BRITISH STANDARD

BS EN 60534-9:2007

Incorporating corrigendum June 2008

Industrial-process control valves —

Part 9: Test procedure for response measurements from step inputs

ICS 23.060.40; 25.040.40

British Standards

National foreword

This British Standard is the UK implementation of EN 60534-9:2007. It is identical with IEC 60534-9:2007, incorporating corrigendum June 2008.

The start and finish of text introduced or altered by corrigendum is indicated in the text by tags. Text altered by IEC corrigendum June 2008 is indicated in the text by AC1 AC1.

The UK participation in its preparation was entrusted by Technical Committee GEL/65, Measurement and control, to Subcommittee GEL/65/2, Elements of systems.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 November 2007

ISBN 978 0 580 63598 4

Amendments/corrigenda issued since publication

Amd. no.	Date	Comments
	30 June 2009	Implementation of IEC corrigendum June 2008

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 60534-9

October 2007

ICS 23.060; 25.040.40

English version

Industrial-process control valves - Part 9: Test procedure for response measurements from step inputs (IEC 60534-9:2007)

Vannes de régulation
des processus industriels -
Partie 9: Procédure d'essai
pour la mesure de la réponse
des vannes de régulation
à des signaux d'entrée échelonnés
(CEI 60534-9:2007)

Stellventile für die Prozessregelung -
Teil 9: Prüfverfahren zur Bestimmung
des Verhaltens von Stellventilen
bei Sprungfunktionen
(IEC 60534-9:2007)

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Ref. No. EN 60534-9:2007 E

Foreword

The text of document 65B/632/FDIS, future edition 1 of IEC 60534-9, prepared by SC 65B, Devices & process analysis, of IEC TC 65, Industrial-process measurement, control and automation, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60534-9 on 2007-10-01.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2008-07-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2010-10-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60534-9:2007 was approved by CENELEC as a European Standard without any modification.

CONTENTS

INDUSTRIAL-PROCESS CONTROL VALVES –

Part 9: Test procedure for response measurements from step inputs

1 Scope and object

This part of IEC 60534 defines the testing and reporting of the step response of control valves that are used in throttling closed-loop control applications. A control valve consists of the complete, ready-to-use assembly of the control valve body, the actuator, and any required accessories. The most probable accessory is a valve positioner.

NOTE For background, refer to technical report ANSI/ISA-TR75.25.02 [6][1].

The object of this standard is to define how to test, measure, and report control valve response characteristics in an open-loop environment. This information can be used for process control applications to determine how well and how fast the control valve responds to the control valve input signal.

This standard does not define the acceptable control valve performance for process control nor does it restrict the selection of control valves for any application. If this standard is used for evaluation or acceptance testing, the parties may agree to documented variations from these requirements.

The information using the defined test methods is specifically applicable to closed-loop feedback control but may have some application to open-loop control applications. It does not address valves used in on-off control service.

Tests specified in this standard may not be sufficient to measure the performance required for all applications. Not all control valve applications will require this testing.

2 Normative references

The following documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60534-1, *Industrial-process control valves – Part 1: Control valve terminology and general consideration*

IEC 60534-4, *Industrial-process control valves – Part 4: Inspection and routine testing*

3 Terms and definitions

For the purposes of this document, the following terms and definitions, as well as those given in IEC 60534-1 and other parts of IEC 60534, apply.

NOTE 1 In the specific area of non-linear dynamics, it was determined that some terms defined in IEC 60050-351 or in [5] lacked the precision desired for these documents. Others were inconsistent with the terminology used in the non-linear control literature.

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[1] Figures in square brackets refer to the Bibliography.

NOTE 2 Reference [6] explains applicable terms and explores control valve static and dynamic response characteristics important for process control. That information will aid correct interpretation and application of the test results obtained from the tests defined in this standard.

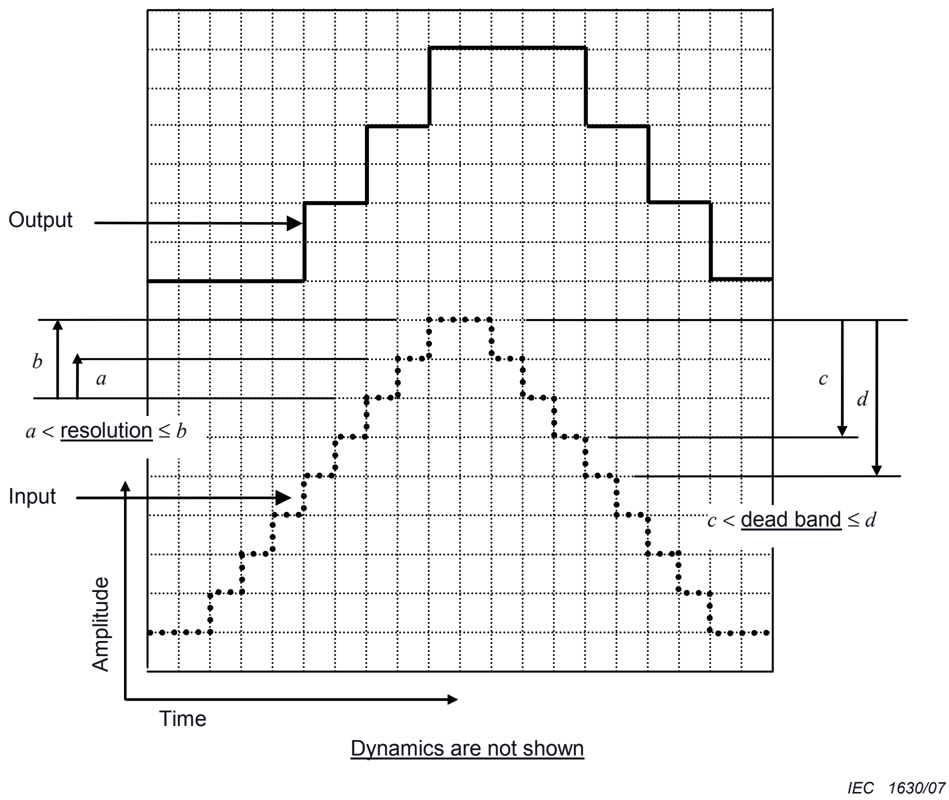


Figure 1 – Dead band and resolution

3.1
closed-loop time constant
time constant of the closed-loop response of a control loop, used in tuning methods such as Internal Model Control (IMC) and Lambda Tuning and is a measure of the performance of a control loop

3.2
dead band
finite range of values within reversal of the input variable does not produce any noticeable change in the output variable

[IEC 60534-4, 3.2]

3.3
dead time
time interval between the instant when a variation of an input variable is produced and the instant when the consequent variation of the output variable starts

3.4
dynamic response
time-dependent output signal change resulting from a defined time-dependent input signal change

NOTE Commonly used input signal changes include impulse, pulse, step, ramp, and sinusoid [4]. Dynamic means that the control valve is moving. Dynamic response can be measured without process loading in bench-top tests, with simulated or active loading in a flow laboratory or under normal process operating conditions.

