NPOI Nitrogen Distribution: Engineering Analysis

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Presentation Overview

- Project Description
- Nitrogen flow rate
- Tank implementation
- Tubing size & pressure drop
- Thermal expansion
- Component list
- Conclusion

Project Description

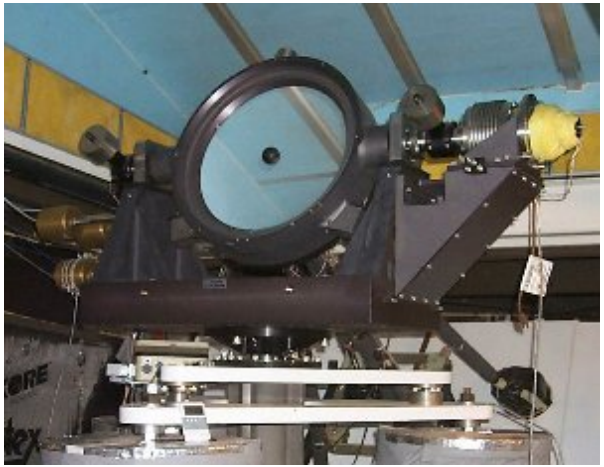
- 1000L Dewar flask supplies nitrogen to three arms of interferometer
- 30 imaging stations (6 active)
- 4 astrometric huts
- 4 sets of gate valves
- Temperature range: -20 to 120ºF

Needed Flow Rate

- 2 active imaging stations
  - 2 mirror cover purges
  - 5 1in bore pneumatic cylinders
- 1 astrometric hut
  - 2 mirror cover purges
- Gate valve station
  - 3 3in bore pneumatic cylinders

Mirror Cover Purge

- 9PSI line pressure
- 0.004in diameter orifice
- $Q = CA_o\sqrt{\frac{2\Delta P}{\rho}}$
- C= 0.75
- 0.5CFH flow rate



www.astronomy.net

Imaging Station Cylinders

- 3 in lizard head & 2 in camera dome
  - Bore= 1in, stroke= 5in
  - $V = 5in \times \frac{\pi}{4} \times (1in)^2 = 3.927in^3$
  - Tubes are also refilled
  - D= 0.375in, Length= 10ft
  - $V = 2 \times 10ft \times \frac{12in}{1ft} \times \left(\frac{\pi}{4}\right) \times (0.375in)^2 = 26.507in^3$

www.airoil.com

Imaging Station Flow Rate

- $Q = \frac{V \times P_{abs}}{28.8 \times t \times P_{atm}} \left[\frac{in^3}{s}\right]$
- $Q = \frac{30.434 in^3 \times 56.3 PSI}{28.8 \times 2s \times 11.3 PSI} \times \frac{25}{12} = 5.484 \rightarrow 6 CFH$
- $P_{atm} = 11.3 PSI \; at \; 7000 ft$

Gate Valves

- Pneumatic cylinders operate gate valves in vacuum tubes
  - Bore= 3in, stroke= 15in
  - Length= 5ft
  - Diameter= 0.375in

www.vatvalve.com

- $V_{cylinder} = L \times A = 15in \times \frac{\pi}{4} \times (3in)^2 = 106.03in^3$
- $V_{tubes} = 10ft \times \frac{12in}{1ft} \times \left(\frac{\pi}{4}\right) \times (0.375in)^2 = 13.254in^3$

Gate Valve Flow Rate

- $Q = \frac{119.282in^3 \times 56.3PSI}{28.8 \times 2s \times 11.3PSI} \times \frac{25}{12} = 21.495 \rightarrow 22CFH$
- Gate valves are actuated consecutively for a total run time of 6 seconds

Total Flow Rate

- Max flow rate in each arm= 25CFH
  - 6 purges= 3CFH constant flow
  - 3 consecutive gate valves= 22CFH
- Max flow rate after tank= 20CFH
  - 4 purges= 2CFH constant flow
  - 3 simultaneous actuators= 18CFH

Tank Implementation

- 5-gallon tanks will reduce load on system
- 5-gallons≅405 ft of supply tubing
- Allows gate valves to react instantly
- Reduces stress in tubing

www.rakutken.com

Tubing Size

- Cleaned and capped copper tubing is available in sizes ranging from $\frac{1}{8}\,in$ to $1\frac{1}{2}\,in$
- Sizes analyzed for this project:
  - ½in= 0.555in ID $2.00 per ft.
  - $^{5}/_{8}$in= 0.68in ID $2.40 per ft.

