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BTeV Pixel Cooling System

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Requirements: Design Drivers

Power 0.5 W/cm^2, total area $\sim$ 0.6 m^2, 30 Stations, 60 half-stations, total heat load $\sim$ 3 kW.

Temperature Constant temperature of -(10–5)°C. Reproducibility is key; uniformity less so, but see mechanical requirements on substrate.

Radiation Length Footprint in tracking volume must be minimal—small compared to active elements ($\sim$ 0.5% of χ_0).

Radiation Tolerance Neutron fluence of $10^{13}/cm^2$ per year. Charged hadron fluence of $10^{14}/cm^2$ per year. Ionizing radiation of more than 2 Megarads per year.

Requirements: Environmental

External Pipes Pipes must be ice and condensation free.

Cable Heat Load Take care of minor heat load (a few mW/cable) in cables within the vacuum vessel.

Safety Safe for personnel and equipment.

Location Cooling and pumping plant roughly 30 m from detector.

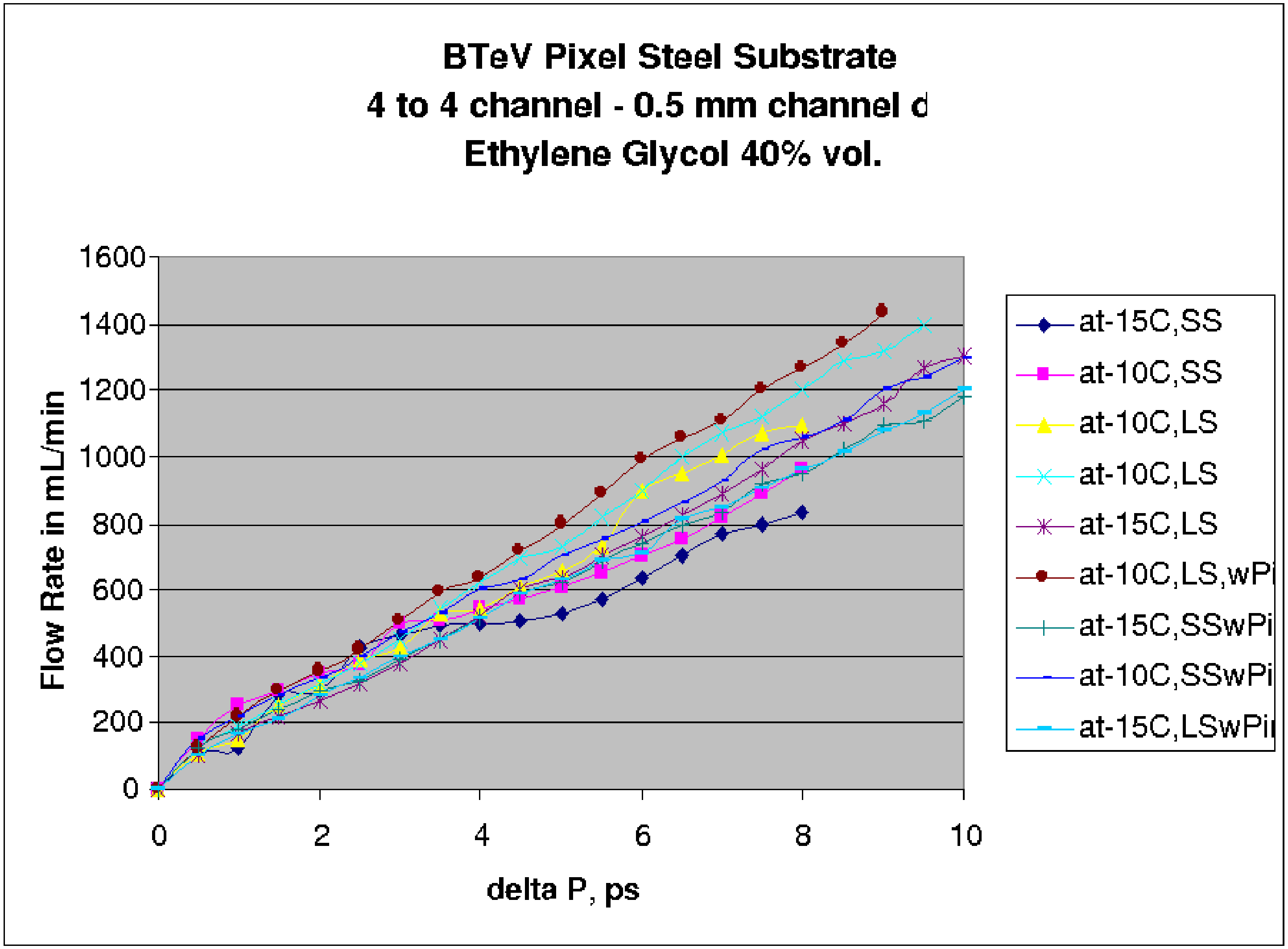
Desires

Below Atmospheric No external leaks, minimize force load on substrate.

