Fermilab

Particle Physics Division
Mechanical Department Engineering Note

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Project Internal Reference:

Project: Coupp Camera Housing

Title: Two design alternatives for the camera housing and Thermal Calculations

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Reviewer(s): none – feasibility design study only – no review warranted.

Key Words: Camera Housing

Abstract Summary: See Ideas Solid Models:
Library: MECH.DETECTORS-COUPP_BUBBLE_CHAMBER
Assembly: CAMERA_HOUSING_ASSY_1
And: CAMERA_HOUSING_ASSY_2

Applicable Codes: n/a

Discussion:
For the 60 kg Coupp bubble chamber immersed in a water veto bath, the image capturing cameras have an operating temperature range of 0 to 45 degree Celsius for the housing. Water bath (water veto) temperature is nominally 40 C (104 F).

Initially, the design specifications (provided in a discussion with Russ Rucinski) call for three degrees of freedom for camera pointing; rotation

(common to both cameras) about a horizontal axis; and rotation (independent for each camera) about the vertical axis.
A week or two after completing the design work for providing such adjustment, Martin Hu indicated (on Thursday November 13th) that the cameras only need alignment positioning in one direction; along the long axis. So, modifications were made on and an alternative design prepared. But by Wednesday, November 19th, Russ indicated they were going forward with an undocumented design by Carl Lindenmeyer. So this note is intended only to pull together the models and calculations made for the engineered designs and document them.

Included in the calculations below, are three different means of cooling the cameras. Initially, the refrigerant based system was conceived because of Russ's statements that the cameras needed to be cooled and this was an 'issue'. Direct cooling with refrigerant provides the most efficient means of removing the heat from the electronics. Schemes using commercial chilled water bath add thermal inefficiencies (delta T across each heat exchanger, circulation pump power, etc) and additional, un-needed equipment (water bath, water pump, etc.) for the convenience of using an off-the-shelf chiller. A refrigerant based system would allow the camera housing temperature to be around 5 C, a temperature which will maximize the electronics lifetime. Two ¼ inch diameter refrigerant lines are all that is needed between the condensing unit and the camera housing, so space impacts are minimized.

Using forced air cooling is also considered. Assuming room temperature air (at 23 C) is ducted into the camera housing and directly cools the camera cooling fins before encounter the warm housing walls will provide a camera housing temperature of about 30 C before exiting the enclosure via another duct. Advantage of such a system is that it is simple to understand and uses only a simple fan with no controls necessary. Downside is the volume used by the air ducts (or single co-axial duct)

The simplest means is to cool the camera via a heat sink to the water veto bath. Simple calculations indicate a camera case temperature of about 42 C (just below the maximum temperature indicated in the documentation). No connections between the camera housing are required. Downside is the increased camera housing temperature.

Radiation Heat Transfer to the Camera from Enclosure

Stefan Boltzman Constant	5.67E-08	W/m2-K4
Water Bath Temperature	102	F
Water Bath Temperature	38.9	C
Water Bath Temperature	312.0	K
Camera Temperature	68	F
Camera Temperature	20.0	C
Camera Temperature	293.1	K
Camera Length	150	mm
Camera Width	55	mm
Camera Depth	60	mm
Area Of Camera Exterior	41100	mm2
Area Of Camera Exterior	0.0411	m2
Enclosure Area	0.176714587	m2
View Factor Encl to Cam	0.232578424	

Black Body Radiation Heat Transfer Can to Camera:
q = A * F * 5.67e-8 * (T4-T4)

q =	1.135144791	Watts
Enclosure Emissivitiy	0.6	
Camera Emissivity	0.85	

Gray Body Radiation Heat Transfer Can to Camera:
assumes camera is small compared to the enclosure size:

q =	4.148592367	Watts

So, plan on the radiation heat transfer applying a heat load to the camera of about 5 Watts.

