Butterfly Valve Generated Noise Calculations
On Standard and Fluted Disc

For

Stealth Valve & Controls Ltd.
1273 North Service Road East
Unit F6
Oakville ON L6H 1A7

Attention: Bruce James

By

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George Feng, Ph.D, P.Eng

and

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D. L. Allen, Ph.D, P.Eng

VIBRON LIMITED
1720 Meyerside Drive
Mississauga, Ontario
L5T 1A3
Ph : (905) 670-4922
Fax: (905) 670-1698

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1. Introduction

The report presents an internationally accepted noise prediction method to calculate the gas flow generated noise through a butterfly valve, either standard or fluted. This method is described in IEC 60534-8-3, second edition, 2000-07 “Industrial-process control valves – Part 8-3: Noise considerations – Control valve aerodynamic noise prediction method” [1]. In this edition, gas flow Mach number at valve outlet is limited to 0.8 while all former methods had limitation of 0.3. This prediction method requires the input of some important valve parameters, such as F_d and F_L etc., which are actually unknown before the valve is made and tested. Typical valves of these parameters for different types of valves are also given in this standard. The main procedures of calculation are based on this standard but additional consideration is given on gas flow because of the high temperature (hence low density and high velocity or Mach number). It is believed that the customer is mainly interested in the internal noise sound power levels and spectrum, no calculation is done on the internal sound pressure levels and external sound pressure levels. The error of this prediction method is reported within 5dB(A) for the majority of noise data from tests under laboratory conditions.

This report covers the noise calculations for standard and fluted butterfly valves; how valve parameters are determined and the discussion of difference in noise generation of standard and fluted valves.

2. Symbols

Symbol	Unit	Description
C_v	gpm/√psid	Flow coefficient
c_P	J/kmol K	Specific heat at constant pressure
c_{VCC}	m/s	Speed of sound in the vena contracta at critical flow conditions
c_2	m/s	Speed of sound at downstream flow conditions
D	m	Valve outlet diameter
Dj	m	Jet diameter at the vena contracta
f_p	Hz	Generated peak frequency
f_R	Hz	
Fd	Dimensionless	Valve style modifier
F_L	Dimensionless	Liquid pressure recovery factor of a valve without attached fittings
M	kg/kmol	Molecular mass of flowing fluid
M_j	Dimensionless	Freely expanded jet Mach number in regimes II to IV
M_o	Dimensionless	Mach number at valve outlet
M_R	Dimensionless	Mach number in the entrance to expander
m	kg/s	Mass flow rate
p_1	Pa	Valve inlet absolute pressure
p_2	Pa	Valve outlet absolute pressure
p_{2B}	Pa	Valve outlet absolute pressure at break point
p_{2C}	Pa	Valve outlet absolute pressure at critical flow conditions
p_{2CE}	Pa	Valve outlet absolute pressure where region of constant acoustical efficiency begins
p_{VCC}	Pa	Absolute vena contracta pressure at critical flow conditions
R	J/kmol K	Universal gas constant = 8314
r_W	Dimensionless	Acoustic power ratio
T_1	K	Valve inlet absolute temperature
T_2	K	Valve outlet absolute temperature
T_{VCC}	K	vena contracta absolute temperature at critical flow conditions
U_p	m/s	Gas velocity in downstream pipe
U_R	m/s	Gas velocity in the inlet of expander
W_a	W	Sound power
W_{aR}	W	Sound power in valve outlet or reduced diameter of expander
W_m	W	Stream power of mass flow
W_{ms}	W	Stream power of mass flow rate at sonic velocity
W_{mR}	W	Stream power of mass flow in valve outlet or reduced diameter of expander
x_T	Dimensionless	Pressure differential ratio factor of a control valve without attached fittings at choked flow

α	Dimensionless	Recovery correction factor
γ	Dimensionless	Specific heat ratio
η	Dimensionless	Acoustical efficiency factor
η_R	Dimensionless	Acoustical efficiency factor in valve outlet or reduced diameter of expander
ρ_1	kg/m^3	Density of fluid at valve inlet
ρ_2	kg/m^3	Density of fluid at valve outlet

3. Descriptions on Gas Flow and Noise Generation in This BFV Application

1) Gas flow

It is assumed that the flow conditions upstram and downstream of the valve are as follows.

