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Machine Design Experiments Using Mechanical Springs to Foster Discover Learning

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Abstract

This paper describes new experiments that were designed to provide engineering students with opportunities for discovery learning experiences with systems using mechanical springs. A suite of practical experiments was developed presenting students with a range of challenges requiring them to analyze, measure, and design springs. Activities in the experiments include:

(1) Identifying spring types (tension, compression, torsion) and appropriate applications (automotive door latches, key fobs, pens).
(2) Disassembling and re-assembling padlocks (with design and manufacturing questions related to the springs used in the locks, and measurement of the stiffness of the shackle compression spring).
(3) Achieving desired stiffnesses through appropriate series and parallel combinations of springs (requiring stiffness measurements of the given springs, and comparing to manufacturer's supplied data).
(4) Experimentally determining shear moduli and stiffnesses of wire and 3D printed springs. Investigating overextension limits of springs.

Introduction

For the typical undergraduate engineering student the topic of mechanical springs is introduced and discussed in several courses. A first exposure may be in a physics course, where springs are modeled as idealized mechanical energy storage components. Springs store potential energy, complementing masses that store kinetic energy and dampers that are resistive and offer no energy storage capability. In an electrical circuit course, springs are often presented as the analog of either capacitors or inductors, depending on whether a force-voltage or force-current analogy, respectively, is used. For mechanical engineering students, real springs are a core component studied in machine design courses, where the nomenclature and design equations are developed for various types of springs. There may be a rudimentary exposure to physical springs in a mechanical engineering laboratory; more often, springs are passed around in class and used as part of demonstrations.

Discovery Learning

The term "discovery learning" covers a variety of instructional techniques, such as active, cooperative, collaborative, project-based, and inductive learning. In these student-centered pedagogical methods, the focus of activity is shifted from the teacher to the learner. The student is not provided with an exact answer or a specified approach but with the materials and resources that can be used to find the answer independently. In the context of a laboratory setting, discovery learning takes place when a challenge is posed and the experimental resources are available for more open-ended investigation, without a 'follow-the-recipe' type manual or detailed instruction. In solving the challenge the student is actively engaged in an investigation that draws on prior experience and knowledge as well as new knowledge. By interacting with, exploring, and manipulating physical components and systems, the student wrestles with the challenge and performs the necessary experiments to gain insight and understanding. Discovery learning methods have been studied in detail and their advantages for promoting and enhancing learning have been well documented.[1-6]

Design of Machine Elements Course

In the College of Engineering at Marquette University the "Design of Machine Elements" course is a required 4-credit junior-level mechanical engineering course with 3 hours of lecture and 2 hours of laboratory each week. In the last several years new laboratory experiments that promote discovery learning have been created for this course. A description of the new Machine Design Laboratory and developed experiments was reported at last year's ASEE Conference.[7]

Each year new laboratory experiences in the "Design of Machine Elements" course are created and previous experiments are re-evaluated, modified, and refreshed. This development process improves the laboratory experiences for students. It ensures that student activities foster discovery learning and are wide-ranging, and the topics are up-to-date. In the past, no experiments that specifically addressed spring design and spring applications were conducted. This void motivated the current work.

Discovery Learning Experiments with Springs

Four sets of experiments in which students analyze and design mechanical springs were developed and are reported below. Each experiment has been designed to foster discovery learning and to challenge students in meaningful ways. The experiments can be conducted in a 20-30 minute session, such that all four can be completed in a 2 hour laboratory section with 2-3 students working in a team.

Experiment 1: Spring Identification and Applications

This experiment investigates various types of springs and their applications. It consists of several tasks. In one task, the student team is presented with ten different springs (Figure 1) and asked to identify each by type (compression, extension, torsional, wave) and end type, and measure each free length and coil diameter. The team is then challenged to answer several questions pertaining to applications, providing examples for the use of each type of spring. The team is also asked to identify real-world objects that have spring-like behavior and describe the source of the elastic nature.