www.lowes.com

Pressure Drop Equations

- $\Delta P = f \frac{L_{eq}}{D} \frac{\rho V^2}{2}$
- f from Moody diagram using Re and (ε/D)
- L_{eq} accounts for bends, tees, and valves
- V is found using $V = \frac{Q}{A_c}$

Actual Pressure Drop

Location	Tubing ID (in)	ΔP (PSI)	Tubing ID (in)	ΔP (PSI)
Total arm (no tank)	0.555	2.9951	0.68	1.1760
Prior to tank	**0.555**	**1.3678**	0.436	4.1693
After tank	**0.555**	**1.2872**	0.436	3.9095
Main line (if feeding all 3 arms)	**0.555**	**1.2766**	0.68	0.4992
Main line (if feeding 2 arms)	0.555	1.0878	0.68	0.4260

Pressure Drop continued

- Pressure drop to manifold= 0.2751PSI
- Large ΔP= Wasted nitrogen
- Goal for ΔP_{max}= 5PSI
- Actual ΔP_{max}= 4.2067PSI
- Use of ½in tubing everywhere means all components will be the same

Thermal Expansion

- Change in length due to change in temperature
- Coefficient of thermal expansion for copper $\alpha = 9.3 \times 10^{-6}/°F$
- Length must account for ten 180° curves and ten 45° bends
- Total length of each arm= 1113.496ft
- Longest tube= 700ft

Thermal Expansion Calculation

- $\Delta L_{hot} = L_o \alpha (T_{max} - T_{install})$
- $\Delta L_{cold} = L_o \alpha (T_{install} - T_{min})$
- $\Delta L_{hot} = 700ft \times 9.3E^{-6}(120 -$

Thermal Expansion Stress

- $Max\ allowable\ \sigma = 6KSI$
- $\sigma = \alpha \Delta T E$
- Modulus of elasticity= 16MPSI
- $\sigma_1 = 9.3E^{-6} \times (120 - 70°\mathrm{F}) \times 16E^6$ =**7.44KSI**
- $\sigma_2 = 9.3E^{-6} \times (70 - -20°\mathrm{F}) \times 16E^6$ =**13.392KSI**

Expansion loops

- Absorbs the change in length to reduce stress
- $L = \frac{1}{12}\left(\frac{3E}{P}\right)^{\frac{1}{2}}(d_o \Delta L)^{\frac{1}{2}}$
- $L = \frac{1}{12}\left(\frac{3\times 16E^6 PSI}{6000PSI}\right)^{\frac{1}{2}}(0.625in \times 7.031in)^{\frac{1}{2}}$
- L= 16.098in

Supply Line to Manifold

- $\frac{1}{2}$ in tee($1.45)
- $\frac{1}{2}$ in ball valve($4.33)
- $\frac{1}{2}$ in tube to $\frac{1}{2}$ female NPT($1.79)
- $\frac{1}{2}$ in female NPT to $\frac{3}{8}$ in barb($3.19)
- Total cost = $10.76

Component List

- Cleaned and capped copper tubing
  - 3700ft of ½in
- 572 fittings
- 39 manifolds
- 500ft of black PVC tubing

Conclusion

- Maximum flow rate of 25CFH
- Total pressure drop= 4.2067PSI
- Tanks will provide instant supply of nitrogen while reducing tubing size
- Expansion loops will be used to lower stress in tubing
- ½in tubing from tank to end of each arm

Questions?

References

- Beasley, Donald E., Figliola, Richard S. (2011). Theory and Design for Mechanical Measurements (5th edition). Danvers, Ma. Wiley & Sons, Inc.
- Pneumatic cylinder: http://www.airoil.com/v6/contents/en-us/d123.html
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- 5 gallon air tank: http://www.rakuten.com/prod/5-gallon-air-tank-4-train-horn-air-suspention-more-free-gauge/248387884.html?listingId=279990422
- Tubing: http://www.lowes.com/Plumbing/Pipe-Fittings/Copper-Pipe-Fittings/_/N-1z10xv9/pl#