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McDonald Observatory REU Program
Summer 2008
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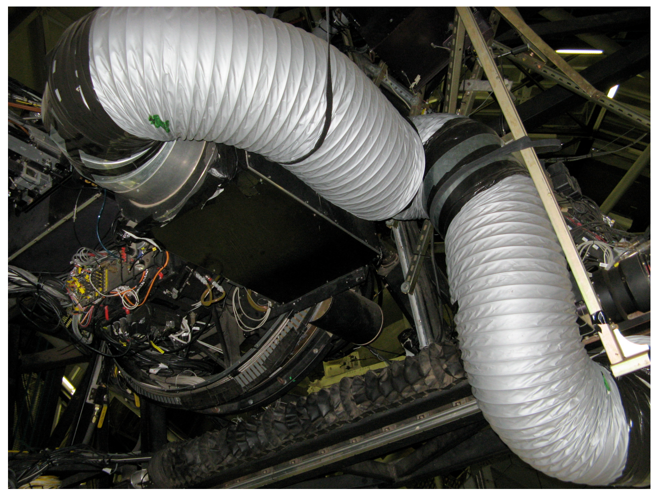
Purpose

The goal of this project was to design and build a new cooling system to replace the existing cooling system for the electronics on the tracker on the HET. The new cooling system needed to keep the electronics box at the ambient temperature of the dome to prevent complications with seeing, as heat generated by the electronics would warm the air over the mirror, and to prevent the electronics themselves from overheating. The new system needed to utilize glycol as the cooling agent and allow rho, the rotating portion of the tracker, its full range of motion.



The existing system consists of a tube attached to the top of the electronics box. Air is pulled from the box into the tube by a vacuum pump. The tube runs over the mirror and down the side of the telescope to exhaust outside of the dome. This solution was only meant to remain in place for six months and as a result has several problems. The tube through which the air travels has a helical wire support structure. Instead of travelling straight through the tube, the air follows the helical path of the wire, which increases the surface area of contact between the air and the tube. This increases heat transfer between the air and the tube wall, raising the temperature of the wall and dumping heat from the tube into the air of the dome. This, combined with the poor insulation of the tube and amplified by existing holes and tears in the wall of the tubing, causes the temperature of the air within the tube to reach ambient by the time the tube is halfway over the mirror. All the heat in the air from the box has been dumped over the mirror. The tube travelling over the telescope also blocks about two percent of the light that would otherwise reach the mirror.

The support structure for the current system undergoes a great deal of stress when rho is at the extents of its rotational range. A piece of unistrut supporting the tube via a harness deflects by several inches, and the harness and the tube itself experience significant tension. The structure atop rho was not designed for the resulting forces, and the cyclic loading experienced by the structure weakens the material and widens existing cracks, especially in the case of the tube itself, where the cracks (tears and holes) are already large.

Preliminary Concepts

A radiator running glycol as the cooling fluid would cool the air drawn through the radiator using a fan. Either we could purchase a radiator that had fans to move the air attached, or we could determine if a radiator we already possessed would suffice and purchase the fans separately. The second option was by far the cheaper, but we didn’t know the cooling capacity of the existing radiator, as the documentation was no longer attached.

We decided to run a closed system in an attempt to eliminate some of the problems with the current system. To move the air once it had been cooled, pipes would run from the chamber above the radiator down to the bottom of the electronics box where the air would be reintroduced into the system. We considered both rectangular piping, such as the kind found in ventilation systems, and cylindrical piping, such as the type in most plumbing systems. We selected cylindrical piping because its shape would reduce turbulence in the air moving through the pipes. Turbulence would slow the flow of the air in the pipes and the resulting friction would heat up the cooled air, reducing the efficiency of the system.

To move the air from the top to the bottom of the system in these pipes, we considered four options. Two consisted of purchasing an additional fan to either push the air through at the beginning of the pipes or pull the air through at the end of the pipes. A third involved relying on the pressure caused by the fans moving air through the radiator to the chamber above to force the air down through the pipes. The final solution, and the solution finally selected, used nozzles to reduce the flow area at the end of the pipes and thus accelerate the air out of the pipes and into the bottom of the electronics box. This solution would both increase the velocity of the air and cause the flow to become turbulent, which would ensure that the air spread across the entire area of the box before starting to rise through the electronics. This additional turbulence would not cause the problems mentioned above because the nozzles would be placed at the end of the piping, right before the air reentered the electronics box.

Information Required

We needed to determine the heat output of the electronics in the box to determine the cooling capacity necessary for our radiator. To do so, we employed the equation

$$\Delta Q = c_p * \dot{m} * \Delta T$$

This required we have the specific heat capacity, density, volume flow rate, and change in temperature of the air. Normally, we could assume the density of air at standard pressure and temperature, but the altitude of the telescope required that we calculate the density of the air using the equation

$$\rho = \frac{p}{R * T}$$

Once the density had been calculated, we measured the temperature of the air at the intake and exhaust of the current system, the velocity of the air at the exhaust (the current system is not airtight so the velocity at the intake would not be accurate, as air would also be drawn in from other openings), and the diameter of the tube through which the air exhausts. Using this information, we calculated the heat output of the electronics. Gathering and using information from the current system, however, contained within it the implicit and invalid assumption that the current system’s heat removal capacity was accurate. To correct for this, we multiplied the heat output by a factor of safety of 1.5.