In a separate activity, the student team analyzes an automotive rear seatback latch (Figure 2) and key fob (Figure 3). (The authors are grateful to STRATTEC Security Corp. for these donations.) The team is asked to identify the types of springs used in the rear seatback latch and discuss the latch operation (lock engagement and release) in the mounting fixture. For the key fob the team is asked to identify the type of spring used in the key release and measure its free length and wire diameter. The team is also asked to explain how the spring stiffness is achieved underneath the buttons.

The purpose of the experiment is for students:

- to gain practical experience with different types of springs,
- to become familiar with spring end types,
- to become familiar with spring applications,
- to become familiar with a spring-cam design.

Experiment 2: Padlock Assembly and Disassembly

This experiment engages students through padlock disassembly and assembly, and asks them to identify components, understand the operation of two different locks, and compare their design features. The student team is presented with two padlocks, one by American Lock and one by STRATTEC Security Corp (Figure 4). The STRATTEC padlock is disassembled for reference, and the team is asked to identify components and understand its operation. The student team then disassembles the American Lock, analyzes its components, and investigates its operation. The team is asked to identify the types of springs used in the two locks. Finally, the team is asked to reassemble the American Lock and discuss which lock is more secure, providing reasons supporting their conclusion.

The purpose of the experiment is for students:

- to gain experience with mechanical component design, in particular, the designs of two different padlocks,
- to gain experience assembling and disassembling mechanical systems with springs and using hand tools,
- to become familiar with die cast components.

Experiment 3: Series and Parallel Combinations of Springs

This experiment investigates designs with springs mounted in various configurations, namely, series and parallel combinations. The student team is given several different springs from a "supplier" (McMaster Carr). The first task is to measure the spring rate of each spring and compare it to the rate indicated by the supplier. The measurement is made using a modified Pasco cart system with the displacement increased incrementally and the corresponding force determined using a force gauge (Figure 5). The team then measures the spring rates of springs arranged in series and in parallel. The challenge is to create a desired rate using a combination of springs in series and parallel.

The purpose of the experiment is for students:

- to apply Hooke's Law,
- to become familiar with the process of verifying specifications from suppliers,
- to gain practical experience with springs combined in series and parallel,
- to gain experience in creating equivalent stiffness systems.

Experiment 4: Measurement of Spring Parameters and Limits

This experiment is comprised of two tasks. In one task, the student team is asked to investigate spring linearity and overextension. The experimental set up includes an aluminum mounting plate, an extension spring, a force gauge, and a ruler (Figure 6). The spring and ruler are both screwed into the mounting plate. The team is asked to determine the force vs. deflection characteristic of the spring through failure (Figure 7). The team is asked to estimate the spring rate, the linear range, the load limit before plastic deformation, and the viable working range of the spring from the force-displacement characteristic.

In a second task, the team is challenged to determine the shear moduli and stiffnesses of helical compression springs. The springs presented to the students are commercial metal wire springs and 3D printed (ABS-M30) springs (Figure 8). The team measures the wire diameter, the coil diameter, the number of coils, and force and displacement values of each spring (Figures 9 and 10). From these values the shear moduli of the spring material are calculated and the stiffnesses are found. The team is required to assess the suitability of the approach for determining material properties. Since it is not commonplace to fabricate springs by 3D printing, these springs prompt a discussion of the feasibility of their use in applications.

The purpose of the experiment is for students:

- to gain practical experience with spring measurement and design,
- to understand spring failure,
- to become familiar with properties of helical compression springs, both metal wire and 3D printed.

Discussion

The four experiments as well as an accompanying laboratory manual were developed in the Fall 2013. For debugging purposes, the experiments were tested with five undergraduate senior students prior to full deployment in the course. This testing aided in evaluating the feasibility of the experiments and in answering questions about the pedagogical value of the different activities. The students chosen for the testing had previously taken the "Design of Machine Elements" course and performed at a high level. Student testing was extremely valuable in identifying activities that needed improvement and items in the manual that needed revision . Based on their feedback, several changes were implemented to further promote discovery learning. Testing with former students is highly encouraged for anyone developing new laboratory experiments.

