POWER FLOW ANALYSIS FOR AMPLIFIER DESIGN AND ENERGY HARVESTING

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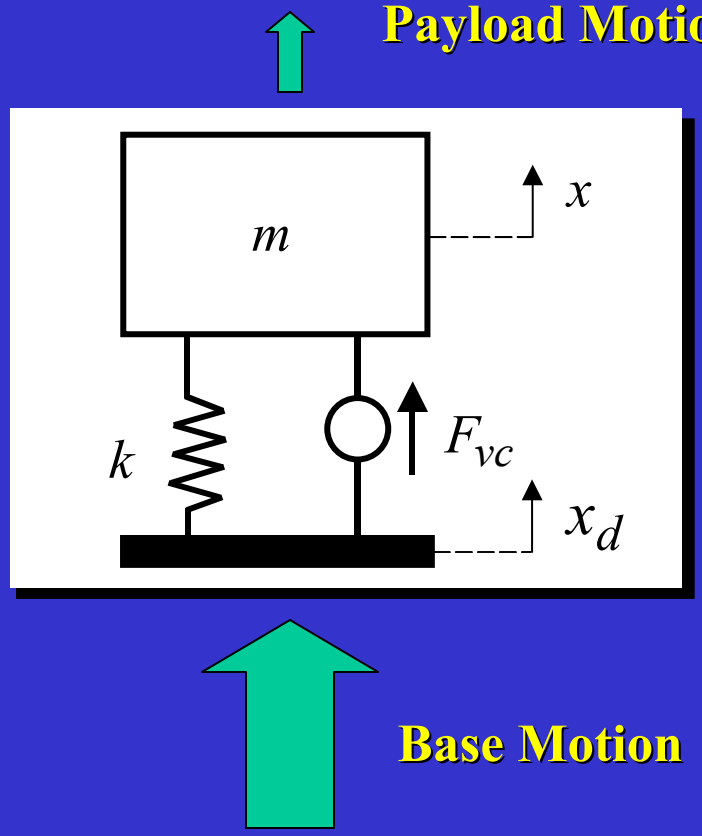
Motivation

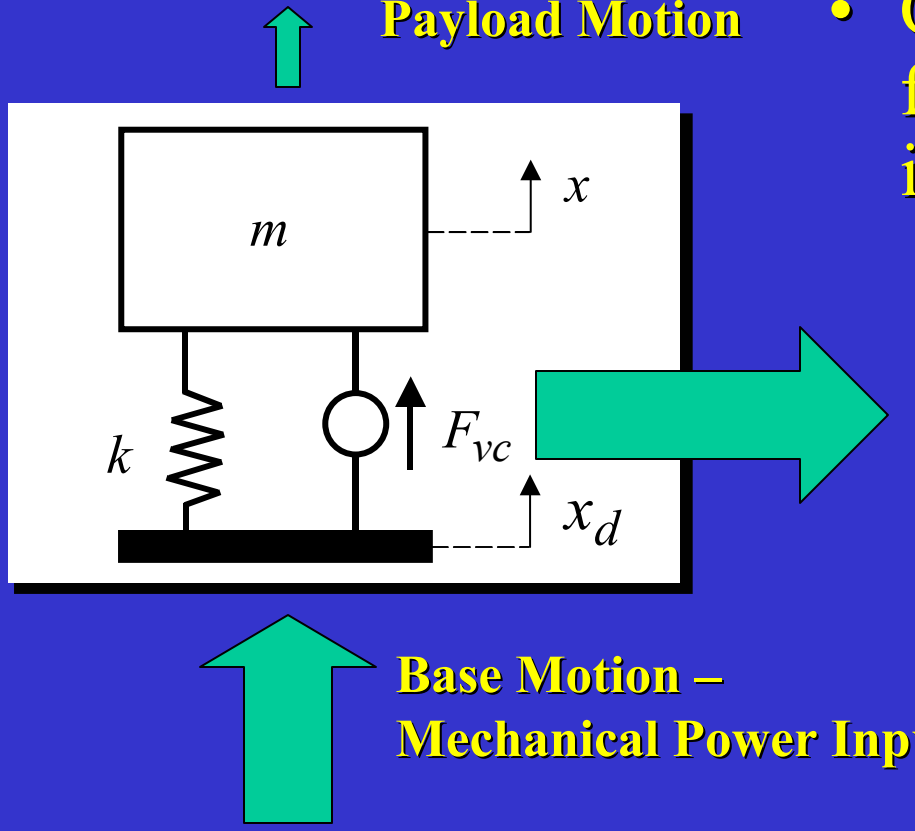
- Power is a limiting factor in a number of active material applications.
- The electromechanical transduction properties of active materials make it possible to ‘harvest’ energy from vibration sources and store it as electrical energy.

