RE<C: Heliostat Cable Actuation System Design

Overview

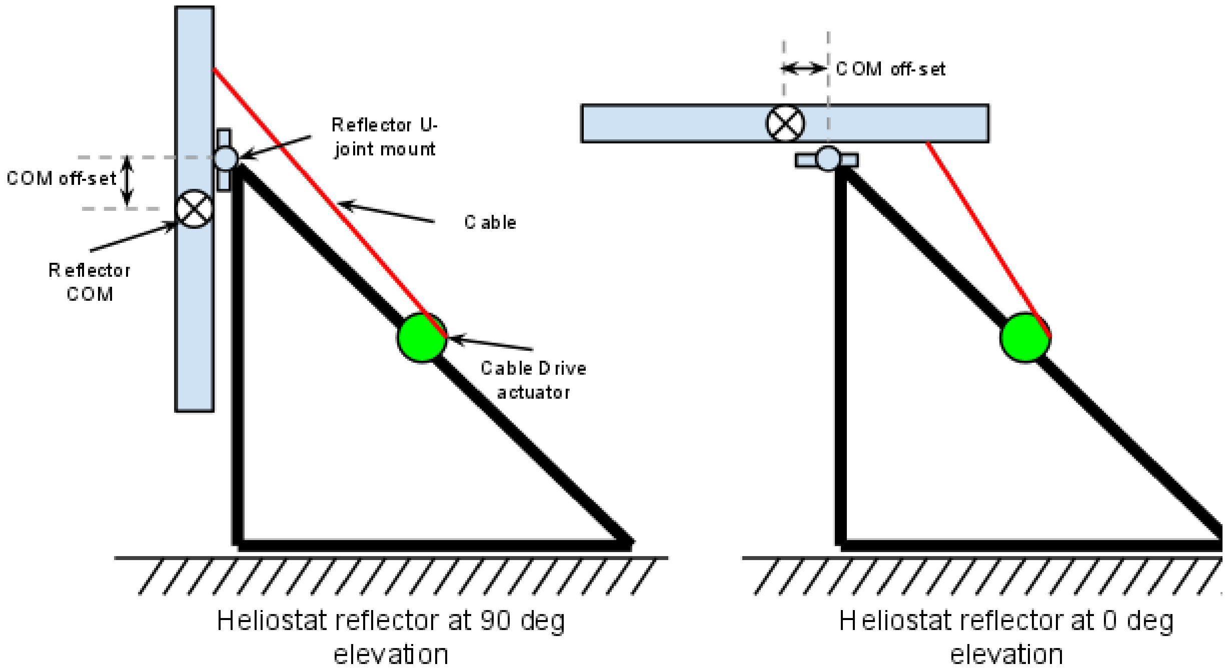
Current heliostat actuation systems are engineered to move large, heavy mirrors using correspondingly large motors and gearboxes that must be able to withstand mirror weight and adverse weather. These systems not only add significant cost to a heliostat, they consume power during operation, reducing the overall power produced by the CSP power plant.

Our design goal was to reduce power consumption, size and cost of the actuator system. As we designed the actuator system from scratch, we realized an electric cable drive system that was constantly in tension was the best method to position the reflector while fulfilling our goals.

