Controllability Index: the effective CONVAL® 8.0 approach to optimize your valve configuration

Abstract

Controllability prediction has been discussed and debated lately in the valve community and an end-user driven practical and objective controllability application guide is expected to be released later this year. To effectively select the optimum valve configuration during the initial sizing and selection phase, a static controllability index method has been proposed and implemented in CONVAL® 8.0. CONVAL® is the leading industry sizing and simulation tool.

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Introduction

So far optimizing a valve configuration from a controllability viewpoint has been an iterative and time consuming process. Several influencing factors, some not directly accessible, had to be evaluated in detail and compared to derive at the best selection. CONVAL® 8.0 provides that task now using a **single controllability index**, even taken any kind of modified characteristics into account. This will practically eliminate the gray area of basic characteristic and nominal flow coefficient selection.

It needs to be understood that this is a static controllability index only. Dynamic aspects such as those induced during the valve production process, or those from the actuator – positioner configuration or those from valve friction effects like "stick-slip" or those from seals in bonnet-, piston- and /or pressure balance trims require engineered solutions in order to optimize the total controllability. There are also applications, such as anti-surge control to protect rotating machines from getting damaged, where the static optimization recommends an equal percentage characteristic, while a linear characteristic will be required from a dynamic viewpoint.

Controllability prediction has been seen as a next logical step in improving the quality of plant performance lately. A control valve controllability prediction discussion paper has been released in 2008. This paper has been debated and discussed during the Valve World 2008 conference. There is a strong drive with the end-user community to develop a practical and objective control valve controllability guideline by end 2009. One key aspect is to improve the controllability analysis during the sizing and selection process.

The index, as proposed, has been implemented into the latest release of CONVAL®, a comprehensive instrumentation and process design engineering tool. Valve sizing and selection including graphical simulation is a key aspect of this tool. The tool has been around for 20 years and is used by a large worldwide community of end-users, engineering contractors and valve suppliers.

Controllability aspects

Of course controllability prediction is much more than a static index. To get an appreciation of all aspects around controllability, one should consult the controllability prediction discussion paper that was issued last year in preparation of a brainstorming session at Valve World 2008 [1].

Lacking an internationally accepted controllability definition makes it even more challenging to get a concerted view on this subject. The discussion paper tried to identify however the essential controllability influencing factors. It even introduced a number of new parameters. It covered static as well as dynamic aspects. For the sizing and selection phase, the phase to find the most suitable control valve for a particular process control application it tabled the essential information required to verify that the selected valve operates within the acceptable controllability bandwidth. The method proposed in this paper is consolidating that essential controllability information into a single index and by comparing that index for a number of possible configurations, the optimum valve configuration can be more effectively derived.

The ValveWorld 2008 brainstorming session yielded following **prioritized controllability dataset** to be optimized during the **sizing and selection process**:

1	✓	Valve characteristic	i.e. equal percentage, linear, modified
2	✓	Valve authority	i.e. dynamic pressure drop ratio available over the complete valve travel
3	✓	Valve style	i.e. globe, rotary, butterfly
4	✓	Valve size / Cv coefficient	i.e. 6 inch, Cv100 = 125
5		Actuator force capacity	
6		Valve inherent rangeability	i.e. Cv100 to Cvmin
7	✓	Fluid properties	i.e. flow conditions / phenomena like cavitation, choked flow, etc.

Table 1

Except for the actuator force capacity, the proposed method is consolidating this dataset into a single index.

Controllability index method

Following controllability index method has been proposed:

1. A static index consolidating the dataset as per table 1 to be optimized during the sizing and selection process
2. A specific index for either flow, pressure (upstream, downstream) or differential pressure control
3. A specific index for either the full working range (follow-up control) , the high capacity working range (setpoint control) or the low capacity working range (startup control)

4. A controllability index CI calculated as

$$CI = \sum_{min}^{max} \frac{r}{n} \qquad if\ \frac{dx}{ds} > 1 \quad r = \frac{\frac{dx}{ds}}{1} - 1 \qquad if\ \frac{dx}{ds} < 1 \quad r = \frac{1}{\frac{dx}{ds}} - 1$$

   a. x = controlled variable
   b. s = stroke, valve opening
   c. r = ratio of slopes
   d. n = number of data points used for the index
   e. min / max

