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THERMAL PERFORMANCE OF THE TEVATRON MAGNETS UNDER HIGHER ENERGY OPERATING CONDITIONS

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ABSTRACT

The paper discusses several alternative ideas to improve the cryogenic performance of the Tevatron magnet strings under high energy, low temperature, operating conditions. A previously developed mathematical model of the Tevatron magnet string has been used to identify temperature profiles during cold compressor operation. Analysis of modeled temperature profiles shows the dominance of the spool heat leak due to a lack of heat transfer between single-phase and two-phase helium within the spool. This paper discusses a strategy for improving the temperature profile across the magnet string by installing a modified Tevatron spool with recoolers, and rearranging weak magnets. The computer simulation was carried out to identify the best location for a modified spool in the string, and preferred locations for weak magnets. Calculations indicated that, if recoolers were added to only one spool in each of the 48 strings of dipoles, the most effective location is in the middle of the string.

INTRODUCTION

The Tevatron magnets are cooled by a hybrid cryogenic system, which consists of a Central Helium Liquefier and 24 satellite refrigerators. Each of the satellite refrigerators cools two 125m long magnet strings of the Tevatron synchrotron.

FIGURE 1 represents a schematic layout of a typical Tevatron magnet string. There are two magnet strings per refrigerator – an upstream string is on the left, and a downstream string is on the right. The superconducting magnets are cooled by supercritical single-phase helium. At the end of each string there is a turnaround box ("T" in Figure 1). The single-phase helium is expanded in a throttle valve into two-phase and returned back to the refrigerator through the magnet strings. There are four so called half cells in a typical magnet string. Each half cell consists of four dipole magnets ("D" in Figure 1), a

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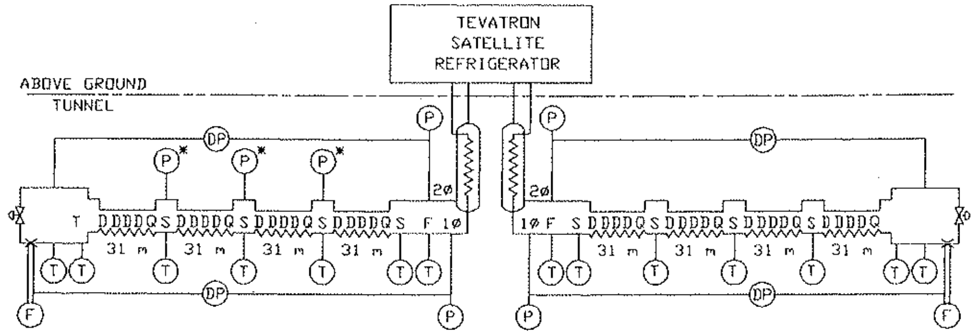

FIGURE 1. Schematic layout of a satellite refrigerator with typical magnet stings.

quadrupole magnet (“Q” in Figure 1), and a Tevatron spool piece (“S” in Figure 1). The refrigerator interfaces with the magnet strings at the feedcan (“F” in Figure 1).

The Tevatron dipole and quadrupole magnets are of a warm iron design. The magnet design is such that half of the single-phase flow cools the magnet coil, passing between the beam tube and the coil. The other half is heat exchanged with two-phase flowing in the annular passages. The two single-phase streams mix at the end of each magnet.

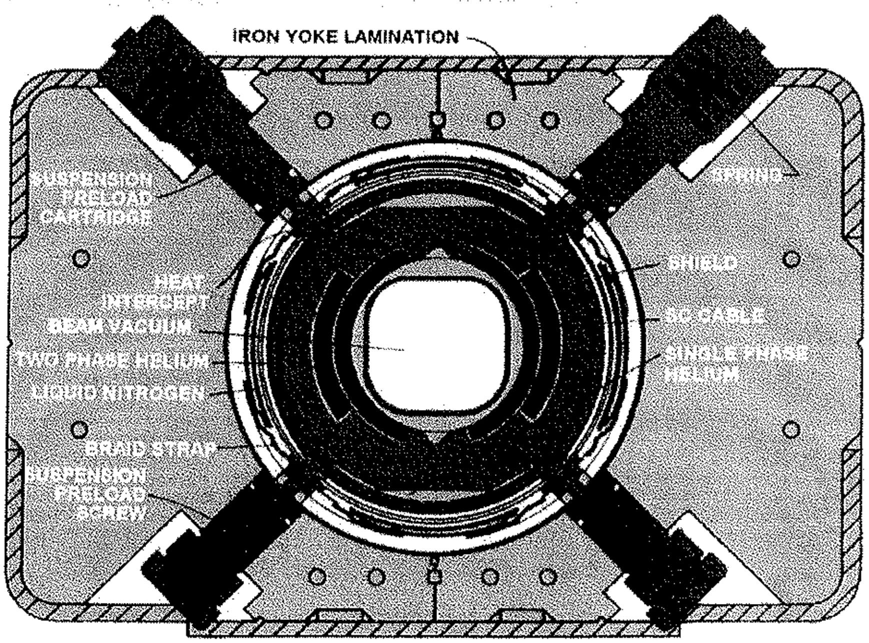

FIGURE 2. Tevatron dipole magnet cross-section.

