LIQUID NITROGEN VALVE SIZING
FOR
D-ZERO UPGRADE

D-ZERO ENGINEERING NOTE # 3823.115 -EN- 430

Sept. 13, 1995

Russ Rucinski
RD/DØ Mech.

Approved: _____

A handwritten signature in black ink, appearing to read 'Russ Rucinski', is written over a horizontal line. The signature is stylized with large, sweeping loops.

Summary

There were 5 control valves and 2 manual valves for the liquid nitrogen distribution system that needed to be sized and procured for the upgrade. This engineering note documents the calculations done to properly size these valves. The table below summarizes the valve choices:

VALVE	DESCRIPTION	Req'd operating Cv	VALVE Cv
D0EVLP	HX2a bypass	0.6	2.0
PV2713N	LN2 subcooler	.06 to 0.6	2.0
MV2716N	subcooler block	1.13	6.0
MV2715N	subcooler bypass	1.13	6.0
PV3035N	Solenoid LN2 supply	.03 to 0.1	.32
PV4305N	VLPC east supply	0.1	.32
PV4405N	VLPC west supply	0.1	.32

Discussion

The raw calculations are attached as an appendix. The calculations jump around a bit. No effort was made to re-organize or rewrite them for the reader. The sizing calcs. on Pages 1 through 4 were first pass calcs. based on pure liquid to the valves with no attention to flashing/choking. The calcs on pages 5 through 8 then refine the calculations by considering the LN2 to the valve inlets to be two phase with quality of 0.032. This is a real situation if the LN2 subcooler is out of service for use as a He cooldown heat exchanger. Also, flashing would occur for this situation and is taken into account. The end result of this refinement pushed the Cv values up by about a factor of 3 over the initial calcs. of pages 1 through 4. The results of the refined (correct) calculations pages 5 through 8 appear in the table above.

The required operating Cv's are smaller than commercially available LN2 control valves. Therefore it has been decided to use Fermilab Saver type control valve assemblies with the valve bullet Cv's listed above. The bullets are 100:1 equal percentage types and provide better control at the lower percentage of valve Cv values. See flow characteristic data and curve for these valves in appendix B. The manual valves will be commercially purchased, probably a Cryolab model CV3-84-5WPG2 or CV8-84-5WPG2 or CVI model V-1060-050-VJ.

Pages 8-10 calculate a minimum required cooldown flowrate as referenced in Cryogenic Systems by Barron. This was done to be sure the valves and piping system did not choke the warm flow so much that cooldown could not be achieved. The minimum mass flow rate needed for a simultaneous, serial cooldown of the refrigerator, solenoid and VLPC system was 6.4 g/s. This warm flow would get choked by an opening less than 0.175" in diameter. A valve with only 10 psi differential across it with this flowrate would need to be $C_v=0.85$. These numbers show that cooldown will be achievable. Firstly, the flow through these components is not serial. The flows get split and sent to vent separately. Secondly, the valves are located upstream of the heat load. And lastly, the C_v of the valves are larger than 0.85 except for the solenoid which has a very low heat load/small flow split and the VLPC's. The VLPC flow split brings the minimal required C_v for a valve situated at the warm outlet of the LN2 circuit to be 0.26. I foresee no problems cooling down the LN2 components.

SUBJECT

LN₂ CRYOVALVES

SIZING

NAME

RUSS RUCINSKI

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DOEULP, LN₂ BYPASS HX2a: DESIGN FLOWRATE OF LN₂
TO HX = 10 gpm