3.5
gain ratio
$\boldsymbol{G}_{\mathrm{R}}$
response gain G_Z divided by the response gain G_{Z02} determined from the multi-step test performed with a step size of 2 %. The ideal gain ratio equals 1,0 for tests about any nominal position

$G_R = G_Z/G_{Z02}$

NOTE Measuring the gain ratio may not be possible if a digital positioner with pulse-modulated output is involved in the system since, on such positioners, the gain measurement may give infinite values.

3.6
input step size
Δs
difference between the beginning and ending signal in a step change expressed as a per cent of the signal span

3.7
limit cycle
oscillation caused by the non-linear behaviour of a feedback system

NOTE 1 These oscillations are of fixed amplitude and frequency and can be sustained in a feedback loop even if the system input change is zero. In linear systems, an unstable oscillation grows theoretically to infinite amplitude, but non-linear effects limit this growth [3].

NOTE 2 The occurrence of the limit cycle may be dependent on current valve position.

3.8
non-linear system
system whose response depends on the amplitude and the nature of the input signal, as well as the initial conditions of the system. As an example, a non-linear system can change from being stable to unstable by changing the size of the input signal

NOTE When a non-linear system is driven towards a set point by feedback control action, it is likely to develop a limit cycle. The amplitude and frequency of such limit cycles are a function of the nature of the non-linearities which are present, and the effective gain of the feedback control action. As the gain of the feedback is increased, the frequency of the limit cycle is likely to increase. More aggressive gain increases may produce behaviour such as bifurcation, frequency doubling and eventually chaotic behaviour.

3.9
overshoot
for a step response, the maximum transient deviation from the final steady-state value of the output variable, expressed as a percentage of the difference between the final and the initial steady-state values

3.10
relative travel
$\boldsymbol{h}$
ratio of the travel at a given opening to the rated travel

[IEC 60534-1, 4.5.4]

3.11
resolution
smallest step increment of input signal in one direction for which movement of the output is observed, expressed as a percentage of the input span

NOTE The term “valve resolution” in this standard means the tendency of a control valve to move in finite steps in responding to step changes in the input signal applied in the same direction. This happens when the control valve sticks in place, having stopped moving after the previous step change.

3.12
step response
time history of a variable after a step change in the input. In this standard, the step response can be stem position, flow, or another process variable

3.13
response flow coefficient
C_R
apparent flow coefficient as determined by testing in an operating type environment. The data available in the operating environment may differ from the laboratory data required by valve sizing standards

NOTE 1 Flow coefficients in current use are K_V and C_V depending upon the system of units. For further information, refer to IEC 60534-1.

NOTE 2 It will be noted that the dimensions and units on each of the following defined flow coefficients are different. However, it is possible to relate these flow coefficients numerically. This relationship is as follows:

$$\frac{K_V}{C_V} = 0{,}865$$

3.14
response gain
G_Z
ratio of the steady-state magnitude of the process change, ΔZ, divided by the signal step, Δs, that caused the change. One special reference response gain is defined as that calculated from the 2 % step size response time test which is designated as G_{Z02}

$$G_Z = \Delta Z / \Delta s$$

$$G_{Z02} = \Delta Z_{02} / \Delta s_{02}$$

3.15
sampling interval
Δt_s
time increment between sampled data points which is the inverse of the sampling rate, f_0

$$\Delta t_S = 1/f_0$$

NOTE As used in this standard, since more than one variable is being sampled, it is the time between the sets of sampled data. Ideally, all variables in one set are sampled at the same time. If data is recorded using analogue equipment, the time constant for the recording equipment should be less than, or equal to, the maximum allowed Δt_S.

3.16
sampling rate
f_0
rate at which data samples are taken or the number of samples per unit time (see 3.15)

3.17

sliding friction
F_R **or** T_R

force or torque required to maintain motion in either direction at a prescribed input signal ramp rate

3.18
static
means without motion or change [4]; readings are recorded after the device has come to rest. Static performance can be measured either without process loading (bench-top tests), with simulated or active loading, or under process operating conditions

NOTE This kind of test is sometimes called a dynamic test [4] which may cause confusion. The static behaviour characteristics identified as important to the control valve performance are the dead band, the resolution, and the valve travel gain.

3.19
steady state
state of a system which is maintained after all transient effects have subsided as long as all input variables remain constant

3.20
step change
nearly instantaneous step change made to an input signal of a dynamic system with the intention of stimulating a step response of the dynamic system. Such a test is used to characterize the step response of the dynamic system

3.21
step change time
Δt_{SC}
time between the start of a signal input step and attainment of its maximum value

3.22
step test
application of a step change to an input signal in order to test the step response dynamics

3.23
step response time
t_{86}
interval of time between initiation of an input signal step change and the moment that the response of a dynamic reaches 86,5 % of its full steady-state value. The step response time includes the dead time before the dynamic response

3.24
stiction (static friction)
resistance to the start of motion, usually measured as the difference between the driving values required to overcome static friction upscale and downscale [5]

3.25
time constant
τ
time required to complete 63,2% (i.e. 1-1/e) of the total change of the output of a first-order linear system produced by a step-wise variation of the input variable

NOTE The term is used in this standard to describe the dynamic characteristics of the analogue measuring instruments.

3.26
valve travel gain
change in closure member position divided by the change in input signal, both expressed in percentage of full span

$G_{\mathrm{X}} = \Delta X / \Delta s$

3.27
valve system approximate time constant
τ'
time constant of a first-order response without dead time, which may fit the actual control valve step response reasonably well. The approximate time constant is defined to provide a basis for comparison of the valve with other time constants, such as the closed-loop time constant for the control loop

NOTE 1 A first-order system reaches 86,5 % of its final step response value in two time constants; the approximate time constant is considered to be one-half of the step response time, t_{86}.

NOTE 2 The use of the approximate time constant in no way implies that the response of the control valve is first-order. The step response of the control valve is typically complex, having dead time initially, followed by potentially complex dynamics before the steady state is achieved. t_{86} includes the dead time in the initial part of the response, as well as the possibility of slower settling in the last portion of the response. Some valve positioner designs attempt to achieve a slow-down in the final part of the response in order to limit overshoot. τ' attempts to produce a simple linear time constant approximation of the control-valve dynamic response, which can be compared to the closed-loop time constant of the control loop on the same basis in time-constant units. It should be noted that as the portion of t_{86} that is dead time increases, this approximation becomes less ideal.