Architecture

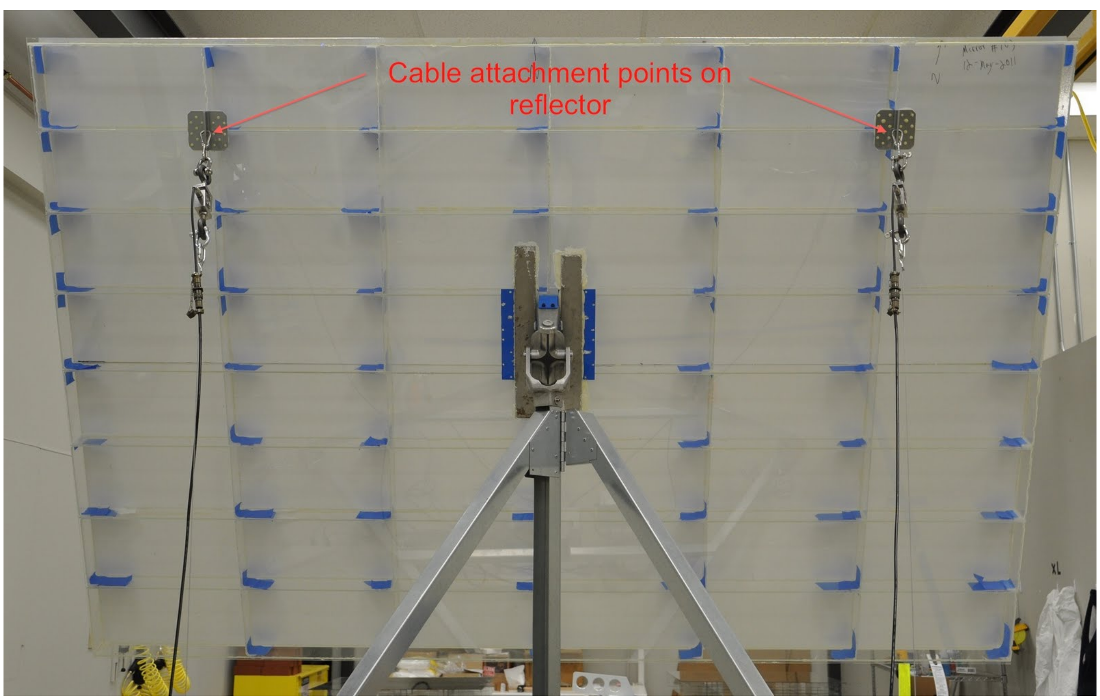
Cables or wires are an efficient and lightweight means of carrying loads, provided those loads always keep the cable in tension. We created this tension by using the heliostat reflector as a counterweight.

Even though we built a lower-weight reflector (20 kg/m^2), it still represents the largest percentage of mass in the heliostat system. Instead of positioning the reflector center of mass directly over the center of the heliostat frame, we chose to offset the center of mass towards the front of the frame and use a cable actuation system to “pull” it back into the desired position. The mass offset provides constant tension in the cables throughout the entire operational regime.



Heliostat reflector angles

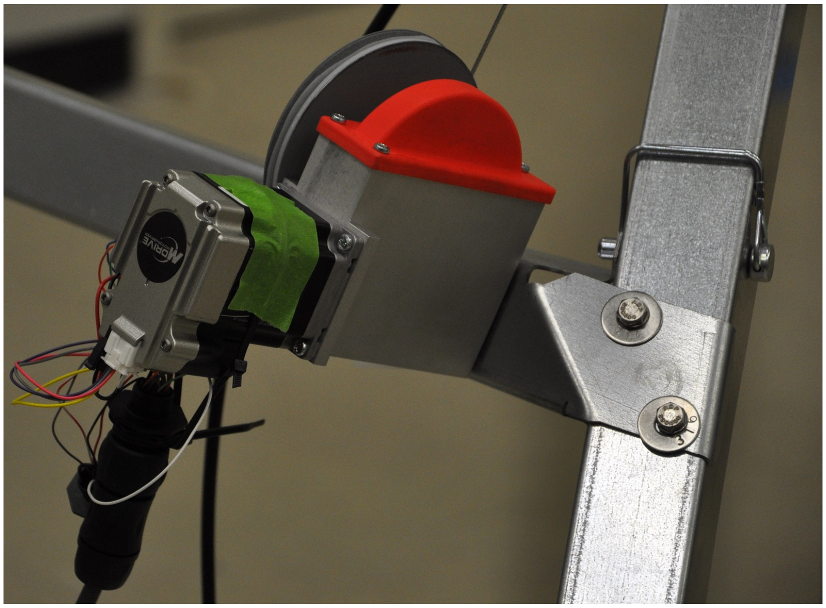
We placed cable attachment points as wide as possible on our reflector to increase the cable's mechanical advantage and allow us to use small, low-power motors with single worm gear reductions to control our heliostat.