WANT SMALL ΔP WHEN EULP OPEN.; OP PRESS = 35 psig

• C_v

$$\Delta P = \frac{\rho}{62.4} \left(\frac{Q}{C_v} \right)^2$$

Q - FLOW RATE gpm

 ρ - DENSITY lb/ft³EQU-2-7
CRANE TECH.
PAPER 410 ΔP - psi

$$\rho_L = .75 \text{ g/cc}, 62.427869 = 46.82 \text{ lb/ft}^3$$

RE-ARRANGING THE EQ'N.:

$$C_v = Q \sqrt{\frac{\rho}{62.4 \Delta P}}$$

SAME $\Delta P = .5 \text{ psi}$

$$C_v = \left(\frac{10}{60} \text{ gpm} \right) \sqrt{\frac{46.82 \text{ lb/ft}^3}{62.4 [0.5 \text{ psi}]} } = \underline{0.20} \text{ NOMINAL}$$

$$C_v = \underline{0.46} \text{ FOR } \Delta P = .1 \text{ psi}$$

PHYSICAL SIZE,

IDEAL WOULD BE $\frac{3}{4}$ " OD NALF TUBE x 2" VJ

CVI MODEL V-1080-050-J

LINEAR FLOW PLUG.

 $\frac{1}{2}$ " IPS INNER x 2" VJC_v = 5.6 13.8 Btu/hr.
= 4 WATTS @ 80 KOR
→ TUBE SIZE WHAT C_v's

15.7 @ 20 K

CRYOLAB

CVB-86-5WTG2

 $\frac{3}{4}$ " OD TUBE x 2 $\frac{1}{2}$ " VJ C_v = 6.6

WITH ACTUATOR, LINEAR FLOW PLUG

5.9 Btu/hr. to 20 K. ($\frac{1}{3}$ LESS THAN CVI)MUCH
LESS
EXPENSIVE
→

CV3-84-5WPG2

 $\frac{1}{2}$ " IPS x 2" VJ C_v = 5.9

WITH ACTUATOR

LINEAR FLOW PLUG.

4.5 Btu/hr. to 20 K

PNEUMATIC ACTUATOR

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PV2713N ; LN₂ SUBCOOLER SUPPLY LINEFLOW RATES: DURING HQ COOLDOWN $\dot{m}_{\max} = 52.5 \text{ g/s}$ DURING LN₂ SUBCOOLING $\dot{m}_{\max} = 3.9 \text{ g/s}$ REF. TODD LEICHT'S LN₂ SUBCOOLER COIL SIZING CALCS. 5/15/95 $\Delta P = 25 \text{ psig}$ NOMINALLY MINIMUM.

$$Q_1 = 52.5 \text{ g/s} \times \frac{1 \text{ gal. LIQUID}}{3060 \text{ grams}} \times \frac{60 \text{ s}}{1 \text{ MIN}} = 1 \text{ gpm. } ①$$

$$Q_2 = 3.9 \times \text{"} \text{"} = .076 \text{ gpm } ②$$

$$C_{V1} = (1 \text{ gpm}) \sqrt{\frac{46.82}{62.4 [25 \text{ psi}]}} = 0.17$$

$$C_{V2} = .076 \text{ gpm} \times \text{"} \text{"} = .013$$

PHYSICAL SIZE :

IDEAL WOULD BE RIGHT ANGLE, 3/8" OD TUBE SIZE
COULD BE STRAIGHT 1" IPS VJ

— CVI TUBE SIZE CRYOVALVES COME IN

1/4" OD , 3/8" OD & 1/2" OD SIZES x 1 1/2" PIPE

V-1300-375-A-J ; FAIL CLOSED

OR

— CRYOLAB CV9-084-5WTR4 WITH ACTUATOR?

$$1/4" \text{ CV} = .7$$

$$3/8" \text{ OD TUBE} \Rightarrow C_V = 1.6$$

$$1/8" \text{ OD VJ.}$$

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LN₂ CRYO VALVES; SIZING

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- MV-2716-N & MV-2705-N SIMPLE BYPASS & BLOCK VALVES @ LN₂ SUBCOOLER

FLOW RATE = 30 gph OR 0.5 gpm

ACCEPTABLE $\Delta P = 0.25$ psi

$$C_v \geq Q \sqrt{\frac{P}{62.4 \Delta P}} = (0.5 \text{ gpm}) \sqrt{\frac{46.82}{62.4 (.25)}} = 0.87$$

THIS VALVE IS IN A $\frac{1}{2}$ " x $1\frac{1}{2}$ " SCH. 10 PIPE
LEADING TO COIL IN SUBCOOLER, SAME SIZE.