3.28
wait time
Δt_W
time spent after a step input change waiting for the response to come to the new steady-state value

3.29
X-Y plot
plot of the output excursions plotted against input excursions. Input-output plots are useful for defining the steady-state characteristics of non-linearities

4 Symbols

Symbol	Description	Unit
C_R	Response flow coefficient (K_v or C_v)	Various (see IEC 60534-1)
Δs	Input step size	% of input range
Δs_{02}	Reference input step size of 2 %	% of input range
Δt_s	Sample interval	s
Δt_{sc}	Step change time	s
Δt_W	Wait time	s
ΔX	Change of closure member position	% rated travel
ΔZ	Process variable change	% of process output
ΔZ_{02}	Process variable change at 2 % input change	% of process output
f_0	Sampling rate	1/s
F_R	Friction force	N
G_R	Gain ratio	1
G_X	Valve travel gain	1
G_Z	Response gain	1
G_{z02}	Response gain at 2 % step input	1
n_{down}	Number of steps (falling signal) in a response time test sequence	1
n_{up}	Number of steps (rising signal) in a response time test sequence	1
h	Relative travel	%
τ	Time constant	s

Symbol	Description	Unit
T_R	Friction torque	Nm
t_{86}	Step response time	s
t_{86B}	Base response time	s
t_{861}	Step response time (increasing signal)	s
t_{862}	Step response time (decreasing signal)	s
t_d	Dead time	s

5 General test procedures

5.1 Test valve conditions

The test valve shall be set to its desired test configuration. This includes configuring the valve assembly with the desired packing type and condition, the positioner if applicable, and the actuator configuration. The positioner configuration shall include any applicable adjustments or parameters (at digital positioners). In some cases, preliminary tests may be performed such as testing to assure there is no excessive overshoot. (Excessive overshoot is not defined here and the amount allowed may vary according to the application but shall be reported.) All applicable characteristics of the valve configuration that would affect test results shall be reported (see 7.1)

5.2 Test system

Testing to determine the response of a control valve requires a signal generator or source and instruments to measure the input signal, the position of the closure member and, for laboratory testing or in-process testing, the desired response variable. The response variable could be derived from other variables that may need to be measured as well.

The tests can be performed manually with appropriate instrumentation but computers are recommended for all, or at least part, of the testing and analyses.

When measuring response time, data shall be collected fast enough to give good time resolution using the requirements for the sampling interval, Δt_S, given in equation (1). Measurement of static behaviour (dead band, gain, and resolution) generally does not depend on sample interval and can be performed using existing field instrumentation, with the sample interval reported.

For a control valve with a pneumatic input signal, the input signal shall be measured as close as possible to the device input port to avoid input distortion caused by the piping. The total time for the complete input signal step change, Δt_{SC}, shall meet the requirements given in equation (2).

The valve position should be measured as close as possible to the closure member or at least at a location that closely approximates the closure member position within the resolution limits given in 5.3. Care should be taken to avoid measurement errors due to excessive elastic deformation, clearances, linkages, etc. In all cases, the location of measurement points shall be reported.

5.3 Measuring instruments

The measurement of each output variable, which includes the combined effects of transducers, any signal conditioning equipment, and recording equipment shall meet the following minimum requirements.

$$\Delta t_S \le \frac{t_{86}}{20} \text{ or 0,5 s, whichever is less} \qquad (1)$$

$$\Delta t_{sc} \leq \frac{t_{86}}{20} \tag{2}$$

Time constant $\tau \leq \frac{t_{86}}{20}$

Instrumentation used to measure the static parameters dead band, gain, and resolution need not meet these requirements but time constants, Δt_s and Δt_{sc}, shall be reported.

NOTE 1 Since t_{86} is dependent on the step size, measuring equipment with a shorter time constant, τ, may be required on smaller step sizes.

NOTE 2 For in-process tests, the flow-meter time constant should not be $\tau \leq \frac{t_{86}}{20}$, unless it is used to measure t_{86}.

If installed in-process instrumentation used to measure t_{86} does not meet these requirements, an external position transducer and recording equipment which meet the above requirements are recommended.

$$\text{Instrument resolution} \leq \left(\frac{\text{valve resolution}}{3}\right), \left[\text{preferably} \leq \left(\frac{\text{valve resolution}}{10}\right)\right]$$

Inaccuracy ≤5 % of full-scale value, preferably ≤2 % of full-scale value.

NOTE 3 The full-scale value is the range of the measured variable known or estimated as the control valve goes from 0 % to 100 % open.

5.4 Process variable

For laboratory and in-process dead-band and resolution testing, a process variable shall be measured, if possible, in addition to the input signal and the position. Reference [6] provides guidance for choosing the best process variable out of those that may be available at a specific plant or laboratory.

The response flow coefficient, C_R, shown below, is a simplified flow coefficient recommended for use as the process variable, if measurement of the variables necessary to calculate it is possible. It is used here because an accurate determination of C is outside the scope of this standard and may not be feasible in many plant and in some laboratory environments. Measurements of dead band and resolution using C_R would equal those using C since changes would be equal within the typical change of input signal. This assumes the flow through the control valve is fully turbulent and not choked. This response flow coefficient is calculated according to equations (3) or (4).

For incompressible flow

$$C_R = \frac{Q}{N_1}\sqrt{\frac{\rho_1/\rho_0}{\Delta p}} \tag{3}$$

where

Q is the liquid flow rate;

ρ_1/ρ_o is the relative density (ρ_1/ρ_o = 1,0 for water at 15 °C);

Δp is the pressure drop across the valve;

N_1 = 1, if C_R is expressed as K_v in m³/h, Q in m³/h and ΔP in bar;

N_1 = 0,865, if C_R is expressed as C_v in gpm, Q in m³/h and ΔP in bar;

Or, for compressible fluid flow,

$$C_R = \frac{W}{N_6 Y \sqrt{x p_1 \rho_1}} \quad (4)$$

where

W is the mass flow rate;

p_1 is the upstream absolute pressure in bar;

x is the pressure drop ratio $x = \frac{\Delta p}{p_1}$ where Δp is the pressure drop;

$\mathrm{Y} = 1 - \frac{x}{3F_\gamma x_T}$, where $F\gamma\, X_T$ can be assumed to be 0,7;

N_6 = 31,6, if C_R is expressed as K_v in m³/h, W in kg/h and ΔP in bar;

N_6 = 27,3, if C_R is expressed as C_v in gpm, Q in kg/h and ΔP in bar

NOTE If the flow through the control valve is not fully turbulent, or choked, such as may occur during “in-process testing”, the actual C could be calculated using the normal flow equations for control valve sizing (IEC 60534-2-1).