Next we calculated the cooling capacity of the radiator we already possessed to see if it could remove the amount of heat output by the electronics. We modeled the radiator as a long tube with a fluid flowing around the outside of the tube (the air) and through the inside (the glycol). This provided us with a set of thermal resistances as heat is transferred from the air to the tube wall ($R_o = \frac{1}{h_o A_o}$), through the tube wall ($R_{wall} = \frac{\ln(D_o / D_i)}{2\pi k L}$), and from the tube wall to the glycol ($R_i = \frac{1}{h_i A_i}$).

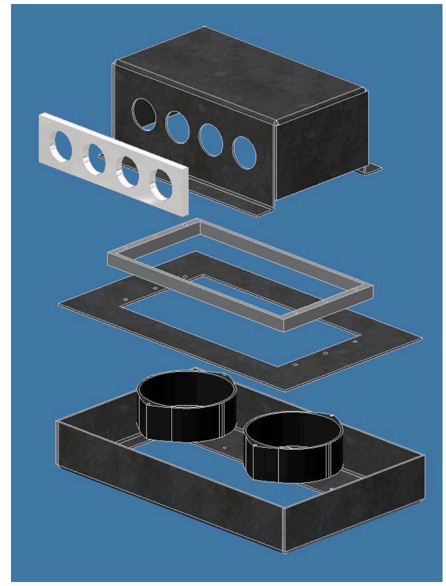
We plugged these resistances into the formula $\dot{Q} = \frac{\Delta T}{R}$ (the resistance is additive: $R = R_i + R_{wall} + R_o$). The resistance through the tube wall proved easy to calculate because all the values required were either material properties or properties of the radiator itself. We found the values of the resistance from the air to the wall and from the wall to the glycol more difficult to calculate because the *h* values depended on the type of flow, the geometry of flow, and the velocity of the flow rate, and several other complicated variables. We made the decision to neglect R_o because the fins on the outside wall of the tubing of the radiator increased the surface area (A_o), making the resistance value negligible compared to R_i. We had calculated R_{wall} and knew the total value of *R* the radiator needed to possess to have the necessary cooling capacity. To calculate R_i, we assumed a reasonable range of velocities for the glycol flowing through the radiator. This reasonable range produced the R_i value required, and the radiator we already had could be used in the new cooling system.

pipes to glycol	Pr	k (W/m*K)	μ (cP)	μ (Pa*s)	s. gravity	ρ (kg/m^3)	Cp (J/kg*K)	Dh(m)
smooth tubes	38	0.25	2.8	0.0028	1.077	1077	3350	0.0117
		Laminar Flow						
velocity (m/s)	Reynold's Number (Re)							
0.25	1,125							
0.5	2,250							
		Transitional Flow	Nusselt Number	***h***	**Ri**			
0.75	3,375		65	1,393	9.30E-03			
1	4,500		82	1,753	7.39E-03			
1.25	5,625		98	2,096	6.18E-03			
1.5	6,750		113	2,425	5.34E-03			
1.75	7,876		128	2,743	4.72E-03			
2	9,001		143	3,052	4.24E-03			
		Turbulent Flow	Nusselt Number	***h***	**Ri**			
2.25	10,126		157	3,354	3.86E-03			
2.5	11,251		171	3,649	3.55E-03			
2.75	12,376		184	3,938	3.29E-03			
3	13,501		198	4,222	3.07E-03			
3.25	14,626		211	4,501	2.88E-03			
3.5	15,751		224	4,776	2.71E-03			
3.75	16,876		236	5,047	2.57E-03			
4	18,001		249	5,314	2.44E-03			

Finding the heat output rate and the cooling capacity rate equal, we needed only to determine the airflow rate ($\dot{m}$) that would move an amount of air through the radiator containing the quantity of heat equal to the cooling capacity per unit time. To do so, we again used the equation $\Delta Q = c_p * \dot{m} * \Delta T$, this time solving for $\dot{m}$.

Construction

To create a closed system, we built a box to house both the radiator and the fans and to mount over the hole left in the electronics box by the current system. We decided to make the box out of sheet metal to reduce the weight of the structure and not inhibit the rotation of rho. A previous design for the electronics box itself had actually been too heavy for the motor which rotates rho to move. We possessed two gages, or thicknesses, of sheet metal on site. Both bent easily enough in the sheet metal bender, a critical part of the design, but neither could be cut using the sheet metal cutter. We decided to use the thinner sheet metal to reduce the weight and cut the metal using a vertical band saw. Once the pieces had been cut, we bent them and riveted them together, attaching the radiator and fans during construction.



We chose aluminum as the material used for the pipes which would transport the cooled air. The other option had been plastic. At first, plastic appeared the cheaper option, but when we discovered already purchased unused lightweight aluminum pipes in one of the storage yards, aluminum became the cheaper choice. We purchased elbows for the pipes and a length of high density polyethylene (HDPE) to make the nozzles. The nozzles would fit inside the pipes and reduce the diameter at the end of the pipes from two to one inch to accelerate the flow of air. An aluminum plate for the manifolds had also been found in the storage yards. One manifold would attach to the sheet metal box at the top and another to the electronics box at the bottom to provide material to weld the aluminum pipes onto the boxes.

Completed Work and Work Remaining

The box housing the radiator and fans has been built. The aluminum pipes, manifolds, and plastic nozzles exist as separate parts needing to be assembled. A method for getting the glycol from a stationary source to a rotating destination must be determined. The tracker will be taken down from the HET in several months, at which point this system will be installed.