STRAIGHT DESIGN WOULD WORK BETTER.

- PV-3035-N SOLENOID LN₂ SUPPLY

EXPECT 2 gph STEADY STATE. — MAX. GUESS IN DP CALCS. .03 gpm

COOLDOWN MAX, $5\frac{9}{5}$ BID SPEC. — .1 gpmS-S. MAX, = $8\frac{9}{5}$ BID SPEC. — .16 gpm $\Delta P = 27$ psig STEADY STATE

$$C_v = (.16 \text{ gpm}) \sqrt{\frac{46.82}{62.4 (27)}} = \underline{.027}$$

- PV-4305-N & PV4405-N EAST & WEST VLPC LN₂ SUPPLY

Flow = 9 gph

 $\Delta P = 20$ psig

$$C_v = (.15 \text{ gpm}) \sqrt{\frac{46.82}{62.4 (20)}} = \underline{.029}$$

FINAL
DESIGN REPORT

LN2 control valve summary

NEW #'S FROM REFINED CALCS
PAGES A5 THROUGH A10

Valve	Description	Flowrate *	Delta P	Nom. Cv	Actuator ?	
D0EVLP	HX2a bypass	.17 gpm	0.1 psi	0.46 (.6)	Fail closed	1/2" OD or 3/4" OD x 2" VJ
PV2713N	Subcooler inlet	.08 to 1 gpm	25 psi +	0.013 to 0.17 (.6)	Fail closed	Flow: SS Subcooling/He cooldown 3/8" OD x 1" VJ
MV2716N and MV27105N	Bypass & Block subcooler	0.5 gpm	0.25 psi	0.87 (1.13)	None, manual	1/2" x 1 1/2" IPS X-FER LINE
PV3035N	Solenoid LN2 supply	0.04 to 0.16 gpm	27 psi +	0.007 to 0.027 (.10)	Fail closed	Flow: Design report/Max. bid spec. 3/8" OD, CALD BOX TYPE
PV4305N and PV4405N	VLPC East & west supply	.15 gpm	20 psi +	0.029 (.10)	Fail closed	3/8" OD, CALD BOX TYPE

* BASED ON PURE LIQUID

+ FLASHING COULD OCCUR

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LN₂ VALVE SIZING

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TAKE A CLOSER LOOK @ VALVE SIZING CONSIDER
2Ø INLET CONDITIONS WHERE APPLICABLE & LARGE ΔP'S.

- DOEVLV FLOWRATE NOT THAT CRITICAL,

$$Q_{1 \rightarrow 2} = .09 \frac{W}{ft} \times 25 ft = 2.25 W$$

$$Q_{3 \rightarrow 4} = 3.6 W$$

$$Q_{EVXLN} = 0.6 W$$

$$Q_{1 \rightarrow 4} = 6.45 W$$

$$h_1 = -124.065 \frac{J}{g}$$

$$\dot{m} = .17 \frac{gal}{min} \times \frac{3060 g}{1 gal} \times \frac{1 min}{60 s} = 8.67 \frac{g}{s}$$

$$h_4 = -124.065 \frac{J}{g} + \frac{6.45 \frac{J}{s}}{8.67 \frac{g}{s}} = -123.32$$

$$P_4 = 5 psig = 1.34 ATM. \rightarrow \text{STILL SUBCOOLED.}$$

ORIGINAL SIZING IS VALID

$$C_v = 0.46 \text{ NOMINALLY}$$

- PV2713N

INLET STATE $P = 3 ATM$ $x = .032$ { REF. EN-422 CALL TO DETERMINE NEEDED FOR A N₂ PHASE CGF
GAS FRACTION = 65 % LIQUID 35 % SLUG FLOW

$$\frac{\Delta P_{\text{LOCKHARTMARTINELLI}}}{\Delta P_{\text{LIQUID ONLY}}} = \frac{53.0}{6.4} = 8.3 \text{ PIPE } \Delta P'S$$

SINCE DOWNSTREAM PRESSURE IS LESS THAN VAPOR PRESSURE
LIQUID FLASHING OCCURS. I WILL USE THE ISA-575-01-1985
STD. TO SIZE THE CONTROL VALVE