- Upstream pressure: 80 Psia
- Upstream temperature: 2200°F
- Downstream pressure: 14.7 Psia
- Design mass flow: 40lbs/sec

In this particular application (flow conditions), the gas flow enters the valve, accelerates to reach local sonic speed at the vena contracta, further accelerates to a supersonic speed to some point downstream of the vena contracta, then it slows down to subsonic flow through a shock wave and reaches the back pressure. The flow capacity of a valve under this flow condition is determined by the upstream flow pressure, temperature and the area of vena contracta and is not affected by the downstream pressure.

The equations governing the flow through the valve are conversation of mass flow and total flow energy.

Assuming the flow is one-dimensional:

Mass flow: $m_1=m_2$

Total energy: $m_1\ (c_PT_1+V_1^2/2)=m_2\ (c_PT_2+V_2^2/2)$

Here V_1 and V_2 are flow velocity at valve inlet and outlet.

The solution of the flow is an iteration process. In this specific application, because of the high temperature of the flow, the density of the gas flow downstream of the valve is very low; the gas flow velocity becomes very high at the design mass flow; the Mach number at valve downstream is about 0.75.

2) Noise Generation

A control valve controls flow by converting pressure energy into kinetic energy. Most of the energy is converted to heat through viscous friction by intense turbulence and shock formation. Some of the kinetic energy is transferred to the pipe wall as vibration, and a portion of this is radiated as noise. The primary noise generating mechanism is the jet of gas formed between the valve and its seat; thus valve noise is modeled as a confined jet. Consequently, the noise-generation mechanisms are turbulent mixing, turbulence boundary interaction, shock, shock/turbulence interaction and flow separation [3].

IEC 60534-8-3 provides a method to predict the valve generated noise and also the downstream flow noise when the downstream Mach number is higher than 0.3 but not greater than 0.8. In this specific application, the downstream Mach number is 0.75 at design mass flow (40lbs/sec); and therefore the noise prediction method is applicable. For higher mass flow rate, the downstream Mach number may exceed 0.8, calculation above the design mass flow rate is not valid and the result is for reference only.

4. Determination of Valve Parameters

Prior to the calculation of valve generated noise, three important valve parameters, F_d, F_L and x_T, have to be determined and they are functions of valve type and opening. Since only partial valve parameters are available for standard BFV and no data are available for fluted BFV from manufacturer, typical values are used to interpolate or extrapolate and correct the required parameters.

4.1 Parameters for Standard BFV

F_L and x_T are available from manufacturer from 10 to 90 degrees of opening.
F_d is available only at full opening, i.e. 90 degrees. The typical F_d vs. $C_v/C_{v70°}$ for standard and fluted butterfly valves and the one point of manufacturer's data are shown in Fig.1 , it can be seen that the manufacturer's F_d at 90 degree is in a good agreement with the extension or extrapolation of the typical standard curve; therefore typical F_d values are used for calculation.

4.2 Parameters for Fluted BFV

No data are available for fluted disc from manufacturer. They are determined as follows.
F_L and x_T are calculated from standard BFV data and the deviation of typical standard and fluted disc, i.e., an increase of 0.05 in F_L and 0.03 in x_T for all disc positions, as shown in Fig. 2.
For the same reason as described in 4.1, typical F_d values are used for calculation.

4.3 Valve Parameters for Noise Calculations

The data used for noise calculations are listed in the following table.

Table 1 – Valve Parmeters

Disc Position (degrees)		10	20	30	40	43 Design Flow	50
Standard	F_L	0.93	0.91	0.88	0.85	0.82	0.8
	x_T	0.55	0.54	0.52	0.48	0.45	0.43
	F_d	0.2	0.23	0.29	0.35	0.38	0.41
Fluted	F_L	0.98	0.96	0.93	0.9	0.87	0.85
	x_T	0.58	0.57	0.55	0.51	0.48	0.46
	F_d	0.06	0.07	0.08	0.11	0.12	0.14

- No calculation is made above 50 degrees because the downstream Mach number exceeds the limit of 0.8.
- All typical values are taken from [1] and [2]

5. Typical Calculation

Typical calculation for fluted BFV at design mass flow conditions is shown as follows.

