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:

[Signature]
### 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:

<table>
<thead>
<tr>
<th>VALVE</th>
<th>DESCRIPTION</th>
<th>Req'd operating Cv</th>
<th>VALVE Cv</th>
</tr>
</thead>
<tbody>
<tr>
<td>D0EVLP</td>
<td>HX2a bypass</td>
<td>0.6</td>
<td>2.0</td>
</tr>
<tr>
<td>PV2713N</td>
<td>LN2 subcooler</td>
<td>0.06 to 0.6</td>
<td>2.0</td>
</tr>
<tr>
<td>MV2716N</td>
<td>subcooler block</td>
<td>1.13</td>
<td>6.0</td>
</tr>
<tr>
<td>MV2715N</td>
<td>subcooler bypass</td>
<td>1.13</td>
<td>6.0</td>
</tr>
<tr>
<td>PV3035N</td>
<td>Solenoid LN2 supply</td>
<td>0.03 to 0.1</td>
<td>0.32</td>
</tr>
<tr>
<td>PV4305N</td>
<td>VLPC east supply</td>
<td>0.1</td>
<td>0.32</td>
</tr>
<tr>
<td>PV4405N</td>
<td>VLPC west supply</td>
<td>0.1</td>
<td>0.32</td>
</tr>
</tbody>
</table>

### 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 CV1 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 Cv=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 Cv 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 Cv 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.
DOE ULP, LN₂ Bypass HX2A: Design flowrate of LN₂ to HX = 10.8 gpm

Want small ΔP when ULP open; OP press = 35 psig

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

\[ Q = \text{flow rate, gpm} \]

\[ \rho = \text{density, lb/ft}^3 \]

\[ \Delta P = \text{psig} \]

\[ \rho = 0.75 \text{ g/cc} \]

\[ 62.4 \times 87869 = 46.82 \text{ lb/ft}^3 \]

Re-arranging the eqn:

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

549 \( \Delta P = 0.5 \text{ psi} \)

\[ C_v = \frac{46.82 \text{ lb/ft}^3}{62.4 [0.5 \text{ psi}]} = 0.20 \text{ \nominal} \]

Physical size,

Ideal would be 3/4" OD tube x 2" VJ

CVI Model V-1080-050-I 1/2" IPS inner x 2" VJ

Linear flow plug, \( C_v = 5.6 \text{ 13.8 BMH/ \( \text{kw} \)} \)

OR,

Tube size what \( C_v \) is 15.7 @ 20k

CV3-84-5WPQ2 3/4" OD tube x 2½" VJ \( C_v = 6.6 \)

With actuator, linear flow plug 5.9 BMH/ \( \text{kw} \) @ 20k  (
\( \frac{1}{3} \text{ less than CVI} \))

CV3-84-5WPQ2 1/2" IPS x 2" VJ \( C_v = 5.9 \)

With actuator, linear flow plug 4.5 BMH/ \( \text{kw} \) @ 20k

Pneumatic actuator
PV2713N; LN$_2$ SUBCOOLER SUPPLY LINE

Flow Rates:
- During He cooldown, $\dot{m}_{\text{max}} = 52.5 \: \frac{\text{lb}}{\text{s}}$
- During LN$_2$ subcooling, $\dot{m}_{\text{max}} = 3.9 \: \frac{\text{lb}}{\text{s}}$

Ref: Todd Leichti's LN$_2$ Subcooler coil sizing calc. 5/15/95

$\Delta P = 25 \: \text{psig nomally minimum}$

1. $Q_1 = 52.5 \: \frac{\text{lb}}{\text{s}} \times \frac{1 \: \text{gal. liquid}}{3060 \: \text{grams}} \times \frac{60 \: \text{s}}{1 \: \text{min}} = 1 \: \text{gpm}$
2. $Q_2 = 3.9 \: \frac{\text{lb}}{\text{s}} \times \frac{1 \: \text{gal. liquid}}{3060 \: \text{grams}} \times \frac{60 \: \text{s}}{1 \: \text{min}} = 0.076 \: \text{gpm}$