Vibration Isolation



- The system under consideration is an active vibration isolation system containing an electromagnetic actuator.

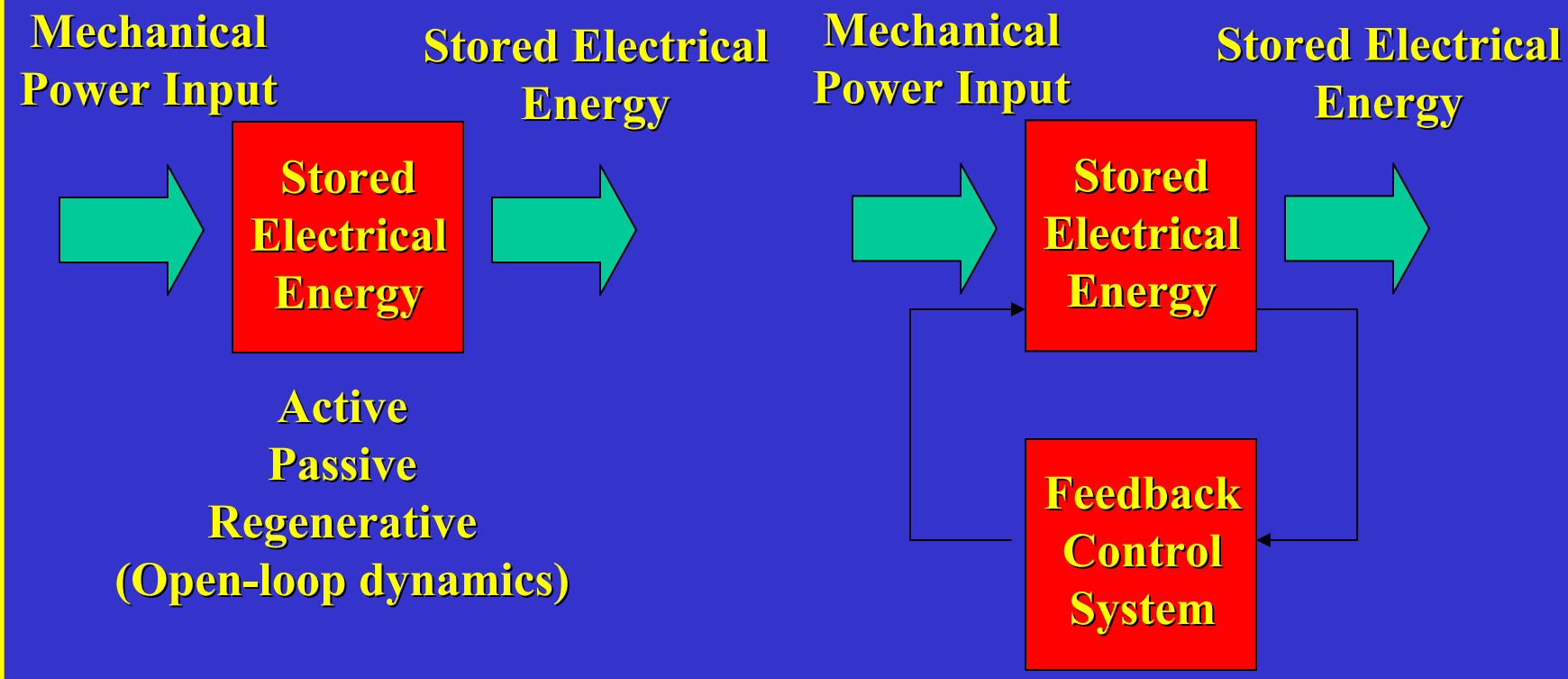
Vibration Isolation



- Can we harvest energy from the vibration isolation system?

