Series Elastic Gearing and Stiffness for an Airborne Energization Leg

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I. Background

For a legged system that undergoes flight phase during a gait cycle, stance phase often occupies a small amount of time. An actuator must output high mechanical power during this short time to add substantial energy to the system. Enabling an actuator to add energy to the system during flight could relax the requirement on actuator power. We consider a leg concept that incorporates a mechanism with kinematic singularities to enable airborne energy storage within a series-elastic actuator (SEA). In flight phase, the SEA advances the mechanism's rotary input until a singularity is encountered, at which point it is unable to advance, but is enabled to wind its spring element to the point that it matches the actuator's maximum torque, T_{max}. Despite singularity conditions at the input, forces at other locations of the mechanism act under very different circumstances. Mechanism kinematics are specified such that a relatively small vertical force at the end-effector from ground contact will easily advance the mechanism into the regular portion of its configuration space, allowing the elastic energy stored in flight to flow into a push-off motion.

For this overarching idea to be successful, details must be considered. The elastic energy stored during flight phase is proportional to $T_{\max}$, which can be increased by gearing. Furthermore, for a given $T_{\max}$, a lower stiffness spring can store more energy. However, there is a limit to how much gearing can be increased and stiffness can be decreased. The cost of increasing gearing is a decrease in motor speed, and the cost for decreasing stiffness is an increase in spring deflection and the speed at which it must deflect to yield useful motions. When these speeds do not match, the planned accumulation and discharge of elastic energy does not occur. We investigate these limitations here.

II. Methods

A dynamic simulation environment was programmed, details can be found in [1]. In all simulations, the robot was dropped from rest at 0.4 m, and is powered by an SEA based on a torque-limited Maxon DCX16L motor receiving a constant input voltage signal. Simulations were run for 6-7 s. Damping was included in the spring, at the rotary input, and from ground contact. Gearing and stiffness of the SEA were varied (Fig. 1). Stiffness is not parameterized directly, but instead by spring deflection, i.e. $k = T_{\max}/\Delta\theta$.

III. Results & Discussion

The maximum jump heights recorded during simulations are shown in Fig. 1. Generally, jump height increased with spring deflection. This is expected since softer springs allow more elastic energy storage. Beyond G=95, maxima can be observed. As spring deflection increases, the speed required to wind it during flight increases, as do damping losses. The sharp drop-offs observed in Fig. 1 indicate where the motor cannot appreciably wind the spring within the duration of flight phase. As the gear ratio is increased, the range of suitable spring deflection shrinks. The intermediate ratio G=115 demonstrated good hopping performance over a large range of stiffnesses.

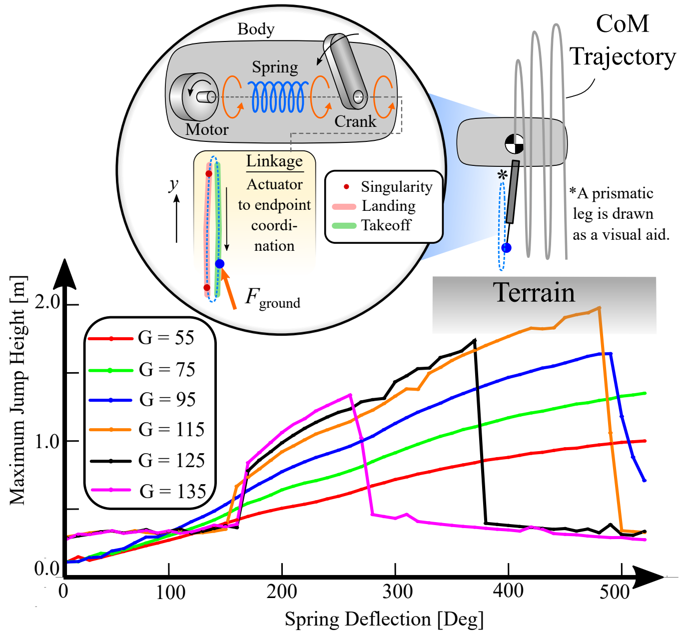

Fig. 1. The effect of spring deflection and motor gearing on jump height.

IV. Conclusion

A novel concept for a hopping leg capable of storing elastic energy in an SEA during flight phase is investigated. The SEA's gearing and stiffness parameters were varied, and the effect on jump height was observed. The results could serve as a starting point for selecting a motor and spring from which to build the SEA.

Acknowledgment

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References

[1] Liu C, Plecnik M, "Evaluating Plane Curves As Constraints for Locomotion on Uneven Terrain," ASME IDETC/CIE, 2020 Aug 17.