Nitrogen Supply and Distribution

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Concept Generation and Selection

Document

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Introduction

The U.S. Naval Observatory (USNO) does research for the Naval Research Laboratory in providing position, navigation and timing for the U.S. Department of Defense. Our sponsor, the Navy Precision Optical Interferometer (NPOI), works under the USNO. The NPOI has its site located just East of Flagstaff, AZ in Anderson Mesa. The research done in this facility involves precise observations of the astronomy needed for navigation use.

On behalf of NPOI, our clients Jim Clark and Steve Winchester have requested an improved nitrogen supply system. This nitrogen supply is used to operate pneumatic actuators at several stations and to purge any humidity or debris from the Siderostat mirrors. The nitrogen will be supplied by a 1000L Dewar tank and must travel down three separate 300m long runs. Each run has eleven stations that consist of a manual shutoff valve and five ports that feed separate regulators. The three different components that will be analyzed include the tubing material, distribution style at each location, and valve style.

Tubing Selection

To reach each station along the 300-meter length arrays, a main supply tubing system needs to be chosen. For this choice, many different materials of tubing were considered. Options such as rubbers, plastics and metals were all considered. Tubing made of plastics included polypropylene and polyethylene. The latter of these two comes very cheap but is not rated for extended outdoor use. Polypropylene boasts a high UV rating but proved to be very expensive and not practical for long lengths. A vinyl option was considered and is very popular in other applications. This would consist of a UV rated polyvinyl chloride, or PVC. Unfortunately under the pressures of the system and the temperatures experienced by the supply line, this option had to be thrown out. In the end, there were only three viable options that would at the very least, cooperate with our constraints. They are as listed and explained below.

The client suggested our first seriously considered material. This tubing material would be a clean and capped coil of copper tubing. Because this material is used in many commercial refrigeration situations, it is relatively cheap and comes pre-cleaned and capped. Installation could occur straight out of the box. Copper is also a fairly soft material, which makes it easier to navigate through the curved channels of the cable trays where they will be placed. Copper tubing can either be put together via soldering or cut open with a simple pipe cutter. This makes for very simple installation and maintenance. Unfortunately, because the copper is so soft and easy to work with, it is also susceptible to wearing due to mechanical vibrations and general abrasions. However, with special care this can be compensated for.

Next in the seriously considered materials is very similar to the copper tubing. Instead of copper though, it is 316 Stainless Steel. Much like the copper, this material can be ordered to come cleaned and capped. Unfortunately this adds considerable cost. Uncapped stainless tubing is still slightly more expensive than the copper, but is much stronger and more resistant to its surroundings. This is definitely something to consider for long-term purposes. This ability also makes the stainless steel a little harder to work with. Although it can still be bent and cut with the same tools as copper, it requires much more effort.

Our last consideration can be found in any automotive vehicle. The door gaskets in most cars are manufactured from ethylene propylene diene monomer EPDM. This is a very versatile material, as it is used in gaskets, tubing, sheeting and many more applications. The tubing cost of the same diameter is very comparable to the copper tubing. It is considered the easiest to work with and requires the least amount of tools to manipulate. The only drawback experienced with this tubing is much less resistance to its surroundings. Although it is rated for UV and will handle vibrations really well, it will not perform as well for extended periods of time. As to the scale of this project and the time length, EPDM does not perform as well as for smaller applications.

Here is a table that describes how the weighting criteria was done (Table 1) as well as the weighting of each material (Table 2). The weighting of the different criteria has been chosen based on how important each standard is compared to the others. Table 2 is developed with a scale of one to five, with five being the most favorable outcome. Based on this table, it was concluded that the cleaned and capped copper was the best option. It was cheap, easy to work with, and exceptional resilient to the surroundings. Stainless steel was about equally resilient, but the cost and stiffness of the material counted against it. EPDM was considered too susceptible to climate changes and sun damage.