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APPENDIX 6; EQN. 61

$$F_F = 0.96 - 0.28 \left(\frac{F_V}{P_c} \right)^{2.0409} \quad 1 \text{ MIN} \quad a$$

P_v - VAPOR PRESSURE OF LIQUID @ INLET = 44.1 psia

P_c - CRITICAL PRESSURE = 492 psia.

$$F_F = 0.96 - 0.28 \left(\frac{44.1}{492} \right)^{1/2} = .876$$

(SUBST. INTO 14a)

$$C_v = \frac{1.0 \text{ gpm}}{0.8} \sqrt{\frac{0.75}{44.1 - (.876)(44.1)}} = \underline{0.463}$$

THIS IS FOR THE CASE OF $X=0.0$ LIQUID @ INLET.

IN ORDER TO COMPENSATE FOR GAS FIND C_v FOR
GAS FLOWING WITH CHOKED FLOW DUE TO VAPORIZING LIQUID

$$P_{rc} = F_F P_v = .876 (44.1) = 38.63 \text{ psia.}$$

$$C_v = \frac{730 W_g}{\sqrt{G P_2 \Delta P}} \left(\frac{\sqrt{T}}{22.8} \right) \quad \text{GAS FLOW EQN IN CVI CATALOG.}$$

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$$W_g = \text{GAS FLOW RATE (lb/sec)} = x \cdot \dot{m}_{\text{LIQUID}} = (.032) \left(52.5 \frac{\text{g}}{\text{s}} \right) \left(\frac{2.2 \text{ lbm}}{1000 \text{ g}} \right)$$

$$= .0037 \text{ lb/sec}$$

$$G = \text{SPECIAL GRAVITY} = 1.0 \quad (\text{@ STP})$$

$$P_2 = \text{DOWNSTREAM PRESSURE} = p_{vc} = 38.63 \text{ psia}$$

$$\Delta P = 44.1 - 38.63 = 5.47 \text{ psi}$$

$$T = \text{ABSOLUTE TEMP (°R)} = 88 \text{ °K} \times 1.8 = 158.4 \text{ °R}$$

SUBSTITUTE INTO CVI EQN BOTTOM OF ^{CALC}PAGE 6,

$$C_v = \frac{730 (.0037 \text{ lb/sec})}{\sqrt{(1)(38.63)(5.47)}} \left[\frac{(158.4)^{1/2}}{22.8} \right] = \underline{0.103}$$

WE NEED PV-2713-N TO HAVE AT LEAST

$$C_v = C_{v \text{ LIQUID}} + C_{v \text{ GAS}} = .463 + .103 = .566 = \underline{0.6}$$

THIS IS QUITE A BIT LARGER THAN ORIGINAL QUICK
ESTIMATE OF 0.17 NOT TAKING FLASHING/CHOKED FLOW
INTO ACCOUNT.

• MV2716N & MV27105N.

NOT CRITICAL VALUES, DEFINITELY SEE SOME $x = .03$ 2Ø LN₂

$$\therefore \text{INCREASE SIZE BY } \frac{0.6}{.46} = 1.30$$

↑
FROM
PV-2713N EXPERIENCE

$$C_v = 0.87 (1.30) = \underline{1.13}$$

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- PV3035N ; FLASHING DEFINITELY OCCURS DUE TO HUGE ΔP . LIQUID TO THIS VALVE WILL STILL BE SUBCOOLED IN NORMAL CIRCUMSTANCES. DURING COOLDOWN OF VLPC, LIQUID WILL BE 2 ϕ

NEED 0.16 gpm ; CAN JUST SCALE NEW CV SIZING FOR PV2713N WITH FLASHING/CHOKED 2 ϕ .

$$C_v = 0.6 (.16) = 0.096 = \underline{\underline{0.10}}$$

- PV 4305N & 4405N ARE SAME SIZE AS PV 3035N

$$\therefore C_v = \underline{\underline{0.10}}$$

- REVISE DUE V.L.P IF IT SEES 2 ϕ DUE TO NO SUBCOOLING.

