RESEARCH & DEVELOPMENT

Creare

Miniature High Vacuum Pumps for Analytical Instruments

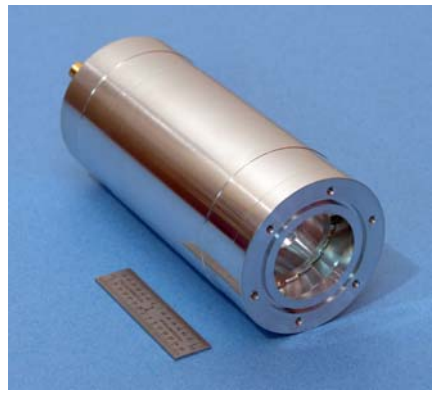
Robert Kline-Schoder
Paul Sorensen

Turbomolecular Pump Advantages

- **Supply clean vacuum at high flow rates**
- **Pump all species, including noble gasses**
- **Small size and mass**
- **Potential for low power consumption**

Creare Miniature Vacuum Pumps

- **Miniature Turbomolecular Pump**
  - 4 L/s pumping speed (air)
  - 1x10^8 compression ratio (N_2)
  - 3-12 W power consumption
  - 10-12 Torr discharge pressure
  - 550 g mass
  - 100,000 RPM rotor speed



- **Extremely Miniaturized Turbo-drag Pump**
  - 4 L/s pumping speed (air)
  - 1x10^8 compression ratio (N_2)
  - 3-12 W power consumption
  - 10-12 Torr discharge pressure
  - 130 g mass
  - 200,000 RPM rotor speed

Miniaturizing TMPs Is a Challenge

- **TMP Tip Speeds**
  - Must be significant fraction of the mean molecular speed
  - For a 2.5 cm pump, speeds > 200,000 rpm are needed
  - This can lead to:
    - Reduced bearing life
    - High power consumption
    - High stresses in rotor
- **Rotor/Stator Clearances**
  - Must be large enough to accommodate manufacturing tolerances and vibration
  - Must be small enough not to degrade pump performance

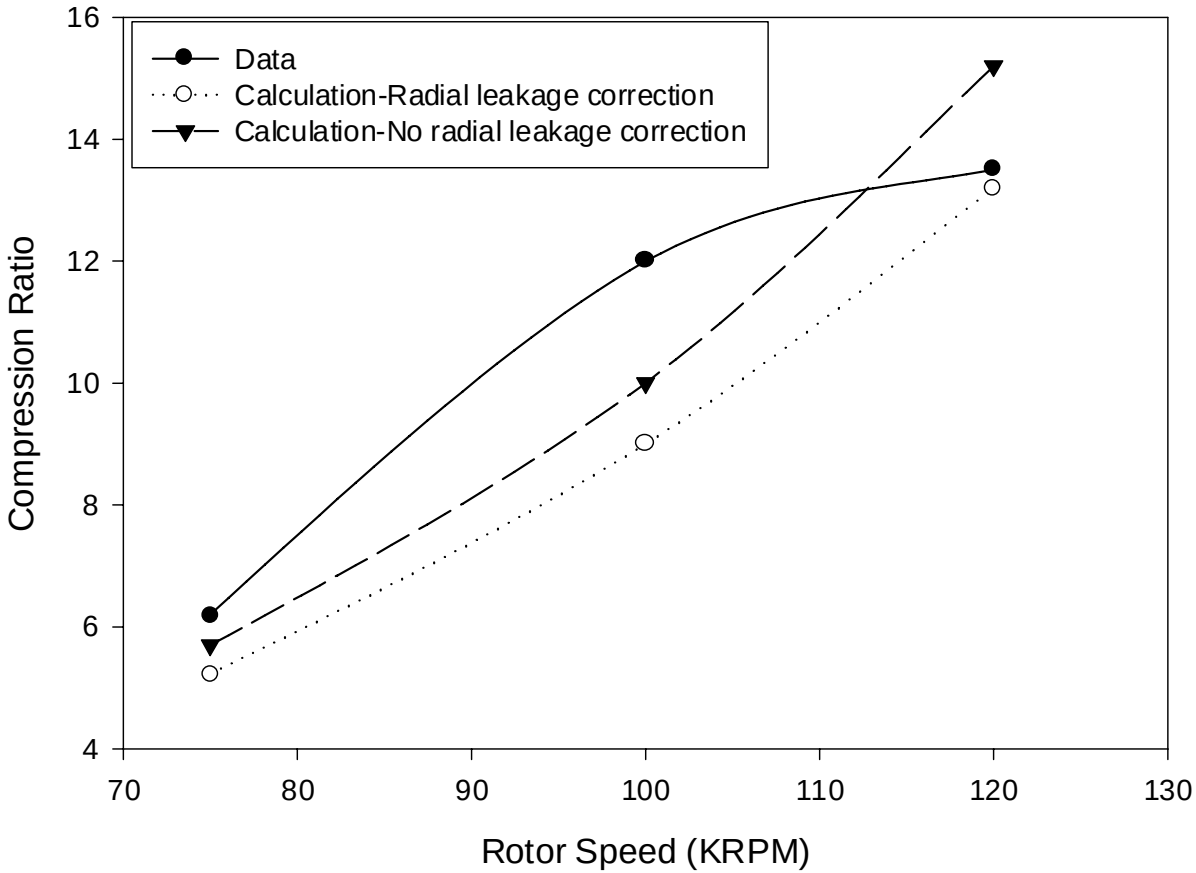
Design Efforts

- **Miniaturization requires optimization of:**
  - Motor
  - Turbo-pump rotor and stator
  - Molecular drag stage
- **Analytical optimization efforts include:**
  - Electromagnetic analysis of motor
  - Structural analysis of pump rotors
  - Bearing life analysis
  - Modeling of turbo and drag stage pumping performance at small size scales

