Magnetostrictive Actuator

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Overview

- Introduction
- Problem Description
  - Project Need & Goal
  - Objectives
  - Constraints
  - Criteria for Design Selection
- Selected Components
- Proof of Concept
- Final Design
  - Exploded View
  - Prototype Fabrication
  - Design Modifications
  - Completed Prototype
- Performance Testing
- Recommended Alternatives to Design
- Bill of Materials
- Conclusions

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

Objective	Measurables	Units
Decrease Hysteresis	Stroke Loss	in/in
Strengthen Magnetic Field	Magnetic Field Strength	A/m*
Increase Output Stroke	Distance	in
Measure Output Force	Force	lbf
Reduce Operation Time	Time	ms
Maximize Work Per Unit Weight	Work, Weight	(lbf·in)/lbf

*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

Power Source

Capacity
Voltage
Cost
Weight
Dimensions

Housing

Compact
Weight
Strength
Heat dissipation
Safety
Non-magnetic

Magnetostrictive Core

Strain
Cost
Output force
Hysteresis
Modulus of elasticity

Solenoid

Conductive material
Usable magnetic field
Cost
Weight
Size
Heat dissipation

Lever

Modulus of elasticity
Output stroke
Durability
Non-magnetic
Dimensions

Hysteresis Control

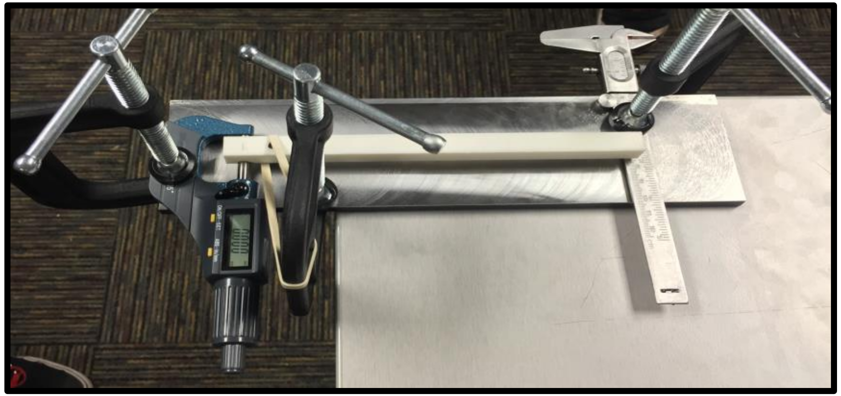
Reliability
Force output
Non-magnetic
Dimensions
Cost

Selected Components

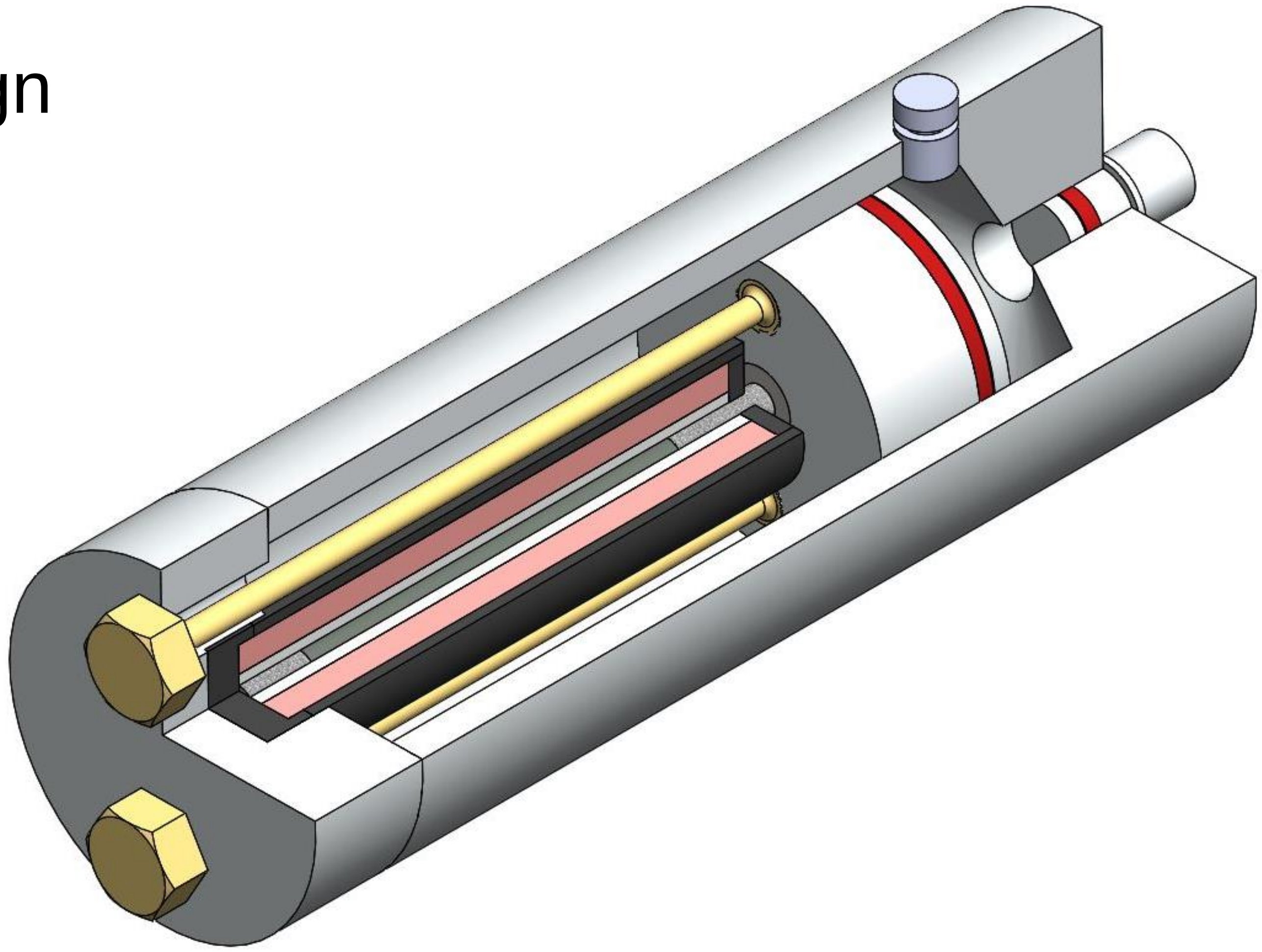
- Power Source: Wall outlet
- Housing: Aluminum cylinder
- Core Geometry: Cylindrical rod
- Solenoid: Copper wire surrounding Terfenol-D core
- Lever System: Linear hydraulic lever
- Hysteresis Control: Pre-stress bolts