$$C_v = .46 (1.30) = \underline{\underline{0.60}}$$

- CHECK COOLDOWN MASS FLOW RATE REQUIREMENTS TO BE SURE VALVE DOESN'T CHOKE FLOW ^{REF. BARRON}

$$\dot{m}_{g2} > \dot{Q}_{ss} / 2 [h_{g2} - h_{f1}]$$

$\dot{Q}_{ss}$ - STEADY STATE ^{HEAT} LOAD
 h_{g2} - ENTHALPY OF FLUID LEAVING $P=1\text{ATM}$
 $T=280\text{K}$

FROM EN-421 ;

h_{f1} - ENTHALPY 35PSIA
 T_{SAT}

$$\dot{m}_{\text{SOLENOID}} + \dot{m}_{\text{VLPC}} + \dot{m}_{\text{REFRIG}} = 1.7 + 17.6 + 10 \text{ gph} = 29.3 \text{ gph}$$

$$\therefore \dot{Q}_{ss} = \dot{m} \cdot h_{fg} = 29.3 \text{ gph} \times \frac{170.33 \text{ WATTS}}{1 \text{ gph}} = 5000 \text{ WATTS}$$

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SUBST.

$$\dot{m}_{g2} > 5000 \frac{1}{s} / 2 \left[290.341 \frac{1}{g} - (-98.938 \frac{1}{g}) \right]$$

$$\dot{m}_{g2} > 6.42 \frac{g}{s}$$

$$V_{\text{sound}} \\ \text{N}_2 \\ T = 280K \\ 1 \text{ atm}$$

$$= 341.2 \frac{m}{s}$$

$$\rho = 0.00122 \frac{g}{cm^3}$$

$$\dot{m} = \rho V A$$

$$A_{\text{minimum}} = \frac{\dot{m}}{\rho V} = \frac{6.42 \frac{g}{s}}{0.00122 \frac{g}{cm^3} (341.2 \frac{m}{s}) (\frac{100 \text{ cm}}{1 \text{ m}})}$$

$$A_{\text{min.}} = .154 \text{ cm}^2$$

$$\frac{\pi d^2}{4} = A$$

$$d_{\text{min}} = \left[\frac{4A}{\pi} \right]^{1/2} = \left[\frac{4(.154 \text{ cm}^2)}{\pi} \right]^{1/2} = .443 \text{ cm}$$

$$d_{\text{min}} = .443 \text{ cm} \times \frac{1 \text{ in}}{2.54 \text{ cm}} = \underline{\underline{0.1745 \text{ INCHES}}}$$

FOR THE LN₂ CIRCUIT, WE CAN & PROBABLY WILL COOLDOWN THE LINE TO THE SUBCOOLER FIRST. ALL THE VALVES MENTIONED ARE ON THE COLD SIDE BEFORE THE HEAT LOADS. ALSO THE SOLENOID, REFRIG., & VLPC WILL NOT BE COOLING @ THE SAME TIME

CALC. ROUGH CV FOR A VALVE FLOWING

$$\dot{m} = 6.42 \frac{g}{s} \quad \text{WARM GAS \& } \Delta P = 10 \text{ psi (ARBITRARY)}$$

FERMILAB
ENGINEERING NOTESECTION
RD, DOPROJECT
DO HELIUM
REFRIG.SERIAL-CATEGORY
3823.115PAGE
A10

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$$C_v = \frac{730 W_g}{\sqrt{G P_2 \Delta P}} \left(\frac{\sqrt{T}}{22.8} \right)$$

$$W_g = 6.42 \frac{g}{s} \times \frac{2.2164}{1000g} = .01412 \frac{lb}{s}$$

$$G = 1$$

$$P_2 = 14.7 \text{ psia}$$

$$\Delta P = 10$$

$$T = 520^\circ R$$

$$C_v = \frac{730(.01412)}{\sqrt{1(14.7)(10)}} \left[\frac{\sqrt{520}}{22.8} \right]$$

$$C_v = \underline{\underline{0.85}}$$

= VLPC FLOW RATE SPLIT, C_v SCALED;

$$m_{\text{REQ'D VLPC}} = \left[\frac{17.6}{2} \right]_{\text{VALVES}} \times \frac{1}{29.3 \text{ gph}} \times (.85) = \underline{\underline{0.255}}$$