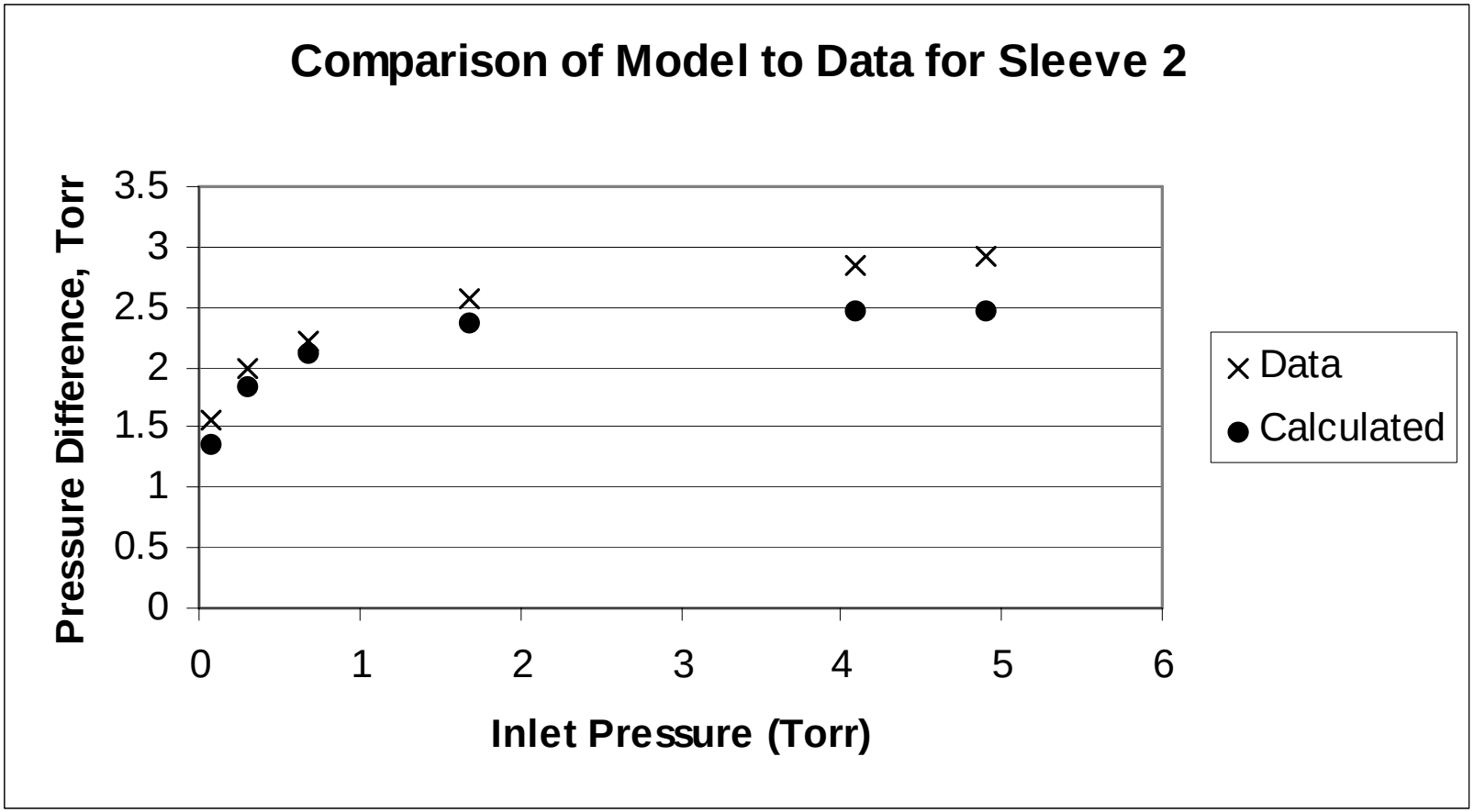
Experiments Complement Analysis

- **Testing is necessary to complement design efforts and verify analytical models:**
  - Motor (bearing and lubricant) life tests
  - Tests of alternative magnet designs for motor
  - Bench tests of individual turbo- and drag-pumping stages
  - Testing of completed pumps