Proof of Concept

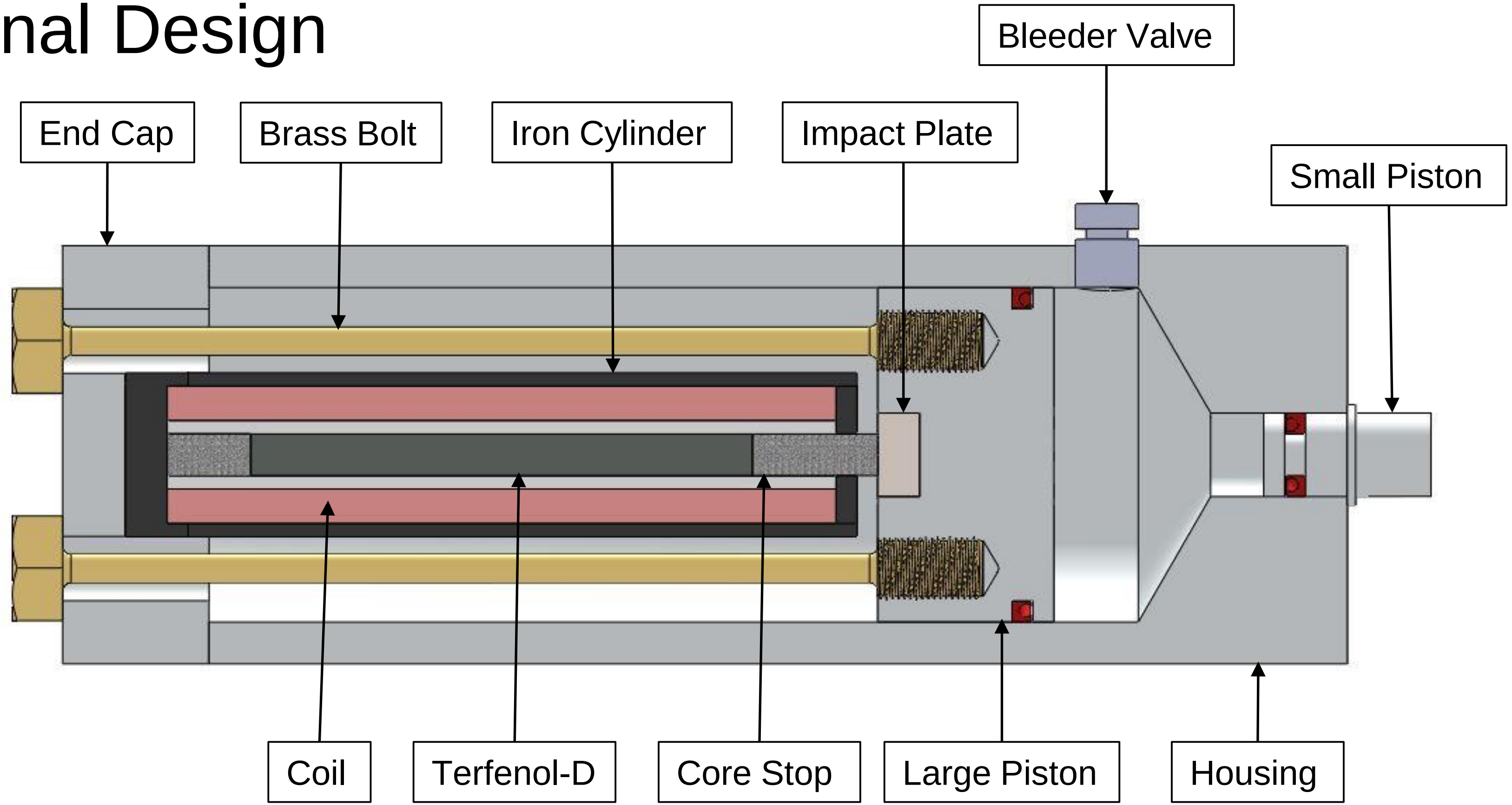
- Design coil to generate a magnetic field
    - 30mT
    - 2A
    - 12V
- Prove that the small stroke can be amplified and measured
    - 75µm converted to ~1.125mm



