Energy Efficient Variable Stiffness Actuators

Conceptual Design and Implementation

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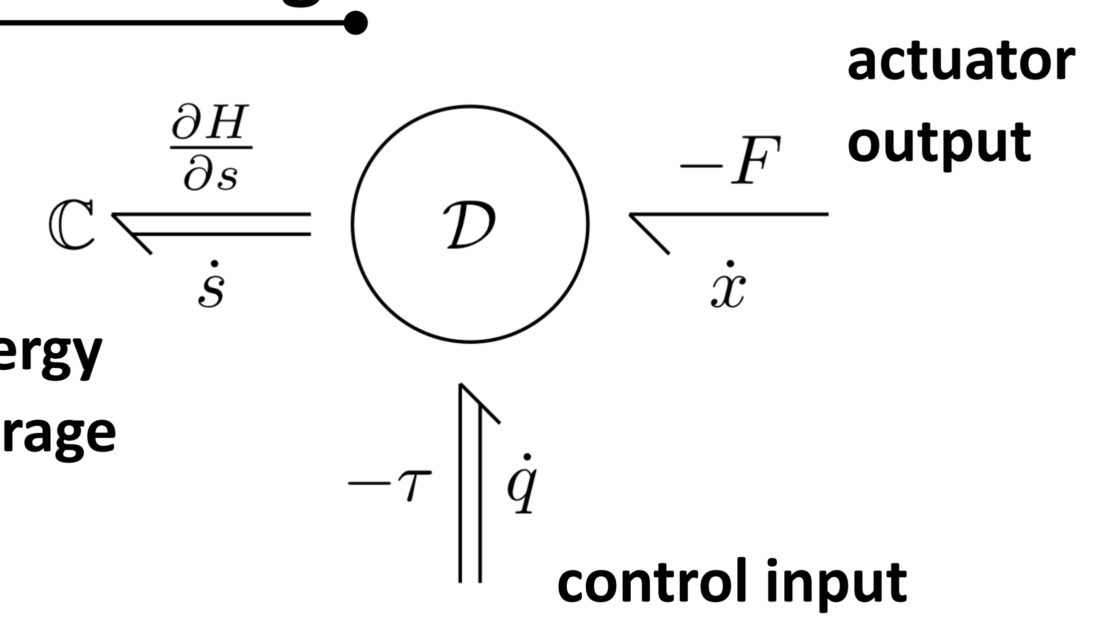
Motivation

Variable stiffness actuators have internal **degrees of freedom** and internal **springs**:

+ the degrees of freedom are used to change the **apparent output stiffness**;
+ the apparent output stiffness can be changed independently of the output position;
+ the springs can be used to store **energy**;
+ the **configuration** of the degrees of freedom determines **power flow** between the **springs** and the **output**.

Goal:
Change the output stiffness without changing the energy stored in the springs.

Port-based Modeling



The **Dirac structure** $\mathcal{D}$ defines the power flows among the bonds:

$$\begin{bmatrix} \dot{s} \\ \tau \\ F \end{bmatrix} = \underbrace{\begin{bmatrix} 0 & A(q,x) & B(q,x) \\ -A^T(q,x) & 0 & 0 \\ -B^T(q,x) & 0 & 0 \end{bmatrix}}_{\mathcal{D}} \begin{bmatrix} \frac{\partial H}{\partial s} \\ \dot{q} \\ \dot{x} \end{bmatrix}$$

Variation of the **energy** in the spring:

$$\frac{\mathrm{d}H}{\mathrm{d}t} = \frac{\partial H}{\partial s}\left(A(q,x)\dot{q} + B(q,x)\dot{x}\right)$$