The heat load of the magnets, static and dynamic, is removed by the single-phase, and then is absorbed by the latent heat of vaporization of the two-phase helium. However, because there is no heat exchange between single-phase and two-phase within the spools, and the fact that for the given heat transfer area in the magnets the temperature difference between the single- and two-phase is too small to drive the heat transfer at the necessary rate, we observe the gradients along the string from feed can to turnaround box is in the range of 200 to 500 mK.

DISCUSSION

A previously developed thermal model of the Tevatron magnet strings was used to identify the temperature profile in the Tevatron magnet string. The detailed discussion of the model used will be presented at this conference [1].

The temperature distribution across the downstream and upstream magnet strings for 0.076 MPa operation mode are presented in FIGURES 3 and 4, respectively. The single-phase helium flows from the feed can, then splits into two flows – inner and outer. The inner flow (upper line) cools the magnet coil, and the single-phase outer flow (intermediate line) heat exchanges with the counter flowing two-phase (lower line). The ordinate represents the temperature across the magnet string, where the abscissa shows component locations for a typical Tevatron Magnet string. The dot in the middle of the upper line (inner flow) represents the location of a thermometer.

The figures show that only x5 half cell is in a thermally favorable location. The lowest quench energy dipoles should be installed in this half cell. This cumulative temperature increase from the feed can to the turnaround box can be explained

