Active Vibration Isolation of Machine Tools Using an Electro-Hydraulic Actuator

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Ground vibrations influence machine accuracy

- Ground vibrations distort the machine and result in loss of machining accuracy
- Insulating the machine from its production environment is difficult
- Hence, necessary to isolate machine from disturbances to maintain accuracy
Vibration isolation: passive and/or active?

**Passive isolators:** High damping and relatively low support stiffness

- Passive isolators offer simple and effective isolation solutions
- Dynamic instabilities like rocking due to the low support stiffness
- Difficult to design when ground vibrates with unpredictable waveform that has broadband spectrum
Active isolators and objectives of this work

Actuator (pneumatic; electromagnetic; piezoelectric; magnetorheological; or, hydraulic)

Actuating principles
- Pneumatic → Unable to support high loads
- Electromagnetic → Low strokes
- Magnetorheological → Suffers from hysteresis
- Piezoelectric → Small deflection capacities

Hydraulic actuators
- High static stiffness
- No hysteresis
- Large deflection
Proposed electro-hydraulic isolation system @ IWU

Working principle: displacement compensation
Actuator dynamics

Valve dynamics:

\[ G_{valve} = \frac{x_v}{v} = K_v \left[ \frac{1}{1 + \left( \frac{2\zeta}{\omega_{n_P}} \right)s + \left( \frac{s}{\omega_{n_P}} \right)^2} \right] \]

Hydraulic and Piston dynamics:

\[ Q_L = K_Q x_v - K_C P_L; \quad Q_L = A_P s x_p + \frac{V_t}{4\beta s} P_L \]

\[ (V_t = V_1 + V_2 = 2V_0; \quad P_L = P_1 - P_2) \]

\[ F_p = P_L A_p = M s^2 x_p + C s x_p + K_L x_p + F_L \]

\[ G_{act} = \frac{x_p}{x_v} = \frac{K_Q / A_p}{s + \left( \frac{K_C K_L}{A_p^2} \right) \left( \frac{s^2}{\omega_h^2} + \frac{2\delta_h}{\omega_h} + 1 \right)} \]

Hyd. stiffness and damping

\[ \omega_h = \sqrt{\frac{4\beta A_p^2}{V_t M}} \]

\[ \delta_h = \frac{K_C}{A_p} \sqrt{\frac{\beta M}{V_t}} \]

Meritt (1967);
Jelali & Kroll (2003)
Parameter identification

System identification:

\[ \min f_{\text{obj}}(x_d) = \sum_{i=1}^{n_p} r_i^2 \text{ such that } lb \leq x_d \leq ub \]

\[ r_i = G_{\text{EHA,measured}} - G_{\text{EHA}}(x_d) \]

\[ x_d \subset \{ K_L; C; \omega_n; \zeta; K_Q; K_C \} \]

\[ G_{\text{EHA}} = \frac{x_p}{v} = G_{\text{valve}}G_{\text{act}} \]

Jelali & Kroll (2003)
Active isolation of machine tools

Transmissibility between ground and tool point:

\[ TR_{qg} = \frac{x_q}{x_g} = \frac{x_p}{x_g} \times \frac{x_q}{x_p} \]

where \( p = 1 \ldots 4 \)

Transmissibility between ground and actuator

Transmissibility between actuator and tool point

\[ TR_{qp}(\omega) = \frac{x_q(\omega)}{x_p(\omega)} = \frac{x_q(\omega)/F_p(\omega)}{x_p(\omega)/F_p(\omega)} = \frac{H_{qp}(\omega)}{H_{pp}(\omega)}; \]

wherein:

\[ H_{ij}(\omega) = \sum_{r} \frac{\Phi_{ir} \Phi_{jr}}{-\omega^2 + i m 2 \zeta_\omega \omega_n + \omega_n^2} \]
Controlled transmissibility

TR between ground and tool point:

\[ TR_{qg} = \frac{x_q}{x_g} = \frac{x_p}{x_g} \times \frac{x_q}{x_p}; \quad p = 1 \ldots 4 \]
Controlled transmissibility

TR between ground and tool point

Uncontrolled Controlled

~10 dB
~20 dB
~7 dB

Front right mount

Rear right mount

~10 dB
~25 dB
Summary

- Designed and developed a novel electro-hydraulic isolator
- Actuator has a high static stiffness to support large inertial loads
- Controlled closed-loop transmissibility shows actuator:
  - Has a high bandwidth (~100 Hz)
  - Can attenuate ground motion transmitted to the tool/table up to 25 dB

Future work

- Further experimental characterization of actuator
- Investigate advanced control strategies
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Thank you for your attention!

Questions?

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