To calculate the percentage change of the process variable when using the response-flow coefficient, defined by equations (3) or (4), the maximum value of C_R (at 100 % valve opening) shall be measured, estimated, or determined from manufacturer-supplied data. The value of C_R at 100 % valve opening used shall be stated in the test results.

The measured process variable will often fluctuate significantly during the course of the testing because of normal fluctuations due to disturbances, etc., in the process itself or because of electrical noise in a plant environment or because of measurement noise. Curve fitting or averaging routines can therefore be applied to the data around key points such as the point where t_{86} occurs and where the total magnitude of the step change is measured. If the tests are performed manually, this may have to be done visually from a plot. In all cases, the raw data shall be plotted and if curve-fitting procedures are applied, the curve-fit data should be plotted along with the raw data. This could be used later or by others to verify calculations as required.

5.5 Nominal test position

The tests shall typically be performed at 50 % valve opening and at other positions that may be specified in lieu of, or in addition to, this position. Testing at additional, or other, positions may be desirable for valve types known to have anomalies at openings other than 50 %. In-process testing may require testing only at the current operating position plus and minus allowed step sizes. All nominal positions at which tests are performed shall be recorded.

6 Examples of step response

Figure 2 and Figure 3 show examples of responses due to input step changes. The response shown in Figure 2 has no overshoot while the one in Figure 3 does. In these figures, there is some measurement noise superimposed on the signal. The input signal is shown along with the response which could be the valve position or a process variable.

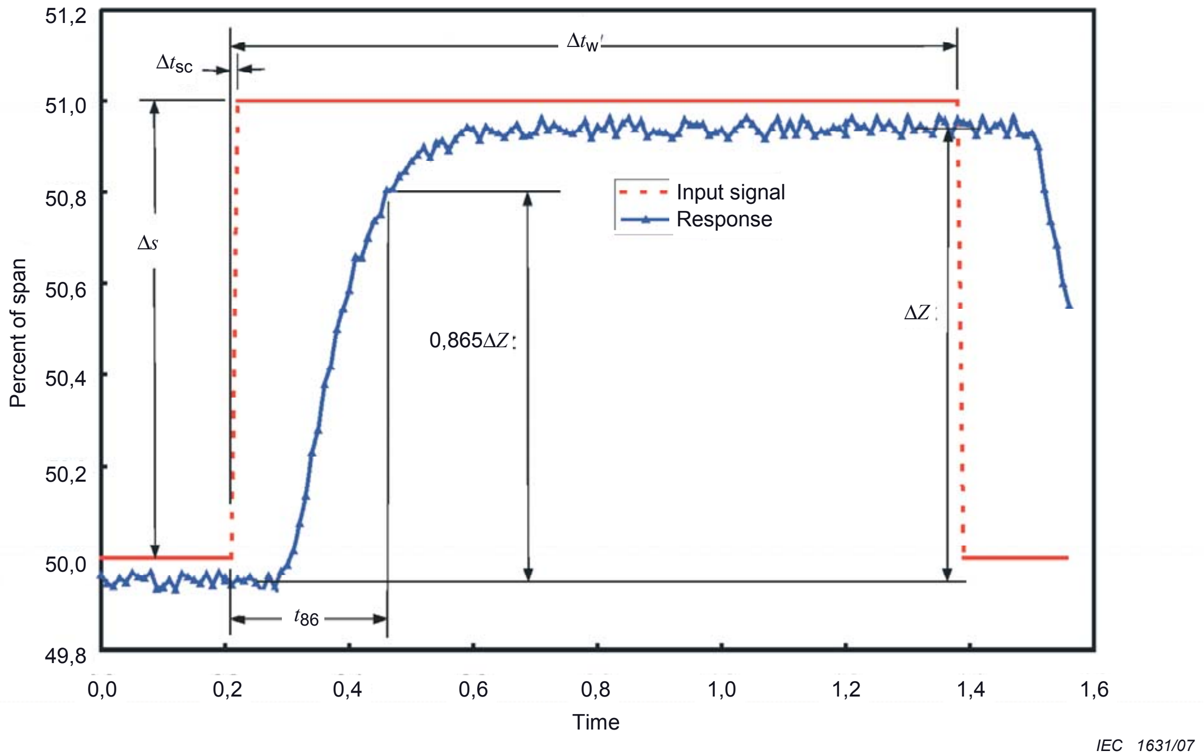


Figure 2 – Typical step change and response without overshoot

When the valve input signal suddenly changes, the valve begins to respond (if the input signal change is large enough) after some delay or dead time, t_d. The response then begins moving toward its final value like that shown, often exponentially. The signal is held constant after the step for a specified amount of time, Δt_w, to allow the response to reach its final new steady-state value. The response time, t_{86}, is defined as the time it takes for the response to reach 86,5 % of its final value from the initiation of the step.