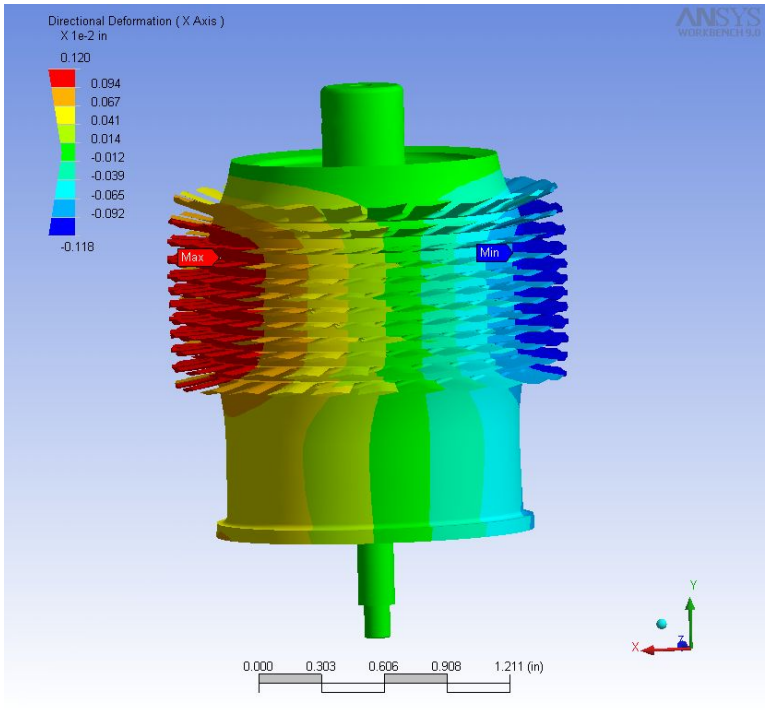
Measurements Verify TMP Blade Model



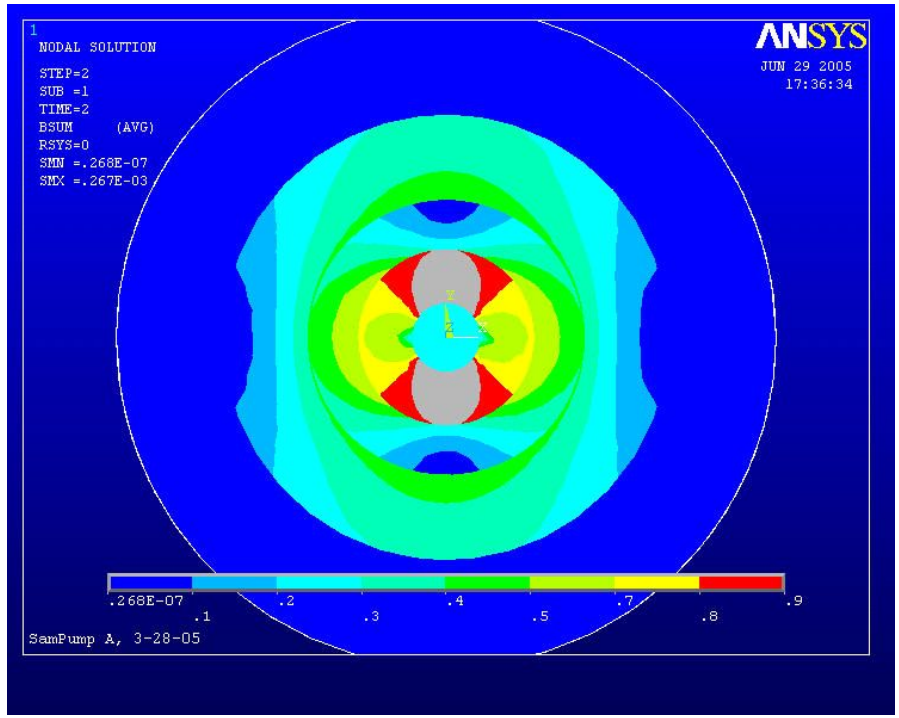
Measurements Verify Drag Pump Model



Structural and Magnetic FEM Results

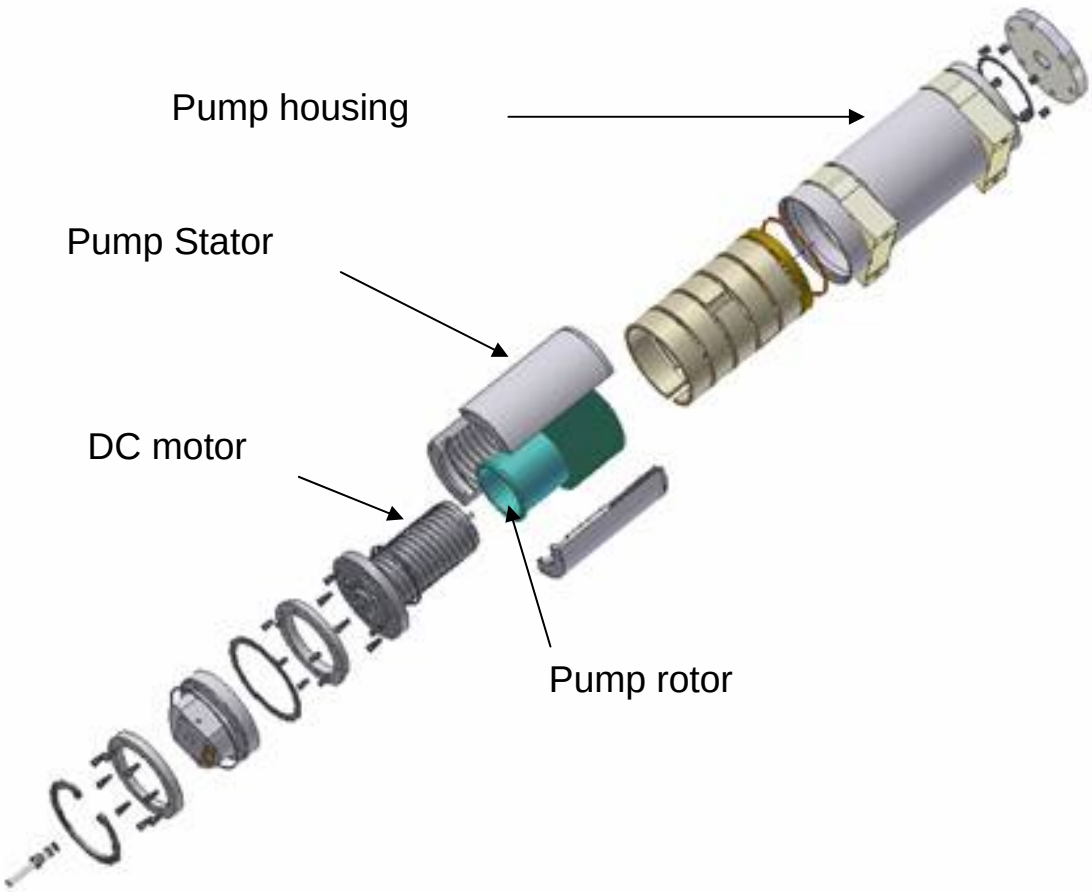


structural analysis used to optimize blade geometry and material choice



magnetic analysis used to optimize magnet choice and minimize power losses

Exploded View of Final Design

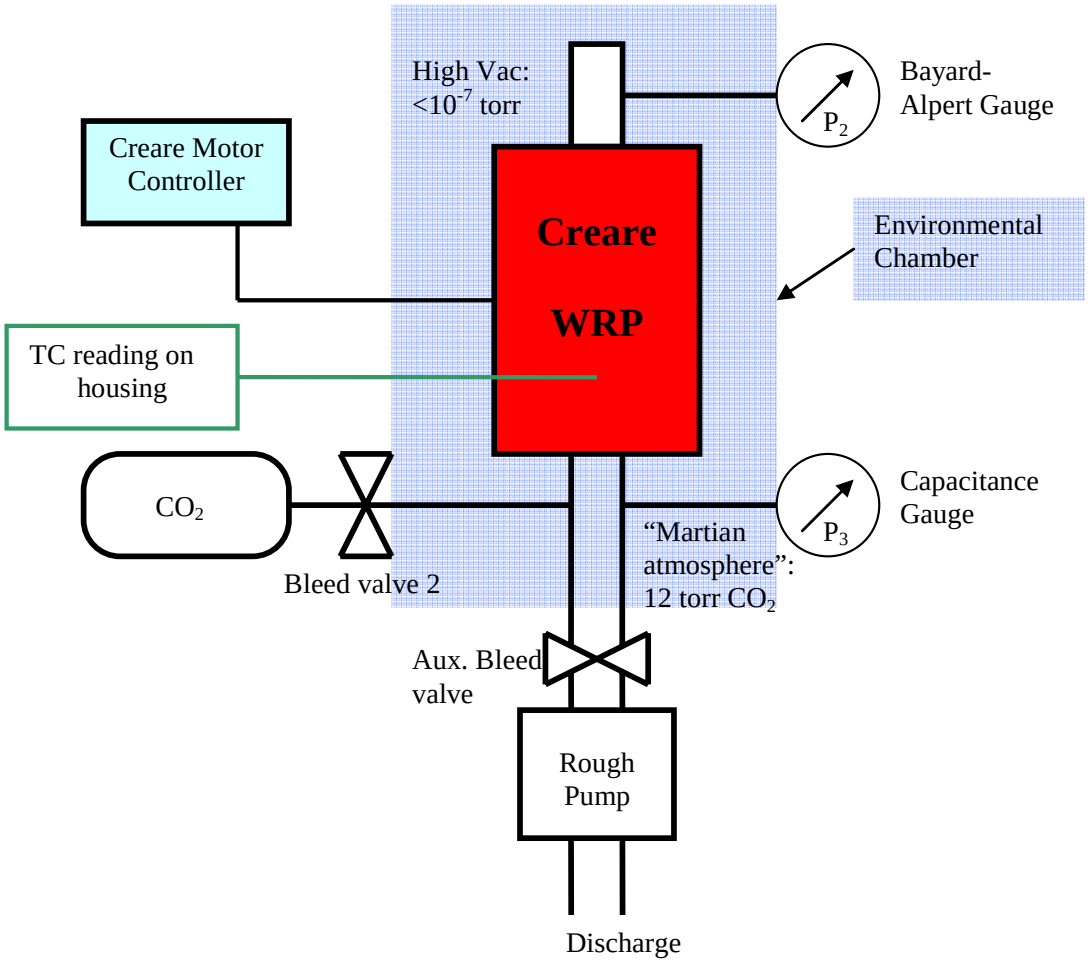


