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A Proposal for a Low Voltage Vacuum Cable Design for the HEC Feedthroughs in the ATLAS Endcap Cryostat

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1 Maximum Current Values

The preamplifiers for the HEC signal readout are located inside the LAr cryostat. It is foreseen that the LV supplies for the preamplifier boards will pass through the signal feedthroughs. The microstrip lines, which carry the signal pulses, are too thin to accommodate the currents of the HEC preamplifier LV lines. This means that special cables have to be devised that will be able to carry the maximum foreseen currents while keeping the heat transfer to a minimum.

Table 1 lists the numbers of the maximum current values for each preamplifier board [1]. Each preamplifier board requires 3 LV supplies. The table contains the highest currents to be expected for each line, regardless of whether the preamplifiers are operated under LAr or ambient temperature.

Board	+8V	+4V	-3/-2V
PSB_1	768	406	89
PSB_2_1	484	319	54
PSB_2_2	705	435	80
PSB_3_1	390	261	43
PSB_3_2	734	450	83
Sum of all above currents: 5.3A			

Table 1: Maximum currents in mA required by the HEC preamplifier boards.

Each of the preamplifier boards requires 2 lines for each of the 3 LV supplies. Each HEC module contains one preamplifier board of each kind. With 8 modules per quadrant, this results in a total current per quadrant of 5.3 A x 2 x 8 = 84.8 A.

2 Current Carrying Capacity and Heat Transfer

In order to come to a solution for electrically safe LV cables we need to find an optimum balance in the cable dimension such that both the ohmic heating during warm testing as well as the heat leakage during cold operations are minimized.

The power dissipated per unit volume p by a current I in a conductor of cross sectional area A is given by

$$p = \frac{\rho I^2}{A^2}$$

where ρ is the electric resistivity. The temperature along the wire is obtained from

$$\frac{d^2T}{dx^2} + \frac{p}{\lambda} = 0$$

where λ is the thermal conductivity. The general solution to this equation, neglecting the temperature dependence of ρ/λ, is given by

$$T = -\frac{p}{2\lambda}x^2 + C_1 x + C_2$$

We assume that during warm testing both endpoints of the feedthrough vacuum cable are fixed at ambient temperature $T_\circ$. The maximum temperature T_{max} due to ohmic heating will then be in the middle of the cable. If we chose $x = 0$ to be in the middle of the wire and the endpoints at $x = \pm L/2$, it follows that $C_1 = 0$ and $C_2 = T_{\text{max}}$. We obtain

$$T - T_{\text{max}} = -\frac{p}{2\lambda}x^2 \qquad \text{or} \qquad \frac{T - T_{\text{max}}}{T_\circ - T_{\text{max}}} = \frac{x^2}{(L/2)^2}$$

where

$$T_{\text{max}} = \frac{I^2 L^2 \rho}{8 A^2 \lambda} + T_\circ$$

During cold operation of the cryostat, one side of the conductor will be at liquid argon temperature (87 K) while the other side will be at ambient temperature (293 K), i.e. $\Delta T = 206$ K. In this case the power dissipated due to thermal conductivity alone is approximately given by

$$P = \frac{\bar{\lambda} A \Delta T}{L}$$

with an average thermal conductivity between 90 K and 300 K of about $\bar{\lambda} = 425\ \mathrm{W\,m^{-1}\,K^{-1}}$.

2.1 Maximum Current Carrying Capacity for all Lines

The electrically safest solution is obtained if each individual feedthrough line is able to carry the maximum current expected during the operation of any of the HEC preamplifier boards. This value is about 770 mA (see table 1) However slightly larger currents are considered in order to provide a safety margin for current fluctuations. Should any of the LV lines reach temperatures around 100^o C or more, it could irreparably damage a number of other connections in the feedthrough. A safe choice is a wire of gauge AWG24, which, as a seven strand wire, has a cross sectional area of 0.227 mm^2. The temperature increase of a 35.5 cm long cable due to ohmic heating by a 900 mA current in such a wire would be about 17^o C.