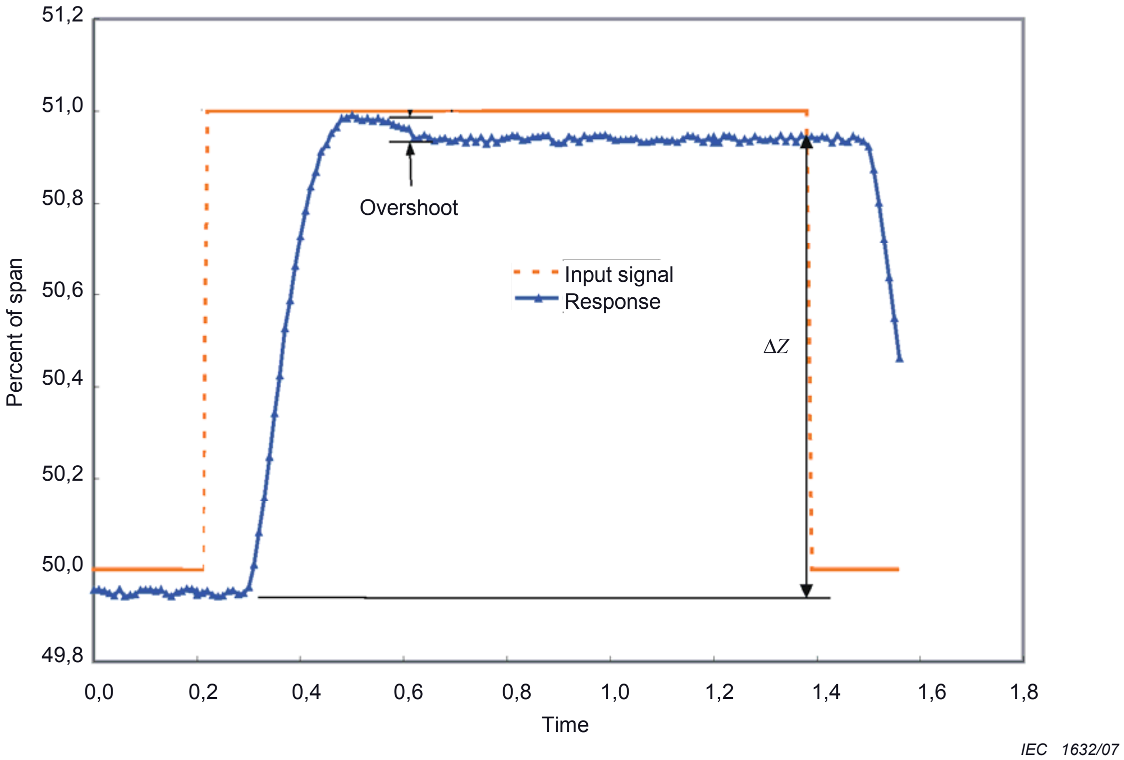


Figure 3 – Step response with some overshoot

7 Tests specified for each of three test environments

Detailed test procedures required for each of the three test environments are listed in the following subclauses along with special recommendations and precautions.

7.1 Bench tests

Bench tests are usually the simplest to perform and often provide much useful information. The results, however, can be significantly different from results from laboratory or in-process tests because there is no flow [6]. The following requirements shall apply.

a) Valve configuration

Complete valve with packing configuration that would be specified for intended service. The valve may or may not be pressurized, but packing should be tightened as it normally would be for typical, or specially defined, conditions. The procedure used for tightening the packing shall follow the manufacturer's instructions meeting the requirements given in IEC 60534-4 and shall be documented. The positioner configuration (if applicable) shall include all relevant adjustments or parameters.

The nominal valve position shall be set at 50 % unless otherwise specified.

Actuator assemblies can also be tested separately (not attached to the valve body assembly) when permitted by the user and preconditioned to all applicable points. Actuator assemblies shall also be installed in a test fixture that includes a normal control valve packing box unless the manufacturer and the user agree to alternative procedures. The packing shall be tightened according to the manufacturer's specifications. The test report shall clearly identify the actuator tested, the test fixture used, the stem friction measured or estimated as available, the procedure used to tighten the packing, and the operating temperatures and pressures.

If a valve is tested in a condition other than that described above, that condition shall be described.

b) Special considerations

Tapping or vibrating the valve under test is not allowed unless required and specified in the test report.

With the valve under test pressure (if applicable), the cycle valve shall be opened then closed 10 times. Then the total friction shall be measured (see Annex A).

c) Measured variables

Input signal and relative travel.

d) Applicable test procedures

Baseline test (see 8.1), small-step tests (see 8.2), and response-time tests (see 8.3)

7.2 Laboratory tests

Laboratory tests are performed in a laboratory with flow. The flow shall be fully turbulent and not choked unless otherwise specified and noted. These tests represent in-process tests more closely than bench tests. The following requirements shall apply.

a) Valve configuration

Complete valve mounted in flow line with packing tightened as it normally would be for typical conditions unless specified otherwise.

The nominal valve position shall be set at 50 % unless otherwise specified.

With the valve running under flow with test fluid, the cycle valve shall be opened then closed 10 times while measuring pressure drops and flows. Then total friction shall be measured (see Annex A).

b) Special considerations

No tapping or extra vibration is permitted. However, there will be some vibration with the flow, which may be measured, especially if it appears to influence the test results.

c) Measured variables

Input signal, relative travel and process variable

d) Applicable procedures

Baseline test (see 8.1), small-step test (see 8.2), and response-time test (see 8.3).

7.3 In-process tests

In-process tests give valve response in actual, or close-to-actual, process conditions. The range of test conditions may be more limited than that possible in laboratory testing, however. It may also be more difficult to get good measurements. Valve input and measurements of some process variables can sometimes be taken direct from existing plant instrumentation if it has the required time constant, sampling rate, resolution, and accuracy. The following requirements shall apply.

a) Valve configuration

Complete valve running at designated process conditions. Total friction shall be measured or estimated, giving the method of estimation. Tests shall be performed at the required positions and conditions. Sometimes, only operation close to the existing operating conditions may be permitted.

b) Special considerations

Limitations in plant operation procedures or safety requirements may not allow the complete test as defined here.

c) Measured variables

Input signal, relative travel, and process.

d) Applicable procedures

Baseline test (see 8.1), small-step test (see 8.2), and response-time test (see 8.3).

8 Detailed test procedures

8.1 Baseline test

The baseline test is normally conducted first but is an optional test. It is used to evaluate measurement noise, the presence of limit cycling of the valve or other similar behaviour, and to determine the baseline response time, AC1⟩ $t_{86\mathrm{B}}$ ⟨AC1. Figure 4 shows the input signal and an example of the position and the response during the test. The following steps are included in this test.

– Set the control signal to the desired base value and allow the valve to come to its steady-state condition. When performing in-process tests, the control signal will normally already be at the desired setting and the controller will be put on manual.
– Monitor variables for 3 min using a sample interval, Δt_s, no longer than 0,5 s or $\frac{t_{86}}{4}$, whichever is shorter.
– Step input up 2 % and continue monitoring variables for another 1 min or longer.
– Repeat stepping in 2 % increments up until there is movement, then step one more time to get the full response.
– Step input down by 2 % and continue monitoring variables for 1 min.
– Repeat stepping down 2 % increments until the valve position returns to approximately its starting position.
– Evaluate the data for evidence of limit cycling. If there is any, estimate the peak-to-peak magnitude and period of the limit cycling.
– For the last 1 min segment in the up direction, determine the response time, t_{861}. If there is overshoot, measure its magnitude and the elapsed time from the step initiation until reaching the final position.
– For the last 1 min segment, after stepping down, determine the response time, t_{862}. If there is overshoot, measure its magnitude and the elapsed time from the step initiation until reaching the final position.

– Determine the base response time [AC1⟩ t_{86B} ⟨AC1] as the greater of t_{861} or t_{862} (see Figure 4).

If there was any overshoot, determine the overshoot and the overshoot time from the largest overshoot for the increasing or decreasing input signal steps.