The revised experiments are being implemented with students in the "Design of Machine Elements" course in the Spring 2014. Feedback from students and teaching assistants has confirmed the value of the experiments in engaging students in the analysis and design of mechanical springs. Students became familiar with different types of springs, experimentally determined parameters of springs, analyzed and designed springs, and gained an understanding of the applicability of different springs to real-world problems.

Conclusion

This paper describes the details of four experiments that specifically focus on the characterization, design, and use of mechanical springs. The experiments were created for a junior-level "Design of Machine Elements" course at Marquette University. The intent of the experiments was to creatively enhance mechanical engineering students' awareness of springs in applications and expand their knowledge and confidence in spring analysis and design. The experiments are predicated on discovery learning methods that are the cornerstone of modern engineering education practice.

References

1. Felder, R.M. and Brent, R., 2009, "Active Learning: An Introduction," *ASQ Higher Education Brief,* 2(4).
2. Goldberg, J.R. and Nagurka, M.L., 2012, "Enhancing the Engineering Curriculum: Defining Discovery Learning at Marquette University," 42nd ASEE/IEEE Frontiers in Education Conference, Seattle, WA, October 3-6, pp. 405-410.
3. Prince, M., 2004, "Does Active Learning Work? A Review of the Research," *Journal of Engineering Education*, 93(3), pp. 223-231.
4. Cleverly, D., 2003, *Implementing Inquiry Based Learning in Nursing*, Taylor & Francis, London, p.124.
5. Prince, M.J. and Felder, R.M., 2006, "Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases," *Journal of Engineering Education*, 95(2), pp. 123-138.
6. Prince, M.J. and Felder, R.M., 2007, "The Many Faces of Inductive Teaching and Learning," *Journal of College Science Teaching,* 36(5), pp. 14-20.
7. Nagurka, M. and Rodriguez-Anton, F., 2013, "Discovery Learning Experiments in a New Machine Design Laboratory," 2013 ASEE Annual Conference, Atlanta, GA, June 23-26.