5.1 Input Conditions

Variable	Value	Unit (SI)		Value	Unit (IMP)
D	0.406	m		16	in
Fd	0.12	Dimensionless			
F_L	0.875	Dimensionless			
M	28.97	kg/kmol	**for air**		
m	18.16	kg/s		40.00	lb/s
p_1	551581	Pa		80	psia
p_2	101325	Pa		14.70	psia
R	8314	J/kmol K			
r_W	0.5	Dimensionless			
T_1	1477.6	K		2200	F
x_T	0.485	Dimensionless			
γ	1.33	Dimensionless			

5.2 Determination of Flow Regimes

$p_{VCC} = p_1*(2/(\gamma+1))^\wedge(\gamma/(\gamma-1))$ = 298054 Pa

$p_{2C} = p_1 - F_L^{2}*(p_1 - p_{VCC})$ = 357475 Pa

$\alpha = p_{VCC}/p_{2C}$ = 0.834

$p_{2B} = p_1*(1/\gamma)^\wedge(\gamma/(\gamma-1))/\alpha$ = 209604 Pa

$p_{2CE} = p_1/22\alpha$ = 30070 Pa

Noise Generation Flow Regimes:

Regime I	If		p_2	≥	p_{2C}	
Regime II	If p_{2C}	>	p_2	≥	p_{VCC}	
Regime III	If p_{VCC}	>	p_2	≥	p_{2B}	
Regime IV	If p_{2B}	>	p_2	≥	p_{2CE}	**True**
Regime V	If p_{2CE}	>	p_2			

Flow through the valve is in Regime IV.

5.3 Calculation of Valve Generated Noise According to the Flow Regime

$\rho_1 = p_1M/R/T_1$ = 1.30 kg/m^3

C_v =(Eq.12 of [2]) = 1975

Eq.12 of [2]: $C=m/(0.667N_6SQRT(F_\gamma x_T p_1 \rho_1))$

$Dj = N_{14}*Fd*SQRT(C_vF_L)$ = 2.29E-02 m

$M_i = SQRT(2/(\gamma-1)*(p_1/\alpha/p_2)^\wedge((\gamma-1)/\gamma)-1)$ = 1.90

$\eta_4 = (1x10^{-4})*(M_j^2/2)*(sqrt(2)^\wedge(6.6F_L^2)$ = 0.001035

$T_{VCC} = 2T_1/(\gamma+1)$ = 1268.3 K

$c_{VCC} = SQRT(\gamma RT_{VCC}/M)$ = 695.8 m/s

$W_{ms} = mc_{VCC}^2/2$ = 4395703 W

$W_a = \eta_4*r_W*W_{ms}$ = 2275.2 W

$f_p = 0.35*c_{VCC}/1.25D_jSQRT(M_j^2-1)$ = 5273 Hz

The outlet temperature is calculated from the conservation of mass flow and total energy through the valve, the following is an iteration process.

$c_P = R/M*\gamma/(\gamma-1)$ = 1156.6 J/kmol K

$T_2 = T_1-(M_oc_2)^2/2c_P$ = 1353.1 K

$\rho_2 = Mp_2/RT_2$ = 0.261 kg/m^3

$c_2 = SQRT(\gamma RT_2/M)$ = 718.7 m/s

$M_o = 4m/\pi D^2c_2\rho_2$ = 0.75

Since M_o exceeds 0.3, proceed with the calculations in clause 7 of [1].