Fabrication Is Challenging

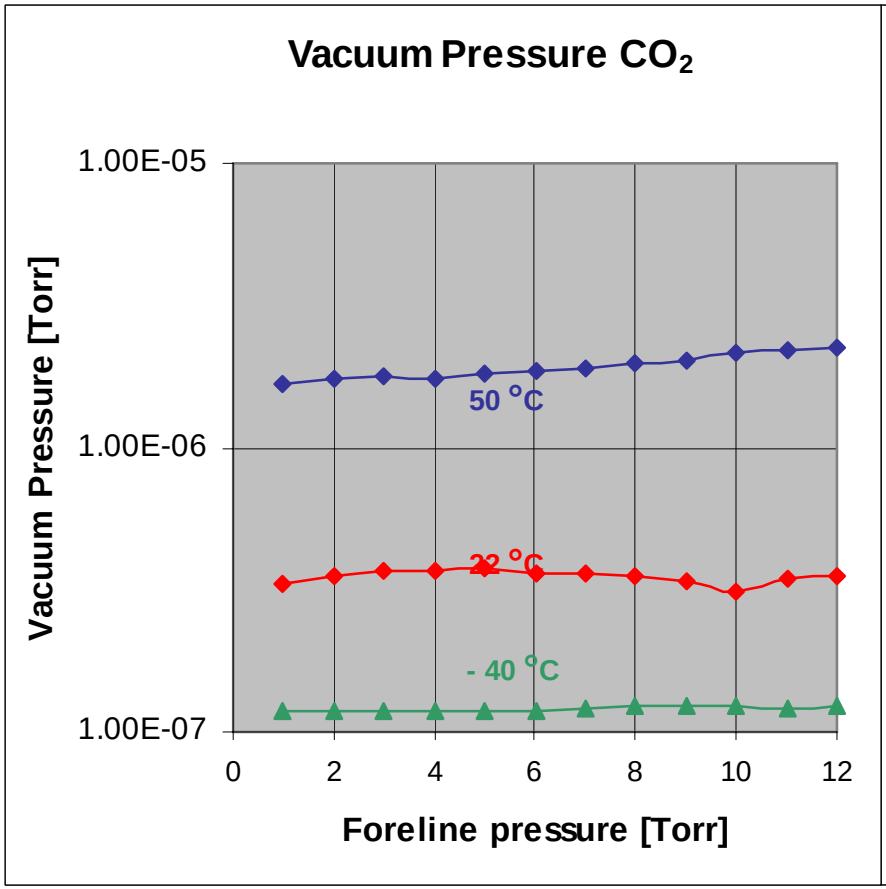
- **Maintaining tight tolerances during machining and assembly:**
  - Must balance desire to minimize inter-stage leakage using small gaps with need to make pump fabrication practicable
- **Balancing rotors**
  - Particularly important at high speeds demanded by miniature TMPs
  - Creare has devoted substantial resources to developing a capability to balance at operating speeds