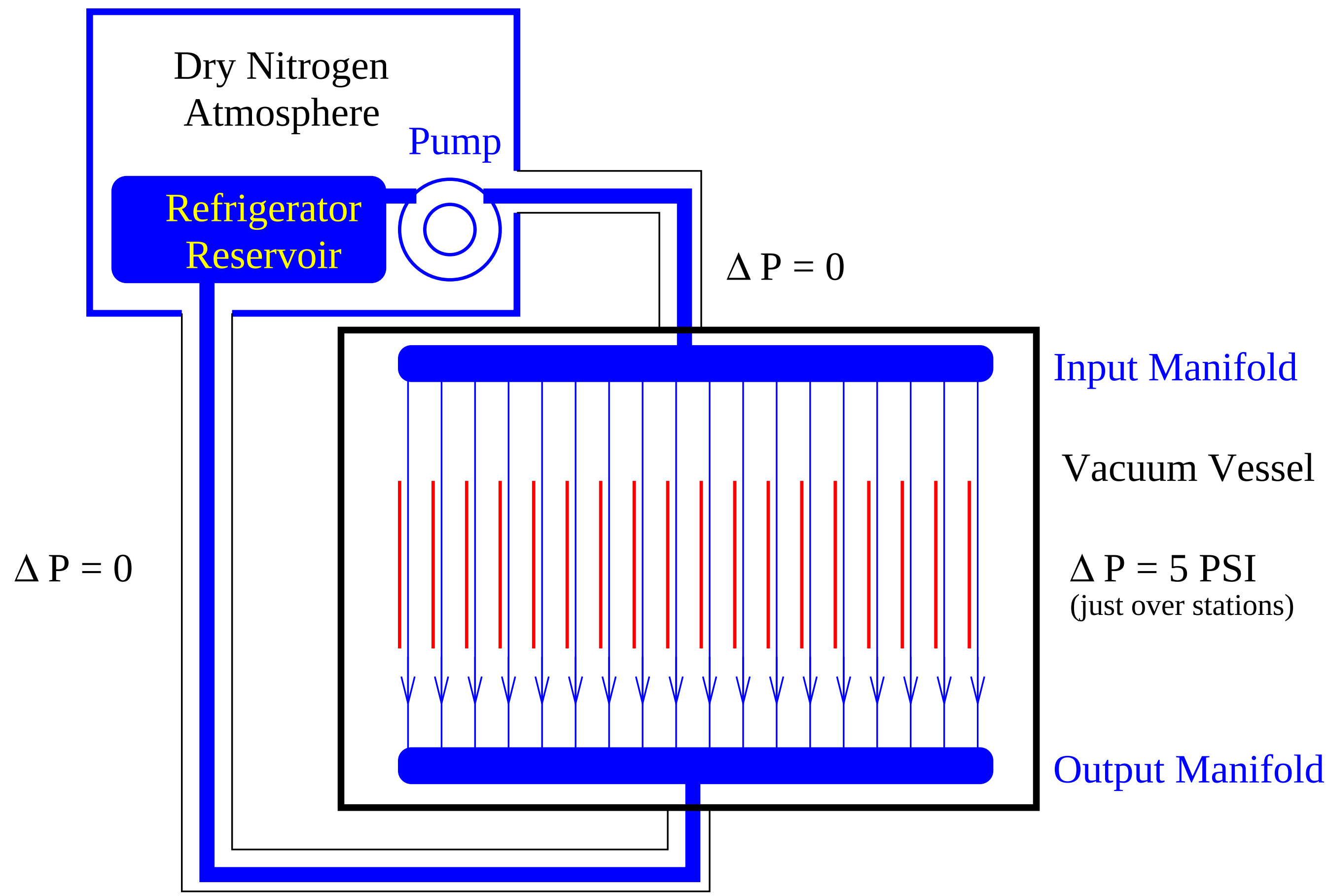
Space Minimize footprint near and in vacuum vessel.