$U_p = 4m/\pi D^2\rho_2$ = 537 m/s

$U_R = U_p/\beta$ = 577 m/s

if valve size = pipe size (d_i=D_i=D)

W_{mR} =$mU_R^2/2*(0.2)$ = 604459 W

if valve size = pipe size (d_i=D_i=D)

M_R =U_R/c_2 = 0.80

η_R =$(1x10^{-3})M_R^3$ = 0.000517

W_{aR} =η_R*W_{mR} = 313 W

f_R =$0.2U_R/D$ = 284 Hz

if valve size = pipe size (d_i=D_i=D)

5.4 Result of Calculation

Valve generated noise sound power and peak frequency:

W_a= 2275 W

L_a= 153.6 dB

f_p= 5273 Hz

Valve downstream flow generated noise sound power and peak frequency:

W_{aR}= 313 W

L_{aR}= 145.0 dB

f_{pR}= 284 Hz

Combined Noise Sound Power Levels at Octave Bands:

Octave Bands	1	2	3	4	5	6	7	8	9	**OA**
Center Frequency Hz	63	125	250	500	1000	2000	4000	8000	16000	**dB**
L_a From Valve	128	131	134	137	140	145	149	148	143	**153.2**
L_{aR} From Downstream Flow	131	136	141	138	134	131	127	124	120	**144.9**
Total L_w	133	138	142	141	141	145	149	148	143	**153.8**
A_{wt}	-26	-16	-9	-3	0	1	1	-1	-7	
A_{wt} L_w	**107**	**122**	**133**	**138**	**141**	**146**	**150**	**147**	**136**	**153.3**

* Distribution of total sound power level to each octave band is referred the method described in [3].

5. Results and Conclusions

Similar calculations as described in section 5 are repeated for all cases listed in Table 1. All calculated results are summarized in the following Table.

Table 2 – Summary of noise calculation results

	Disc Position	degree	10	20	30	40	43	50
Standard	Mass Flow Rate	lbm/sec	1	8.5	21	35.25	40	*54.3*
	Sound Power Level	dB	138	147	151	153	154	*156*
	Peak Frequency	Hz	16k	6k	3k	2k	1643	*1300*
	A weighted Sound Power Level	**dBA**	**135**	**147**	**151**	**153**	**153**	***153***
	c_v		46	397	1001	1749	2039	*2847*
	M_o		0.02	0.17	0.4	0.71	0.75	*0.98*
Fluted	Mass Flow Rate	lbm/sec	1	8.5	21	35.25	40	*54.3*
	Sound Power Level	dB	130	148	152	153	154	*156*
	Peak Frequency	Hz	64k	20k	11k	6k	5k	*3830*
	A weighted Sound Power Level	**dBA**	**129**	**145**	**150**	**153**	**153**	***155***
	c_v		45	387	974	1697	1975	*2753*
	M_o		0.02	0.17	0.4	0.71	0.75	*0.98*

In the above table, disc position is referred to standard discs only and there may be a small deviation for fluted discs. Comparison between standard and fluted disc is made based on same mass flow rate. The main results are as follows.

- For all mass flow rates, required C_v for standard disc is a little higher than that for fluted disc. The relationship between C_v with standard disc and disc position is shown in Fig.3.
- For most mass flow rates, noise sound power levels generated by standard and fluted discs are almost the same, except the 1lbm/sec flow rate at which the sound power generated by fluted disc has very high frequency and main part of the noise energy is beyond audible range.
- For all disc positions, noise peak frequencies generated by fluted disc is higher than that of standard disc, this is because the existence of flutes makes the flow shed from the disc in smaller vortexes.
- Up to 21lbm/sec, the A-weighted sound power levels are lower through a fluted disc than through a standard disc because the higher peak frequency for a fluted disc. From 35.25lbm/sec and up, the A weight sound power levels from a fluted disc is the same as those from a standard disc because the peak frequency from a fluted disc is also in the sensitive range of human ears. The results at 54.3lbs/sec show higher A-weighted sound power for fluted disc, which is not reliable and for reference only because the downstream Mach number (=0.98) exceeds 0.8, i.e. the limit IEC 60534-8-3.

Conclusion: The flutes mainly change the peak frequency of generated noise, which makes the noise quieter to human ears at low mass flow rates but may not make any difference at higher mass flow rates.

