QCAM 3D Printed Springs

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Strategic Partnership with Quality Control in Additive Manufacturing (QCAM) Consortium

Kansas City National Security Campus (KCNSC)

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Purpose

KCNSC is requesting a mechanism powered by a 3D printed spring. The mechanism must meet the following criteria:

- Roll a 1-1/16" diameter steel ball 6' to 7' on a horizontal surface.
- Spring printed out of Polyamide 12 (PA12) using the Hewlett Packard Multi Jet Fusion (HP MJF) printing process.
- Spring design and testing addresses:
  - Spring constants
  - Fatigue responses
  - Elastic response to polymers
  - Viscous responses to polymers

NMSU's 3D Printed Spring team met and exceeded all expectations listed above.

Physics

Equations of Equilibrium of an Elastic Material

Hooke's law is the relationship between nodal force and moment vector *{F}* and nodal displacement vector *{u}*, which is denoted with the tensor coefficient described as spring stiffness matrix *[k]*, which determines how far the spring will displace for a given force, expressed in Equation 1.

$$\{F\} = [k]\{x\} \quad (1)$$

The Principle of Minimum Potential Energy states that the displacement configuration that satisfies equilibrium conditions is the one that minimizes the total potential energy.

$$\Pi = U_e + V \quad (2) \qquad k = mv^2/(\Delta x)^2 \quad (4)$$

$$\tfrac{1}{2}k(\Delta x)^2 = \tfrac{1}{2}mv^2 \quad (3)$$

References

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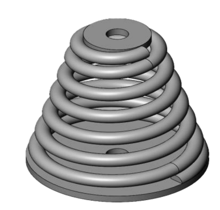
Final Design

The three springs listed below were each printed in two different orientations, horizontal and vertical.

Conical Spring

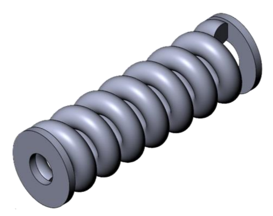


- Print orientation critical factor
- Non-linear spring stiffness coefficient

Wave Spring

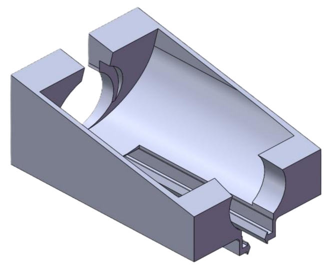
- Technical design with wide applications in multiple industries.

Helical Spring

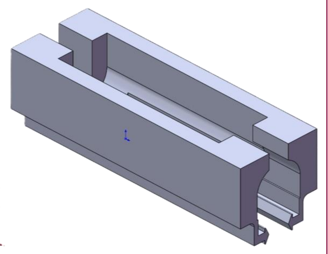


- Primary ideal spring
- Most practical and traditional spring
- Multiple stiffness coefficients
- High Stiffness is ideal for cyclic loading

Conical & Wave Spring Housing Unit



Helical Spring Housing Unit



The table below shows dimensions of the three final springs.

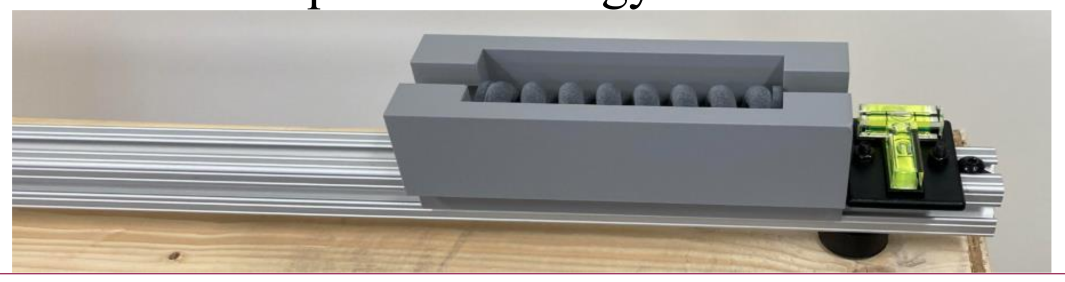
Type:	Length: (in)	Diameter: (in)	Diameter Of Coil: (in)	Number Of Coils:	Pitch:
Conical Spring	4.20	(OD) 4.00 (ID) 1.49	0.35	6.00	0.61
Helical Spring	4.15	1.23	0.35	7.00	0.54
Wave Spring	1.37	3.25	N/A	5.00	1.197

Mass-Displacement Testing

- Weighted mass for force displacement.
- Mass added until springs stopped compressing and no visible displacement.
- Displacement different for each variation of the springs due to printing orientation.
- Printing orientation affected initial lengths of each spring.
- 0 – 500 grams.