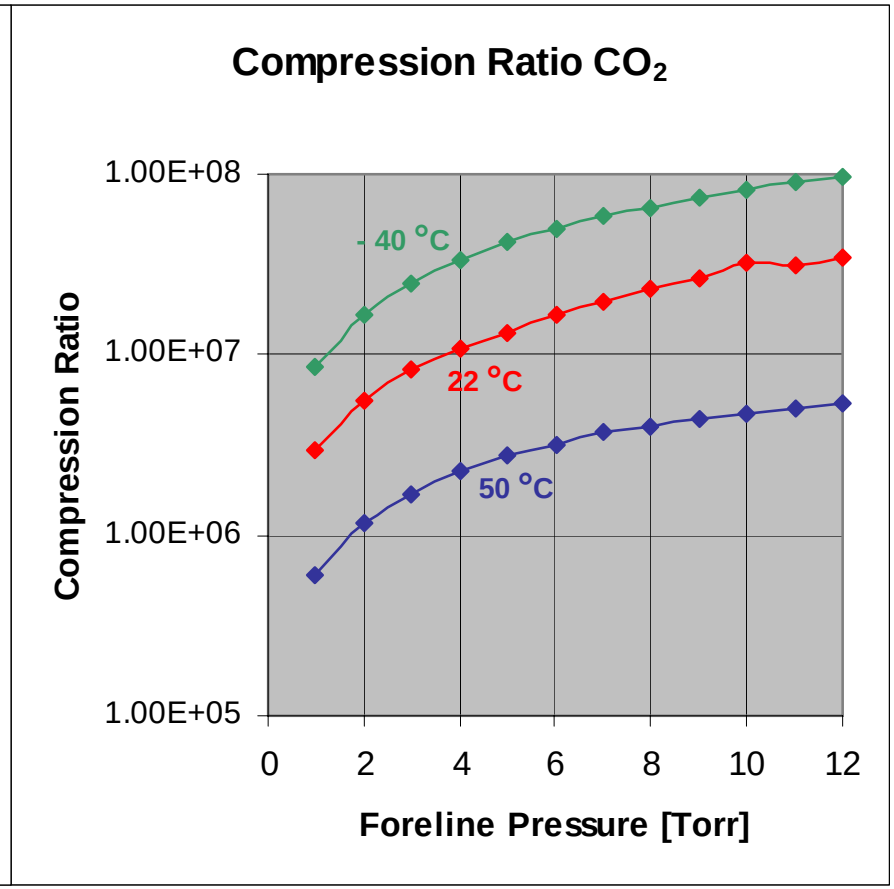
Precision Machining and Assembly

Compression Ratio Test Setup

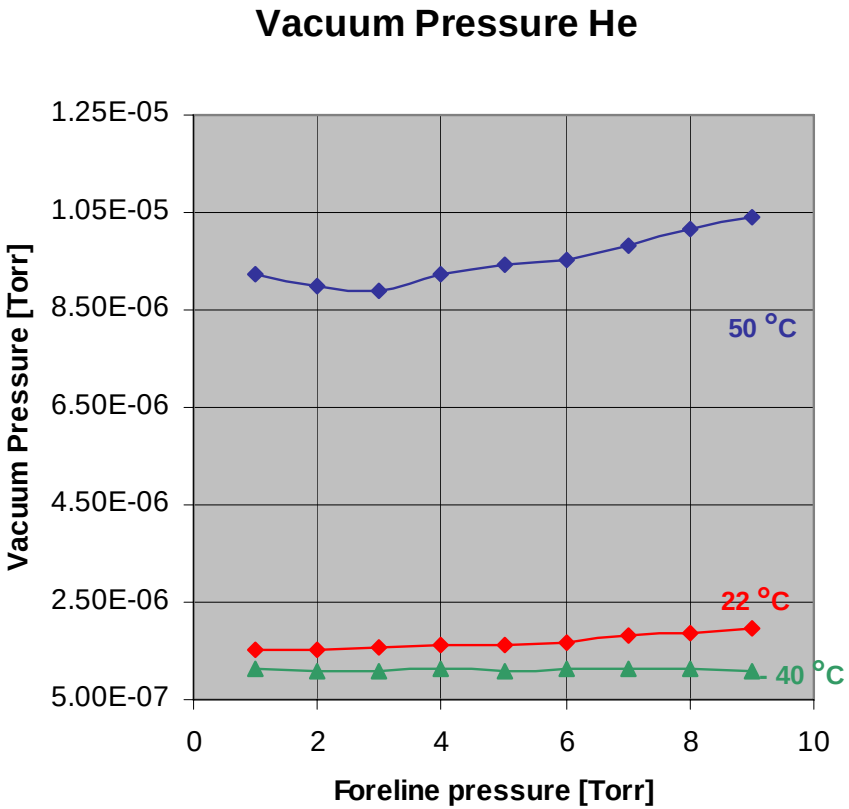


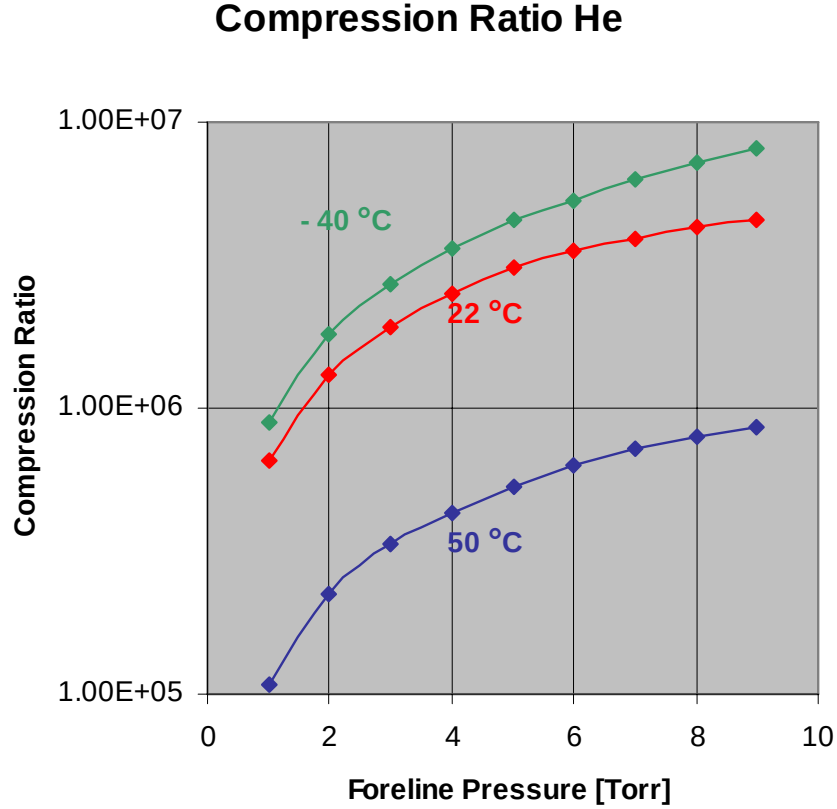
Compression Ratio Test Data: CO_2