Final Design



Final Design



Exploded View

Prototype Fabrication

Aluminum Endcap

Aluminum Housing

Core Setup

Brass Pre-stress bolts

Small Piston

Large 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)
    - Current, voltage, and resistance measurements across circuit
    - Multimeter

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

- Magnetic Field Testing
    - Magnetic field experienced by the Terfenol-D
    - Gauss Meter

Electrical Results

- Coil circuit data
    - Expected Values
        - 120V
        - 1.2A
        - 94Ω
    - Measured Values
        - 125V
        - 0.72A
        - 96Ω

Magnetic Field Results

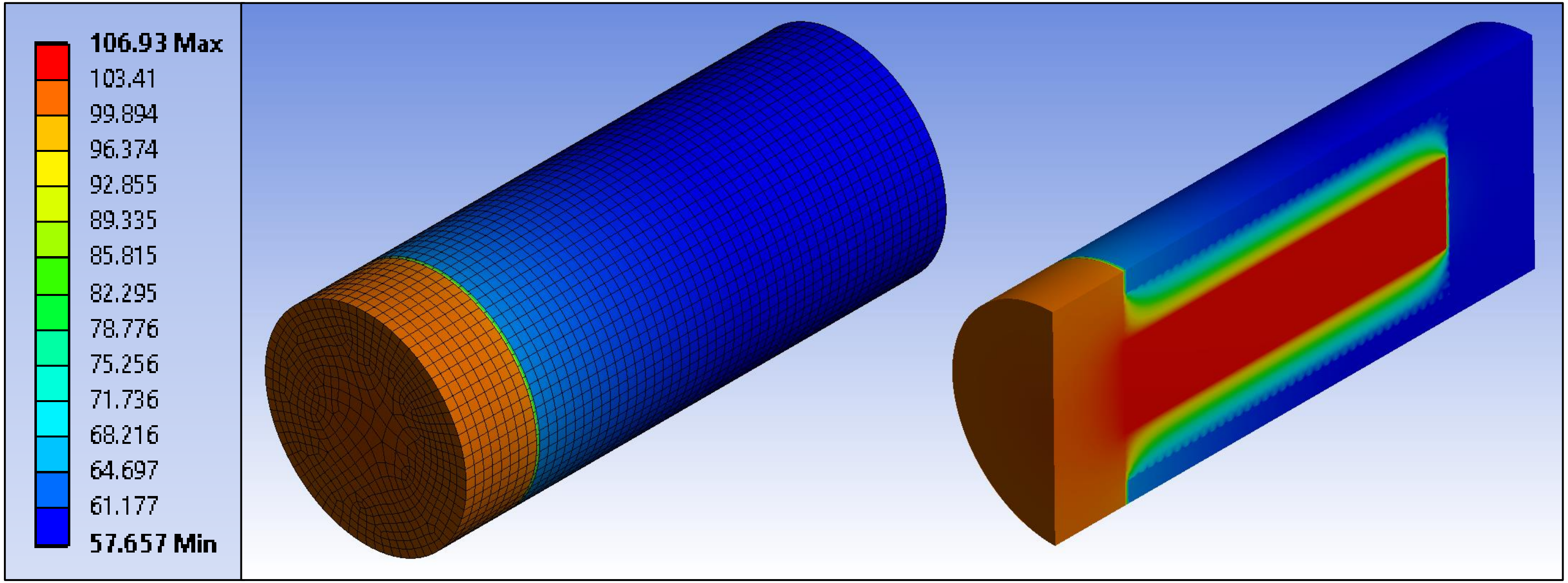
- Location: Center of Solenoid

- 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
    - Without a lever system: ~30μm

- Loaded, 125V
    - Without a lever system: ~60μm
    - With lever system: ~960μm
    - 1:16 ratio


Mitutoyo
ABSOLUTE
ORIGIN
ON/OFF
+/−

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

Item	Individual Cost ($)	Quantity	Total Cost ($)
Aluminum	41.52	2	83.04
Iron Tube	138.00	1	138.00
Iron Rod	171.00	1	171.00
Solenoid	790.00	1	790.00
Brass	10.97	1	10.97
Terfenol-D	447.00	1	447.00
Large Seal	5.56	1	5.56
Small Seal	3.94	1	3.94
Brake Fluid	9.95	1	9.95
Total Cost*			1672.01

*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

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Questions?