Magnetostrictive Actuator

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April 29, 2016
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Introduction

• Honeywell Aerospace designs and manufactures numerous products and services for the commercial and military aircraft industry

• Honeywell contacts initiating the project are Michael McCollum, the Chief Engineer of Pneumatic Controls Technology and Mitchell Thune, a recent NAU graduate who is working with Michael McCollum on this project

• The clients want to replace their electromagnetic solenoid with a magnetostrictive material, Terfenol-D, in the pneumatic control systems used on commercial airliners

• Terfenol-D is a magnetic shape memory alloy that elongates when an external magnetic field is applied
Problem Description

• Determine the feasibility of using Terfenol-D in aircraft valve systems by designing and constructing a prototype actuator

• Identify a solution to hysteresis in the magnetostrictive material

• Create a lever system to produce a 1:10 input to output stroke
Project Need
• Currently, there are no feasible actuators for aircraft valve systems using the magnetostrictive material Terfenol-D

Project Goal
• Develop a viable actuator that utilizes the magnetostrictive properties of Terfenol-D
## Objectives

<table>
<thead>
<tr>
<th>Objective</th>
<th>Measurables</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decrease Hysteresis</td>
<td>Stroke Loss</td>
<td>in/in</td>
</tr>
<tr>
<td>Strengthen Magnetic Field</td>
<td>Magnetic Field Strength</td>
<td>A/m*</td>
</tr>
<tr>
<td>Increase Output Stroke</td>
<td>Distance</td>
<td>in</td>
</tr>
<tr>
<td>Measure Output Force</td>
<td>Force</td>
<td>lbf</td>
</tr>
<tr>
<td>Reduce Operation Time</td>
<td>Time</td>
<td>ms</td>
</tr>
<tr>
<td>Maximize Work Per Unit Weight</td>
<td>Work, Weight</td>
<td>(lbf-in)/lbf</td>
</tr>
</tbody>
</table>

*All magnetic and electric measurements use S.I. units*
Constraints

• At least 25lb of force exerted

• Need at least 0.03in stroke (based off of 3in length rod)

• Must cost less than $5000

• Must be smaller than 3 x 5 x 12in

• Coefficients of thermal expansion must be balanced throughout device

• System must be cooler than 500°F

• Greater than or equal to 1:10 ratio of input to output distances
# Criteria for Selection

<table>
<thead>
<tr>
<th><strong>Power Source</strong></th>
<th><strong>Housing</strong></th>
<th><strong>Magnetostrictive Core</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>Compact</td>
<td>Strain</td>
</tr>
<tr>
<td>Voltage</td>
<td>Weight</td>
<td>Cost</td>
</tr>
<tr>
<td>Cost</td>
<td>Strength</td>
<td>Output force</td>
</tr>
<tr>
<td>Weight</td>
<td>Heat dissipation</td>
<td>Hysteresis</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Safety</td>
<td>Modulus of elasticity</td>
</tr>
<tr>
<td></td>
<td>Non-magnetic</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Solenoid</strong></th>
<th><strong>Lever</strong></th>
<th><strong>Hysteresis Control</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductive material</td>
<td>Modulus of elasticity</td>
<td>Reliability</td>
</tr>
<tr>
<td>Usable magnetic field</td>
<td>Output stroke</td>
<td>Force output</td>
</tr>
<tr>
<td>Cost</td>
<td>Durability</td>
<td>Non-magnetic</td>
</tr>
<tr>
<td>Weight</td>
<td>Non-magnetic</td>
<td>Dimensions</td>
</tr>
<tr>
<td>Size</td>
<td>Dimensions</td>
<td>Cost</td>
</tr>
<tr>
<td>Heat dissipation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Selected Components

- Power Source: Wall outlet
- Housing: Aluminum cylinder
- Core Geometry: Cylindrical rod
- Solenoid: Copper wire surrounding Terfenol-D core
- Lever System: Linear hydraulic lever
- Hysteresis Control: Pre-stress bolts
Proof of Concept

• Design coil to generate a magnetic field
  ○ 30mT
  ○ 2A
  ○ 12V

• Prove that the small stroke can be amplified and measured
  ○ 75μm converted to ~1.125mm
Final Design
Final Design

- End Cap
- Brass Bolt
- Iron Cylinder
- Impact Plate
- Bleeder Valve
- Small Piston
- Coil
- Terfenol-D
- Core Stop
- Large Piston
- Housing
Exploded View
Prototype Fabrication