Table 1: Weighting Criteria for the Decision Matrices

	Current Supply	Cost	Ease of Installation	Maintenance	Environmental Constraints		Final Weigh t
Current supply	0	0	0	0	0	0	0
Cost	1	0	0	0	0	1	11%
Ease of Installation	1	1	0	0	0	2	22%
Maintenance	1	1	1	0	0	3	33%
Environmental Constraints	1	1	1	0	0	3	33%

Table 2: Decision Matrix for Tubing Selection

	Cost	Ease of Installation	Maintenance	Resistance to Surrounding	
Copper	**4**	**3**	**5**	**4**	**4.07**
316 Stainless Steel	**1**	**2**	**4**	**5**	**3.52**

EPDM	**3**	**5**	**3**	**3**	**3.41**
	11%	**22%**	**33%**	**33%**	

Distribution Selection

Three different manifold systems were chosen for our supply system designs. The three systems we narrowed down are a tee to manifold, individual tees, and flow through manifolds. For each of these manifold systems there will be a valve at each manifold, as requested by our client. From each port, there is a regulator that will be connected to each line. Therefore, a number of parts are included for each manifold assembly, taking into account the 11 stations at the observatory site.

The tee to manifold includes a tee from the main line connected to a five-port manifold. There are 11 stations for this supply assembly. Total manifold parts includes:

-11 valves
-11 tees
-11 tubes from tee to manifold
-11 tube to FPT(Female Pipe Thread) fittings
-11 manifolds

Figures 1 and 2 below show the manifold fixture and assembly, respectively.

Figure 1: 5 port manifold [1].

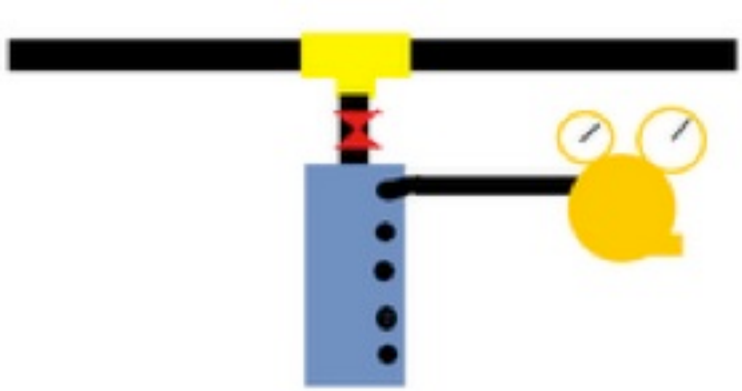

Figure 2: Tee to manifold design

Our second design selection uses five individual tees connected into the supply line. For the 11 stations, this design assembly includes:

-55 valves
-55 tees
-55 tubes from tee to regulator
-55 tube to FPT(Female Pipe Thread) fittings

The assembly of the individual tee assembly is shown in Figure 3 below.

Figure 3: Individual tee assembly [2].

The last design choice for our manifold assembly is a flow through manifold system. For the 11 stations, this assembly includes:

-11 valves
-11 manifolds
-55 MPT pipe fittings
-55 pipe to FPT fittings

Figure 4 below shows a flow through manifold with 4 ports, however our design would include five ports coming out. A basic drawing of this manifold station is shown in Figure 5.

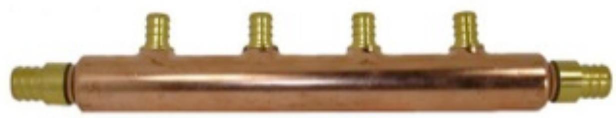

Figure 4: Flow through manifold [3].

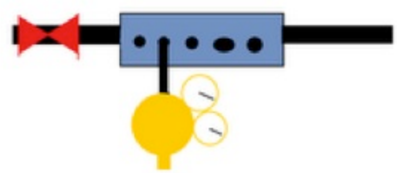

Figure 5: Flow through assembly

Based on our weighted scale and comparing each manifold design, the tee to manifold design out weighed the other two. Figure 6 below shows the criteria we based criteria on. The tee to manifold design had lower cost, installation and is efficient with the surrounding environment. This final design chosen leaves small room for a pressure drop and friction within the tubing system

Table 3: Decision Matrix for Distribution Style

	Cost	Ease of Installation	Maintenance	Resistance to Surroundings	
Tee to Manifold	3	3	5	5	4.07
Individual Tees	2	1	2	2	1.65
Flow Through	2	2	3	3	2.53
	11%	33%	22%	33%	

Valve Selection

The final component of this system is the manual shutoff valve that is located prior to each manifold. An effective valve will be easy to operate, have a small flow restriction (low equivalent length), and be low cost. The three different valves that were analyzed include ball, gate, and angle valves.