Prototype reflector with cable attachment points

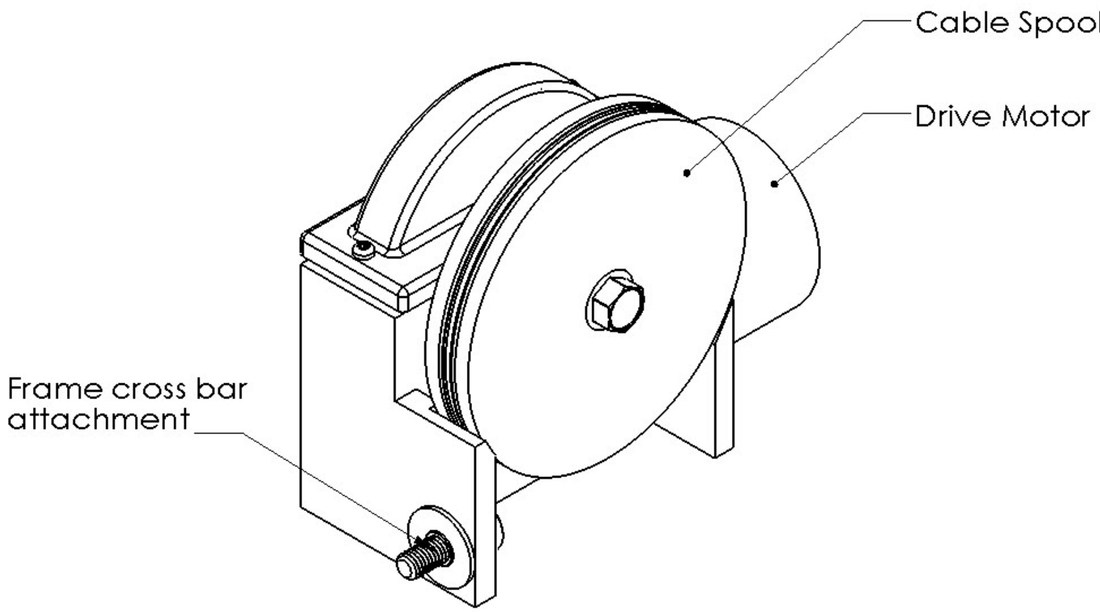
Actuator Design

The cable drive design we used is similar to an electric winch, with an electric motor driving a spool through a gear set winding cable in or letting cable out at a controlled rate. A single worm gear set was chosen for its compact form factor, high gear ratio, and low cost.