CAMERA Internal Heat Load	14	Watts each
CAMERA Internal Heat Load	28	Watts total

Total Heat Load (Camera Internal and Radiation):

	33.0	**Watts**
	112.6	**BTU/hr**

Consider Air Cooling:
q = mdot * Cp * Delta T

Ambient Air temperature in Hall	72	F
Ambient Air temperature in Hall	22.2	C
Ambient Air temperature in Hall	295.3	K
Maximum Camera Case Operating Temperature	113	F
Maximum Camera Case Operating Temperature	45.0	C
Maximum Camera Case Operating Temperature	318.1	K
Cp for Air at 300 K	1.007	kJ/kg-K
Density of Air at 300 K	1.1614	kg/m3
Assume inlet temperature is	23.0	C
Assume outlet temperature is	30	C
Required Flow rate (kg/s)	0.004681515	kg/sec
Required Flow rate (m3/s)	0.004030924	m3/sec
Required Flow rate (cfm)	0.006851429	cfm
Air Inlet Duct Diameter	4	cm
Air Inlet Duct Diameter	0.04	m
Air Outlet Duct Diameter	5	cm
Air Outlet Duct Diameter	0.05	m
Inlet Air velocity	3.207707382	m/s
Inlet Air velocity	10.52128021	fps
Outlet Air velocity	2.052932724	m/s
Outlet Air velocity	6.733619336	fps
Air Inlet Duct Length	3	m
Air Inlet Duct Length	9.84	ft
Air Outlet Duct length	3	m
Air Outlet Duct length	9.84	ft
Viscosity, (Centipoise) for Air	0.029	centipoise at 300K
Reynolds number (inlet air)	5138.526005	
friction factor, f	0.012454934	for laminar flow (actually in the transitional region)
Delta P of inlet air, Pa	49.01876237	Pa
Delta P of inlet air, in w.c.	0.20	inches w.c.
Delta P of inlet air, Pa	16.06246805	Pa
Delta P of inlet air, in w.c.	0.06	inches w.c.
Total System Delta P	0.26	inches w.c.

A typical 4.69 inch square fan willl do this flow.

Conclusion: Air cooling works, but has the feature of requiring large (2 to 3 inch diameter ductwork into and out of the camera enclosure. This reduces the volumn of the veto and results in a camera case temperature being at the upper end of the acceptable range.

Consider Refrigerant Based Cooling:

Smallest Air Cooled Condenser Package offered by Emerson using R134a is:

Model	M2FH-0017	
Capacity	1150	BTU/hr
Refrigerant	134a	
Evaporating temperature	25	F
Evaporating temperature	-3.9	C
Condensing temperature	90	F
Condensing temperature	32.2	C
Compressor Model number	ARB13CE	
Compressor Horse Power	1/6	HP
Capacity	337.0	W
Capacity	0.337	kW
Liquid Enthalpy at condensing temperature	244.8	kJ/kg
Vapor Enthalpy at Evaporating temperature	396.4	kJ/kg
Change in Enthalpy	151.6	kJ/kg
Required Mass Flow Rate	0.00222	kg/sec
Required Mass Flow Rate	2.22	g/sec
Specific Volume of vapor at cond. Temp.	0.0251	m3/kg
Density of vapor at cond. Temp.	39.841	kg/m3
Density of vapor at cond. Temp.	39840.6375	g/m3
Vapor Volumetric Flow rate	5.58015E-05	m3/sec
Desired Vapor Velocity	3	m/sec
Vapor line inner diameter	4.87	mm
Vapor line inner diameter	0.192	inches
Nominal vapor line size	1/4	inches
Capillary line size (inner diameter)	0.031	inches
Capillary line length	79	inches

Capillary data from www.jbind.com

Conclusion: A closed loop refrigerant system using environmentally benign R134a refrigerant, a very small, commercially produced compressor and condensor unit, a 1/4 inch return line, a 0.083 inch o.d. capillary feed line provides more than ample cooling to camera assembly at a temperature near the low end of the camera range. Lower operating temperature for electronics usually results in longer lifetime.

Consider Conduction Based Cooling:

Assume a one centimeter thick, 15 cm wide copper plate is used as a flat surface to mount the cameras on. The edge of the copper plate is brazed or soldered to the camera housing so its temperature is maintained at the both temperature of 40 C.

Camera Power	14	W
Thermal conductivity of copper	375	W/m-K
Thickness of copper	0.01	m
Width of copper	0.15	m
Area of Copper for conduction	0.0015	m2
Length from center line of camera to shell	0.075	m
Q = kA/L * Delta T		
Delta T = Q * L / (k*A)	1.87	K

So, with a bath temperture of 40 C, the camera housing can be at about 42 C, below the 45 C maximum temperature indicated by the camera manual.