The power dissipated due to thermal conductivity of an AWG24 wire of 35.5 cm length inside an ATLAS feedthrough amounts to:

$$P = 10^{-6} \frac{206 \cdot 425 \cdot 0.227}{0.355} \text{ W} = 56 \text{ mW}$$

There are 64 lines per connector and 4 LV connectors per HEC feedthrough. Each of the connectors provides a thermal transfer of 3.6 W, leading to a 14.3 W heat loss due to LV connections alone for each of the 4 HEC feedthroughs per endcap.

Note that the TDR values [2] for the feedthrough heat losses are 11.5 W for cables per feedthrough plus 3.5 W per bellow. The TDR also states a maximum value for heat loss per feedthrough due to cabling of approximately 15 W.

Clearly, a heat loss of 14.3 W for 4 LV feedthrough connections alone is a large increase in the heat leakage due to cabling, if one considers that each of the signal connections only dissipates 0.38 W

2.2 Hybrid Solution

The adopted solution is provided by dividing the current loads into 3 different groups and using a different wire gauge for each group. For the required range of cross sections, even number wire gauges are readily available as 7 strand wires. (Odd gauges are single stranded and specialty items.) The cross sectional area, heat loss and maximum temperature for a maximum anticipated current are given in table 2.

The LV voltage currents naturally group into 4 sections of $I_{\mathrm{max}} \sim 150$, 400, 550 and 900 mA. Safe wire choices for these groups would be AWG30, AWG28, AWG26, AWG24. A commercially available connector exists that accepts AWG24 to AWG28 wires. Therefore the maximum current loads are grouped in 400, 550 and 900 mA.

wire gauge	# lines needed	cross section [mm^2]	I_{max} [mA]	T_{max} ^{o}C	heat loss [W]
AWG28	28	0.089	400	40.3	0.022
AWG26	20	0.141	550	36.5	0.035
AWG24	16	0.227	900	36.9	0.056

Table 2: Maximum current loads and heat loss for 4 different wire sizes. The specification numbers given refer to one wire each.

The adopted layout for a connector is

●○●○●○●○⊗○⊗○⊗○⊗⊗⊗⊗○⊗○⊗○⊗○●○●○●○●
●○●○●○●○⊗○⊗○⊗○⊗⊗⊗⊗○⊗○⊗○⊗○●○●○●○●

where
○ = 400 mA capacity (AWG 28; 28 lines total)
⊗ = 550 mA capacity (AWG 26; 20 lines total)
● = 900 mA capacity (AWG24; 16 lines total)

Such a layout provides a pair of lines for each of the LV supplies while it has a symmetric design, which reduces the possibility of cabling errors. Alternating large and small wire diameters might help to reduce any possible stress build-up due to the different heat leakage of each wire gauge. The maximum temperature difference to be expected between the largest wire and the metal pin carrier material is approximately 5^oC.

Since 2 preamplifier boards can be supplied by one connector (that includes 4 spare 900 mA lines per connector), only 4 LV connectors are needed per quadrant instead of the initially foreseen 6 connectors. Assuming a heat loss of 0.38 W per signal connector, the total heat loss per HEC feedthrough for the case of 4 or 6 LV connectors due to cabling is given in table 3.

	heat loss
1 LV connector	2.21 W
4 LV + 26 signal connectors	18.7 W
6 LV + 24 signal connectors	22.4 W

Table 3: Heat loss of hybrid LV connections.

Note however, that it is very difficult to calculate the exact temperature gradient along the conductor with the cabling for the warm electronics in place. At this point we are only considering the simple case of a conductor with one end at LAr temperature and the other at ambient temperature. The balance of the heat leakage along the wire versus the heat transfer across the ceramic or glass material in the pin carrier has to be such that no condensation occurs on the pins of the ambient flange. While the TDR is stating a heat loss allocation of 7 mW per channel, all of the LV lines would exceed this value with a maximum heat transfer of 56 mW for the 900 mA line (see table 2). To avoid condensation on the pins, heating is likely to be required near the LV connectors, over and above the foreseen ambient flange heating resistances.

References

[1] J. Fent, private communication.

[2] CERN/LHCC/96-41 LAr Calorimeter TDR chapters 3.1 and 4.3.1.