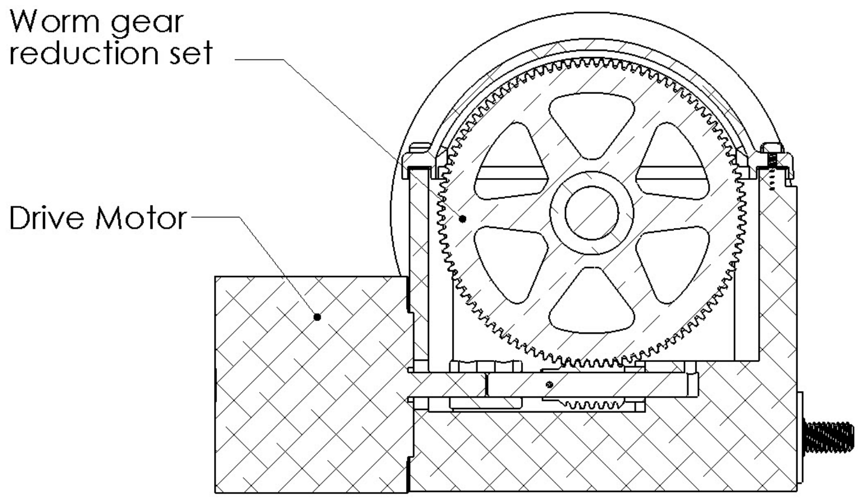


Prototype cable drive mounted on frame

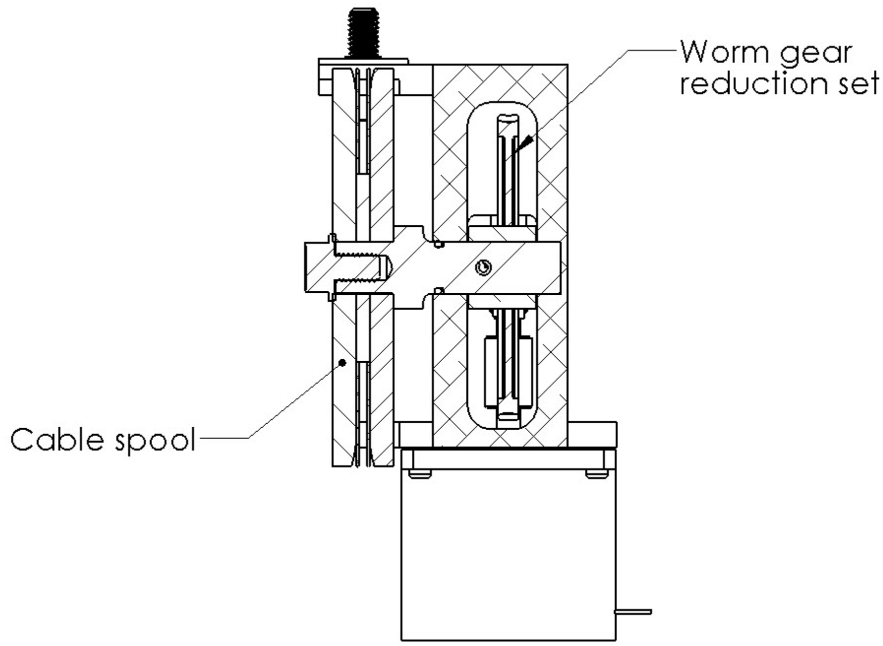
We found in our analyses that the motor power requirements were skewed by the need to stow the reflector fast due to bad weather, not by slow sun tracking. Motor torque requirements were a function of combined wind and gravitational loads, coupled with the gearing design. Our choice of slow emergency stowage requirements allowed us to use a low power, NEMA 23-style motor. The anti-backdrive behavior of the worm drive allows the use of motors with comparatively low holding torque.



Isometric view of heliostat actuator



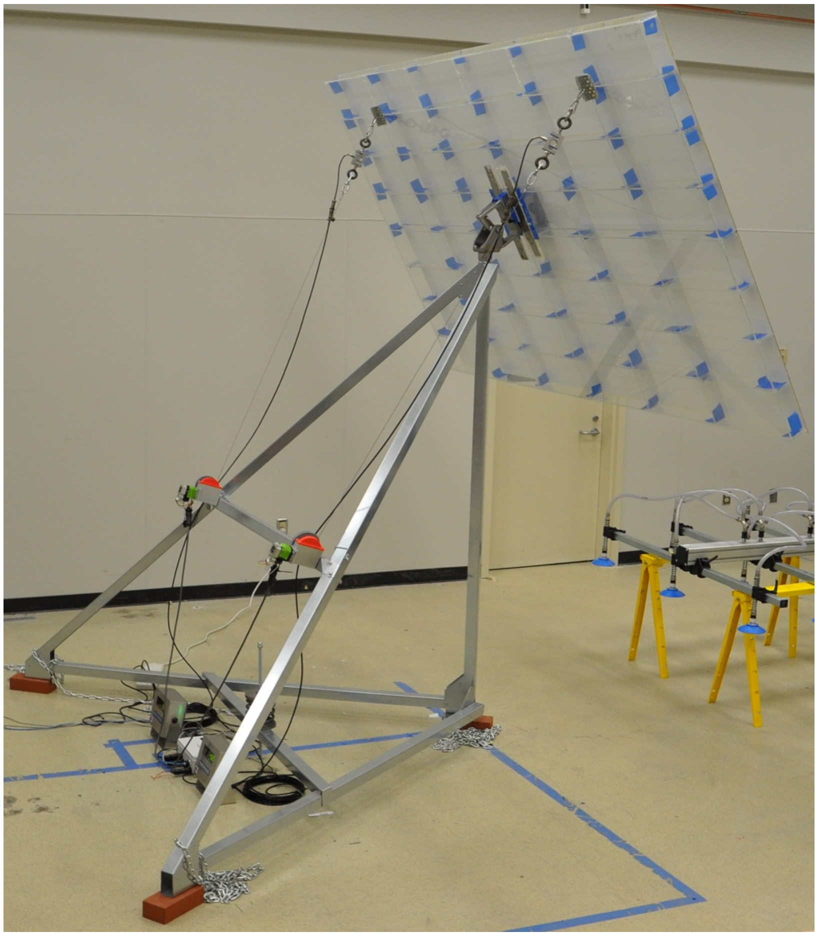
Cable drive actuator showing worm gear reduction