Range	Control	Min	Max
Full working range	Follow-up control	min*	100
High capacity working range	Setpoint control	50	100
Low capacity working range	Startup control	min*	50

min* = the minimum stable controlled variable

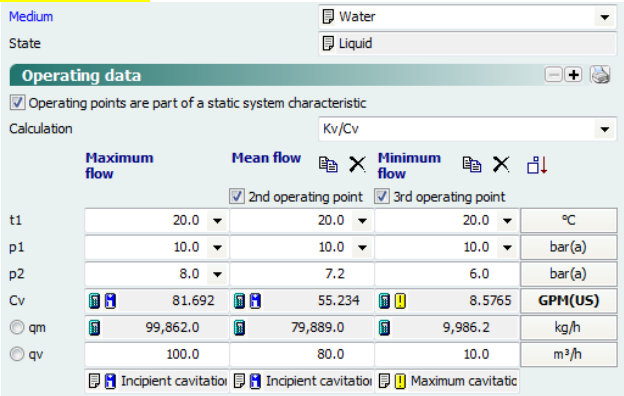
5. An index varying between 0 (i.e. the theoretical ideal control) and a maximum value. This maximum is not necessarily the same for the different control strategies, but for all practical purposes it is below 2

Controllability index implementation

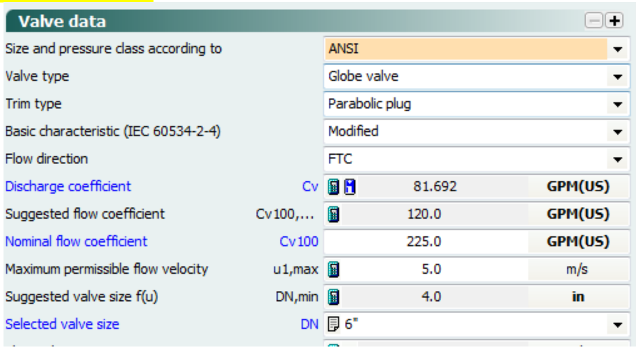
A sequence of screen prints has been used to describe and document the index implementation. A process case having choked flow below 40% travel has been chosen. Unless noted otherwise flow control is assumed. The screen prints are taken from the CONVAL® 8.0 pre release version. The final look and feel may vary.

1. **Process data / Valve data / Phenomena** :

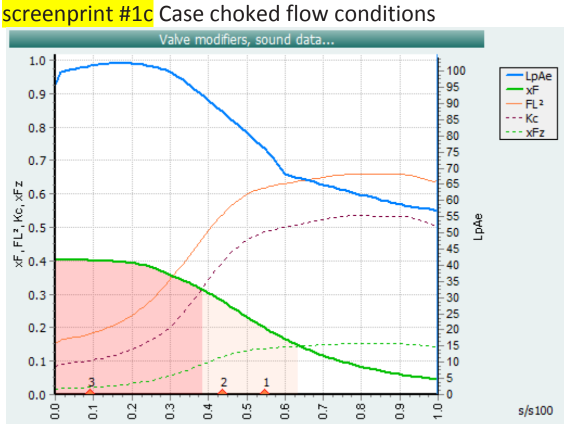
screenprint #1a Case process data



screenprint #1b Case valve data

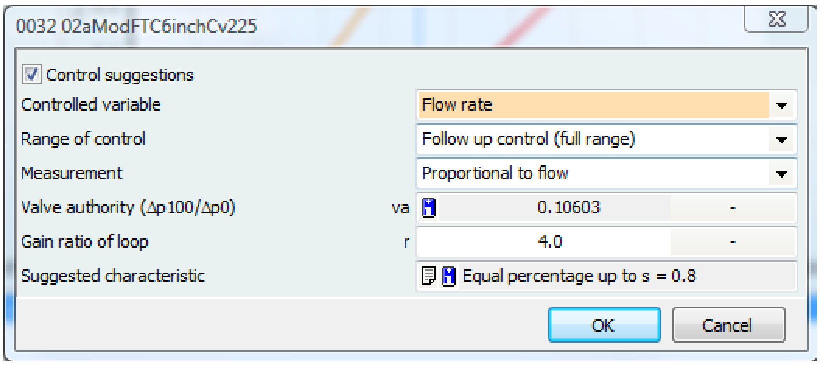


screenprint #1c Case choked flow conditions



2. **Control parameters** : Pop-up window when viewing the main characteristics screen with its 4 windows and clicking the *control* button

Screenprint #2 Control parameters pop-up window

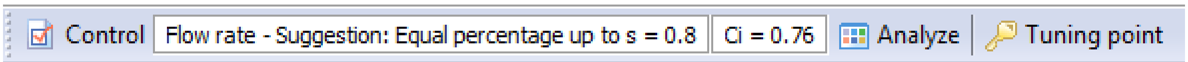


- Controlled variable x = (mass) flow rate
- Range of control = full control range
- Valve authority = 0.1
- Gain ratio of loop = 4, i.e. the loop gain ratio over the full stable working range should be below 4, i.e. a gain between 0.5 and 2
- Suggested characteristic = equal percentage

