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Technical Note No. 50
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WARM-UP HEATERS FOR THE SSC

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Summary

This note describes a method to efficiently heat up a half cell of SSC magnets in approximately one day by use of band heaters attached to the outer skin of a dipole magnet.

Discussion

A string of Tevatron magnets are warmed up to repair a correction element which fails on the average of once every five months.[1] For planning purposes, the SSC is taken to require warmup at a similar rate. From helium temperature to 225K the warm-up will proceed rapidly by simply using gaseous helium from the compressor discharge at 285K. At some point, say $\sim$225K, the warm-up will slow down since a large ΔT no longer exists to heat up the iron. By turning on electrical band heaters the warm-up can proceed rapidly to above ice temperature where the magnets are then opened up for repairs. To minimize the heat leak to the 4K magnet, the power cables are not normally connected to the 300K surfaces. This procedure requires that the insulating vacuum be broken with nitrogen gas at $\sim$200K. The electrical bus is then manually connected to a 300K connector in the vacuum tank and the warm-up continued above ice temperature using the installed heaters. The spoiling of the insulating vacuum also accelerates the warm-up. To gain entry for repairs this vacuum normally will be spoiled anyway.

Analysis

Magnet weight - 1.5×10^4 lb., 6.81×10^6 gm.

Enthalapy of iron - $h_{300K} = 81 j/gm$, $h_{200K} = 39$ j/gm.

$q = m\Delta h =$ $6.81 \times 10^6 (81-39) = 2.86 \times 10^8$ j.

Assuming a Watlow model B10J 3 ARI heater, rated at 2400 w each, then the required capacity to heat up the iron 100°K in 8 hours with a 15% safety factor is;

$$q_{reqd} = \frac{2.86 \times 10^8 j \times 1.15}{8h \times 3600 \frac{s}{h} \times 1000 \frac{w}{kw}} = 9.9 \text{ kW}$$

The number of heaters required:

$$N \text{ req'd} = \frac{9.9}{2.4} \approx 4 \text{ each} .$$

Assuming the four heaters are connected in parallel to provide the appropriate redundancy and the five dipoles in each half cell are connected in series, then 100A at 480V is required to power the section.

To reach 285K throughout the iron, one operates the heaters above this temperature to achieve the appropriate heat transfer. Using a thermal resistance concept, the following is an estimate of the maximum heater temperatures as shown in Table 1.

Material	Thermal Resistance $R_{th}\left(\frac{cm^2K}{w}\right)$	Thermal Conductivity $K(w/cm^{\circ}k)$	Radius $r(cm)$	Contact Resistance $\frac{1}{h_c}\ \frac{cm^{2\circ}K}{w}$
Ext. gas film	0.18		14.2	0.18
Shell	3.45	0.152	13.8	
Int. gas film	5.64		13.3	5.28
Iron	15.48	0.81	13.3	
Gas Film	0.465		5.5	0.18
ΣR_{total}	25.2			

Table 1

$$U_o = 1/R_{total} = \frac{1}{25.2} = 0.040\ \frac{w}{cm^2K}$$

$$A = 2\pi\ rl = 2\pi \times 14.2 \times 4 = 356.8\ cm^2$$

$$T_{max} = T_o + \frac{q}{UoA} = 285 + \frac{2400}{0.040 \times 356.8} =$$

$$T_{max} = 453^{\circ}K\ (180^{\circ}C)$$

This temperature will be considerably reduced by circulating helium gas through the magnet at the same time the heaters are energized. This will increase the longitudinal conduction and also minimize the contact resistance of the gas film at the interfaces.

The advantages of this system over internal heaters is that it puts the heat where you want it, in the iron rather than in the coil or gas. The thermal time constant of the iron is in our favor and it puts a limit on the coil temperature. The machine will necessarily have vacuum barriers which define isolatable sections. Assuming a section every 1200m; this will require ≈1000 SCF of nitrogen gas to break the vacuum.

There is one other factor that also must be considered during warm-up. If one installs heaters directly in the iron, then the iron will grow radially due to the heat input prior to the stainless steel skin. A comparison between the thermal expansion of the iron[2] to that of the stainless[3] shell for an additional 20K differential temperature yields an added stress in the shell as shown in Table 2.

