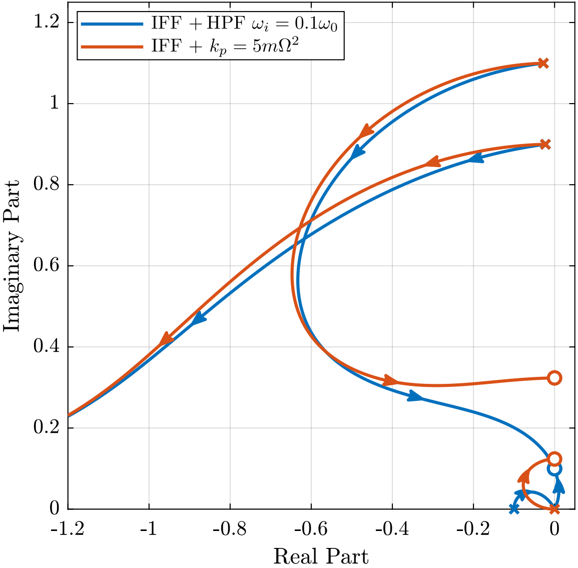
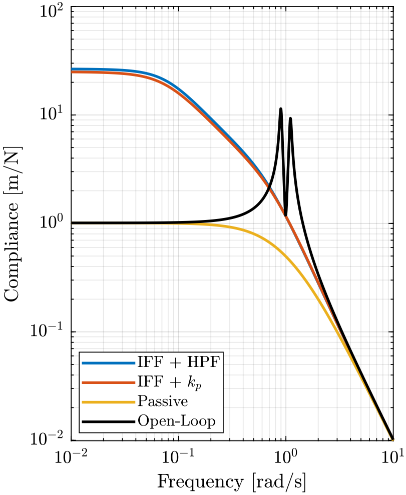
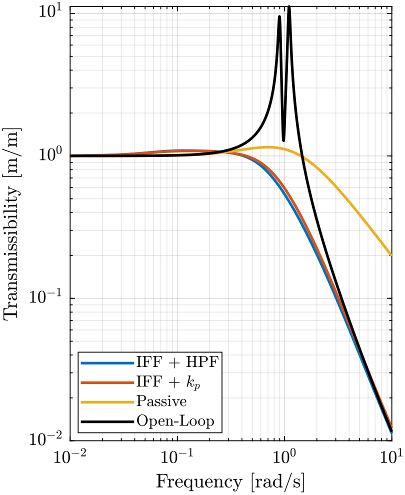


Fig.: Root Locus for the two proposed modifications of decentralized IFF, $\Omega = 0.1\omega_0$

Comparison Transmissibility and Compliance



(a) Compliance



(b) Transmissibility

Fig.: Comparison of the two proposed Active Damping Techniques, $\Omega = 0.1\omega_0$

Thank you!

Contact: dehaeze.thomas@gmail.com
https://tdehaeze.github.io/dehaeze20_contr_stewa_platf/