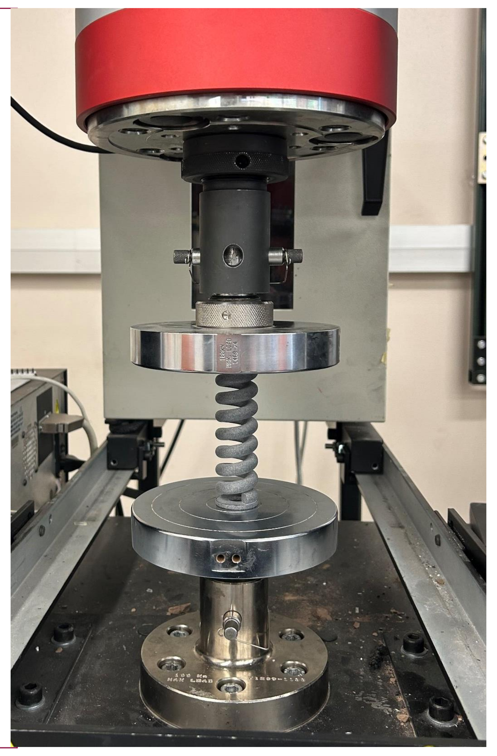
Test-Track Testing

- Tests for variations of each individual spring.
- Track test was tested over a distance of seven feet.
- Each spring pulled to be compressed either 10mm or 15mm.
- Calculate average velocity through five trial runs.
  - Input into the energy equations to calculate kinetic and potential energy.



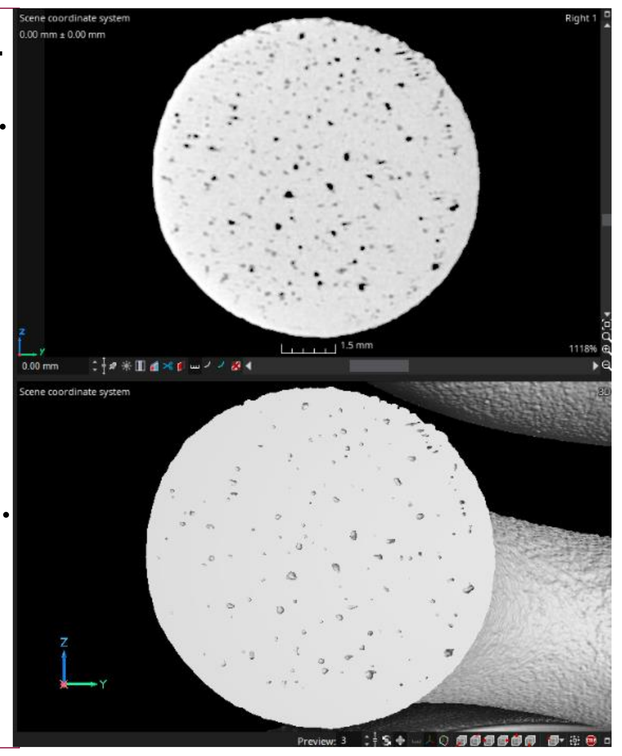
Cyclic Testing

- Low cyclic testing with Instron Tensile Tester.
- Low Frequency with high amplitude for high-stiffness helical springs.
- 3.5 mm Amplitude
  - 3.5 seconds per cycle
  - 0.2857 Hz
  - 1028 cycles per hour
- Limited to 500 Cycles.

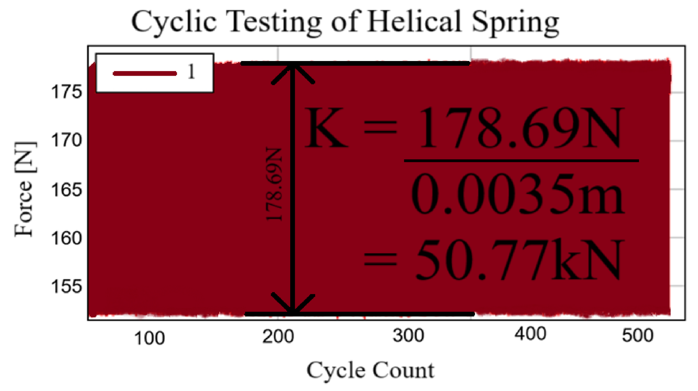


CT Scanning

- Porosity Study on high-stiffness helical springs.
  - Prior to Cyclic Testing
  - After Cyclic Testing
- Microtube allows for examination of pores down to the 32 microns.
- Mainly looked for pore diameter, sphericity, and pore quantity.