Temperature	$\left(\frac{L293-LT}{L293}\right) \frac{IN.}{IN.}$ Expansion Iron	$\left(\frac{L293-LT}{L293}\right) \frac{IN.}{IN.}$ Expansion Stainless	Stress in Shell Due to Thermal Contraction (psi)	Additonal Stress Due to Being 20°K Higher (psi)	Total Stress in Shell (psi)
	$\times 10^5$	$\times 10^5$			
200	101	139	10640	5684	16324
220	80.7	111	8484	5908	14392
240	59.6	81.7	6188	6132	12320
260	37.7	51.4	3836	6328	10164
280	15.1	20.5	1512	6552	8064
300	-8.3	-11.1			

Table 2

Where the values shown due to thermal contraction at the same temperature are obtained by

$$\text{Thermal Stress} = (139-101) \times 10^{-5} \times 28\times 10^{6} = 10640 \text{ psi}$$

The total stress induced in the shell due to the iron being 20 K higher is obtained by

$$\text{Thermal Stress} = (139-80.7) \times 10^{-5} \times 28\times 10^{6} = 16324 \text{ psi}$$

Therefore the stress attributable to the heating of the iron prior to the stainless is

$$16324-10640 = 5684 \text{ psi}$$

Since the shell is already thermally stressed due to welding $\sim$10-20 Ksi, the additional stress due to cryogenic temperature $\sim$10 Ksi, plus the heating up of the iron prior to heating the shell could cause local yielding, which is an undesirable situation.

Acknowledgments

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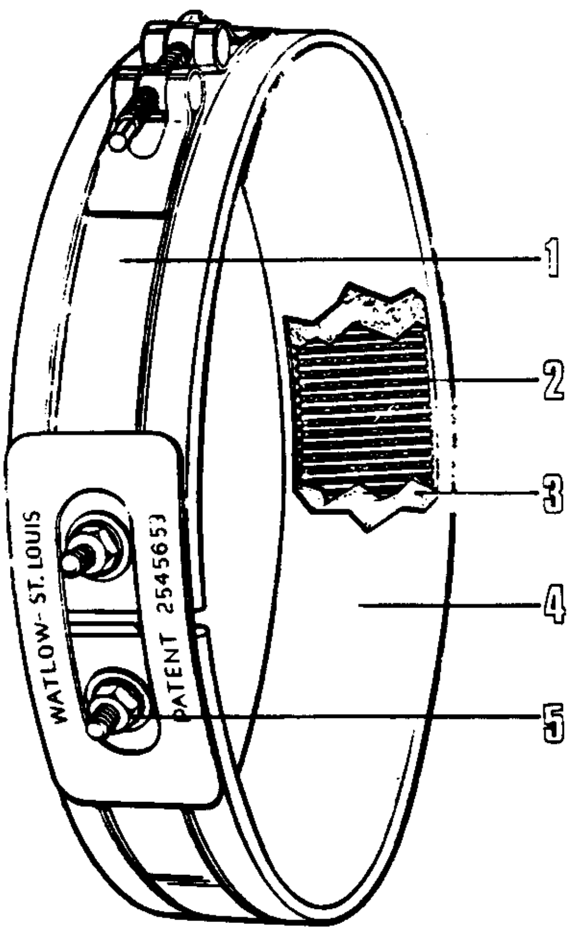
References

1. C. Rode, personal communication.

2,3 Selected Cryogenic Data Notebook, Jensen et al., August 1980, pp. IX-W-1.1 and IX-X-1.

Mica Band Heaters



Features

1 The low-expansion clamping strap, invented by Watlow, draws the heater tightly and evenly to the cylinder surface. The 360° clamping action exerts pressure directly over the windings.

The low rate of thermal expansion of the clamping strap means the hotter you run the tighter the fit. This is a very important factor in the long life of any heater.

2 The high temperature resistance ribbon is precisely wound by our exclusive system to provide even heat to the cylinder. Each size and rating is computer engineered for maximum life characteristics.

3 Mica has excellent dielectric strength. A strip only 1/64" thin on both sides of resistance winding provides complete electrical insulation. Heat quickly transfers through the mica, to the sheath, away from the windings. Mica withstands high voltage spikes, resists moisture, and is inert to most chemicals.

4 The specially treated sheath material has high emissivity and good conductivity to efficiently transmit heat from the windings to the cylinder of your equipment. The strength of this rust-resistant steel helps make possible the overall thinness of the heater, approximately 5/32".

5 Post terminals are securely riveted to the windings for a positive, trouble-free connection. Screw thread size is 10-24.

If you have problems with abrasion, flexing or contamination, one of the lead arrangements will help you prolong the life of the heater.

Fast, easy installation

One-piece heaters are simply slipped over the cylinder end. The clamping strap is tightened in place with a single screw.

Two-piece heaters are used when one piece units cannot be slipped into place due to an obstruction. The clamping strap has the same single-screw adjustment.

Two-piece heaters 3" wide or less have four terminals, one at each end of each half. Each half is rated at ½ voltage and ½ wattage for connecting in series.

On two-piece heaters wider than 3" each half has two terminals at the same end and is rated at full voltage and ½ wattage for parallel connection.

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