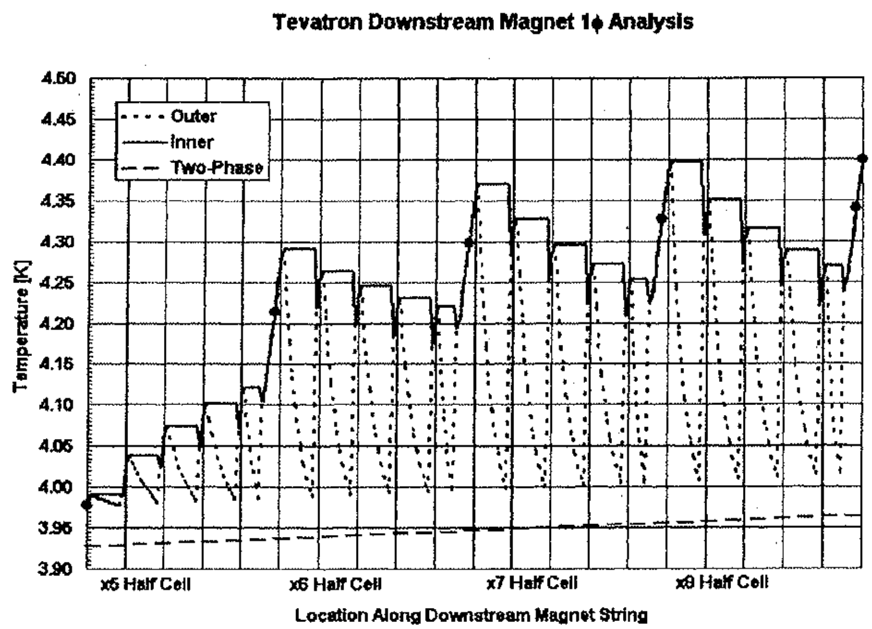

FIGURE 3. Simulated temperature distribution across a downstream magnet string

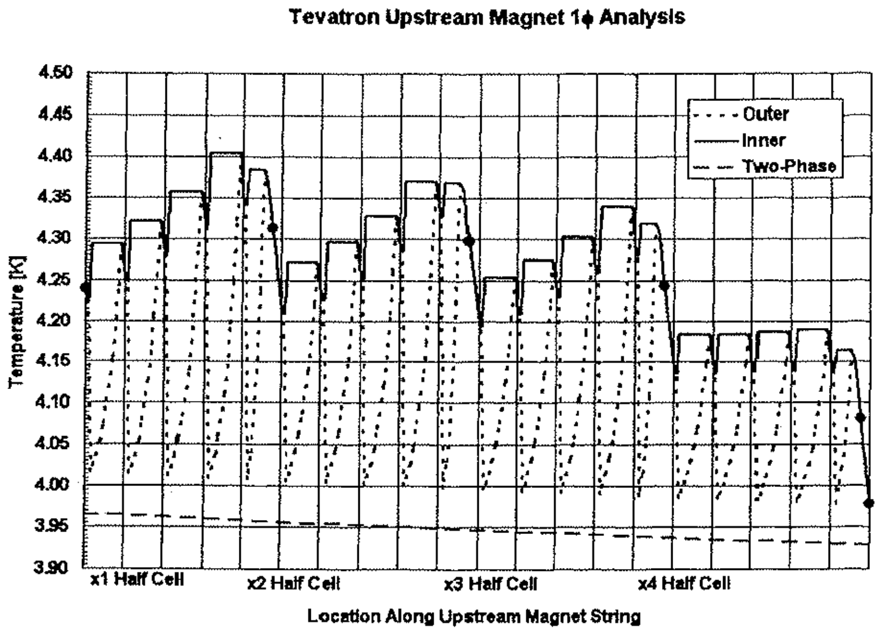

FIGURE 4. Simulated temperature distribution across an upstream magnet string

with the fact that the heat transfer surface is fixed and the temperature difference between the single and two-phase is too small to drive the heat transfer at the necessary rate. The spool heat leak has the strongest effect on the magnet temperature profile. This is due to the fact that there is virtually no heat exchange between the single-phase and the two-phase streams within the Tevatron spool. As a result, a dipole magnet located immediately downstream (helium flow direction) from a spool is the warmest in a half cell. Therefore, when an opportunity arises we rearrange the magnets in the way that high quench performance magnets are located just downstream (helium flow direction) of a spool. After shuffling magnets we raise magnets operating temperature, and thus the two-phase pressure. This results in an energy savings.

Another way to improve quench performance of the Tevatron is to better equalize magnet temperatures across the strings. This can be achieved via upgrade of the existing Tevatron spool pieces by adding a single-phase to two-phase heat exchanger [2]. It would add more heat transfer surface, thus enhancing the single-phase to two-phase heat transfer.

The limited number of spare Tevatron spools and the upgrade cost would not allow us to modify each spool in the Tevatron without significant interruption of the physics program. We have carried out simulations to identify the best locations for one the modified spool per magnet string. Calculations indicated that, if recoolers were added to only one spool in each of the 48 strings of dipoles, the most effective location would be in the middle of the strings.

Ultimately, a recooler should be located on the single-phase outlet from the spool. This ensures that the recooler removes the spool heat leak. This would lower single-phase inlet temperature to the next half-cell. However, the single-phase flow direction is coherent with proton beam direction only for the downstream string, which means that for the spool located in the upstream string a recooler should be mounted on the upstream (proton beam direction) side of the spool. The existing spool design is such that it is considerably more costly and difficult to install a recooler on the upstream (proton beam direction) end of a spool. As a result, recooled spools are only being constructed with the heat exchanger on the downstream (proton direction) end. Installation of a recooled spool on an upstream string results in the spool heat leak being added to the single phase after recooling.

FIGURES 5 and 6 represent the resulting temperature profile of a downstream and an upstream magnet string, respectively, with modified spool pieces located in the middle of the strings; at x7 and x3 half cells. The recooler lowers the outlet single phase temperature from the spool by about 350 mK for the downstream magnet string. The effect is less significant for the upstream string due to the fact that the recooler is located on the downstream (proton beam direction) end of a spool. Verification of the simulated data is very difficult due to the limited thermometry available. We have rearranged the magnets to better fit their quench performance at nine locations. We successfully raised the operating temperature of the magnets at those locations. This fact, coupled with the modified spool tests conducted at Magnet Test Facility at Fermilab [3], proves that the discussed methods help to improve the cryogenic performance of the Tevatron magnet strings under high energy, low temperature, operating conditions.

A limited number of the Tevatron spools have been modified. We have currently restricted recooler spool installation to the x7 or x8 half cell locations in order to maximize the impact. With the addition of the recooled spool, a second thermally favorable location in the downstream magnet string has been established. Having an additional thermally favorable location is particularly important with our desire to operate the Tevatron at higher energy. Rearranging magnet locations to best match their quench performance allows us to raise the operating temperature of the satellite refrigerators, thus saving energy and lowering operating costs.