Stored Electrical Energy

Regenerative Systems



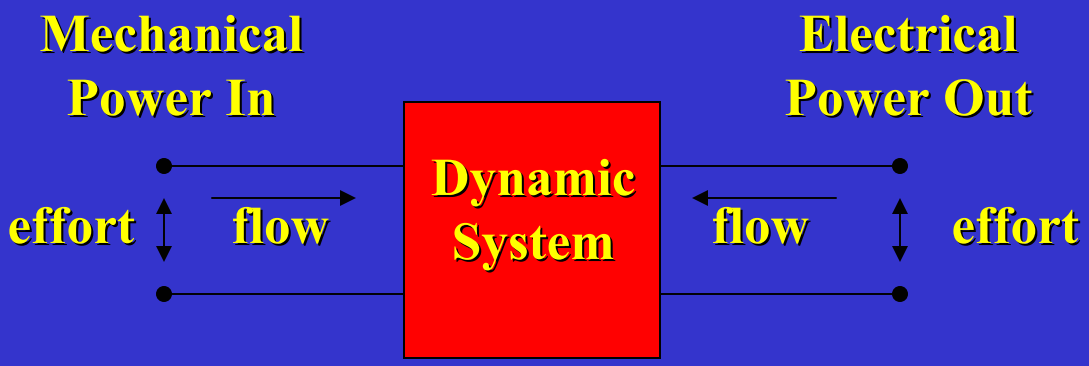
Regenerative Systems

- Can we change the power flow characteristics of the system using feedback control?
- How does feedback change the vibration isolation characteristics of the closed-loop system?

Approach

- Develop nondimensional state-space model of active isolation system with an electromagnetic actuator.
- Examine power flow characteristics as a function of feedback parameters.
- Determine regions of optimal power regeneration and examine the effect of vibration isolation.

Power Flow Modeling



$$P(j\omega) = \frac{1}{2} Re\left[\overset{\text{effort}}{e(j\omega)}\overset{\text{flow}}{f^*(j\omega)}\right],$$

Power Flow Modeling

Inverse of time constants

Electromechanical Coupling

$$A = \begin{bmatrix} -\beta & 0 & -\psi \\ 0 & 0 & 1 \\ 1 & -1 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$C_{\tilde{v}} = \begin{bmatrix} -\tilde{g}_1 & -\tilde{g}_2 & -\tilde{g}_3 \end{bmatrix}$$

Feedback Control Gains

Control Studies

- Three control cases were studied
  - Resistive Control
  - Mechanical Feedback
  - Flow Control

