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New Constant-force Mechanism Configurations

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In machine design it is often desirable to correlate output force with displacement. Incorporating a translational spring into the design creates a linear relationship between force and displacement. In contrast, if a constant output force is desired independent of displacement, solutions include pneumatic or hydraulic systems or complicated systems of weights or springs. A simple lightweight mechanical device that exhibits constant-force output over a significant displacement would have the potential of replacing complicated current systems. It could also provide an improved solution for systems where a constant-force output is desirable but has not yet been proven feasible.

A patent has been issued for a compliant slider-crank constant-force mechanism. Physical realizations of this mechanism are under development at BYU.[1] The mechanism can be formed from a variety of rigid and compliant segment combinations in order to create a slider-crank mechanism with constant output force. One of the obstacles in implementing compliant constant-force mechanisms is that performance of actual realizations of the mechanism suffers due to friction between moving parts. Most realizations of the mechanism are also made up of numerous parts, which can be prohibitive for high volume applications or for applications where manufacturing techniques are limited such as with Micro Electromechanical Systems (MEMS). In a crank-slider mechanism friction is inherently introduced into the mechanism through the sliding components. By introducing components that help reduce the friction caused by the slider link (e.g. linear ball bushings, case-hardened race, precision linear tracks) the complexity and the cost of the mechanism increase.

It has been proposed that an alternative configuration for a constant-force mechanism could include the same crank-slider mechanism with a spring fixed to the slider. If a spring—such as a compliant parallel guiding mechanism (see Figure 1) or an orthoplanar spring—were used that would maintain rigid linear orientation as well as translate, the friction would be removed from the slider link and the overall complexity of the design could possibly be reduced. Implementing such a spring would eliminate the need for the extra components used to orient the slider in a traditional slider-crank mechanism. This change would reduce friction and also have the potential for reducing the complexity, weight, and cost of the mechanism in certain applications.

This research has developed new configurations that incorporate the existing crank-slider model along with the resistance of the added translational spring. The new configurations were broken into five classes (1A, 1B, 2A, 2B, 3A) following the pattern of previous work with crank-slider constant-force mechanisms.[2] Fourteen new compliant constant-force mechanism configurations that include a translational spring element in place of a slider link have been defined. These new configurations correlate to previous compliant configurations. A mathematical model has been generated that predicts output force and stiffness for a given set of geometry and energy storage parameters. Given this model, two optimizations were performed that minimize the variation of the output force from constant-force by adjusting the link length ratio and the torsional energy storage parameters. This optimization was performed for several values of the non-dimensional parameter representing the added translational spring element, and the effect of this parameter on the model was examined. It was found that the configurations with a translational spring have poorer performance than their traditional slider counterparts. However, Classes 2A, 2B, and 3A maintain a relatively high value of constant-force over a range of translational spring parameter values.

Several sketches of possible mechanisms were developed and some general guidelines for design were formed. Figure 1 shows a possible mechanism that implements a folded-beam parallel guiding mechanism. Through this research several observations have been made and some recommendations for designers have been formulated. The new configurations should be considered for applications where the advantages of the new configurations—low friction, low part count, reduced supporting equipment required—give significant value to the component or product being designed. If the value added by these advantages is less significant or if the design need is for high performance within the minimum space possible, the previous configurations should be considered. A prototype of a Class 3A mechanism with a folded beam mechanism as the translational spring element was designed, built and tested to verify the analytical model. Figure 2 shows a photograph of the prototype. The prototype performed well and its performance was close to the performance predicted by the model.

There are several areas for future work including developing a stress parameter for the new configurations so that the design of the new constant-force mechanisms can be automated. Another area of work would be to explore entirely different configurations that depart from the crank-slider configuration. Additionally, more physical development of the configurations discussed in this research needs to occur in order to facilitate implementation in real products.

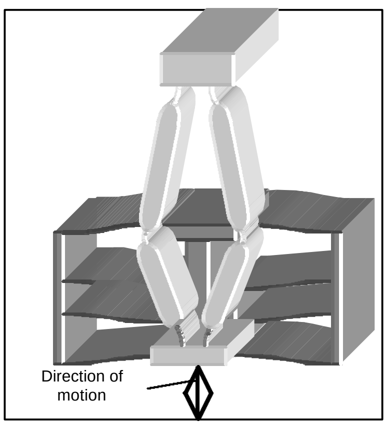

Figure 1: An example of a compliant constant-force mechanism using a folded-beam parallel guiding mechanism for the translational spring and the slider

Figure 2: A photograph of a Class 3A prototype using a folded-beam parallel guiding mechanism for the translational spring and the slider

[1] Midha, A., Murphy, M.D., and Howell, L.L., 1995, “Compliant Constant-force Mechanism and Devices Formed Therein,” US patent 5,649,454.
[2] Howell, L.L., Midha, A., and Murphy, M.D., “Dimensional Synthesis of Compliant Constant-Force Slider Mechanisms,” Machine Elements and Machine Dynamics, DE-Vol. 71, 23rd ASME Biennial Mechanisms Conference, 1994, pp. 509-515.