- **This conclusion is from the point view of flow generated noise only, the effects of noise generated by the vibration of valve body and connected pipes are not considered here.**

7. References

1. IEC (International Electrotechnical Commission) 60534-8-3, “Industrial-process control valves – Part 8-3: Noise considerations – Control valve aerodynamic noise prediction method”, second edition, 2000-07
2. ANSI/ISA-75.01.01-2002 (IEC 60534-2-1 Mod), “Flow Equations for Sizing Control Valves”, Approved 3 July 2002
3. Bies, D.A. and Hansen, C.H., “Engineering noise control”, second edition, 1996
4. Beranek, L.L. and Ver, I.L., “Noise and vibration control engineering”, 1992

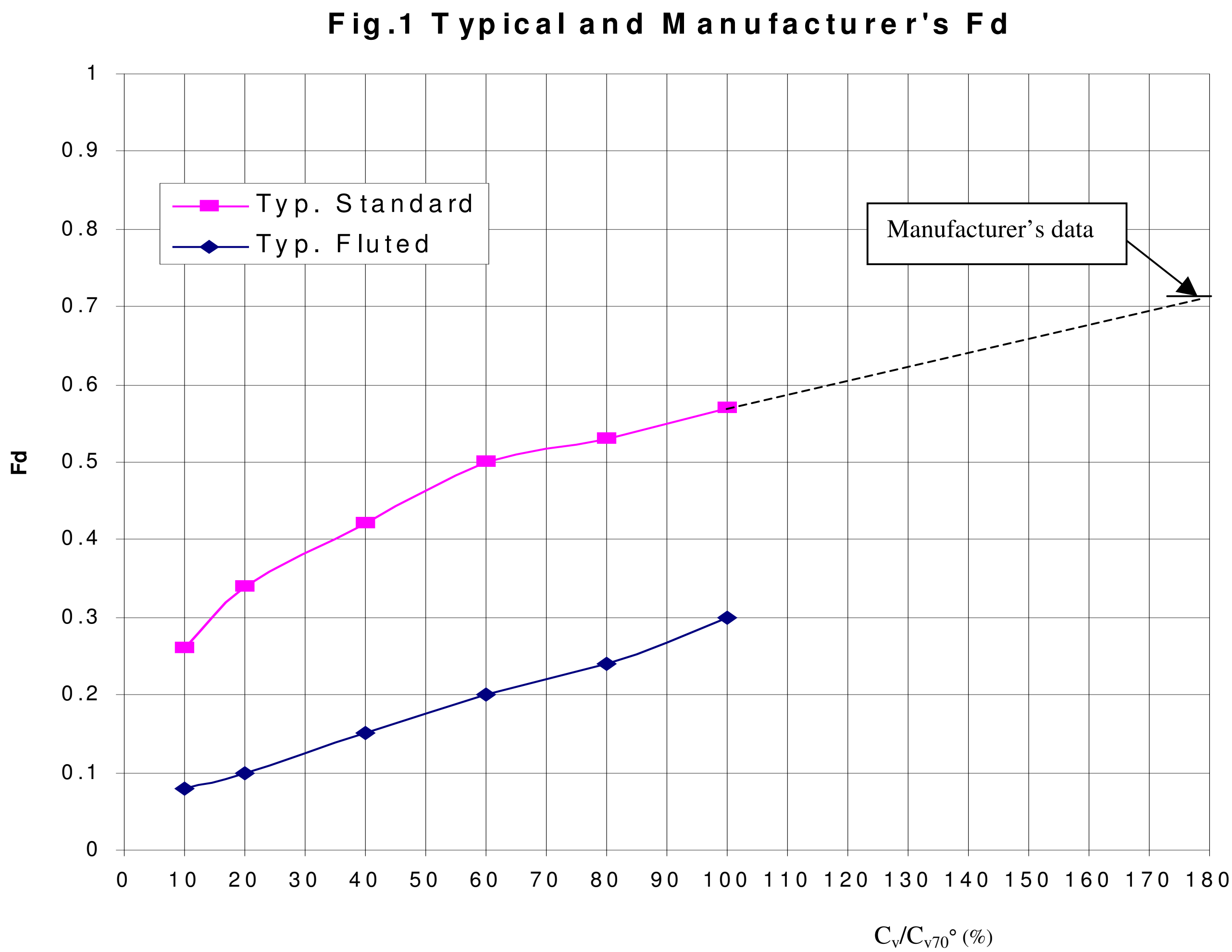
Fig.1 Typical and Manufacturer's Fd
Typ. Standard
Typ. Fluted
Manufacturer's data
Fd
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Cv/Cv70° (%)