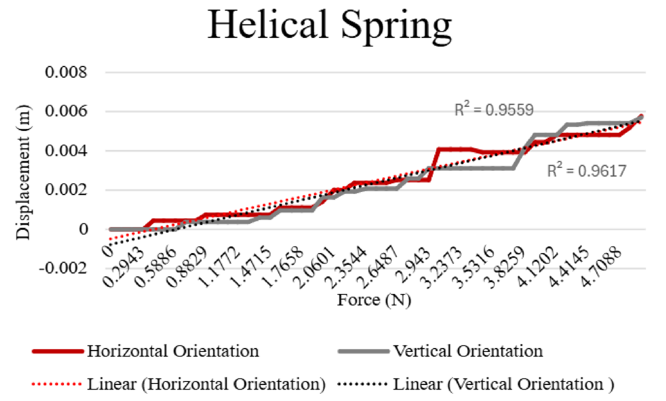


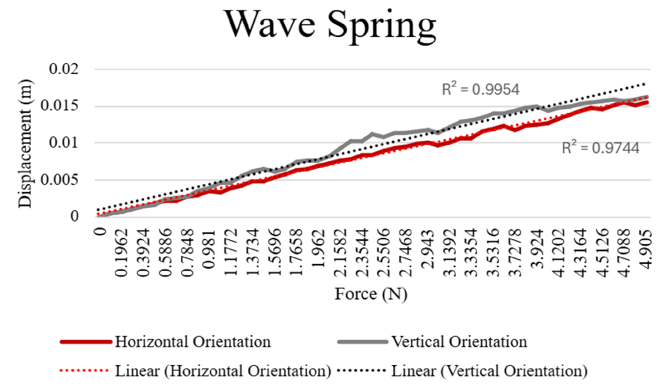
Results & Discussions

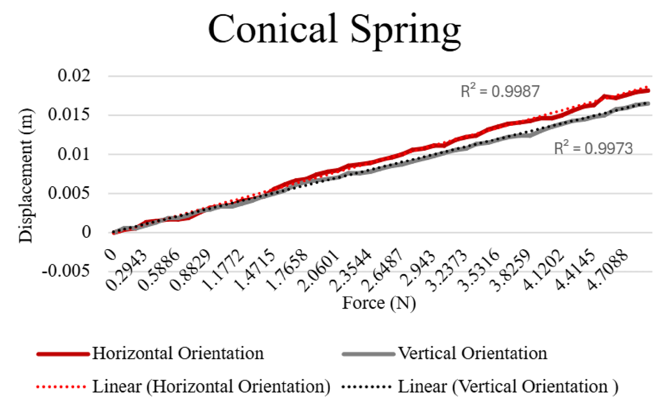


Cyclic Testing showed:

- Spring constant of 50.77 kN.
- No fatigue over time in a low-cyclic environment.

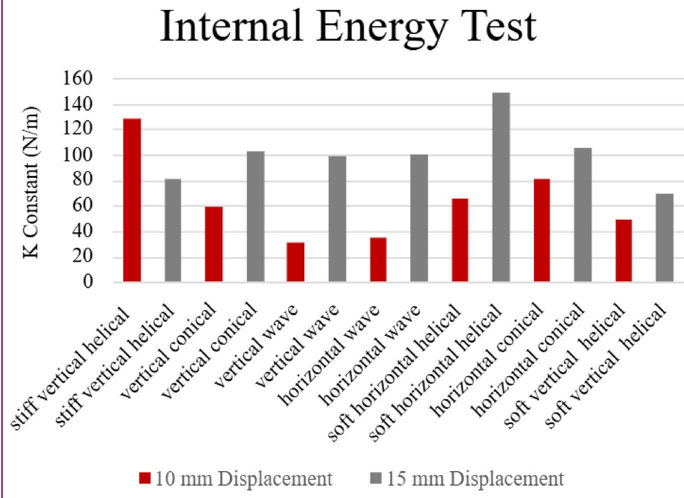






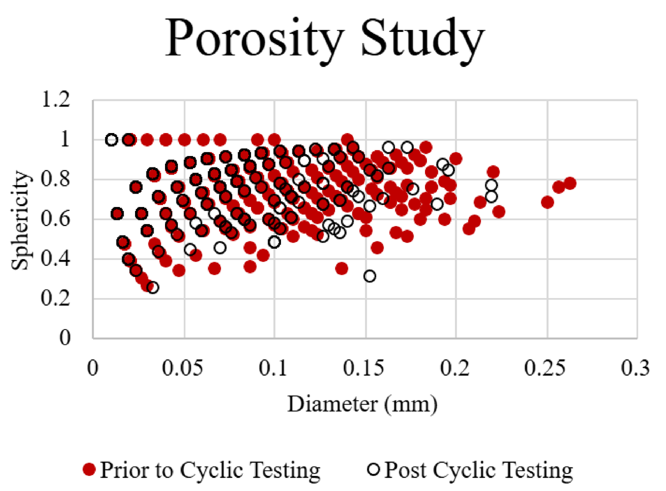
Mass-Displacement Static Tests showed:

- Under small loads, springs constants were approximately linear.
- 17.8% stiffer helical spring in the vertical orientation.
- 12.8% stiffer wave spring in horizontal orientation.
- 7.8% stiffer conical spring in vertical orientation.



Test Track Dynamic Tests showed:

- Stiffer helical springs have average dynamic spring constant of 104.519.
- Softer helical springs have average spring constant of 58.843.



Porosity Study showed:

- Cyclic Testing led to pore compaction.
- 24.5% decrease in pore count.
- No propagation occurred.
- 21.5% decrease in pore diameter.

Unclassified Unlimited Release
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