Known Solution: Water Glycol

Mixture of 40% Ethylene Glycol–60% Water by volume has a freezing point of -20°C, flow, and cooling properties similar to water. Very good coolant, almost unbeatable in heat capacity/mass in single phase. Solution adopted by CDF and D0, and studied by Atlas and CMS. Local expertise: besides Fermilab also have Charles Newsom (SELEX) and Steve Blusk (CDF). Starting to study its properties:


BTeV Pixel Steel Substrate
4 to 4 channel - 0.5 mm channel d
Ethylene Glycol 40% vol.
Flow Rate in mL/min
1600
1400
1200
1000
800
600
400
200
0
0
2
4
6
8
10
delta P, ps
at-15C,SS
at-10C,SS
at-10C,LS
at-10C,LS
at-15C,LS
at-10C,LS,wPi
at-15C,SSwPi
at-10C,SSwPi
at-15C,LSwPi

We can sketch what such a system, ignoring monitoring and controllers, looks like:



Note that this system already gives up on one of the two desires: there are large manifolds inside the vacuum vessel.

Open Questions

Manifold to Station Connection between manifolds and stations. Will likely introduce another large ΔP and has to account for half station motion.

RF Shield Clearly want only one cooling system penetrating the vacuum wall, but heat load, operating temperature, and pressure drops on the RF shield are as yet unknowns.

Alternatives: Hydrocarbons

Very successful at CLEO where Kerosene-like cleaning fluid, PF-200, is used to cool beryllium beam pipe. This fluid is no longer available. Its successor is called PF145. Butane is also an option. If material is driving factor these become attractive.

Advantages

Radiation Length Factor of 2 longer than water. Need more flow due to reduced heat capacity. Net winner.

Insulators Leaks less catastrophic.

Disadvantages

Compatibility Not known with beryllium or glassy carbon. Probably not a problem based on CLEO experience.

Flammable Too bad about that, but a fact of life. Means more onerous safety regime.

Alternatives: Two Phase

Excellent study by Terry Tope (Fermilab Engineer) shows that taking advantage of heat of vaporization leads to a much more efficient cooling system. He considered two coolants: Butane and R134a (freon replacement used in auto air conditioners). About 1/2 of the fluid gets vaporized in the module cooling channels. Comparing for the same Heat Flow:

Coolant	Radiation Length (cm)	Mass Flow/H_2O	ΔP (PSI)
Water-Glycol	35.2	1.0	4.7
R134a	26.5	0.028	0.021
Butane	72.6	0.014	0.012

Advantages

Radiation Length Even R134a (Radiation length 80% of water) is a winner due to vaporized fraction.

ΔP Reduced by 2 orders of magnitude. Allows for a much reduced footprint near vacuum vessel.

Disadvantages

More Complex Absolute pressure must be controlled.

Compatibility R134a contains chlorine and thus is likely to attack beryllium. Testing at Wayne State.

Alternatives: Flowless

It is scary to think about the consequences of a coolant leak within the vacuum vessel. Systems that required no flow or at least brought the heat to edge of the modules would eliminate or reduce this worry.

Diamond Substrate Has thermal conductivity of 850 W/m^2–°C (measured at Wayne State). Not good enough: $\Delta T > 10°C$ for similar material as beryllium substrate.

Heat Pipes Tubes filled with wick. Liquid in tube evaporates at hot end, condensed at cool end, and wicks back. Manufactured by Thermacore. Plenty of heat conduction, but tube walls have to be steel or copper. Breaks material budget.

Solid State Use the Peltier Effect (reverse thermocouple), commercially manufactured by Marlow, but requires high Z materials. Take heat flowlessly through vacuum vessel wall?

Other Possibilities Microtubes and microcoolers. Development project, HERETIC, funded by DoD to cool single chips. Need to investigate further.

Cyrogenic Option More painful cooling system, but simpler substrate (silicon to match CTE). Better for outgassing. Other consequences?

Plans

A water-glycol system is the baseline. Best alternative at the moment is a two phase system with Butane or other hydrocarbon. Working on glassy carbon and beryllium+epoxy compatibility study with water-glycol, butane, PF145, and R134a at Wayne State. Will include radiation tolerance study at Fermilab. Have in hand glassy carbon tubes and beryllium coupons and building a pressure control system for R134a.

Continue to consider flowless alternatives. I am not optimistic, but the improved reliability would be a big plus.

Once compatibility and radiation study is done, begin engineering design. Sometime next year.

Initial thoughts on a cyrogenic system.

Conclusion

Still in the "Consideration of Alternatives" stage. Have a baseline, water-glycol, and alternatives are judged versus it.

Two-phase hydrocarbon looks very promising.

Compatibility and radiation tolerance study being ramped up.

Flowless alternatives considered, but not bearing fruit.