$C_v_1 = \left( \frac{1 \: \text{gpm}}{\Delta P} \right) \sqrt{\frac{46.82}{62.4 \: [25 \: \text{psi}]}} = 0.17$

$C_v_2 = 0.076 \: \text{gpm} \times \frac{1}{\Delta P} = 0.013$

Physical Size:
- Ideal would be right angle. $\frac{3}{8}$" OD tube size could be straight.
- CVI tube size cryovalves come in $\frac{1}{4}$" OD, $\frac{3}{8}$" OD and $\frac{1}{2}$" OD sizes vs $\frac{1}{2}$" pipe

V-1300-375-A-J; Fail closed

OR
- C940LAB CV9-084-5 WTR4 with actuator?
  - $\frac{1}{4}$" CV = .7
  - $\frac{3}{8}$" OD tube $\Rightarrow CV = 1.6$
  - $\frac{1}{2}$" OD VJ.
- **MV-2716-N & MV-2705-N**: Simple bypass & block valves on LN2 subcooler.
  - Flow rate = 30 gpm or 0.5 gpm
  - Acceptable ΔP = 0.25 psi
  - 
  \[
  C_v = \frac{Q}{\sqrt{\frac{P}{62.4 \Delta P}}} = \left(0.5 \text{ gpm}\right) \sqrt{\frac{46.82}{62.4 (0.25)}} = 0.87
  \]
  - This value is in a ½" x 1½" Sch. 10 pipe leading to coil in subcooler, same size.
  - Straight design would work better.

- **PV-3035-N**: Solenoid LN2 supply.
  - Expect 2 gpm steady state. Max. guess inΔP = 0.03 psi
  - Cool down: Max. = 5 9/16 B10 spec. = 0.1 gpm
  - Max. = 8 9/16 B10 spec. = 0.16 gpm
  - \[ΔP = 27 \text{ psig} \text{ steady state}\]
  - \[C_v = \left(0.16 \text{ gpm}\right) \sqrt{\frac{46.82}{62.4 (27)}} = 0.27\]

- **PV-4305-N & PV-4405-N**: East & west ULCR LN2 supply.
  - Flow = 9 gpm
  - \[ΔP = 20 \text{ psig}\]
  - \[C_v = \left(0.15 \text{ gpm}\right) \sqrt{\frac{46.82}{62.4 (20)}} = 0.29\]
**LN2 control valve summary**

<table>
<thead>
<tr>
<th>Valve</th>
<th>Description</th>
<th>Flowrate</th>
<th>Delta P</th>
<th>Nom. Cv</th>
<th>Actuator</th>
<th>Flow:</th>
</tr>
</thead>
<tbody>
<tr>
<td>D0EVL1P</td>
<td>HX2a bypass</td>
<td>.17 gpm</td>
<td>0.1 psi</td>
<td>0.46</td>
<td>Fail closed</td>
<td>½&quot; OD x ⅜ OD x 2&quot; VS</td>
</tr>
<tr>
<td>PV2713N</td>
<td>Subcooler inlet</td>
<td>.08 to 1 gpm</td>
<td>25 psi</td>
<td>0.013 to 0.17</td>
<td>Fail closed</td>
<td>⅜&quot; OD x ⅜ IPS x-FER LINE</td>
</tr>
<tr>
<td>MV2716N and MV27105N</td>
<td>Bypass &amp; Block subcooler</td>
<td>0.5 gpm</td>
<td>0.25 psi</td>
<td>0.87</td>
<td>None, manual</td>
<td>⅝&quot; OD x ⅝ IPS</td>
</tr>
<tr>
<td>PV3035N</td>
<td>Solenoid LN2 supply</td>
<td>0.04 to 0.16 gpm</td>
<td>27 psi</td>
<td>0.007 to 0.027</td>
<td>Fail closed</td>
<td>Flow: Design report/Max. bid spec.</td>
</tr>
<tr>
<td>PV4305N and PV4405N</td>
<td>VLPC East &amp; west supply</td>
<td>.15 gpm</td>
<td>20 psi</td>
<td>0.029</td>
<td>Fail closed</td>
<td>⅜&quot; OD * cool box TYPE</td>
</tr>
</tbody>
</table>