3. **Characteristics Valve toolbar / Controllability Index** :

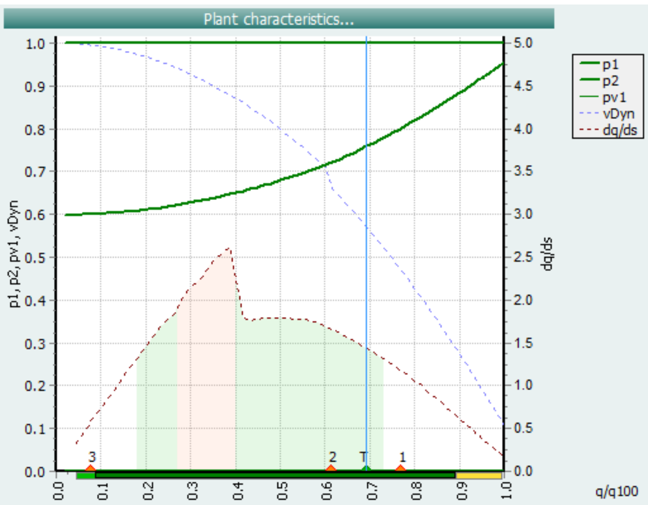
Screenprint #3 Characteristics valve toolbar

- Controlled variable = (mass) flow rate
- Suggested characteristic = equal percentage
- Controllability index = 0.76
- *Analyze* button: ability to analyze various configurations – see screen print #5
- *Tuning point* button: ability to visualize the (dx/dh)x on the corresponding quadrant – see screenprint #4b



Gain curves : Screen prints are the bottom right flow characteristics window (#4a) and the top left plant characteristics window (#4b)

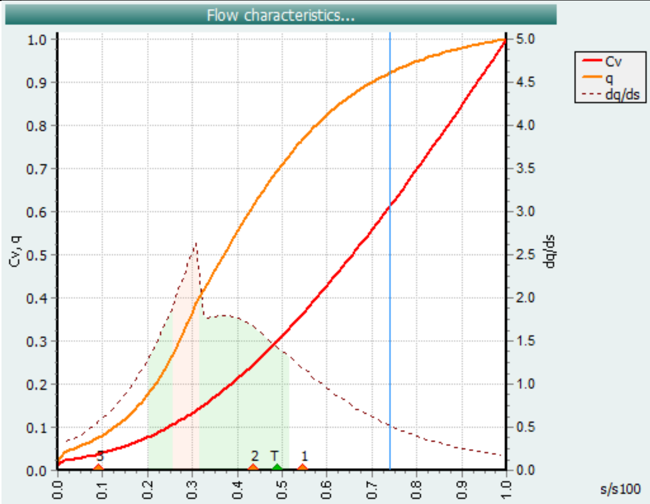
screenprint #4b Top left plant characteristics window



a. The gain curve can be made visible when pressing the Tuning Point button - see screenprint #3 above
b. When the cursor is at the tuning point, the solid dark green bar below the graph covers all 3 working points
c. This curve is used to calculate the controllability index – as specified by the base of CI calculation
d. Visualizing in colored shading the range where the gain ratio over the full stable working range is below the value indicated in screen print #2

screenprint #4a Bottom right flow characteristics window

a. Visualizing 3 graphs a) installed characteristic Cv, b) inherent characteristic q and c) actual gain dq/ds all shown on the travel axis s/s100
b. Indicating the 3 working points: 1 = maximum flow, 2 = normal flow, 3 = minimum flow
c. Indicating the optimum tuning point T, i.e. that valve position where the complete flow control loop is best tuned for the full stable working range
d. Visualizing in colored shading the range where the gain ratio over the full stable working range is below the value specified - see screen print #2
    i. In green color when the gain is within the specified limits of stable control
    ii. In red color when the gain is outside the specified limits, risking unstable control



5. **Controllability index cross tabulations** : characteristics versus working ranges for this case by clicking the *analyze* button on the valve toolbar – see screenprint #3

Screenprint #5 Controllability index cross tabulation

Controlled variable: Flow rate

Name

Characteristic	Full range	High capacity	Low Capacity
Name : 0032 02aModFTC6inchCv225 [Cv: 225, 6", Modified, d: 76mm]			
Equal percentage	0.58	0.45	0.72
Modified	0.76	0.70	0.82
Linear	1.42	1.06	1.83

The index for the full working range varies between 0.58 for an equal percentage characteristic and 1.42 for a linear characteristic. For this case similar variations are seen for the high capacity and the low capacity ranges,

Multiple cases can be analyzed for controllability as well.