Core Setup

Brass Pre-stress bolts

Aluminum Endcap

Aluminum Housing

Large Piston

Small Piston
Prototype Fabrication

Core Stops

Steel Impact Plate

Heat Fitting
Design Modifications

• Two brass pre-stress bolts instead of four steel bolts
• Smaller pre-stress bolt diameter
• Stainless steel impact plate on large piston
• Iron core assembly moved inside endcap for support
• Heat fit iron washer inside the iron cylinder
• Bleeder valve inserted into fluid chamber
• Chamfer angle in fluid chamber changed from 45° to 60°
Completed Prototype

Core Assembly

Complete Assembly
Performance Testing

• Electric Circuit Testing (Magnetic Field Data/Solenoid)
  o Current, voltage, and resistance measurements across circuit
  o Multimeter

• Thermal Output Testing
  o Simulation: ANSYS Workbench used to find temperature distribution and maximum possible values

• Magnetic Field Testing
  o Magnetic field experienced by the Terfenol-D
  o Gauss Meter
Electrical Results

• Coil circuit data
  o Expected Values
    ▪ 120V
    ▪ 1.2A
    ▪ 94Ω
io Measured Values
    ▪ 125V
    ▪ 0.72A
    ▪ 96Ω
Magnetic Field Results

- Location: Center of Solenoid

- Calculated
  - 107.5mT minimum

- Measured
  - 153mT
  - Concentrated by iron casing and iron core stop
Thermal Results

• Heat Testing
  • ANSYS Workbench was used to simulate a simplified temperature distribution for the device. Thin layers of insulation are added at key points to reduce the temperature near the fluid chamber.
Performance Testing

- Stroke Output Testing
  - No loads applied: testing the Terfenol-D’s reaction to the applied magnetic field
  - Loads applied: testing the Terfenol-D’s reaction with hysteresis control in place
  - Total device output: testing the stroke magnification due to the hydraulic chamber
  - Digital Dial Indicator
Stroke Output Results

• Unloaded, 125V
  o Without a lever system: ~30μm

• Loaded, 125V
  o Without a lever system: ~60μm
  o With lever system: ~960μm
  o 1:16 ratio
Recommended Alternatives to Design

- Using Cenospheres instead of hydraulic fluid
  - Implement hourglass shape chamfer inside fluid chamber

- Replace bolts with an elastic cable
  - Use locking hooks to attach cable

- Experiment with Terfenol-D powder to create a ferrofluid

- Use a direct current power source
## Bill of Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Individual Cost ($)</th>
<th>Quantity</th>
<th>Total Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>41.52</td>
<td>2</td>
<td>83.04</td>
</tr>
<tr>
<td>Iron Tube</td>
<td>138.00</td>
<td>1</td>
<td>138.00</td>
</tr>
<tr>
<td>Iron Rod</td>
<td>171.00</td>
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<td>171.00</td>
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<tr>
<td>Solenoid</td>
<td>790.00</td>
<td>1</td>
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<tr>
<td>Brass</td>
<td>10.97</td>
<td>1</td>
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<tr>
<td>Terfenol-D</td>
<td>447.00</td>
<td>1</td>
<td>447.00</td>
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<tr>
<td>Large Seal</td>
<td>5.56</td>
<td>1</td>
<td>5.56</td>
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<tr>
<td>Small Seal</td>
<td>3.94</td>
<td>1</td>
<td>3.94</td>
</tr>
<tr>
<td>Brake Fluid</td>
<td>9.95</td>
<td>1</td>
<td>9.95</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td></td>
<td></td>
<td><strong>1672.01</strong></td>
</tr>
</tbody>
</table>

*Estimated without shipping costs, taxes, and manufacturing costs
Conclusions

• Honeywell International Inc. tasked the team with designing and prototyping an actuator that utilizes Terfenol-D, a magnetic shape memory alloy that elongates in response to the application of a magnetic field.

• Modifications have been made to the original prototype design in order to resolve issues that arose before construction and account for stresses and dimension restrictions.

• An actuator that utilizes a magnetostrictive material, Terfenol-D has been constructed. The actuator creates a minute stroke using a magnetic field.
Conclusions

- Design modifications were made to improve manufacturability and assembly.
- We have not exceeded our budget requirement.
- Performance analyses have demonstrated that magnetic field is produced, stroke is amplified, and the experienced heat generation is acceptable.
Acknowledgements

• Honeywell Contacts
  o Mr. Mitch Thune
  o Mr. Mike McCollum
  o Mr. Mike Downey

• NAU Staff Consultants
  o Dr. Srinivas Kosaraju
  o Dr. Constantin Ciocanel
  o Dr. Sagnik Mazumdar
  o Professor John Sharber
  o Mr. Christopher Temme

• NAU Fabrication Shop
  o Mr. Tom Cothrun
References


M. McCollum, 'Solenoid Design: Pneumatic Controls Engineering - Lecture 9', Online.


Questions?