* Based on pure liquid

† Flashing could occur

NEW Draft from refined calcs

Pages A5 through A10

R. Rucinski 9/11/95
DOE-viP
SERIAL-CATEGORY PROJECT
FERMILAB

SUBJECT NAME
DATE /REVISION DATE

ENGINEERING NOTE

LN₂ VALVE SIZING

TAKE A CLOSER LOOK AT VALVE SIZING CONSIDER ZP INLET CONDITIONS WHERE APPLICABLE & LARGE QP'S.

- DOEVLP FLOWRATE NOT THAT CRITICAL,

\[ Q_{1-2} = 0.09 \left( \frac{\text{lb}}{\text{hr}} \right) \times 25 \text{ ft} = 2.25 \text{ W} \]
\[ Q_{3-4} = 3.6 \text{ W} \]
\[ Q_{\text{EVXLN}} = 0.6 \text{ W} \]

\[ h_x = -124.065 \frac{\text{J}}{\text{g}} \quad \rho = 0.17 \frac{\text{g}}{\text{cm}^3} \times 3060 \frac{\text{g}}{\text{gal}} \times 1 \frac{\text{gal}}{60 \text{s}} = 8.67 \frac{\text{g}}{\text{s}} \]
\[ h_y = -124.065 \frac{\text{J}}{\text{g}} \times \frac{6.45 \frac{\text{J}}{\text{g}}}{8.67 \frac{\text{g}}{\text{s}}} = -123.32 \]
\[ P_y = 5 \text{ psig} = 1.34 \text{ atm.} \rightarrow \text{STIL SUBCOOLED.} \]

ORIGINAL SIZING IS VALID \( C_V = 0.46 \text{ NOMINALLY} \)

- PV 2713 N

INLET STATE \( P = 3 \text{ atm} \times 0.032 \) (REF. EN-422) NEED FOR A N₂ PHASE CHG

GAS FRACTION = 65% LIQUID 35% SLUG FLOW

\[ \frac{\Delta P}{\text{LiquatMartineilli}} = 53.0 = 8.3 \quad \text{PIPE OP'S} \]

SINCE DOWNTOWN PRESSURE IS LESS THAN VAPOR PRESSURE
LIQUID FLASHING OCCURS. I WILL USE THE ISA - 575-01-1985
STD. TO SIZE THE CONTROL VALVE
LN\textsubscript{2} VALVE SIZING

TAKE A CLOSER LOOK AT VALVE SIZING CONSIDER 20 INLET CONDITIONS WHERE APPLICABLE & LARGE QPs.

- DEVELOP FLOWRATE NOT THAT CRITICAL

\begin{align*}
Q_{1+2} &= 0.09 \text{ ft}^3/\text{s} \times 25 \text{ ft} = 2.25 \text{ W} \\
Q_{3+4} &= 3.6 \text{ W} \\
Q_{\text{EVXLN}} &= 0.6 \text{ W}
\end{align*}

\textit{APPENDIX B;} \text{ EQUATION B1}

\begin{align*}
F_e &= 0.96 - 0.28 \left( \frac{2060}{920} \right) \text{ in} \text{ min} \\
\rho_v &= \text{ VAPOR PRESSURE OF LIQUID AT INLET} = 44.1 \text{ psia} \\
\rho_c &= \text{ CRITICAL PRESSURE} = 492 \text{ psia}.
\end{align*}