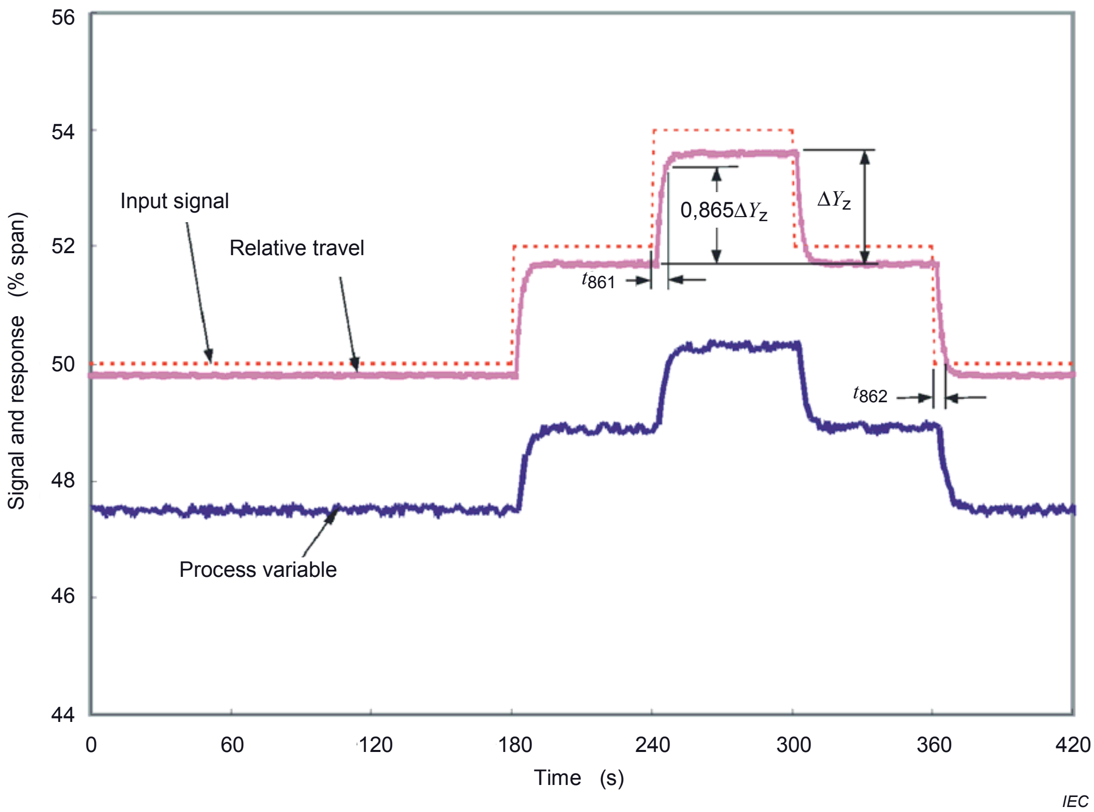


Figure 4 – Example step and response during baseline test

8.2 Small-step test

The small-step test is performed to determine dead band and resolution. This test may be omitted by agreement if the response-time test provides the required information to the required accuracy. Figure 5 shows the signal versus time for a typical small-step test. It begins after setting the input signal to the nominal value and waiting at least 3 min if the optional baseline test was not run or 30 s if the baseline test was run (the small-step test may begin right after the optional baseline test).

From this point, step up Δs and then wait a specified time, Δt_w. Monitor input signal, position, and (for laboratory and in-process testing) process variable (or variables necessary to determine response flow coefficient, C_R) with a sampling interval of Δt_s. Continue this process for n steps. At this point, wait another two time periods, $2\Delta t_w$, then decrease the signal n number of steps, and wait Δt_w after each step. Wait another $2\Delta t_w$ again, and repeat the same series of steps up and down.

The parameters Δs, Δt_w, Δt_s, and Δt_{sc} shall meet the following criteria.

$\Delta s \leq ½$ (smaller of resolution or dead band)

NOTE Since approximate resolution and dead band may not be known beforehand, one can use Δs = 0,1 % full scale and then verify afterwards that the specified conditions have been met. It is possible that dead band and resolution are smaller than the limit-cycle peak-to-peak magnitude. If that is the case, the true dead band and resolution cannot be measured but their values can be stated to be no greater than the limit-cycle peak-to-peak magnitude.

$$n \geq \text{greater of 4 or the quantity} \left[\frac{1{,}2\,(\text{dead band} + \text{resolution})}{\Delta s}\right]$$

This requirement should assure that there be at least one step in addition to the step causing initial movement.

$$\Delta t_s \leq \text{lesser of} \left(\text{[AC1⟩]}\ \frac{t_{86B}}{20} \text{ or } 0{,}5\text{ s} \ \text{⟨AC1]} \right)$$

NOTE If t_{86b} is not available because the optional baseline test was not run, an approximate t_{86} may have to be determined using Δt_s = 0,5 or a lower value during this test and then adjusting Δt_s accordingly, using $2t_{86}$ in place of t_{86b}.

$\Delta t_w \geq 4$ (process measurement time constant) or ≥30 s if the process measurement time constant is not known

[AC1⟩] $\Delta t_{sc} \leq \frac{t_{86B}}{20}$ ⟨AC1]

See above note if the baseline test was not performed.