Power Flow Modeling

$$\tilde{P}_{el} = \frac{P}{\frac{1}{2}\omega_n k X_{od}^2}\psi$$

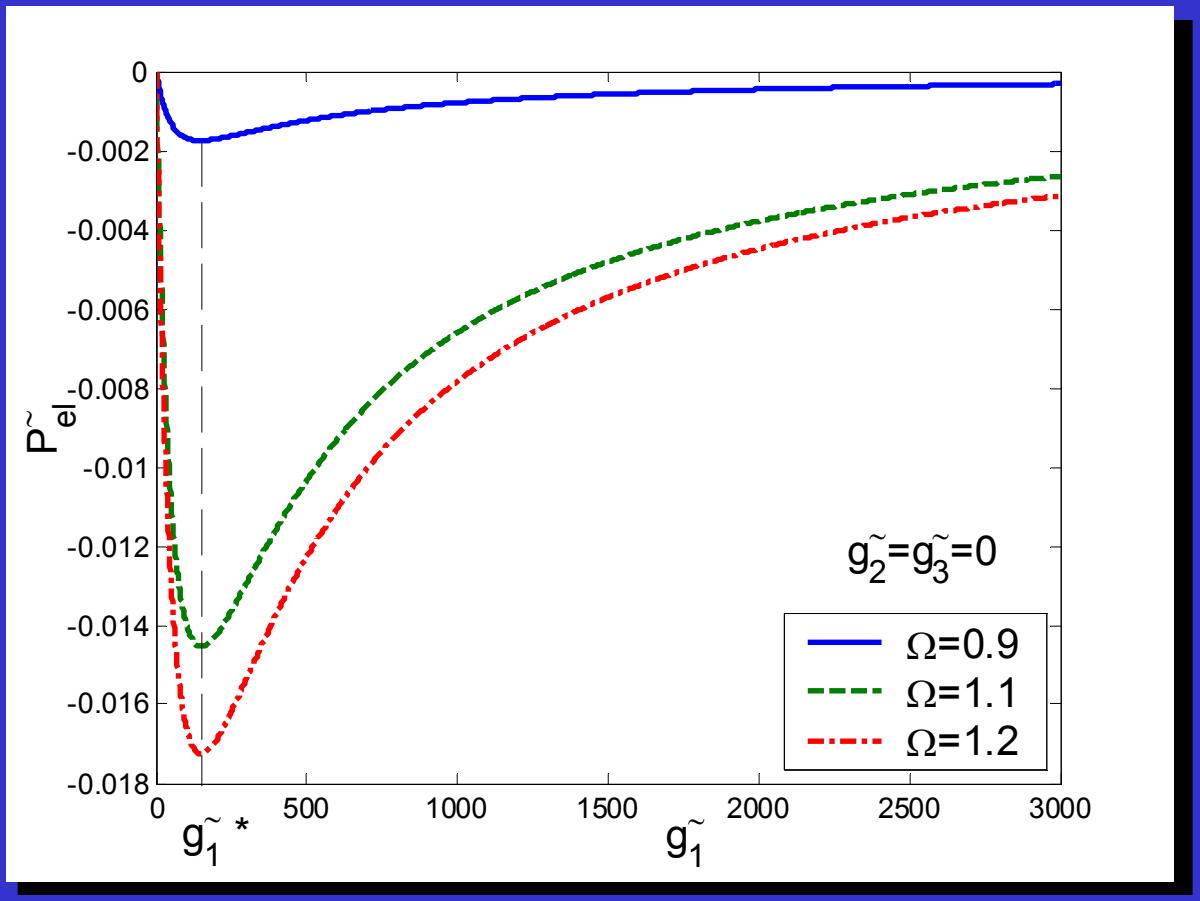
Nondimensional Power

Rate of energy exchange in the spring

$$= \frac{\Omega^4}{|\Delta|^2}\left(\left(a_1 b_1 - a_0 b_2\right)\Omega^2 + a_0 b_0\right),$$

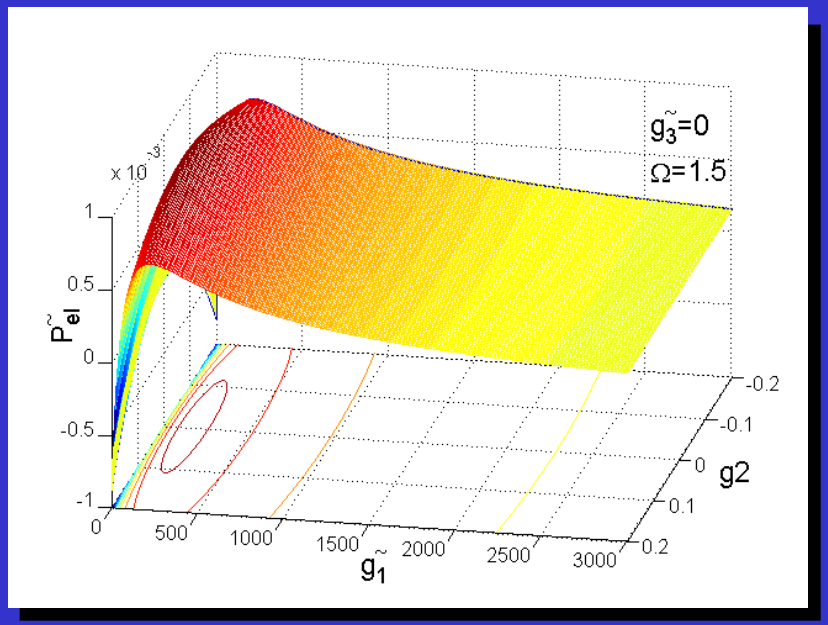
The advantage to this approach is that the nondimensional power is only a function of two parameters and the three control gains.

