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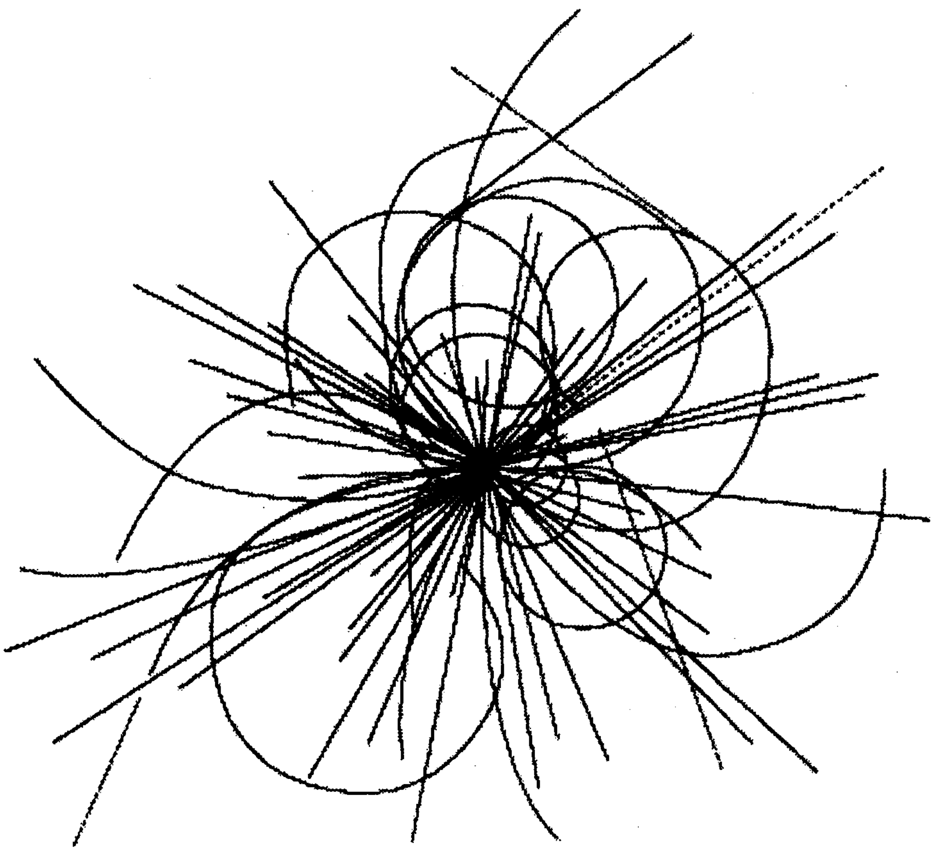

Superconducting Super Collider Laboratory

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Design of Tunnel Cooling System*

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DESIGN OF A TUNNEL COOLING SYSTEM

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ABSTRACT

Based on a thermal analysis of the SSC main tunnel and requirements for space conditions in the underground electronics niches, thermal cooling systems will be required to reject the heat dissipated underground. Many systems were considered and compared to decide the optimum solution. Construction documents are being prepared and contract administration will proceed as technical and non-technical objectives are pursued.

INTRODUCTION

Like all existing large accelerators, the SSC is being built underground for reasons of radiation safety. All of the magnets, power supplies, control electronics, and instrumentation will be located either in the underground tunnel or the tunnel niches. In order to maintain the alignment of the accelerator magnets and keep the electronics operating reliably, a stable temperature not exceeding 80°F will be critical.

The spacing of the niches will be every 0.3 miles, with the shafts to the surface every 2.7 mile, which limits direct assess to the niches. The following paper will point out the specific needs that demand a controlled environment in the tunnel and niches.[1,2]

REQUIREMENTS FOR THE TUNNEL AND NICHES ENVIRONMENT

Niche Electronics

Within the niches the following electronics transfer heat to air and must not be subjected to temperatures greater than 80°F or temperature variations greater than 5°F per day.

- Corrector power supplies
- Beam position monitors
- Timing system
- Cryogenics controls
- Vacuum systems
- Beam loss monitors
- Quench protection

For each of these systems to consistently perform as designed and calibrated, the environment must be maintained within the prescribed limits. Total heat rejected in each niche will be 12 kW.

Tunnel Environment

To ensure the precision of the alignment of the magnets is not adversely affected, a stable of the tunnel temperature must be maintained. Thermal stability is also a requirement of the bellows in the spool pieces and the scraper alignment. Temperatures must be maintained below 85°F and not exceed a gradient of 7.2°F/half-sector. Heat loads within the tunnel originate from the following sources:

- Power cables
- Corrector cables
- Dump resistor cables
- Transformers

Total heat rejected in a typical sector will be 216 kW.

