Energy Efficient Variable Stiffness Actuators: Conceptual Design and Implementation

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I. INTRODUCTION

In this poster, we present the modeling and design of energy efficient variable stiffness actuators. A port-based modeling framework is used to analyze power flows between the actuator, the actuated system and the controller. Design guidelines are derived and a novel actuator design concept is presented, of which the apparent output stiffness can be changed without using energy. A prototype realization of this concept has been realized as a proof of concept.

II. PORT-BASED MODELING FRAMEWORK

The generic port-based model of a variable stiffness actuator is graphically depicted in Fig. 1 by using bondgraphs.

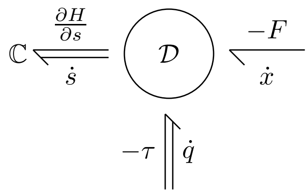

Fig. 1. Generalized representation of a variable stiffness actuator.

The $\mathbb{C}$-element represents the internal springs of the actuator, characterized by a state s and an energy function $H(s)$. The *control port* is characterized by generalized forces and generalized velocities $(\tau, \dot{q})$, where q is the configuration of the internal degrees of freedom. The *output port* connects the variable stiffness actuator to the load and is characterized by force and velocity $(F, \dot{x})$. The power continuous Dirac structure $\mathcal{D}$ determines the power flow between the different bonds and can be expressed by

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

The rate of change of the energy stored in the springs is

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

and, therefore, it follows that the stiffness can be changed without using any energy if $\dot{q} \in \ker A(q,x) \forall x, q$.

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III. A NOVEL VARIABLE STIFFNESS ACTUATOR DESIGN CONCEPT

A novel actuator design concept has been derived and is shown in Fig. 2. The mechanism relies on a lever arm with variable length, effectively realizing a continuous transmission between the output and the internal spring.

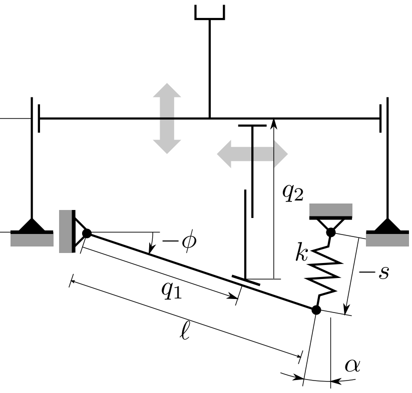

Fig. 2. An energy efficient variable stiffness actuator concept.

The apparent output stiffness K is given by:

$$K = \left(\frac{\ell}{q_1}\right)^2 k \tag{1}$$

i.e., it depends only on the degree of freedom q_1. Because the change of stiffness is completely decoupled from the control of the output position, the stiffness can be changed without using energy. A protype realization of this concept is presented in Fig. 3.

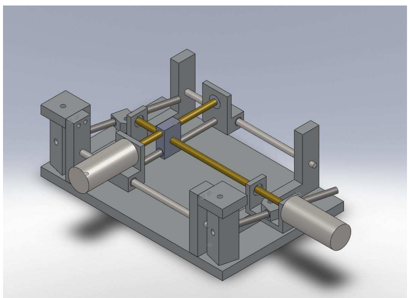

Fig. 3. Prototype realization of the variable stiffness actuator.

REFERENCES

[1] L.C. Visser, R. Carloni, R. Ünal, S. Stramigioli, "Modeling and Design of Energy Efficient Variable Stiffness Actuators", *Proc. IEEE Int. Conf. on Robotics and Automation*, 2010.