Experiment 1

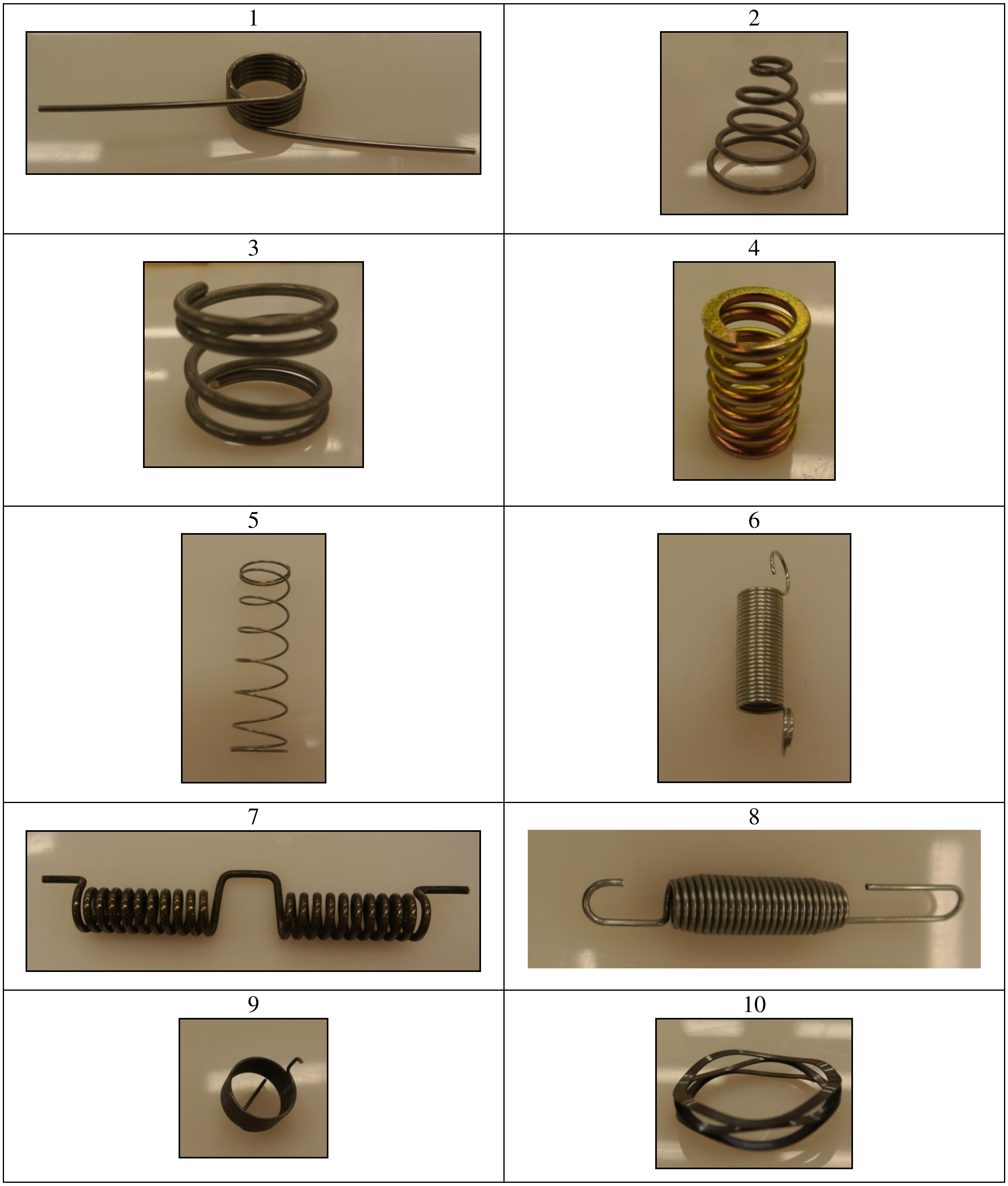

Figure 1. Ten different types of springs to be identified.

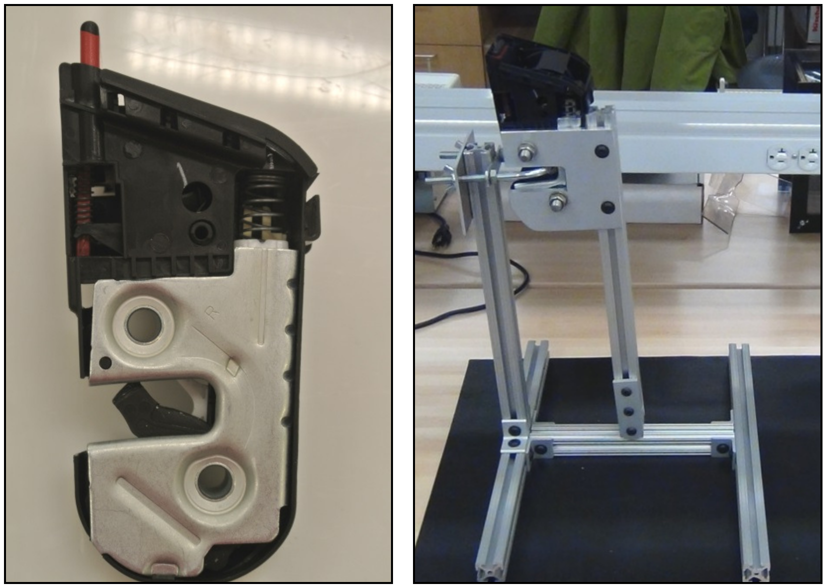

Figure 2. STRATTEC Seatback latch (left) and test fixture (right).