Optimization

A number of control valve process cases, each with possible valve configurations have been analyzed and optimized using CONVAL® 8.0. A couple of optimization cases are summarized below.

One case is an example of various configurations, globe valves as well as rotary valves from different manufacturers for an uncomplicated process case. The results for the full control range for both flow control and differential pressure control are shown in Table 2 on the right.

The index varies between 0.44 and 1.50 for flow control and about the same for differential pressure control.
Coloring is on a <u>relative comparison</u> basis, i.e. red is worst controllability case while green is best controllability case in a given range of cases

To even better optimize one would like to analyze controllability as well as reliability. With the CONVAL® team the author is currently working on a model for a reliability index.

CONTROL VALVE CONFIGURATION OPTIMIZATION TABLE

Case 0601 > uncritical application > water, 20 Deg C > p1 3.1 to 3.0 bara > p2 3.2 to 2.8 bara > q 200 to 50 t/h		Process Valve authority	Valve Valve type (style)	Valve Selected Valve size	Valve Nominal flow coefficient	Static Controllability index Full control range	
Essential controllability parameter ranking --->		3	4	5	nl		
		Vdyn		DN [in]	Cv100	Flow control	Differential pressure control
Globe generic	0601	0.069	globe	12	1502	0.46	0.77
Globe vendor X	0602	0.050	globe	12	1776	0.46	0.80
Globe vendor X	0603	0.050	globe	12	1790	1.50	1.30
Globe vendor X	0604	0.032	globe	12	2250	0.77	0.85
Globe vendor X	0606	0.064	globe	12	1570	0.44	0.48
Globe vendor X	0607	0.050	globe	12	1790	1.20	1.40
Rotary vendor X	0608	0.075	rotary	8	1440	0.57	0.63
Rotary vendor X	0609	0.054	ball	8	1710	0.48	0.53
Rotary vendor X	0610	0.058	bfly	8	1650	0.56	0.57
Rotary vendor X	0611	0.073	rotary	16	1460	1.10	0.81
Rotary vendor X	0612	0.061	bfly	8	1610	0.69	0.60
Rotary vendor X	0613	0.044	rotary	12	1896	0.95	0.88

Table 2

Case 0032
> p1 constant 10 bara, water at 20 Deg C, **choked flow conditions, maximum cavitation**

CONTROLLABILITY INDEX VARIATION TABLE

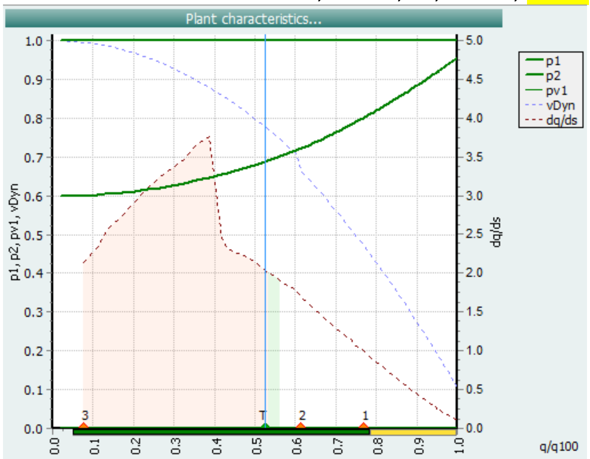
	flow control				**p2 press control**				**diff press control**			
	Cv100				*Cv100*				*Cv100*			
char	*100*	*125*	*150*	*225*	*100*	*125*	*150*	*225*	*100*	*125*	*150*	*225*
lin	0.4	0.6	0.75	1.4	2.25	2.05	1.9	1.35	0.55	0.4	0.35	1.0
mod	0.35	0.35	0.45	0.75	1.75	1.85	1.7	1.0	0.35	0.45	0.45	0.7
eq%	0.8	0.7	0.6	0.6	1.25	1.6	1.5	0.6	0.95	1.05	1.0	0.85