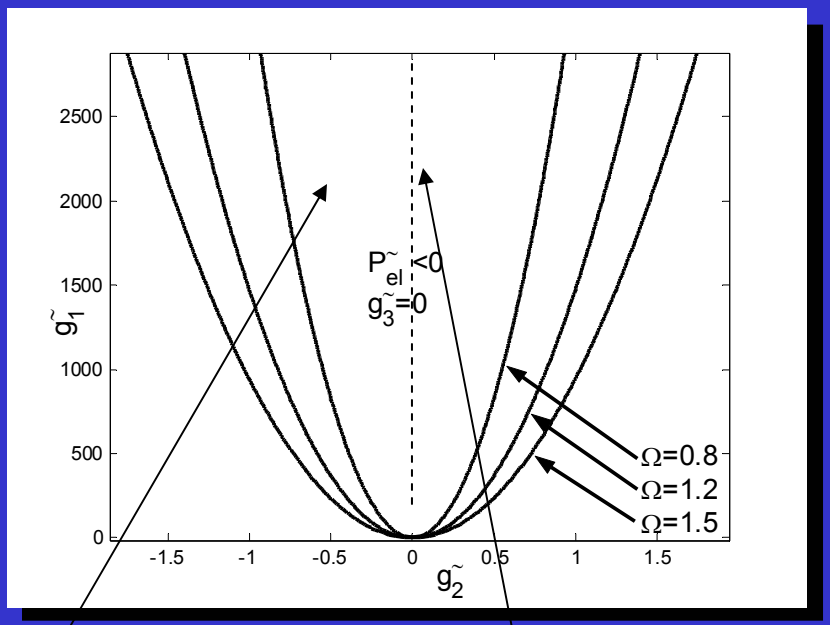
Case 1: Resistive Control



System is regenerative for any value of the current gain.