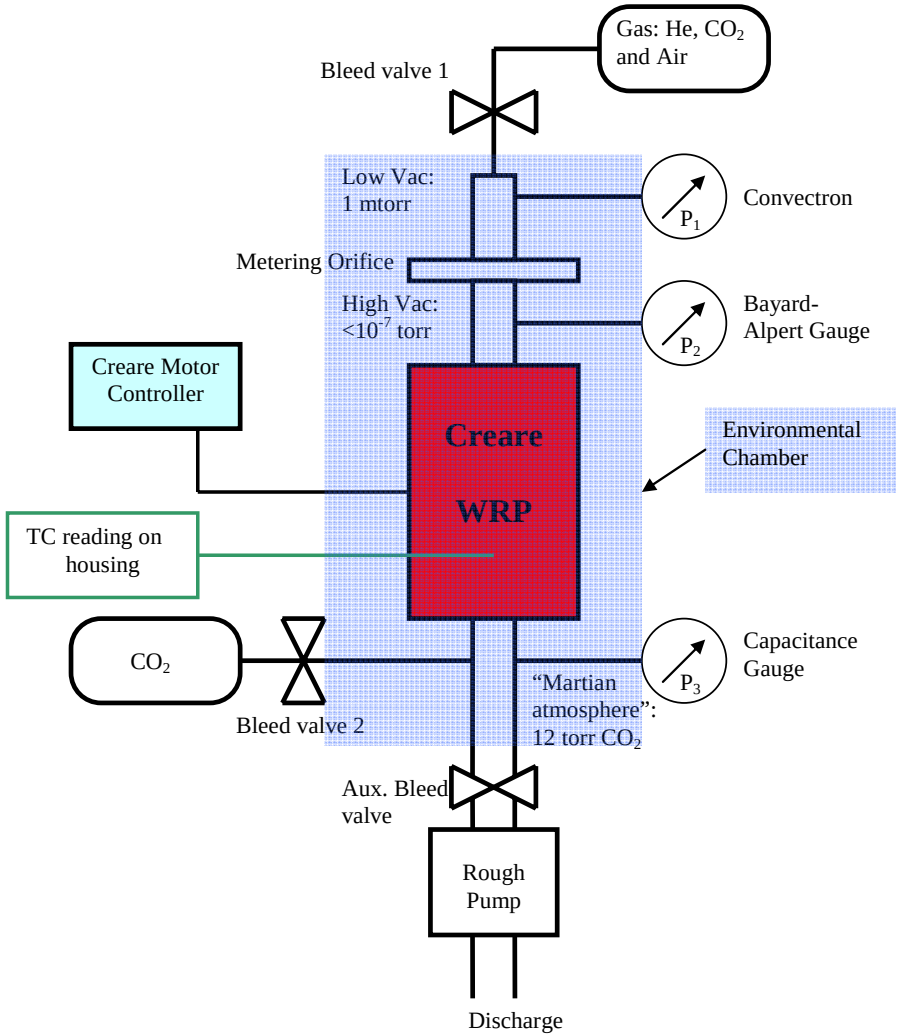


Compression Ratio Test Data: He

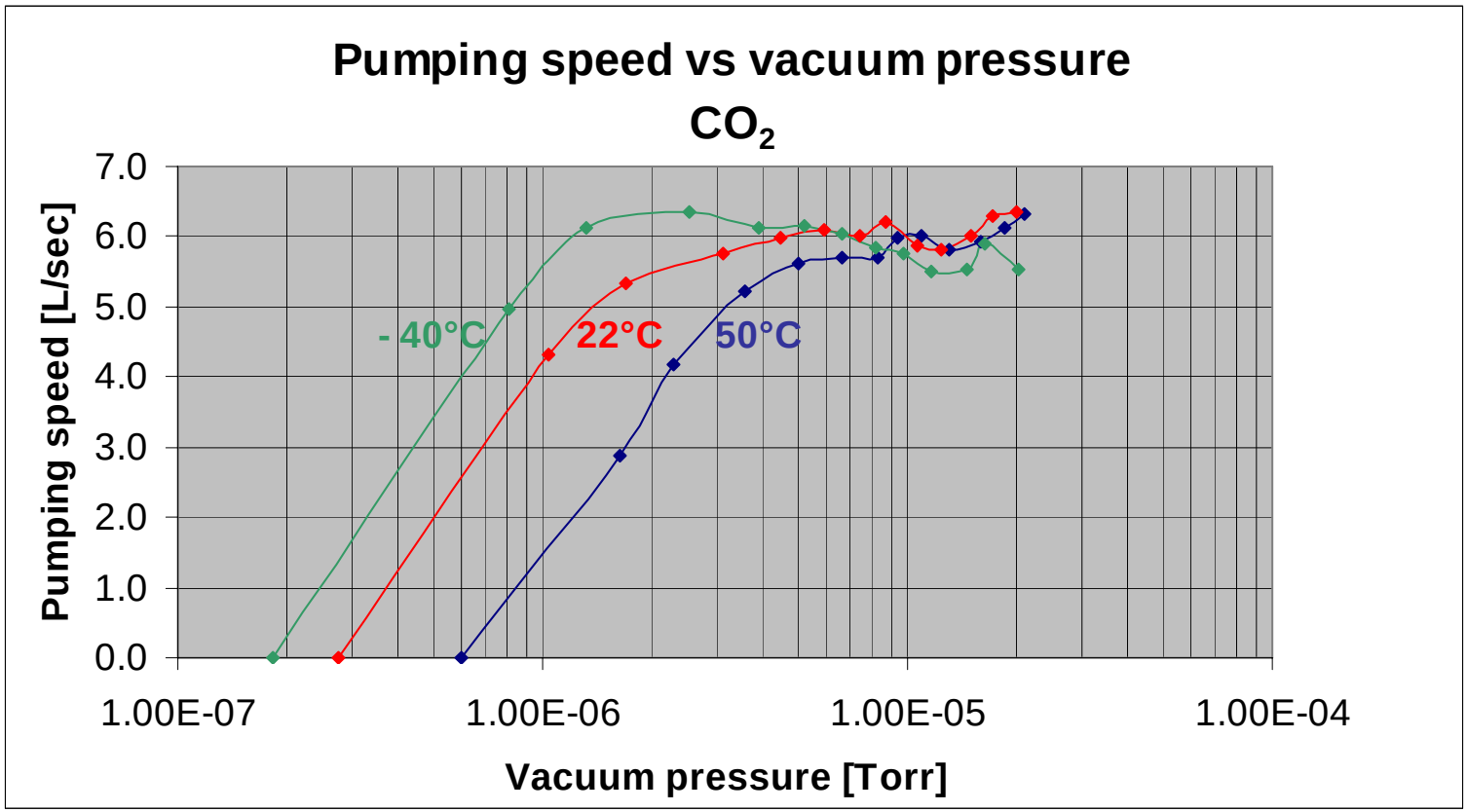




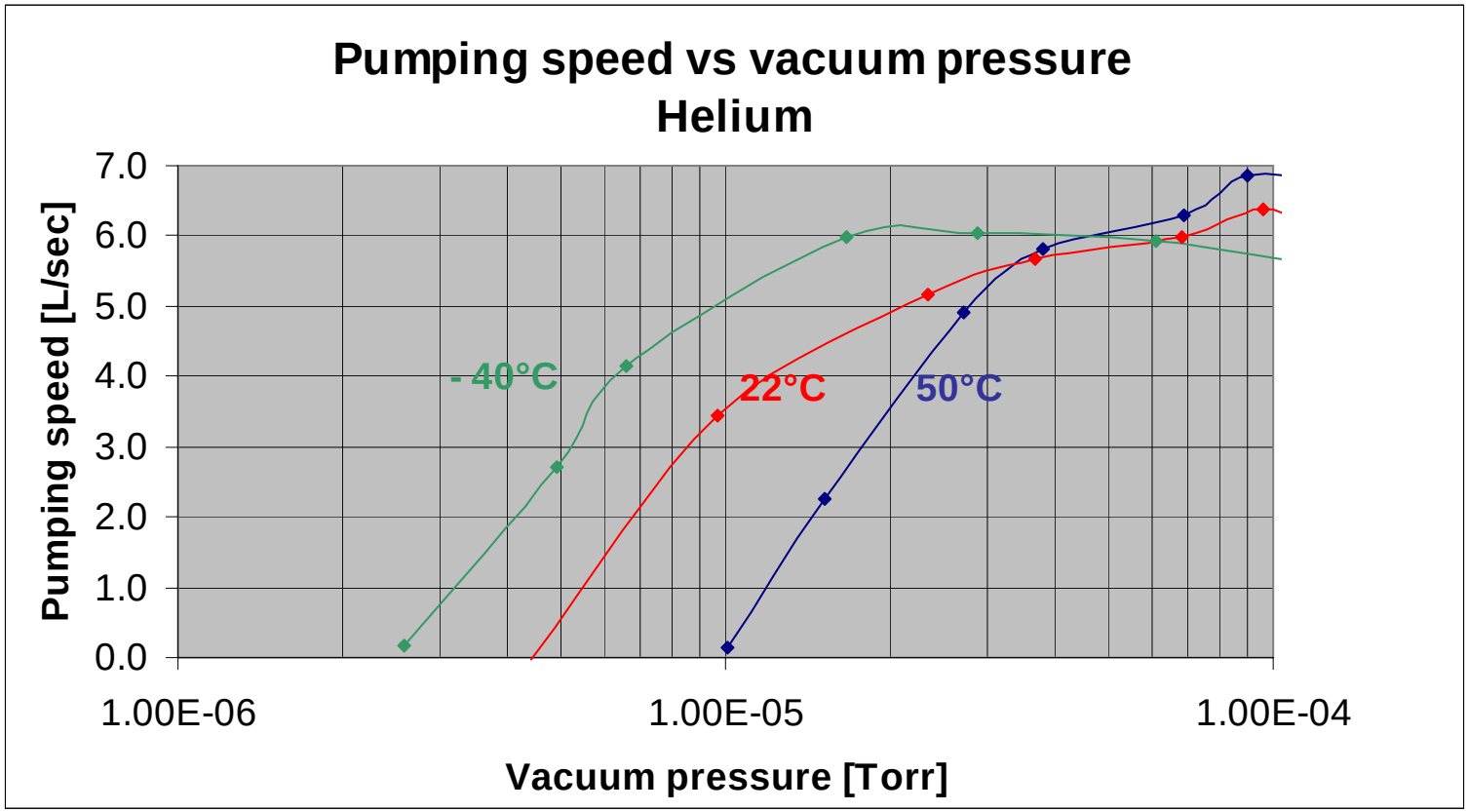
Flow Test Setup



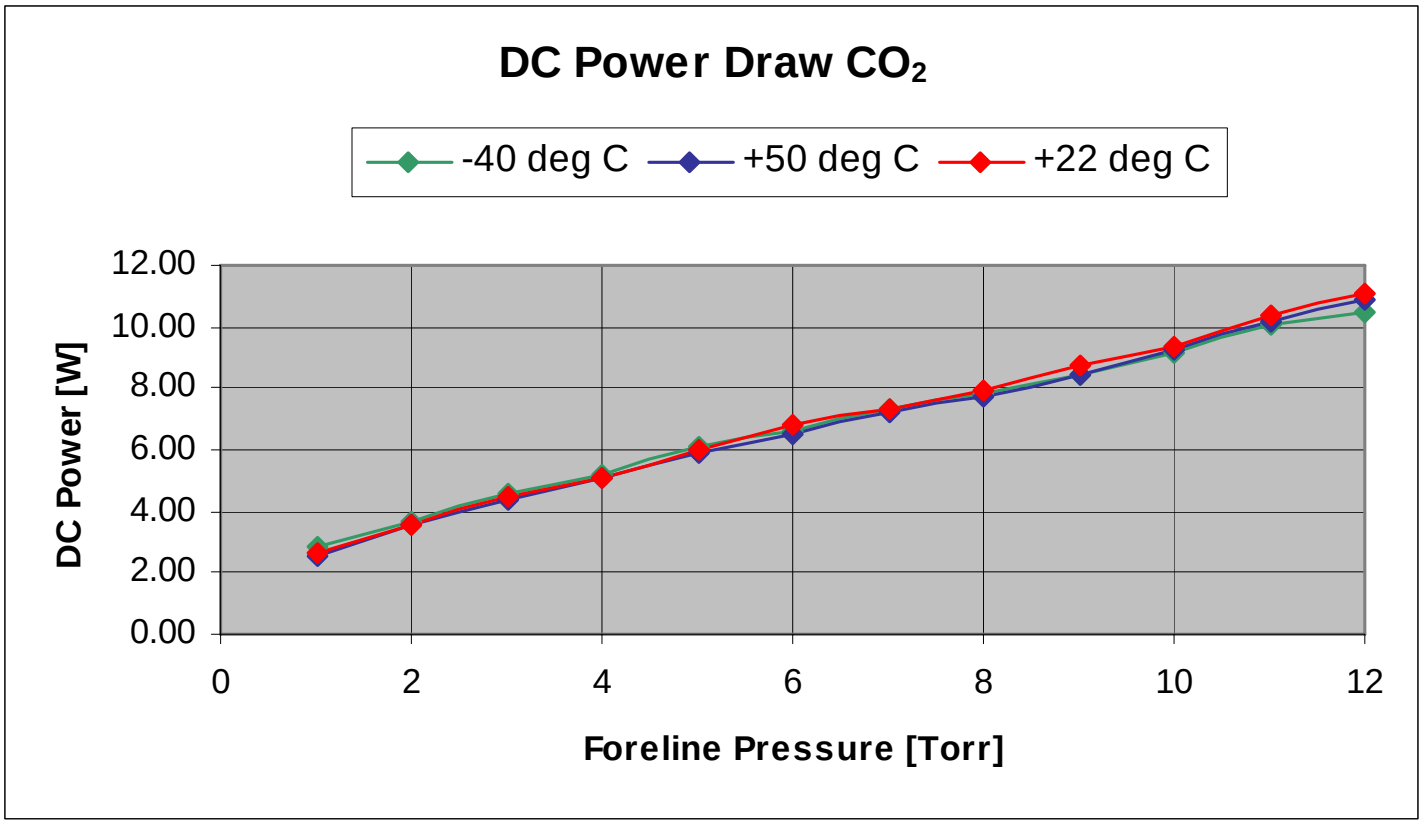