Fig.2 Manufacturer's and Typical FL and xT

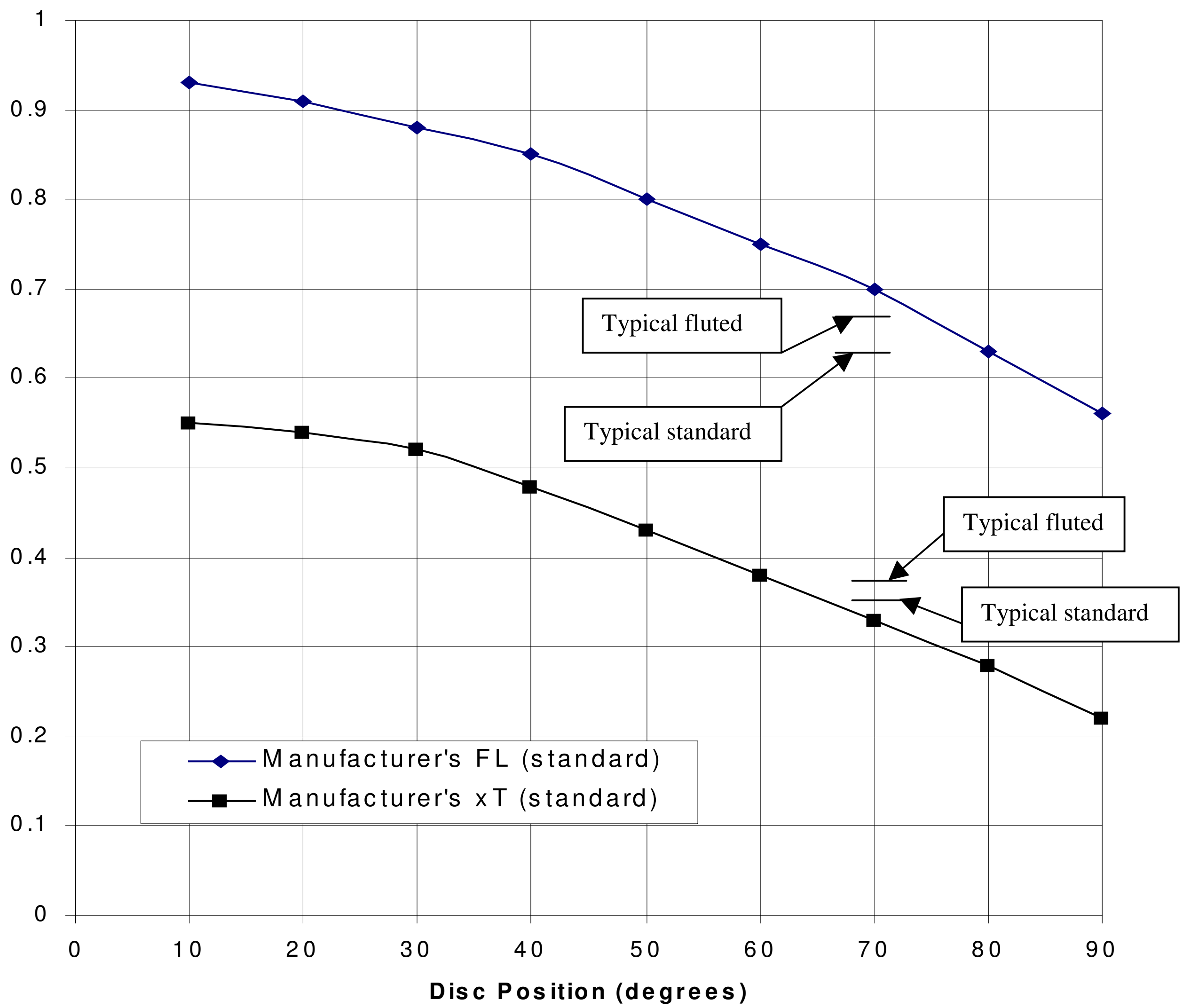

Fig.3 Valve Cv and Disc Position