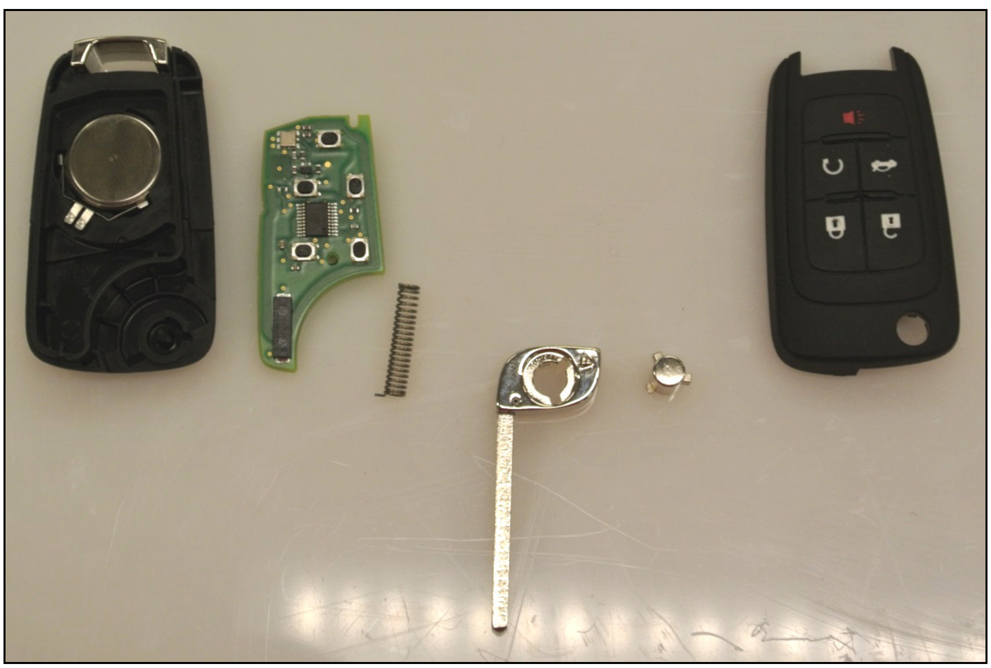

Figure 3. STRATTEC Key fob disassembly.