Case 2: Mechanical Feedback

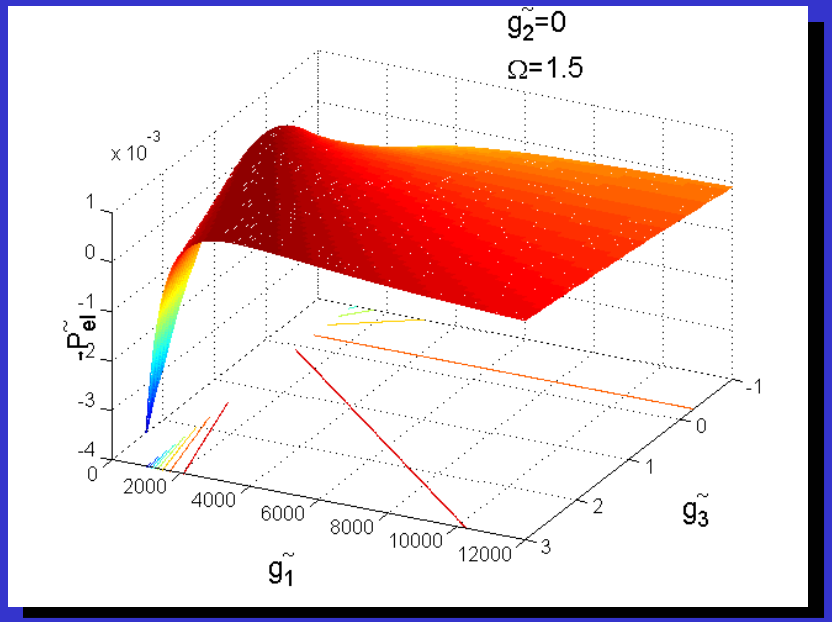


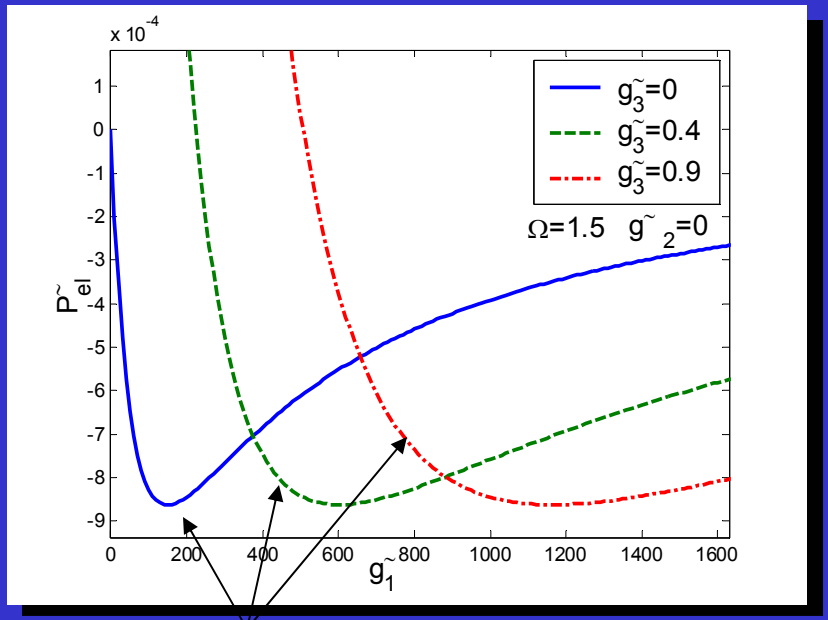


Regenerative System

Optimal always occurs when position gain is zero.