Table 3

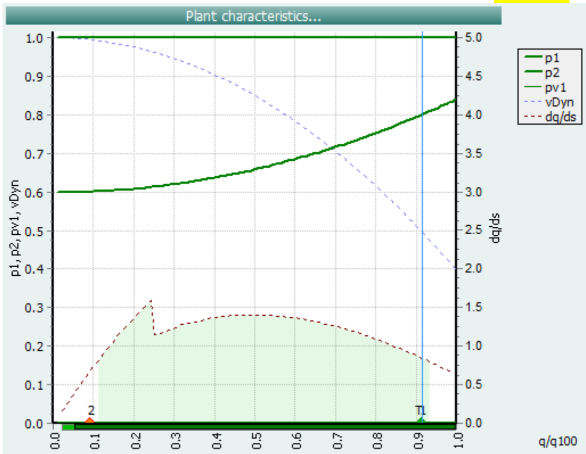
In another process case, the effect of the basic characteristic versus nominal flow coefficient has been summarized in a cross tabulation for flow, downstream pressure and differential pressure. In this process case the optimum is significantly different for the 3 control modes – see left

In the screenshots below the gain curves for flow control before and after optimization are compared

BEFORE OPTIMIZATION: Flow, Linear, 6",Cv 225, **CI 1.4**



AFTER OPTIMIZATION: Flow, Mod, 4",Cv 100, **CI 0.37**



Conclusion

A static controllability index has been developed, implemented and validated in CONVAL® 8.0 to optimize your valve configuration during the sizing and selection phase. Numerous cases have been run ensuring the index correctly predicts the controllability for flow, pressure and differential pressure control. Except for actuator force capacity all essential controllability sizing parameters have been taken into account.

This index has to be seen as a starting point to predict control valve controllability. Similar activities are underway to conceive and implement a reliability prediction index.

For more detailed and/or tutorial type information the interested reader should explore the Conval College Controllability Videos [3]

A special thanks to Dirk Hackländer and Andreas Vogt from First GmbH for implementing this method promptly into CONVAL® 8.0 and to Holger Siemers for verifying a large number of CONVAL® cases to ensure the index predictions matched our current controllability experiences as compiled in the CONVAL® Cases Databank.

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22 July 2009

Profile

	*Henk Hinssen has been working 32 years for ExxonMobil as engineering associate and retired in 2007. He is an active member of the WIB Controllability Workgroup. He is a Steering Committee member of Valve World since 2006*

References

[1] Control Valve Controllability Prediction Workshop Discussion Paper – 12 pages – 05 June 2008 – WIB Control Valve Workgroup

[2] CONVAL® College Controllability Overview video / screencast – September 2009

[3] CONVAL® College Videos – Mastering valve controllability chapter 11 - 8 videos – October 2009

[4] CONVAL® Cases Databank – December 2009

screenprint #7 Advanced Conval College Videos

CONVAL© College **Videos**

INTO HIGHER GEAR

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7 ADVANCED SIZING

7.01 Control valve graphics - part 2
7.02 Two phase flow
7.03 Split range applications
7.04 Multicomponents valve sizing
7.05 Sizing silencers
7.11 Estimating meter reading uncertainty

8 DEEPER INTO PHYSICAL PROPERTIES

8.01 Specific Gravity
8.02 Standard Conditions
8.03 Thermodynamic module
8.04 Isentropic coefficient surprise

9 CUSTOMIZATION

9.01 Language
9.02 Folder locations
9.03 Units of Measure
9.04 Templates
9.05 Dialog settings
9.06 Page formats
9.07 Printing Options
9.08 User Defined Fields
9.09 Schemes
9.10 File extensions

GETTING THE MAX OUT OF IT

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10 OPTIMIZING VALVE RELIABILITY

10.01 Reliability Overview
10.02 Reliability Index Overview
10.03 Reliability Flowcharts
10.04 Understanding Outlet velocity
10.05 Understanding xFz
10.06 Understanding Choked flow

11 MASTERING VALVE CONTROLLABILITY

11.01 Controllability Overview
11.02 Controllability Index Overview
11.03 Impact basic characteristic
11.04 Impact flow reserve / valve authority
11.05 Impact flow direction
11.06 Impact process data quality
11.07 Reducing number of operating points
11.08 Understanding rangeability

12 MASTERING VALVE PERFORMANCE

12.01 Performance Overview
12.02 Performance Index Overview
12.03 High Performance Control valve applications

BEST TO KNOW

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13 TRAPS and WORKAROUNDS

13.01 Converting training license file to full license file
13.02 You can't find a parameter - it probably sits under the "+"
13.03 Performance challenges
13.04 Deleting a dropdown
13.05 Conval not reacting like Windows
13.06 Vista challenges
13.07 Mixing Min, Norm and Max

14 FOR THE CONVAL ADMINISTRATOR

14.01 Managing the valve database
14.02 Getting into sizing automation
14.03 Exploring Conval parameters

15 WAYS TO DISCOVER EVEN MORE

15.01 What's new in Conval 8
15.02 End Users wishlists