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An Intermediate Solution to the Magnet Cooling Problem

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An Intermediate Solution to the Magnet Cooling Problem. (An Option to No Chiller or a Full 600 Ton Chiller System)

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Background

The magnet cooling system, as it is currently envisioned and funded, can maintain the coil temperature to a nominal average of 75 °F during limited circumstances. At this operating condition, the magnet low conductivity water (LCW) inlet temperature should be 65°F (corresponding to a wet bulb temperature of 35°F assuming a ΔT in the water/water heat exchanger of 20°F and a ΔT in the wet cooling tower of 10°F). Whenever the ambient wet bulb temperature exceeds 35°F, the LCW system will not be able to maintain the required coil temperature. When this occurs, the coil temperature will rise until it reaches a new equilibrium temperature, dependent on the outside ambient conditions.

From a review of the BNL temperature and humidity data over a 45 year period (see Table 1), it is expected that conditions will be such that during a significant number of days of a typical year; primarily in the months April through November, the magnet will operate at average temperatures above 75°F. During this period, the average coil temperature can potentially reach 110°F. This 35°F increase over the normal coil operating temperature can cause a significant rise in the temperature of the magnet steel which is the backbone of the detector and the basis of alignment of all detector subsystems. Additionally, if the magnet steel is assembled at or reaches a temperature below the nominal magnet operating temperature during shutdown, this ΔT could be 45°F. As the magnet cycles through this range of temperatures, the coils and return steel "creak and groan" or stick and slip as thermal strains increase. Since this will not occur in a consistent manner, surveyed locations of detector system elements will not necessarily be maintained.

Table 1) BNL Temperature Data

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Mean Max. Temp (1949-1992)											
38	39	47	58	68	77	82	80	74	64	53	42
Avg. Wet bulb(1960-1969)											
24	25	30	41	50	60	65	64	58	46	39	27

In addition to system alignment and the potentially non-linear behavior of the magnet structure, another significant disadvantage of allowing the coil temperature to run uncontrolled is the thermally induced strains in the coil packages. The energized magnet coils are under a significant compressive stress due to magnetic forces. The addition of significant thermal compressive stresses can exceed the allowable shear stress for the epoxy used to pot the coil packages together.

Before the energized magnet system reaches thermal equilibrium, temperature differences between the aluminum coils and the return steel are at a maximum. Thermally induced compressive stresses add to the magnet forces because of the large difference in the coefficient of thermal expansion (COTE) between the aluminum coils and the cooler return steel, between which the coil packages are constrained. Between each coil assembly, maintaining their position relative to one another, is a set of bumpers. These bumpers are carefully designed to be stiff enough to maintain the appropriate relative coil position yet compliant enough to limit coil strain due to thermal expansion. This set of requirements is difficult to meet in the bumper design if the full 35-45°F range of coil temperatures is allowed to occur. On the other hand, if the maximum temperature range between power on and power off can be limited to 20-25°F (say 90°F average coil temperature), the bumper design and material choice becomes more simple.

Because of the qualitatively predicted behavior, it has been suggested that a water chiller be added to the magnet cooling water system which would limit the coil operating temperature swings to 1-2°F. This would lock in the coil temperature and alleviate undesirable magnet system temperature fluctuations. (At least ensure that the range of nominal coil/steel temperatures never rises above those of the WAH/Assembly Building air temperature fluctuations when the magnet is not operating.) The chiller system originally envisioned and described to perform this task was a "brute force" solution; i.e., providing all the necessary magnet cooling capacity without the benefit of any precooling from the tower water.

Several alternatives to allowing the magnet temperature to run "open loop" with the ambient outside conditions, or providing a full chiller system of significant cost, are described below. A "rough order of magnitude" cost is also included.

Alternative 1 (no cost)

One alternative is to shut the magnet down during periods where the ambient outside conditions are such that maximum average coil temperature cannot be maintained at or below 90°F (wet bulb above 50°F). Obviously, there are some significant negative effects on the STAR experimental program if the number of days that this shut down is necessary becomes excessive. From Table 1, it looks

like this condition will occur, at times, during the months of May or June through September. RHIC will likely be shut down for 3 of these months.

Alternative 2 ($75K)

A second alternative is to spend more money on a larger water/water heat exchanger. This larger heat exchanger would allow the removal of more heat from the LCW with tower water (say a 10°F ΔT between tower and LCW instead of 20°F as in the baseline system). When compared to the above alternative 1, this alternative would cut the number of days when the experiment had to be shut down by allowing operation at wet bulb temperatures up to 60°F. These conditions should occur during a relatively small number of days; from Table 1 this occurs only in the months June through August. We would really need to look at the hourly data and the magnet system time constant to estimate the approximate number of operating days possible.

Alternative 3 ($250K)

A moderate cost alternative to no chiller is a reduced chiller capacity. This could be appropriately accomplished by adding a smaller capacity (200-300Ton) chiller and modifying the LCW heat exchanger. The heat exchanger would allow precooling of the LCW with the relatively cool tower water, and then completing the LCW cooling with the reduced capacity chiller. This would once again allow the coils to operate below 90°F, but without sacrificing STAR operating and data collection time.

Conclusion

For the reasons stated above, it is obvious that limiting the temperature fluctuations within the magnet to 25 °F is desirable and warranted. For this reason, STAR Management has agreed to specify that 90°F should be the maximum average coil operating temperature. The STAR collaboration will, by utilizing one of the above alternatives or another alternative not yet proposed, agree to abide by this agreement.

The coil temperature could be maintained at the maximum allowable temperature of 90°F, even during a magnet shutdown, by controlling the mixture of tower inlet and outlet water to always provide the heat exchanger with 60°F inlet water. Because the LCW will be circulating even when the magnet is off (to reduce corrosion), the magnet temperature can be maintained at 90°F at all times by adding a few kW of heat to the water. Additional heaters may be required to accomplish this, or it is possible that the heat added by the circulation pumps could be enough. The advantages of maintaining a constant

coil temperature (at least while the magnet power is on or the cooling water circulating), if any, will have to be investigated and decided upon by the magnet design group.