Negative Stiffness Spring System for Morphing Aircraft Actuation Energy Balancing

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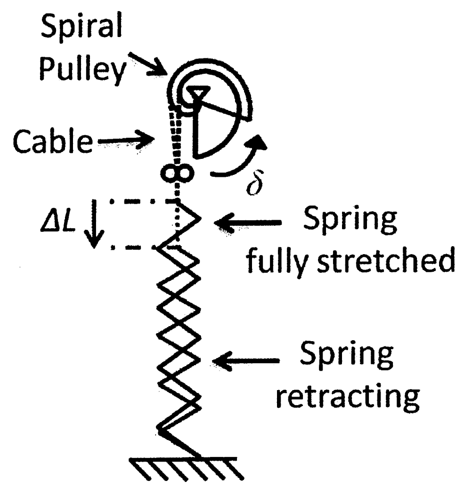
This work introduces a novel concept for minimizing the actuation requirements of compliant morphing aircraft systems by using a negative stiffness spring system to offset the structural stiffness of the morphing component. The concept employs a spiral spooling pulley system with tailored kinematics to convert linear springs with positive stiffness into torsion springs with effectively negative stiffness, allowing them to offset the inherent stiffness of compliance based morphing concepts. This allows for removal of the requirement for the actuation system to overcome the structural actuation energy through a passive energy balance.

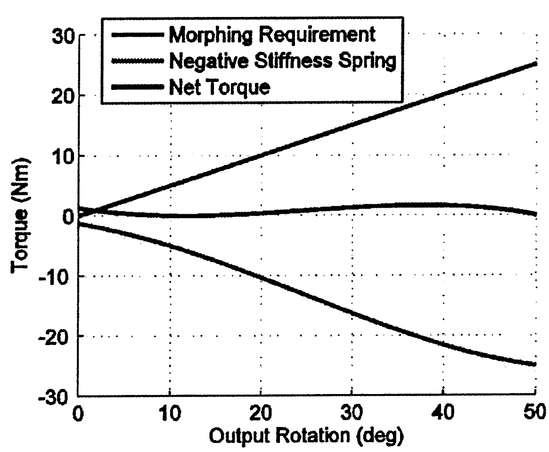
The concept presented here is an evolution of previous work by the authors which employed a similar spiral spooling pulley system to modify the force versus displacement output curves of actuation systems to improve their performance [1]. This work found that reductions in actuator size of 50% were possible, and improvements in energy efficiency of 100% could be obtained compared to traditional kinematic systems. The current work substitutes a pre-tensioned extension spring for the pneumatic actuator. This creates a passive system with a torque versus displacement profile that can be optimised to match, and therefore offset, the requirements of driving a torsional spring load. This creates a system that is in torque equilibrium over a wide range of rotation angles. An actuation system driving the combined system would therefore only need to overcome the aerodynamic and inertial loads and any friction effects present. For compliant span morphing systems (e.g. elastomeric matrix composite skins over zero-Poisson's ratio honeycomb cores [2]) and active camber systems (e.g. the Fish Bone Active Camber morphing concept [3]), the structural stiffness is often the dominant load. Given that linear springs have higher energy density and specific energy storage than actuators, the required energy to overcome structural compliance can be achieved at a lower mass through the present approach. Furthermore, the use of a passive system to overcome the structural energy leads to reductions in the power requirements of the actuation system.

The derivation of a quasi-static model for the concept will be shown. The configuration of components will first be discussed, using figures such as the figure below. Then the kinematics of the spiral pulley will be presented, followed by the development of the equations, which describe the torsional mechanics.



Schematic of spiral spooling pulley and driving spring

Example outputs of the system model, such as that shown in the figure below, will provide insight into how the concept works. Integration of the system into span morphing and camber morphing systems will then be discussed. Of chief importance is the use of a driving mechanism, which uses torque and rotation, which is easily achieved in both cases.



Torque versus deflection for example system, showing the near zero net torque resulting from integration of a negative stiffness spring system

The system model will then be employed within an optimization routine to optimise the geometry of the spiral pulley and driving spring for several different representative design loads. The stiffness of the design loads and the required amount of rotation will be based on realistic requirements taken from span and camber morphing demonstrators in the literature.

Finally, a benchtop demonstrator of the concept will be built and tested. A linear extension spring converted to produce torsional stiffness will be used as a stand in for the morphing concept. The evolution of net system torque with rotation will be measured, and the ability of the system to hold deflection at virtually any point will be shown.

References

1. Woods, B.K.S., Friswell, M.I. and Wereley, N.M., "Advanced Kinematic Tailoring for Morphing Aircraft Actuation," *AIAA Journal* (2014) accessed January 31, 2014. doi: http://arc.aiaa.org/doi/abs/10.2514/1.J052808
2. Vocke, R.D., Kothera, C.S., Woods, B.K.S. and Wereley, N.M., "Development and Testing of a Span-Extending Morphing Wing," *Journal of Intelligent Material Systems and Structures*, July 2011, 22(9):879-890.
3. Woods, B.K.S., Bilgen, O., and Friswell, M.,I., "Wind Tunnel Testing of the Fishbone Active Camber Morphing Concept," *Journal of Intelligent Material Systems and Structures*, Submitted January 2013, At press.