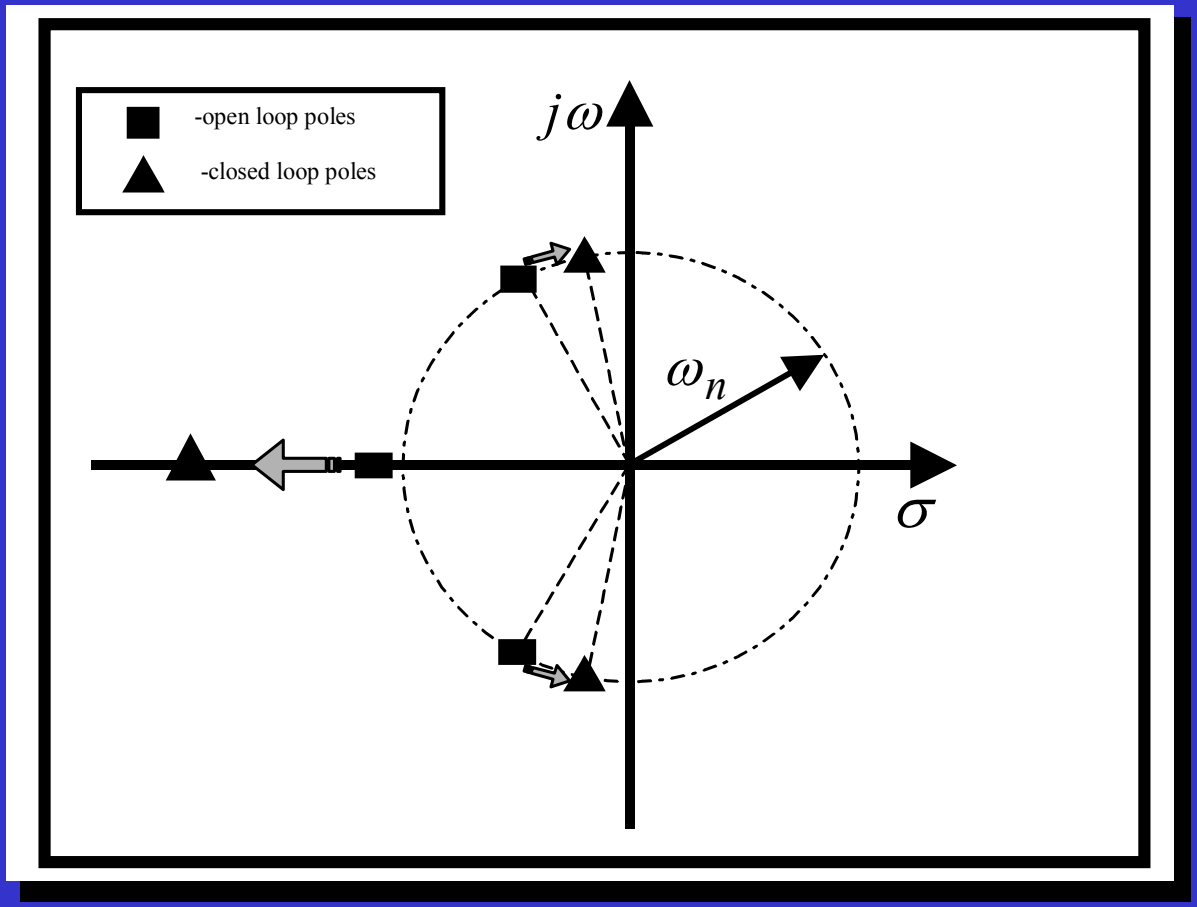
Case 3: Flow Control





Shape of regenerative region can be controlled with feedback.

Effect on Vibration Isolation

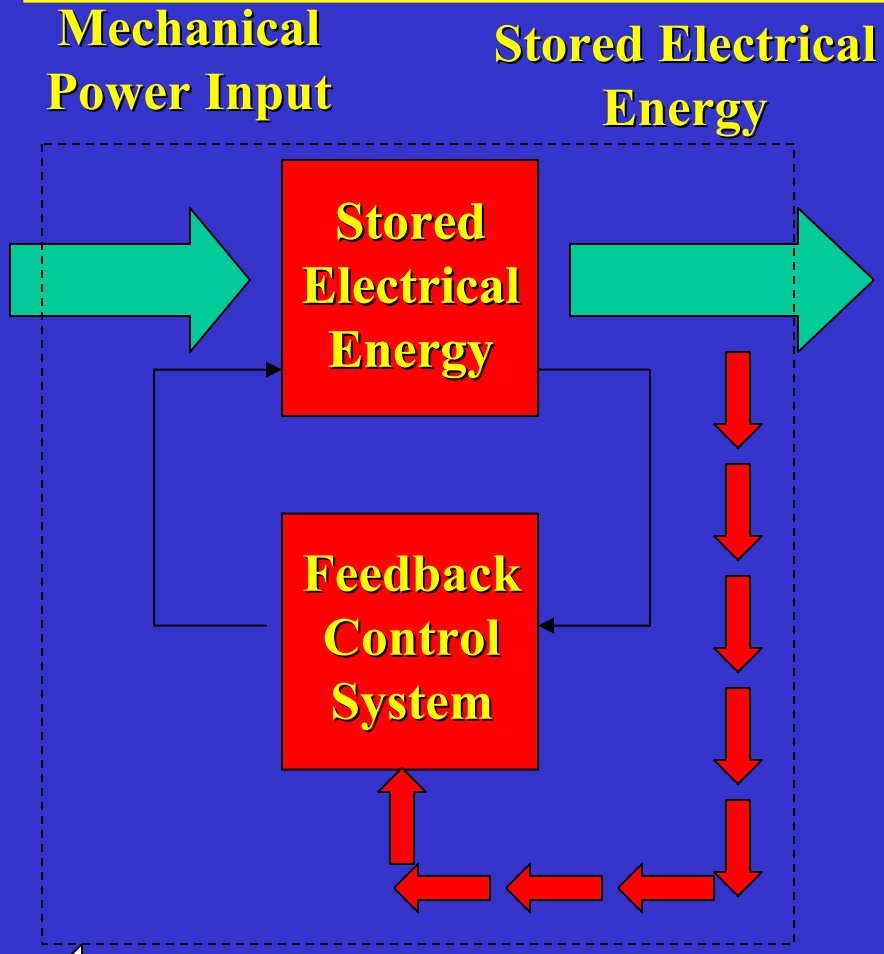


The amount of vibration isolation was REDUCED in all cases studied. This indicates that there is a fundamental tradeoff in achieving a regenerative isolation system.

Conclusions

- The effect of feedback on the regenerative properties of a vibration isolation system was studied.
- The results demonstrated that feedback could be used to ‘tune’ the mechanical system to maximize energy regeneration.
- This study demonstrated that energy regeneration was always accompanied by an INCREASE in the vibration of the payload.

Practical Question



- Will the amount of regenerated energy be greater than the amount of energy required for the feedback control system?