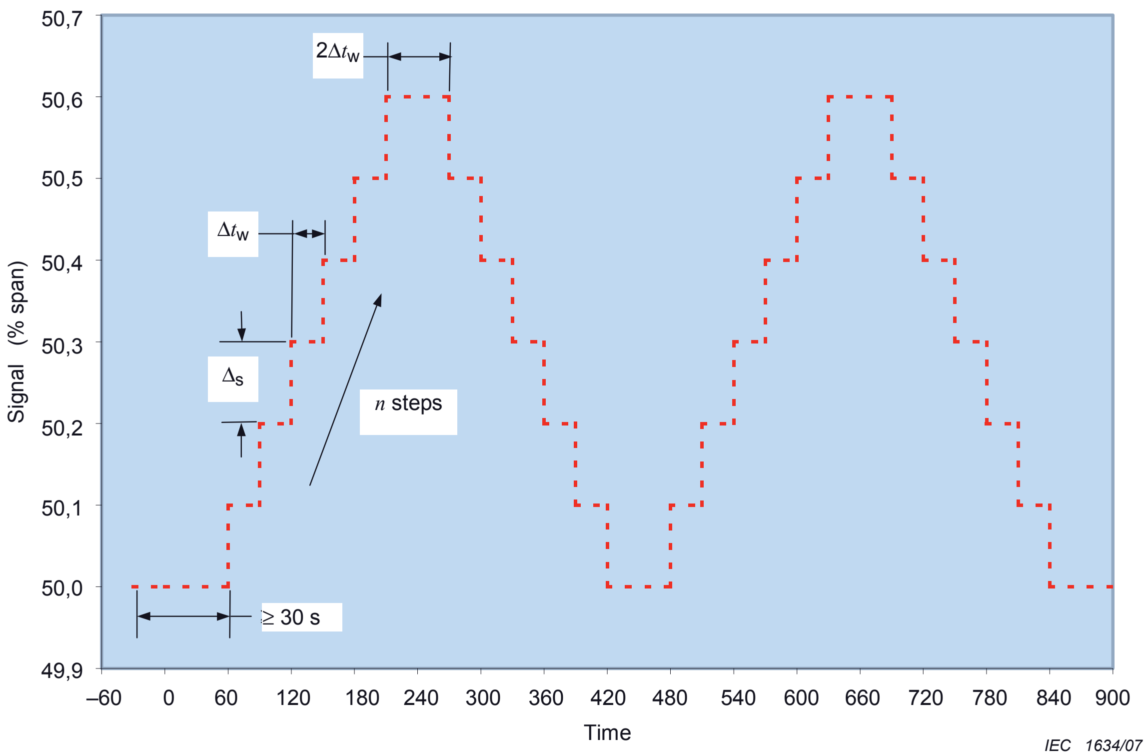
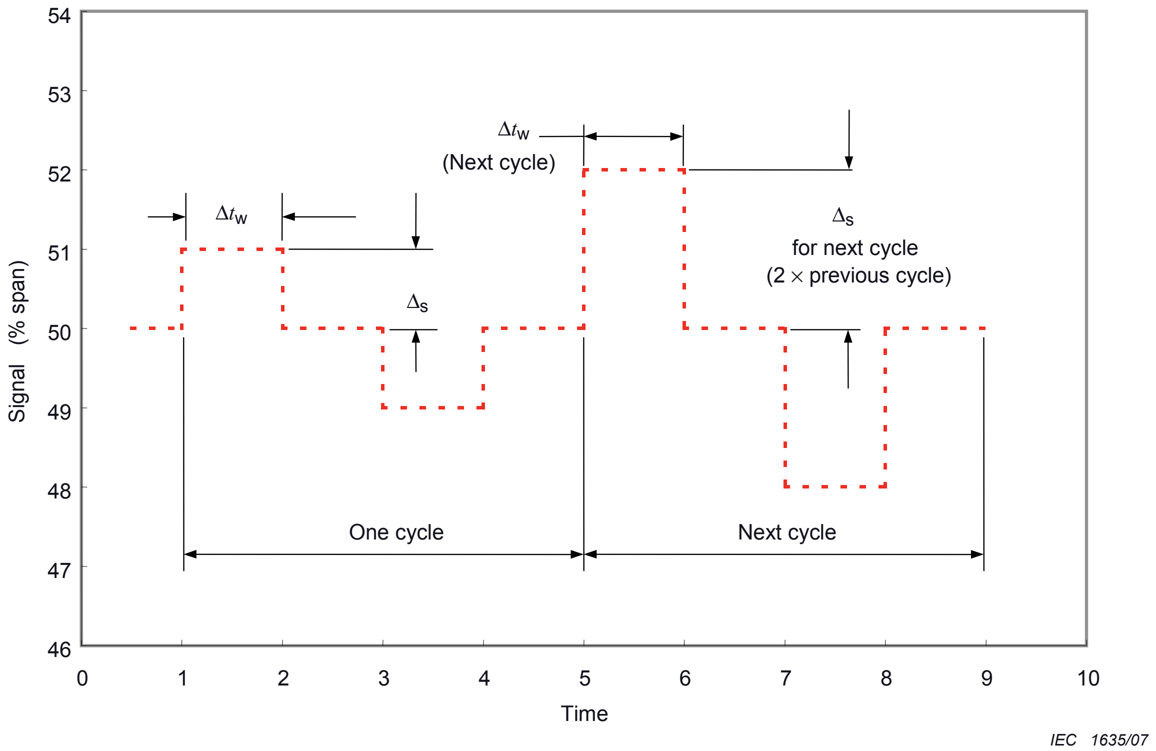


Figure 5 – Signal sequence for small-step test

8.3 Response-time test

The response-time test consists of a series of steps designed to determine the response time, t_{86}, versus step size, Δs, at each of an increasing sequence of step sizes. Response-time tests can also provide approximate values for dead band and resolution. If less precise values for dead band and resolution are acceptable, response-time tests may be used in place of small-step tests. The wait time at the nominal input signal at the beginning can also be increased to 2 min to determine limit cycling rather than performing the optional baseline test.



NOTE The normal nominal position of 50 % is shown but may have other values as required.

Figure 6 – Sample signal step sequence for response time tests

For each step size, a step (or series of steps) up, two (or series of steps) steps down, and then a step (or series of steps) up, each single step followed by a wait time Δ_W, shall be taken. The number of steps down, n_{down}, is two times the number of steps up n_{up}; so the signal returns the nominal value after the second set of steps up.

The input signal and relative travel are recorded during each step.

Figure 6 shows a case where the number of steps up, n_{up}, equals one, the number of steps down, n_{down}, equals two, and the number of steps back up, n_{up}, equals one.

The step size for the first response test shall be set equal to the smallest step size equal to, or just greater than, the resolution (or dead band if it is smaller) from the step-size sequence listed below.

If the small-step test was not run and the step-response test is used to determine the approximate dead band and resolution, the step size for the first response test shall be 0,1 % (unless dead-band and resolution magnitudes or requirements are known to be higher).

Step size sequence: Δs = 0,1 %; 0,2 %; 0,5 %; 1,0 %; 2,0 %; 5,0 % and 10,0 % of input signal span.

Then continue with the next larger step size until a response-time test has been performed with the step size set to each succeeding step size in the above sequence (unless limited by operation conditions). Larger step sizes such as 20 % and 50 % may be used if desired and if operation conditions allow for this.

For example, if the resolution is found to be 0,3 % and is smaller than the dead band, response-time tests shall be performed with Δs set to 0,5 %, 1 %, 2 %, 5 %, and 10 % of the input signal span. (The maximum step size may have to be limited in laboratory and in-process testing in order not to disturb the process or to avoid water hammer, etc.)