A ball valve is a simple type of valve that utilizes a sphere with a hole through the middle. If the hole is set parallel to line flow, the valve will allow flow to occur with very little restriction. A simple 90º rotation of the handle on top of the valve will stop the flow because incoming fluid will encounter the side of the sphere with nowhere to go. This style of valve is very easy to use, low cost, and durable.

Figure 6 - Brass ball valve [4].

A gate valve operates by pulling a rectangular "gate" out of the path to allow flow, and lowers it to the bottom surface to prevent flow. This design allows for reliable flow rate changes, but is quite restrictive even when fully open. Regulators will be located in each line, so there is no need to use a valve that can alter flow rate. Gate valves have a flow coefficient of 0.15, which is three times higher than that of a ball valve.

Figure 7 - Brass gate valve [5].

Angle valves are based off of gate valves, but with a 90º elbow built into the valve assembly. If a sharp bend must be placed in the line near the valve, having a 90º bend in the valve would eliminate the need to purchase an elbow. Since angle valves have a built-in elbow, the flow coefficient is higher than that of a gate valve. The flow coefficient is 2.0 which is forty times higher than a ball valve, and more than thirteen times higher than a gate valve. The equivalent length is directly proportional to the flow coefficient, so if it is forty times higher, the equivalent length will also be forty times higher.

Figure 8 - Brass angle valve [6].

Table 4: Decision Matrix for Valve Selection

	Cost	Ease of Operation	Maintenance	Flow Restriction	
Ball Valve	4	5	3	5	4.4
Gate Valve	3	3	2	4	3.08
Angle Valve	3	3	2	3	2.75
	11%	33%	22%	33%	

The decision matrix shows that ball valves are the best choice in every aspect of our comparison. Ball valves have the lowest flow coefficient, cost, and time needed to go from open to close. Due to its simple design, it is safe to assume that ball valves are also more reliable than the other options.

Sizing of Components

In order to obtain a more accurate cost of each component, the tubing size must be calculated. The valves, tees, manifolds, and fittings are all dependent on the size of the supply tubing. If the diameter of the tubing is too small, the pressure drop across the length of each run will be too large to efficiently supply the furthest location with the required pressure. Inversely, if the diameter is too large, the pressure drop will be very low, but cost will be too high. In order to optimize the tubing diameter, a MATLAB code was created that calculates the pressure loss and equivalent length for different diameters.

The pressure drop in a tube is calculated using equation 1 as shown below:

$$Pressure\ Loss: \Delta P = f \frac{L_{eq}}{D} \frac{\rho V^2}{2} \quad (1)$$

Where:
f= Friction factor
L_{eq}= Equivalent length of pipe, [m]
D= Tube diameter, [m]
ρ= Density of fluid, [kg/m^3]
V= Fluid velocity, [m/s]

The equivalent length of pipe is calculated using equation 2 as shown below:

$$Equivalent\ length: L_{eq} = \frac{K_L D}{f} \quad (2)$$

Where:
K_L= Flow coefficient, 0.05 for ball valve
D= Diameter of flow through component, [m]
f= Friction factor

The only unknown in the variables listed above is the friction factor. Obtaining the friction factor is done by interpreting the Moody chart for the known Reynold's number. The Reynold's number is obtained using the density, velocity, pipe diameter, and dynamic viscosity, which are all known. The MATLAB code that was created calculates the values for equations 1 and 2 by prompting an input value for the pipe diameter, the number of tees and valves, and the line pressure. The density, dynamic viscosity, and flow coefficient are independent of the changing variables so they are stored as constant variables in the code. Diameter is changed to obtain a pressure loss that is below the threshold of 5PSI.