Conceptual Design

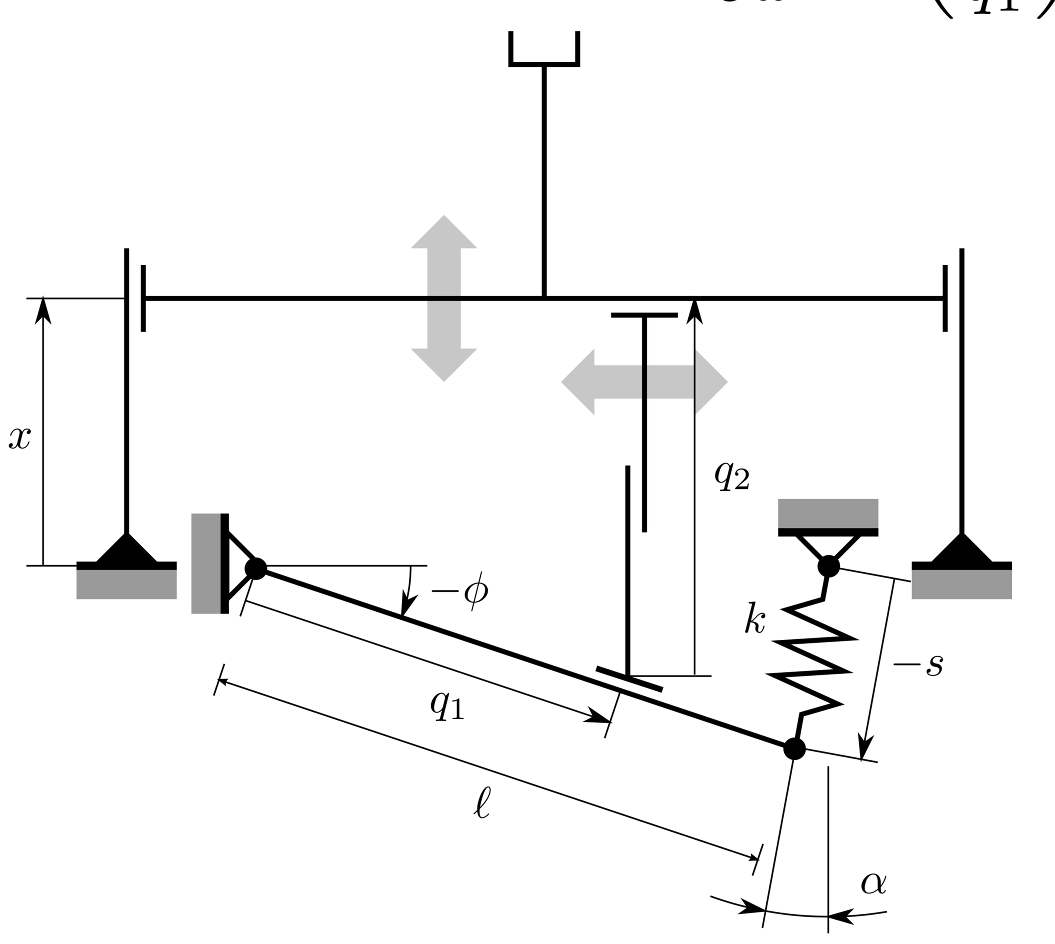
The energy in the spring changes with **no power flow via the control port** if:

$$\dot{q} \in \ker A(q,x), \qquad \forall q, x$$

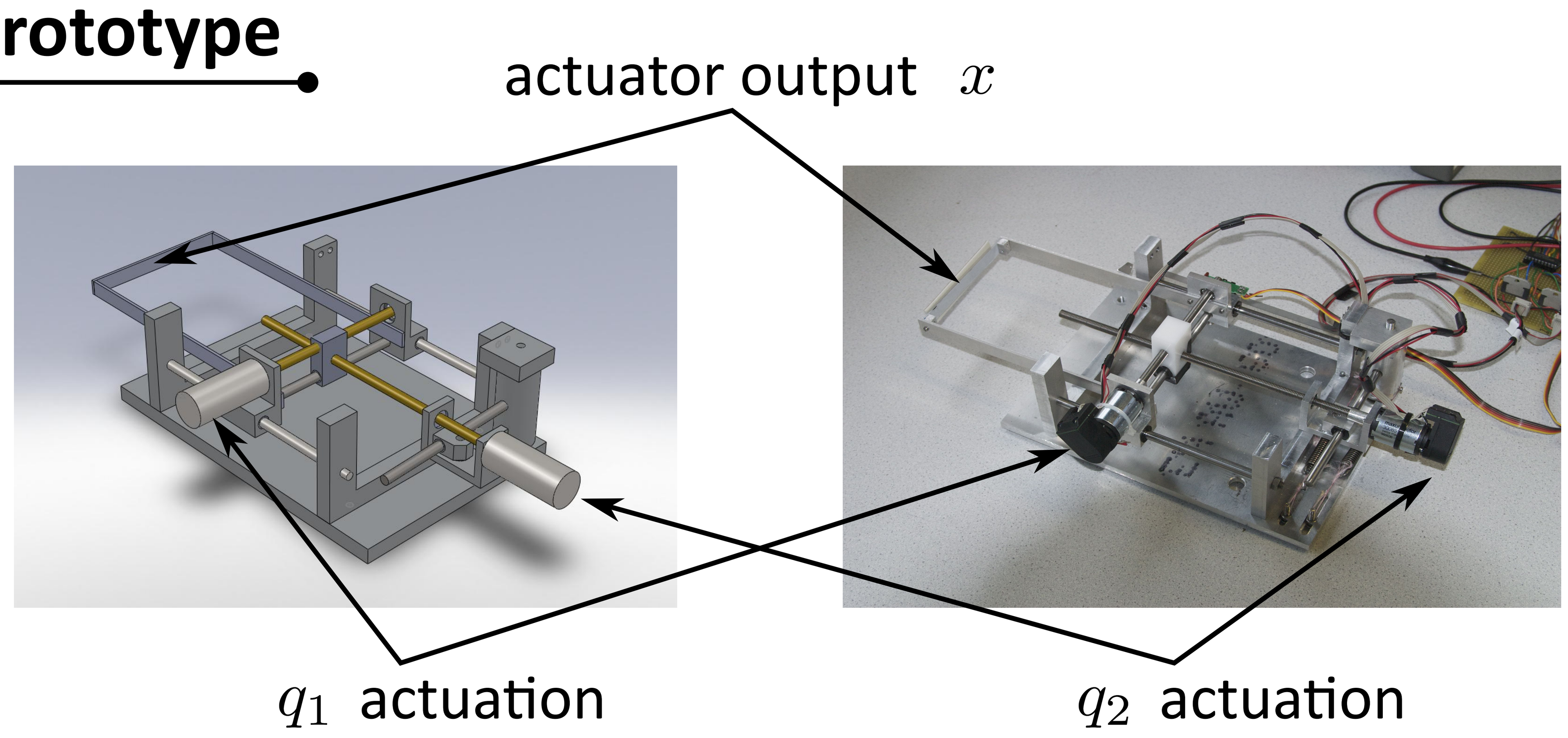
The conceptual design has:

$$A(q,x) = \frac{\ell}{q_1}\begin{bmatrix} \sin\phi & 1 \end{bmatrix}$$

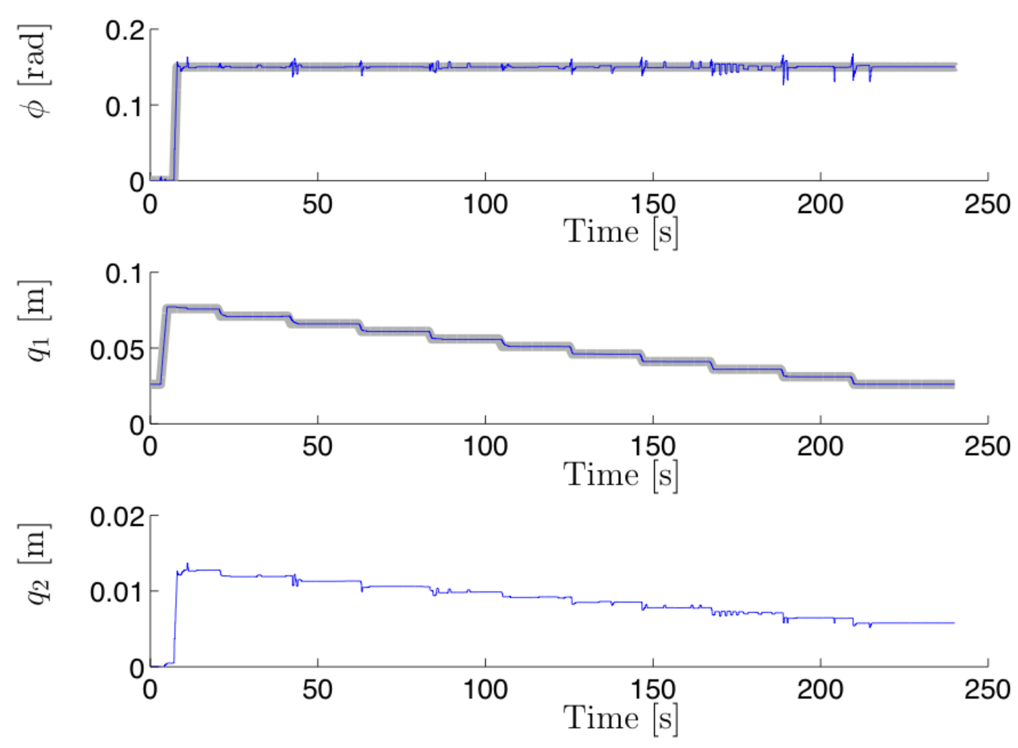
The output stiffness is: $K := \dfrac{\partial F}{\partial x} = \left(\dfrac{\ell}{q_1}\right)^2 k$

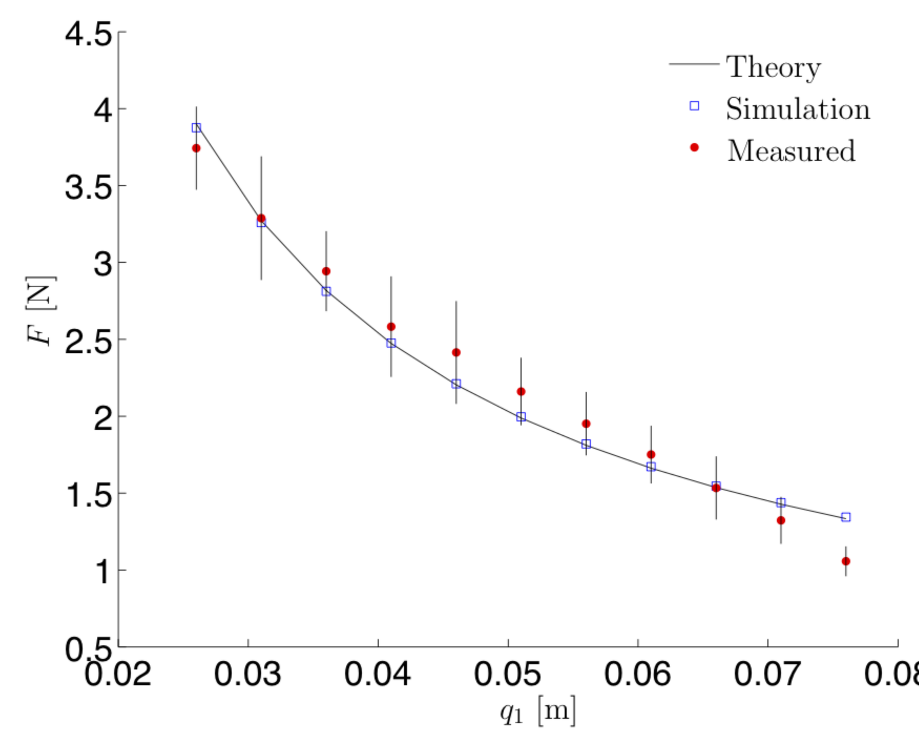


Prototype



+ Output **position** and **stiffness** are mechanically **decoupled**.
+ The **output stiffness** can be changed **without changing the energy stored** in the springs.





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