SPRING-POWERED ELEVATOR PROTOTYPE

POLE-CLIMBING “SPACE ELEVATOR” MECHANISM

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1. Project Summary

The Spring-Powered Elevator Prototype project focused on the design, fabrication, and testing of a purely mechanical system capable of climbing a vertical steel pole using energy stored in a constant-force coil spring. The project was conducted as part of a team-based mechanical engineering design course, with final performance evaluated through a competitive pole-climbing demonstration.

The primary objective was to develop a lightweight and mechanically simple device that could climb a 7 ft (84 in) vertical pole as quickly and reliably as possible while adhering to strict constraints on materials, mass, and allowable energy input. Only supplied materials were permitted, the mechanism was required to remain intact throughout the climb, and no electrical or motorized components were allowed.

The final design employed a wheel-based climbing approach driven by a two-stage gear train optimized to convert the limited output of the constant-force spring into sufficient torque at the drive roller. Components were modeled in SolidWorks and manufactured using a combination of CNC machining and FDM 3D printing. Iterative refinements were implemented to address friction, weight reduction, and manufacturability within the limited project timeframe.

During the competition, the prototype successfully climbed 62 in (5.17 ft) of the pole—approximately 81 % of the total height—in approximately 0.6 s, achieving first place among all teams. It was the only mechanism to surpass the halfway mark. The completed system had a total mass of 169 g and met all project constraints, demonstrating effective application of the engineering design process under significant design and time limitations.

2. Problem Statement

2.1 Background and Motivation

The concept of a space elevator proposes transporting payloads along a stationary vertical structure rather than relying on conventional propulsion systems. While full-scale space elevators face significant material and environmental challenges, the underlying problem of efficient vertical climbing along a fixed structure remains relevant to practical engineering applications such as inspection robots, maintenance systems, and hazardous-environment automation.

In this project, a vertical steel pole was used as an analogue for a space elevator cable. The engineering challenge was to design a purely mechanical climbing mechanism capable of ascending the pole without the use of motors, electronics, or external power sources, while operating under strict material and time constraints.

2.2 Project Context and Contributions

The project was completed as a team-based mechanical engineering design exercise conducted over an academic term. All teams were provided with the same limited set of materials and were required to design, fabricate, and test a functional prototype. Final performance was evaluated during a timed competition.

Individual contributions focused on mechanical concept development, gear-train analysis, CAD modeling in SolidWorks, CAM preparation, CNC machining, and iterative design refinement based on test and competition performance.

Within the team, responsibilities were divided across mechanical concept development, gear-train analysis, CAD modeling in SolidWorks, CAM preparation, CNC machining, and iterative design refinement based on testing and competition performance.

3. Assumptions and Constraints

3.1 Assumptions

- The steel pole surface was assumed to be uniform along its length.
- Friction between the drive roller and pole was assumed to remain constant during the climb.
- Energy losses due to bearing friction and gear meshing were assumed to be minimal but non-negligible.
- The constant-force spring was assumed to deliver approximately uniform force over its operating range.

3.2 Design Constraints

- Only supplied materials were permitted.
- No motors, electronics, or electrical energy storage devices were allowed.
- The mechanism had to remain fully intact throughout the climb.
- The total system's mass was strictly limited.
- The climb had to be completed within a single energy release from the spring.
- Design, fabrication, and testing were constrained by a single academic term.

4. Design Methodology

A structured engineering design process was followed throughout the project. Initial problem requirements were translated into functional objectives, followed by concept generation, evaluation, and selection.

Multiple climbing concepts were brainstormed and evaluated based on simplicity, mechanical efficiency, manufacturability, and robustness. Early concepts included inchworm-type mechanisms, braking-based climbers, and wheel-driven designs. A wheel-based approach was selected due to its continuous motion capability, mechanical simplicity, and favorable torque-to-speed characteristics.

Analytical calculations were performed to estimate torque requirements, gear ratios, and expected climb performance based on spring force and frictional limitations. CAD models were developed to validate packaging, alignment, and manufacturability prior to fabrication. Prototypes were iteratively refined through testing and redesign.

5. Engineering Design and Implementation

The final prototype consisted of a constant-force coil spring, a two-stage spur gear train, a primary drive roller, and a supporting structural frame. The spring was wound prior to deployment and released to drive the gear train, converting stored potential energy into rotational motion at the drive roller.

The gear ratios were selected to balance torque output and rotational speed, ensuring sufficient traction at the pole interface while minimizing energy losses. The frame was designed to maintain alignment between the roller and pole while minimizing mass.

Most structural components were CNC-machined from MDF due to material availability and the need for rapid fabrication and iteration. Select components were fabricated using FDM 3D printing to allow for complex geometries and rapid iteration. Bearings and shafts were incorporated to reduce friction and improve mechanical efficiency.

6. Testing and Validation

Bench testing was conducted to verify gear alignment, spring performance, and roller traction prior to competition. Incremental testing was used to identify frictional losses, structural weaknesses, and assembly tolerances.

Performance testing involved timed vertical climbs on the steel pole under competition conditions. Observed issues such as slippage, misalignment, and excessive friction were addressed through iterative design modifications.

During the final competition, the prototype demonstrated stable operation and rapid ascent, successfully climbing 62 in of the 84 in pole in approximately 0.6 s. The mechanism exhibited consistent traction and structural integrity throughout the climb.

7. Results and Discussion

The final prototype exceeded initial performance expectations, achieving the fastest climb and greatest height among all competing teams. The high climb speed and distance demonstrated effective conversion of limited spring energy into mechanical work.

Performance limitations were primarily attributed to frictional losses and finite spring energy. Further improvements could be achieved through lighter materials, optimized gear profiles, and improved roller surface treatments.

8. Conclusion and Recommendations

This project successfully demonstrated the team's ability to design and fabricate a high-performance, purely mechanical pole-climbing mechanism under strict material, mass, and time constraints. The final prototype achieved first place in the competition while meeting all material, mass, and design requirements.

Future work could explore alternative materials, improved friction management, and more efficient energy storage mechanisms. The project provided valuable experience in mechanical design, rapid prototyping, and iterative problem-solving under real-world constraints.