Ondulé | Designing and Controlling 3D Printable Springs

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How can we embed springs in 3D-printable objects?
Making a spring man using our design tool...
But let’s take a step back...

How can we add deformation to 3D printed objects?
Linkage
Megaro et al. SIGGRAPH'17
© Disney
Lattice Pattern

Iwafune et al. SIGGRAPH ASIA'18
Telescoping
Yu et al. SIGGRAPH’17

Here is a 3D printed version of the same telescope.
But one of the most common deformable structures in manufacturing that has not been extensively studied is
Helical Spring
Benefits of Helical Spring

compress
extend
twist
bend
energy
shape approximation

Youtube Source: https://www.youtube.com/watch?v=aMAdgMDgTgQ
Key Challenges

- The mechanical performance of 3D-printed helical springs are not known
- Design, customize, and control spring deformation behaviors can be difficult

Research Questions

- Do 3D printable springs follow mechanical theory?
- How can we isolate the deformation behaviors in a spring?
- How to lower the barrier to create and control springs in CAD design tools?
RQ1: Do 3D printable springs follow mechanical theory?

**Mechanical Experiments**

**Material Properties**
- Young’s modulus (E)
- Shear modulus (G)

**Spring Parameters**
- Spring diameter (D)
- Wire thickness (d)
- Number of coil turns (N)

**Experiment 1:**
3D-printed rod material property tests (E & G)

**Experiment 2:**
3D-printed spring tensile tests

**Experiment 3:**
3D-printed spring torsion tests
# 3D-Printed Spring Tensile Tests

<table>
<thead>
<tr>
<th>Condition</th>
<th>Wire Thickness (mm)</th>
<th>Diameter (mm)</th>
<th>Length (mm)</th>
<th>Turn Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire Thickness ($d$)</td>
<td>2, 3.4, 4.8, 6.2, 7.6</td>
<td>32</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Diameter ($D$)</td>
<td></td>
<td>25, 30, 50, 60</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Spring Length ($L$)</td>
<td>4</td>
<td>32</td>
<td>25, 45, 65, 85</td>
<td></td>
</tr>
<tr>
<td>Turn Number ($N$)</td>
<td>4</td>
<td>32</td>
<td>50</td>
<td>4, 6, 8, 10</td>
</tr>
</tbody>
</table>

- 100% infill lines infill pattern
- 90° printing angle
- 17 3D-printed springs

$$k = \frac{F}{x} \quad k' = \frac{d^4 G}{8D^3 N}$$

![Experiment Results](image1)

![Theoretical Predictions](image2)
The tensile and torsion behaviors of 3D-printed helical springs closely mirror theoretical predictions.
RQ2: How can we isolate the deformation behaviors?

Deformation Techniques
Ondulé Deformation Techniques

Individual Behavior

- **Linear Only**
  - Prismatic Joint

- **Twist Only**
  - Revolute Joint

- **Bend Only**
  - Chained Knuckle Joint

Compound Behavior

- **Linear + Twist**
  - Cylindrical Joint

- **Bend + Twist**
  - Chained Ball Joint

- **Freeform**
  - (no joints)
Ondulé Deformation Techniques

Compress + Extend Only: Prismatic Joint
Ondulé Deformation Techniques

Twist Only: Revolute Joint
Ondulé Deformation Techniques

Bend Only: Chained Knuckle Joint
Linear + Twist: Cylindrical Joint

Ondulé Deformation Techniques
Ondulé Deformation Techniques

Bend + Twist: Chained Ball Joint
Ondulé Decorative Spring

Original Model

Deformation Spring

Deformation + Decorative Springs
allows novice designers to add deformation behaviors to static 3D-printed objects using embedded springs and joints.

Ondulé Design Tool

RQ3: How to lower the barrier to create and control springs in CAD design tools?
Ondulé Design Tool

3D Seahorse Model

Rhino Modeling Scene

Spring Generation Panel

Spring Stiffness Control Panel

Spring Behavior Design Panel
1. Body Selection
2. Spring Generation
3. Spring Length Change

Generate the medial axis
Calculate the size
Ondulé Design Tool

Spring Generation

1. Body Selection
2. Spring Generation
3. Spring Length Change

Generate the medial axis
Calculate the size

Generate a spiral
Create the deformation spring
Generate the medial axis
Calculate the size
Generate a spiral
Create the deformation spring
Ray-tracing to find a spiral
Create the decorative spring

1. Body Selection
2. Spring Generation
3. Spring Length Change

Ondulé Design Tool
Spring Generation
Ondulé Design Tool

Spring Stiffness Control

1. Default Stiffness
2. Stiffness Adjustment
3. Spring Update

control the spring stiffness
Spring Deformation Behavior Design

Joint Generation

1. Default Joint Design
2. Behavior Design
3. Joint Update
Spring Deformation Behavior Design

- Linear Only
- Twist Only
- Bend Only
- Linear + Twist
- Bend + Twist

Ondulé Design Tool
Ondulé Applications
Tangible Prop for Storytelling

Storytelling Authoring Interface

Circuitry

3D-Printed Prop
Future Work

Geometry Constraints
Spring Robustness
Simulation
Summary

A new approach to allow novices to convert a static 3D shape into a deformable object with embedded 3D-printed springs and joints.

Conducted mechanical experiments
Proposed a set of deformation techniques using springs and joints
Developed a design tool
Built a set of example applications supported by Ondulé

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Thank you! Questions?