Flow Test Data: CO_2



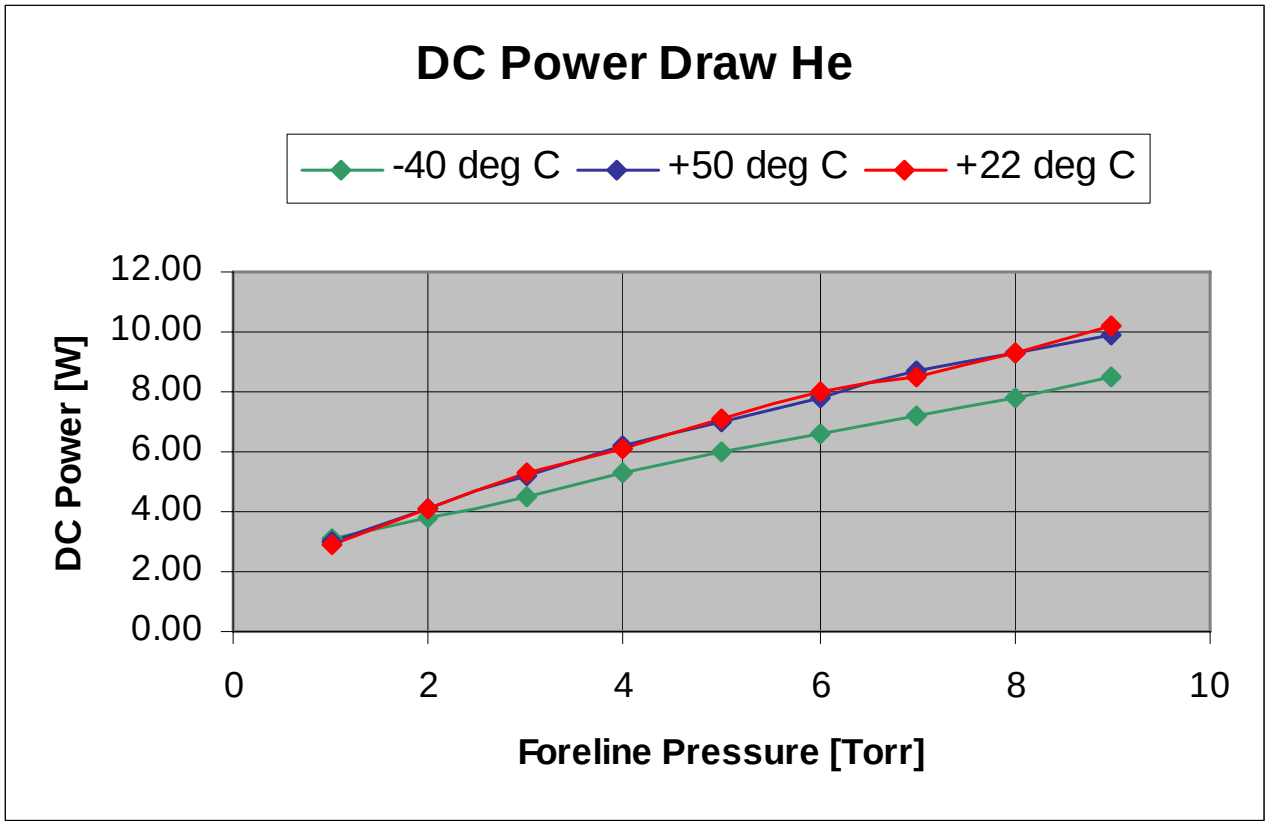
Flow Test Data: He



Power Draw Data: CO_2



Power Draw Data: He



Summary

- **Designing and building an effective miniature vacuum pump is a highly interdisciplinary effort (mechanical, thermal, fluid, and electrical requirements)**
- **Analysis crucial for balancing competing requirements**
- **Experiments are essential to qualify models and verify performance**