\textit{(SUBST. INTO 14a)}

\begin{align*}
F_e &= 0.96 - 0.28 \left( \frac{44.1}{492} \right) = 0.876 \\
C_V &= \frac{1.0 \text{ gpm}}{0.8 \sqrt{0.75 \frac{44.1 - (0.876)(44.1)}{44.1}}} = 0.463
\end{align*}

\textit{THIS IS FOR THE CASE OF X=0.0 LIQUID AT INLET.}

\textit{IN ORDER TO COMPENSATE FOR GAS FIND CV FOR GAS FLOWING WITH CHOKE FLOW DUE TO VAPORIZING LIQUID.}

\begin{align*}
F_c &= F_e \rho_v = 0.876 (44.1) = 38.63 \text{ psia} \\
C_V &= \frac{-730 W_0}{\sqrt{GP_2 \Delta P}} \left( \frac{\sqrt{T}}{22.8} \right) \text{ GAS FLOW EQN IN CVI CATALOG.}
\end{align*}
W_g = GAS flow rate (10^6 sec) = \times M_{liq} = (0.032)(52.5 \frac{g}{sec})(\frac{2.2 \text{ lbm}}{1000 \text{ g}})

= 0.0037 \frac{lbm}{sec}

G = SPECIFIC GRAVITY = 1.0 (at STP)

P_2 = DOWNSTREAM PRESSURE = f_{sc} = 38.63 \text{ psia}

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

T = ABSOLUTE TEMP (°R) = 88 °K \times 1.8 = 158.4 °R

SUBSTITUTE INTO CVN EQUATION BOTTOM OF PAGE 6,

C_v = \frac{730 (0.0037 \frac{lbm}{sec})}{\sqrt{(1)(38.63)(5.47)}} \left[ \frac{(158.4)^{1/2}}{22.8} \right] = 0.103

WE NEED PV-2713-N TO HAVE AT LEAST

C_v = C_{v, liq} + C_{v, gas} = 0.463 + 0.103 = 0.566 = \frac{0.6}{3}

THIS IS QUITE A BIT LARGER THAN ORIGINIAL QUICK ESTIMATE OF 0.17 NOT TAKING FLASHING/CURVED FLOW INTO ACCOUNT

- MV2716N & MV2710SN

NOT CRITICAL VALUES, DEFINITELY SEE SOME X = 0.03 2 ø LN2

- INCREASE SIZE BY \frac{0.6}{0.46} = 1.30

FROM PV-2713N EXPERIENCE

C_v = 0.87 (1.30) = 1.13

\frac{3}{3}
LN2 CRYO VALVE SIZING

- PV 3035N: 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 20.

   Need 0.16 gpm; can just scale new Cv sizing for PV 2713N with flashing/choked 20.

   \[ \text{Cv} = 0.6 \times 0.16 = 0.096 = \frac{0.10}{2} \]

- PV 4305N & 4405N are same size as PV 5035N

   \[ \text{Cv} = 0.10 \]

- Revise Dh E VLP if it sees 20 due to no subcooling.

   \[ \text{Cv} = 0.46 \times 1.30 = 0.60 \]

**CHECK COOLDOWN MASS FLOW RATE REQUIREMENTS**

To be sure valve doesn't choke flow, refer to:

\[ m_{g2} > \frac{Q_{ss}}{2 [ h_{g2} - h_{f1}] } \]

From EN-421:

\[ m_{solenoid} + m_{VLPC} + m_{refriger} = 1.7 + 17.6 + 10 \text{ gph} = 29.3 \text{ gph} \]

\[ Q_{ss} = m \times h_{fg} = 29.3 \text{ gph} \times \frac{170.33 \text{ watts}}{1 \text{ gph}} = 5000 \text{ watts} \]
\[ \dot{m}_{\text{g2}} > 5000 \frac{1}{2} \left[ 290.341 \frac{1}{3} - (-98.938) \right] \]

\[ \dot{m}_{\text{g2}} > 6.42 \frac{g}{s} \]

\[ V_{\text{sound}} = 341.2 \frac{m}{s} \quad \rho = 0.00122 \frac{g}{cm^3} \]

\[ \dot{m} = \rho V A \]