Cable drive actuator showing worm gear and cable spool

Due to the high load carrying capability of cables, we were able to use a 0.0625” (1.6mm) diameter, 7x19 strand core, stainless steel cable for each cable drive actuator. This cable has a break strength of 480 lbf (2100 N) and the maximum expected cable tension is ~ 200 lbf (890 N).

The actuator housing is made of only a few parts and is completely sealed from the environment when fully assembled, protecting the gear set and retaining lubricants. We designed the actuators to ship attached to the heliostat frame crossbar, minimizing field labor installation costs. Maintenance and replacement of the cable actuators is quick and simple, since the actuators are modular and easily accessible.



Fully assembled prototype heliostat with actuators. The black cables are tension measurement cables. The control cables are silver and thinner, but can be seen to be under tension.

Reliability Testing

Reliability testing for cable actuators is critical, since the actuators are the one heliostat component that moves the most during operation. We performed cyclic load testing on the actuators, accumulating over 50,000 cycles on a single actuator, to identify early points of failure.

We iterated on the actuator design and incorporated several improvements to arrive at our final prototype heliostat actuator. These improvements included:

- Implementing a spirally wound cable spool (instead of an adjacently wound spool) just wide enough to accommodate a single cable width to reduce cable tangling and bunching after repeated winding/unwinding.
- Separating the gear set from the cable spool will prevent the possibility of cables ending up in gear teeth.
- Using preformed wire rope and swivel attachments to minimize any build up of torsion in the cable.
- Adding guide features on the actuator housing that prevent the cable from leaving the spool even if cable tension is lost.

Video: Heliostat cable drive actuators

Conclusions

Holistically re-thinking a heliostat's actuation system architecture enables significant cost reductions. Design simplifications arise from using forces operating on the system to their maximum benefit. Utilizing gravity on the reflector to create cable tension for the actuators is a good example of this. Gravity is one of the strongest forces operating on the system, and seeing it as a force to be utilized, not overcome, allowed us to see new design possibilities with a cable actuation system.

Big cost reductions can be made at the overall system level, but they don't stop there. Cost reductions must be evaluated for each component, including considerations for installation, maintenance and reliability. For example, cable drive motors trade lower holding torque for a lower overall power draw. This reduces motor cost and parasitic power demand, but means a weaker motor.

Future Research

Areas for future work:

- **Unintended mirror motion:** Since our design only uses two cables, we can't fully restrain the mirror and cannot entirely prevent it from being tilted completely back. It's possible that a gust of wind could blow the mirror center of mass towards the actuators, relieving the cable tension and putting the mirror in a place where the cable actuators couldn't move it.

  While we did not test full-scale heliostats under real wind conditions to see if this situation would occur, our flow visualization experiments indicate that under steady wind loads this would not occur. However, our studies of surface level wind conditions inform us that the wind is anything but steady, and that wind gusts can come from many directions.

- **Environmental hardiness:** The desert is a harsh environment with grit, salinity, cycling temperatures, UV rays, and wildlife. While we didn't perform a long term reliability study, it is important to test the entire cable drive system under these adverse conditions and verify operation of each component.

- **Cable flutter:** Like violin or piano strings, the cables between the actuator and the reflector have the potential to vibrate. Wind vibration across the wires can lead to premature failure. We didn't test to see if this would occur, but a simple solution to prevent this from happening is to spirally wrap another wire strand around the outer diameter of the cable. This technique breaks up the air flow and prevents vibration, and is commonly used in car and truck radio antennas.