Experiment 2

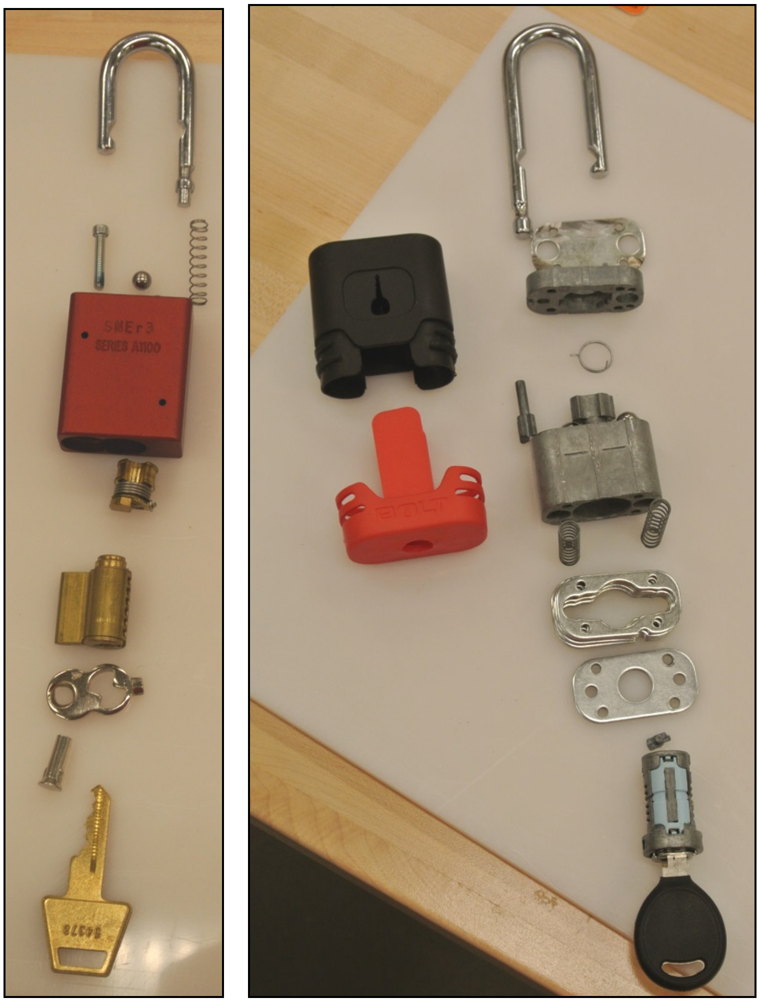

Figure 4. American Lock (left) and STRATTEC (right) padlocks disassembled.

Experiment 3

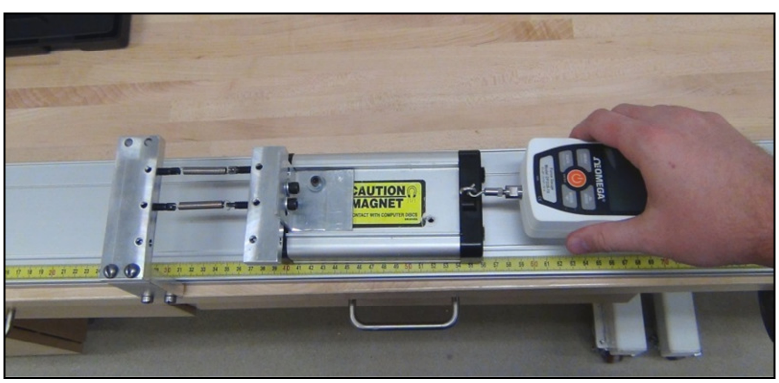

Figure 5. Determining stiffness of parallel springs with Pasco cart system and force gauge.

Experiment 4

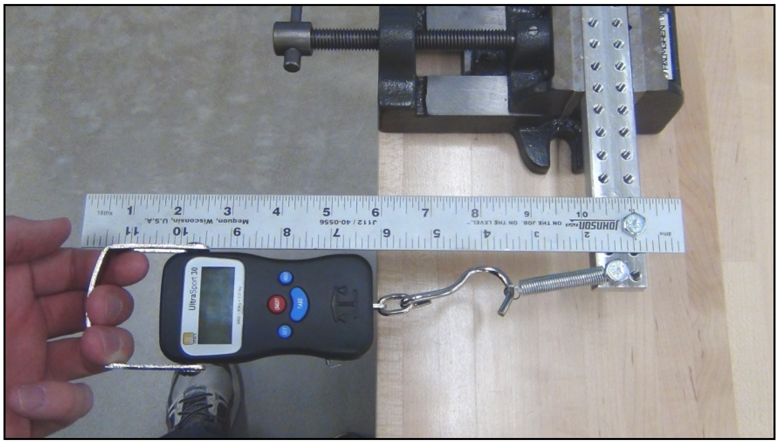

Figure 6. Spring rate measurement setup.

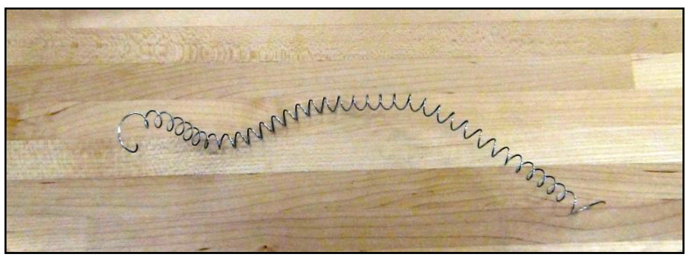

Figure 7. An overextended spring.