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

\[ A_{\text{min}} = 0.154 \text{ cm}^2 \]

\[ \frac{\pi d^2}{4} = A \]

\[ d_{\text{min}} = \left[ \frac{4A}{\pi} \right]^{\frac{1}{2}} = \left[ \frac{4(0.154 \text{ cm}^2)}{\pi} \right]^{\frac{1}{2}} = 0.443 \text{ cm} \]

\[ d_{\text{min}} = 0.443 \text{ cm} \times \frac{1 \text{ in}}{2.54 \text{ cm}} = 0.1745 \text{ inches} \]

For the LN2 circuit, we can probably will cooldown the line to the subcooler first. All the values mentioned are on the cold side before the heat loads. Also, the solenoid, refrigeration, and VLP will not be cooling at the same time.

Calc. rough CV for a value flowing

\[ \dot{m} = 6.42 \frac{g}{s} \text{ warm gas} \quad \Delta P = 10 \text{ psi} \quad (\text{arbitrary}) \]
LN2 CRYO VALVE SIZING

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

\[ W_g = 6.42 \times 10^9 \times \frac{2.216}{10000} = 0.1412 \text{ lb} \]

\[ G = 1 \]

\[ P_2 = 14.7 \text{ psia} \]

\[ \Delta P = 10 \]

\[ T = 520^\circ R \]

\[ C_v = 0.85 \]

VLPC FLOW RATE SPLIT, CV SCALED:

\[ m_{\text{VLPC}} = \left[ \frac{17.6}{2} \right] \times \frac{1}{29.3 \text{ gph}} \times (.85) = 0.255 \]
<table>
<thead>
<tr>
<th>Valve</th>
<th>Description</th>
<th>Flowrate</th>
<th>Delta P</th>
<th>Nom. Cv</th>
<th>Actuator</th>
<th>Final Control Valve Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOEVLP</td>
<td>HX2a bypass</td>
<td>.17 gpm</td>
<td>0.1 psi</td>
<td>0.6</td>
<td>2.0</td>
<td>Based on 2 phase x=0.032</td>
</tr>
<tr>
<td>PV2713N</td>
<td>Subcooler inlet</td>
<td>.08 to 1 gpm</td>
<td>25 psi</td>
<td>.06 to 0.6</td>
<td>2.0</td>
<td>Flow: SS Subcooling/He cooldown, Flash</td>
</tr>
<tr>
<td>MV2716N and MV27105N</td>
<td>Bypass &amp; Block subcooler</td>
<td>0.5 gpm</td>
<td>0.25 psi</td>
<td>1.13</td>
<td>None, manual</td>
<td>Flow: Design rpt/Max. bid spec., Flash</td>
</tr>
<tr>
<td>PV3035N</td>
<td>Solenoid LN2 supply</td>
<td>0.04 to 0.16 gpm</td>
<td>27 psi</td>
<td>0.03 to 0.1</td>
<td>1.32</td>
<td>Flashing, choked flow, neglect subcoo</td>
</tr>
<tr>
<td>PV4305N and PV4405N</td>
<td>VLPC East &amp; west supply</td>
<td>.15 gpm</td>
<td>20 psi</td>
<td>0.1</td>
<td>2.0</td>
<td></td>
</tr>
</tbody>
</table>

* PURCHASE, CRMOB or CVI, 1/2" IPS
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
<table>
<thead>
<tr>
<th>#</th>
<th>VOL</th>
<th>TIME</th>
<th>PRESS</th>
<th>%OPN</th>
<th>FLOW(GPM)</th>
<th>CV</th>
<th>TRAVEL(INCH)</th>
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<td>2</td>
<td>30</td>
<td>28</td>
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<td>1.1E-03</td>
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<td>60</td>
<td>0.065</td>
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<td>28</td>
<td>65</td>
<td>0.0917</td>
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