LN2 control valve summary

Valve	Description	Flowrate	Delta P	OPERATING Nom. Cv	FERMI VALVE Cv	Actuator ?	
D0EVLP	HX2a bypass	.17 gpm	0.1 psi	0.6	2.0	Fail closed	Based on 2 phase $x=0.032$
PV2713N	Subcooler inlet	.08 to 1 gpm	25 psi	.06 to 0.6	2.0	Fail closed	Flow: SS Subcooling/He cooldown, Fl
MV2716N and MV27105N	Bypass & Block subcooler	0.5 gpm	0.25 psi	1.13	6*	None, manual	
PV3035N	Solenoid LN2 supply	0.04 to 0.16 gpm	27 psi	0.03 to 0.1	.32	Fail closed	Flow: Design rpt/Max. bid spec., Flash
PV4305N and PV4405N	VLPC East & west supply	.15 gpm	20 psi	0.1	.32	Fail closed	Flashing, choked flow, neglect subcoo

* PURCHASE , CRYOLAB OR CVI 1/2" IPS

↑ CONTROL VALVE SIZE
100 TO 1 EQUAL %
FINAL CONTROL VALVE ASS'YS.

Cv Measurement Project:

A Cv Test of RD/EAD Cryo Valves

August 1984

written by Paul Zielbauer

advised by Pancho Hall

submitted to

Stan Stoy

Associate Department Head

RD/EAD Cryogenics

CV VS TRAVEL

B2

CV VS TRAVEL

B3

>>> DATA LISTING <<<

CV-0.32

FLOW FORWARD

#	VOL	TIME	PRESS	%OPN	FLOW(GPM)	CV	TRAVEL(INCH)
0	0	30	28	0	0	0	0
1	0	30	28	10	0	0	.0625
2	2	30	28	20	1.1E-03	1.1E-03	.125
3	7.3	30	28	30	3.9E-03	3.8E-03	.1875
4	23.6	30	28	40	.0125	.0124	.25
5	40.3	30	28	45	.0213	.0212	.2813
6	67	30	28	50	.0354	.0352	.3125
7	90.3	30	28	55	.0477	.0475	.3438
8	123	30	28	60	.065	.0647	.375
9	173.6	30	28	65	.0917	.0913	.4063
10	238.3	30	28	70	.1259	.1253	.4375
11	324.3	30	28	75	.1714	.1705	.4608
12	436	30	28	80	.2304	.2292	.5
13	548	30	28	85	.2896	.2881	.5313
14	698	30	28	90	.3689	.3669	.5625
15	1038.3	30	27.5	100	.5487	.5507	.625

>>> DATA LISTING <<<

CV-2.0

FLOW FORWARD

#	VOL	TIME	PRESS	%OPN	FLOW(GPM)	CV	TRAVEL(INCH)
1	0	30	28	0	0	0	0
2	14.3	30	28	10	7.7E-03	7.7E-03	.0625
3	49.3	30	28	20	.0262	.0261	.125
4	139	30	28	30	.0682	.0678	.1875
5	170	30	28	40	.0898	.0894	.25
6	231.3	30	28	45	.1224	.1217	.2813
7	299	30	28	50	.158	.1572	.3125
8	439.3	30	28	55	.2322	.2309	.34375
9	548.3	30	28	60	.2899	.2884	.375
10	750.3	30	28	65	.3967	.3946	.40625
11	957	30	28	70	.5068	.5041	.4375
12	1257.3	30	28	75	.6645	.6609	.46875
13	1451.3	30	28	80	.7721	.768	.5
14	2051.3	30	28	85	1.0843	1.0784	.53125
15	2975.7	30	28	90	1.5727	1.5642	.5625
16	4235.3	30	28	100	2.5556	2.5419	.625