Tubingsize.m*

```
Kvalve= 0.05;                   %Flow coefficient for ball valve
Ktee= 1.0;                      %Flow coefficient for line flow in flanged tee
D= Dinch*0.0254;                %Diameter in meters
e= 0.015*10^-3;                 %Equivalent roughness


Qcfh= 10;
Qcfm= Qcfh/60;
Q= Qcfm*0.00047;                %Volumetric flow rate, m^3/s
v= Q/((pi/4)*D.^2);             %Velocity

L= 300;                         %Length, m
rho= 4.77635;                   %Density, kg/m^3
mu= 17.164*10^-6;               %Dynamic Viscosity, Pa s

Re= (rho*v*D)/mu;               %Reynold's number

f= 0.25/((log10((e/(3.7*D))+5.74/(Re.^0.9))).^2);   %Friction factor


Leqtee= (Ktee*D)/f;             %Equivalent length of each tee
Leqvalve= (Kvalve*D)/f;         %Equivalent length of each valve


Ltotal=L+(N*Leqtee);            %Total equivalent length

disp('Equivalent length=')
disp(Ltotal)

Pdrop= f*((Ltotal/D)*((rho*v.^2)/2));   %Pressure drop in line
```

Figure 9: Majority of the MATLAB code that calculates pressure drop.

Running different tube sizes with a line pressure of 60PSI and eleven valves and tees gave a drastic change in pressure drop. If ¼in (0.33in inner diameter) copper tubing were used, the pressure drop would be over 20PSI. Using this tubing size would mean that the supply tank would have to be refilled before the tank pressure approaches 80PSI. Doing so would be wasteful, time consuming, and more expensive in the long run. However, changing to ⅜in (0.436in inner diameter) copper tubing will keep pressure drop below 5PSI, which was the set limit for pressure drop.

```
>> Tubingsize
What is diameter?0.311
How many tees?11
How many valves?11
What is line pressure?60
Equivalent length=
  301.9618

Total Pressure Drop
   22.0117

>> Tubingsize
What is diameter?0.436
How many tees?11
How many valves?11
What is line pressure?60
Equivalent length=
  302.5099

Total Pressure Drop
    4.4621
```

Figure 10: Output of code showing selected inside diameter of 0.436in

Conclusion

In conclusion, many decisions have been made for the whole nitrogen supply system. To supply the length of the 3-300 meter arms a central supply line. This supply line will be attached at the center to a 1000-liter Dewar that carries liquid nitrogen. Gaseous nitrogen will be taken from the top to supply the whole observatory facility. The main supply line down each of the three arms will consist of a system of copper tubing soldered together to make the full length of the array. Copper tubing was selected based on its malleability, cost and resistance to its surroundings. Because copper is very soft, it is easy to work with. Copper by nature is also resistant to corrosion and other characteristics encountered outdoors in Flagstaff. Also, because of the commercial use of copper, it can be acquired easily and cheaply all ready to use, capped and cleaned.

Located at each station along the arrays will be placed a manifold. This manifold will be attached to the main supply line by a simple brass T-connector. Brass T-connectors are easy to install and are very compatible with most tubing systems. Attached to this T-fitting will be a hose with a valve installed to be able to shut off nitrogen flow during maintenance disassembly. This valve is then attached to the manifold itself. Each of the stations requires five supply lines, which will be accounted for in a five-port manifold. Each of these ports will be attached to a regulator, which will ensure the correct pressure for each application. Hopefully, this whole system will be centrally installed at each station for ease of operation and maintenance.

Valves chosen for this application must be quick and easy to use. There also has to be little fluid flow obstruction. Ball valves were found to be the most efficient for fluid flow and the easiest to use. A simple turn of ninety degree ensured complete closure or openness. As these types of valves are already implemented on site, this should keep cost down, and the operation of these valves in this climate have been proven.

For now, these sections consist of the whole nitrogen supply system designed. Further analysis and testing of course will be taken, but for now these are decisions made for the Navy observatory array nitrogen supply system.

References

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[2] CO2/Nitrogen Manifold. Brew Tree. <http://www.brewtree.com/catalog/>

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[4] Brass ball valve. ZORO Tools. <http://www.zorotools.com>

[5] Brass gate valve. Sears plumbing. <http://www.sears.com>

[6] Brass angle valve. NIBCO. <http://www.nibco.com>

[7] McMaster Carr. <www.mcmaster.com>