HEAT TRANSFER PROCESS IN TUNNEL AND EXTERIOR ROCK REGION

In developing the system to extract the heat from the niches and the tunnel, the heat transfer process in the tunnel and the surrounding rock region was analyzed. If the rock could be used as the heat sink and had sufficient capacity to maintain the tunnel and niche temperatures within the allowable limits, the heat extraction system would be greatly simplified.

Generation of Thermal Layer around Tunnel

Transferring heat through the tunnel wall generates a thermal layer from the wall surface out to a distance where, beyond which for practical purpose, there is no heat flow. Within the region of the thermal layer, the heat transfer process can be described by an energy-balance equation and Fourier Equation, i. e., net rate of heat entering through the bounding surfaces is equal to the rate of storage of energy in this region and heat flux is proportional to the temperature gradient.

Based on these principles, there must be a temperature gradient in the rock region to force heat flow to the deep rock. By testing rock samples and taking bottom-hole temperatures at SSC monitoring wells, values were determined for conductivity, specific heat, thermal diffusivity, and undisturbed ambient rock temperatures at the tunnel depth. As heat is continually added in the tunnel and niches, the temperatures of the rock in the thermal layer continues to rise as the energy is stored in an ever increasing volume of rock. To determine tunnel and niche temperatures, a heat transfer model was developed and solved by the integral method. The solution has proved to be a very good approximation for the exact solution.[3,4] For these calculations it was assumed the rock mass was infinite, homo-geneous, initially at 70°F, and the flow of groundwater was so small its effect was insignificant. Using this information it was determined that with only the heat transfer into the rock, within five hours, the niche air temperature will exceed 105°F and the tunnel temperature will exceed 90°F in 200 days.

DEVELOPMENT AND COMPARISON OF TUNNEL COOLING SYSTEM

Many cooling systems were considered during the study. These systems can be classified into three groups based on their transport media: air cooling system, air/refrigerant cooling system, and chilled water cooling system.

Air Cooling System

In this system, cooling air is supplied from one shaft and removed from the next shaft. Fans are used in the niches to transfer the heat to the tunnel. When cooling air is forced through the tunnel, the distributed heat in the tunnel as well as the niche heat load is picked up and warm air will be exhausted at the next shaft.

This is the simplest system because only air is involved in the whole process below grade. The highest tunnel temperature that would occur at the niche closest to the exhaust shaft must still be no greater than 75°F to adequately cool the niche. But to keep the temperature gradient to less than 10°F, the air volume required is so great the size of the shafts would have to be greatly enlarged. At the supply shafts, the rock becomes an additional heat source instead of a heat sink because the supply air temperature is lower than the rock temperature.

Air/Refrigerant Cooling System

This method uses direct-expansion (DX) units to reject heat from the niches to the tunnel. This allows the tunnel temperature to reach the maximum limit of 85°F while cooling is provided for the niches. Cooling air is forced to flow from one shaft to be removed at the next shaft, picking up the heat from the distributed tunnel loads and the niche DX units.

The rock will remove some heat from the tunnel where the temperature is greater than 70°F, however, the work of compression of the DX units increases the load in each sector by approximately 50 kW. This system requires an even greater amount of air to maintain the temperature gradient and the reliability of the DX units represents a very serious maintainability and reliability concern.

Chilled Water Cooling System

Because the greatest concentration of heat load is in the niche, the best approach is to extract the heat as directly as possible from the heat source. This is the basic principle of the chilled water cooling system.

In this system chilled water is distributed through the tunnel in an insulated chilled water supply pipe to each niche. Within the niches, terminal units consisting of coils and fans provide cool air and transfer the heat to the water. The return pipe is left uninsulated so it can absorb the distributed heat loads in the tunnel, thereby creating an environment in the tunnel that is practically isothermal. Chilled water is supplied from a chiller above ground and circulated to the tunnel.

Minimal air flow through the tunnel will increase the heat transfer to the return line and will be utilized to maintain humidity control and ventilation requirements. Estimates of installed and operating costs indicate the chilled water cooling system has the lowest initial and life cycle cost.

CONCLUSION

Due to the geotechnical conditions of this region, the SSC tunnel is basically in a warm, dry, insulating rock that is ideal for tunneling but does not function well as a heat sink. This condition is especially critical in tunnel niches where the heat load is concentrated and exceeds the heat dissipation capability of the surrounding rock. A cooling system had to be designed to extract the heat in order to provide a constant ambient temperature suitable for the operation of the electronic systems. Studies have determined the chilled water cooling system can best meet the criteria.

Ten identical cooling systems will be provided with a sum total capacity of 1500 tons produced by chillers at alternating remote sites. A major element of the initial cost will be the 100 miles of steel pipe required. More than 300 fan coil units, each with a capacity of 4 tons, will be installed in the adits and niches. The operation of these equipment will be controlled by multiple direct digital control panels networked locally into ten systems, which in turn will be networked into a site-wide system .

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