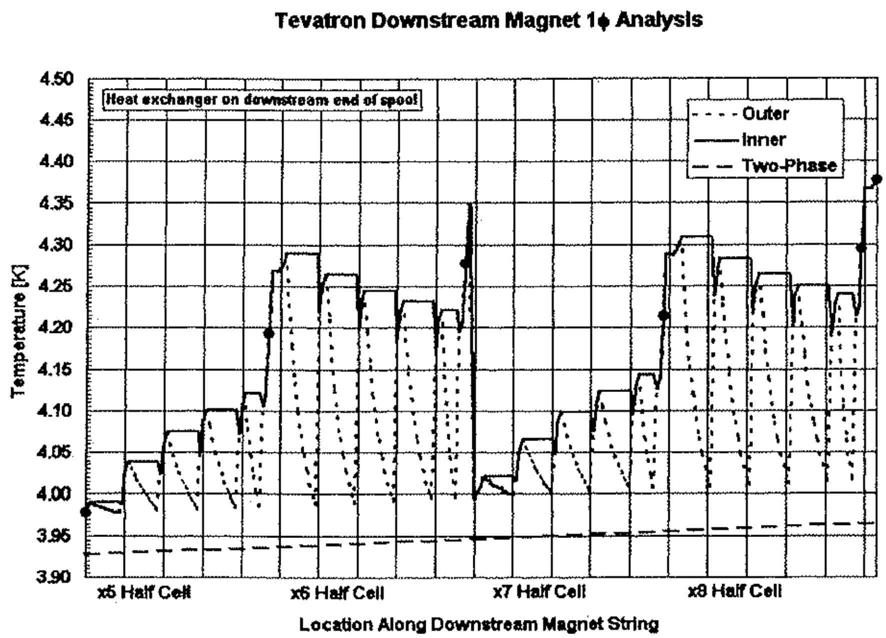

FIGURE 5. Downstream magnet string with modified spool at x7 half cell

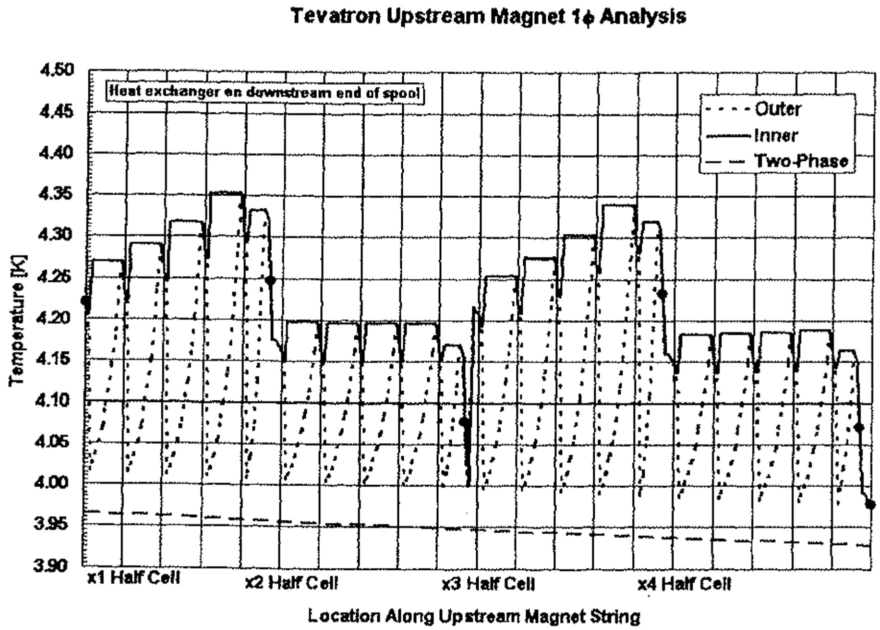

FIGURE 6. Upstream magnet string with modified spool at x3 half cell.

CONCLUSION

A previously developed mathematical model of the Tevatron magnet string was used to improve the cryogenic performance of the Tevatron magnet strings under high energy operating conditions. Modified spools were used to improve the temperature profile of the Tevatron magnet strings. Calculations indicated that, if recoolers were added to only one spool in each of the 48 strings of dipoles, the most effective location is in the middle of the string. With a limited number of modified spools available, a desire to lower operating costs and limited cryogenic capacity, modified spools have been installed in these half cells, creating an additional thermally favorable location for the Tevatron magnets. Relocating the lower quench performing magnets to those locations allowed the increase of operating temperature thus lowering operating costs.

REFERENCES

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2. Theilacker, J. C., Klebaner, A. L. "Thermal Modeling Of The Tevatron Magnet System," to be presented at this conference.
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