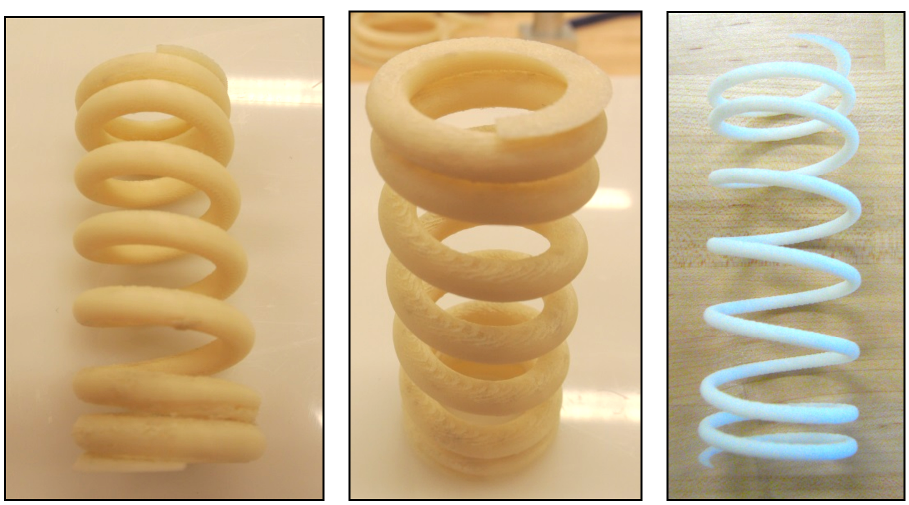

Figure 8. 3D printed springs.

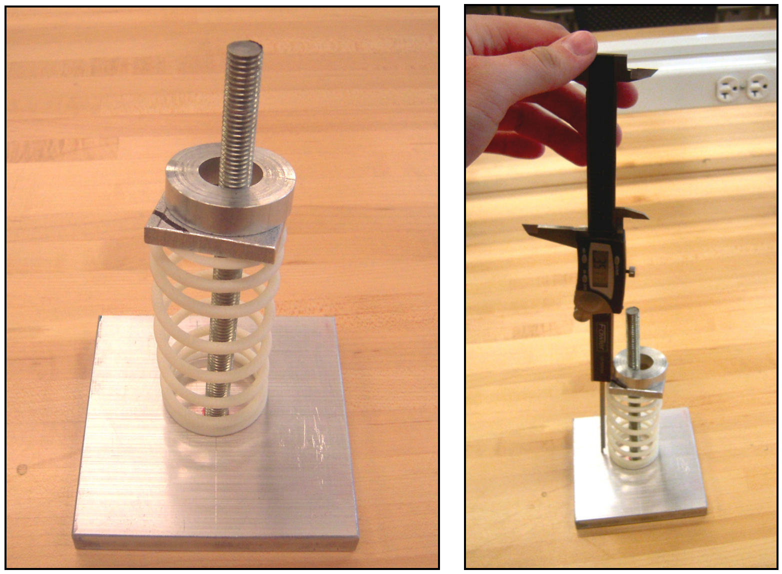

Figure 9. Testing 3D printed springs.

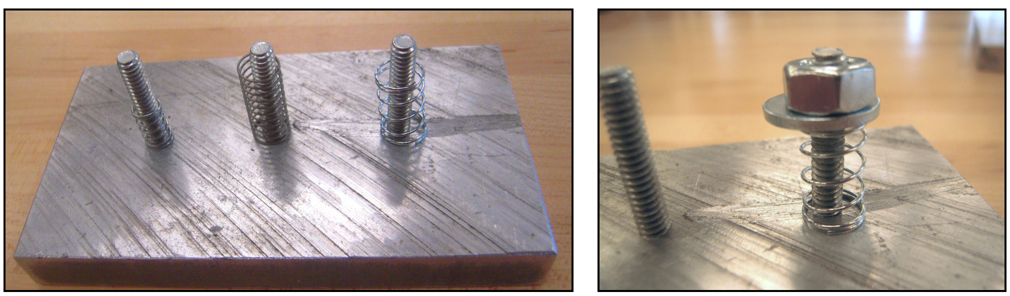

Figure 10. Fixture for testing mechanical wire springs.