The minimum number of steps up, n_{up}, required for each step size is set below so the total input signal change (the number of steps times the step size) in one direction exceeds the quantity 1,2 (dead band + resolution).

$$n_{up} \geq \left[\frac{1{,}2\,(\text{dead band} + \text{resolution})}{\Delta s} \right]$$

This should assure that the signal changes enough to overcome dead band and to move at least one more time in the same direction. Very small step sizes may therefore require more steps.

$$n_{down} = 2n_{up}$$

$$\Delta t_w \geq 5 \times t_{86}$$

Since t_{86} is not known for the particular step size in advance, the minimum allowed Δt_w for the previous, smaller, step can normally be used to meet this requirement.

$$\Delta t_s \leq \frac{t_{86}}{20}$$

[AC1⟩ $\Delta t_{sc} \leq \frac{t_{86B}}{20}$ ⟨AC1]

Values of t_{86} are then determined for each step size from the position data and can be tabulated or presented in a plot. The requirements are listed below.

Data from each response-time test is used to determine the gain G_z by taking the response, ΔZ from a step near the end of a series of steps in the same direction where there appears to be a full response, and dividing by Δs. The gain found from the 2 % response-step test, G_{z02}, is used as a reference gain to determine the gain ratio $G_R = \frac{G_z}{G_{z02}}$.

Δs – for the first response time test, Δs shall be set equal to the smallest step size equal to, or just greater than, the dead band from the step-size sequence.

9 Presentation of test results

9.1 General information

The following general information about the test piece is required in the presentation of test results. Any other conditions affecting the test results (such as deviations from recommended conditions) shall be reported.

– Description of the tested valve, actuator, and positioner, including name of manufacturer, model, serial number, single- or double-acting, and air action.
– Description of the test equipment used, including time constants of transducers and signal conditioning instruments used to measure each variable, names of persons testing and reducing data, and date of test.

- Valve calibration results: signal range, range of valve position, and packing system (for example, tightened to the normal operating state, as defined by the manufacturer), positioner gain and cam characteristic (or positioner parameters) as applicable.
- For laboratory and in-process tests, the process variable including the location of measurement devices and the range used to calculate the percentage of span shall be identified. The description of the process variable should also include an estimate of the response time between the valve movement and the measured change in the response variable.

Where possible, the friction load shall be measured (Annex A) and reported. On the valve assembly, the point where the position measurement is taken relative to the closure member shall be identified. The settings of any other adjustable parameters that could affect the rest of the results shall be recorded.

9.2 Test results

Test results shall be presented in tabular and graphical formats that identify the minimum requirements indicated below as applicable. Figure 7 and Figure 8 are example plots showing results from small-step tests and step-response tests.

9.2.1 Baseline test

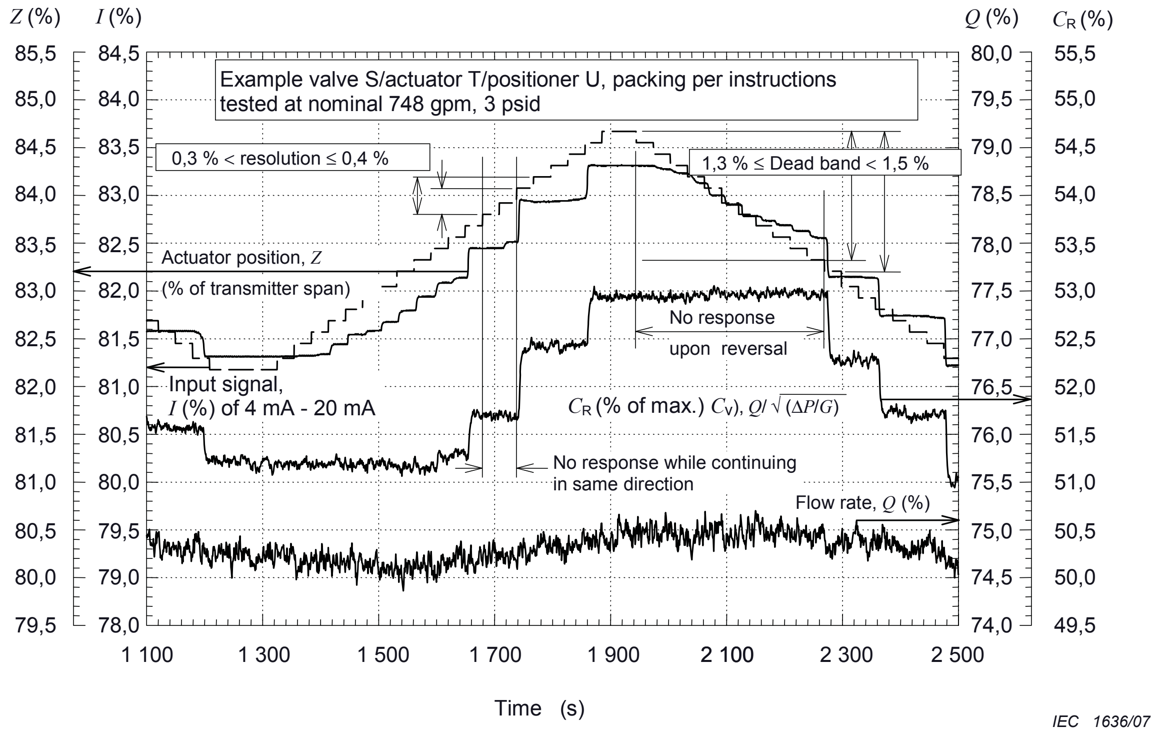
- Relative travel, h
- Test parameters Δt_{s} and Δt_{sc}
- Test results t_{86}, limit cycling peak-to-peak magnitude and period (if any), and overshoot magnitude, and settling time

9.2.2 Small-step test

- Relative travel, h
- Test parameters Δt_{s}, Δt_{sc}, Δt_{w}, Δs, and n
- Test results dead band and resolution
- Limit cycling peak-to-peak magnitude and period (if any) if baseline test not performed

9.2.3 Response-time tests

- Relative travel, h
- Test parameters Δt_{s}, Δt_{sc}, Δt_{w}, n_{up}, n_{down} and Δs for each step size used
- Test results – for each step: t_{86}, overshoot magnitude, and time, and gain ratio $\frac{G_{\mathrm{z}}}{G_{\mathrm{z02}}}$
- Limit cycling peak-to-peak magnitude and period (if any) if baseline test is not performed
- Range of dead band and resolution if small-step tests is not performed
- Results of additional tests or additional data or characteristics may be included at the manufacturer's option or user's request.



NOTE The calculated values of dead band and resolution shown are based on the response coefficient C_R calculated from Q (which was not a true representation of the valve response) and the valve pressure drop (ΔP). It should be noted that the measured relative travel, h, would not be a true representation of valve response in this case, possibly because of lost motion between the position measurement point and the closure member.

Figure 7 – Sample data from small-step test (Δs = 0,13 %) performed in a process loop

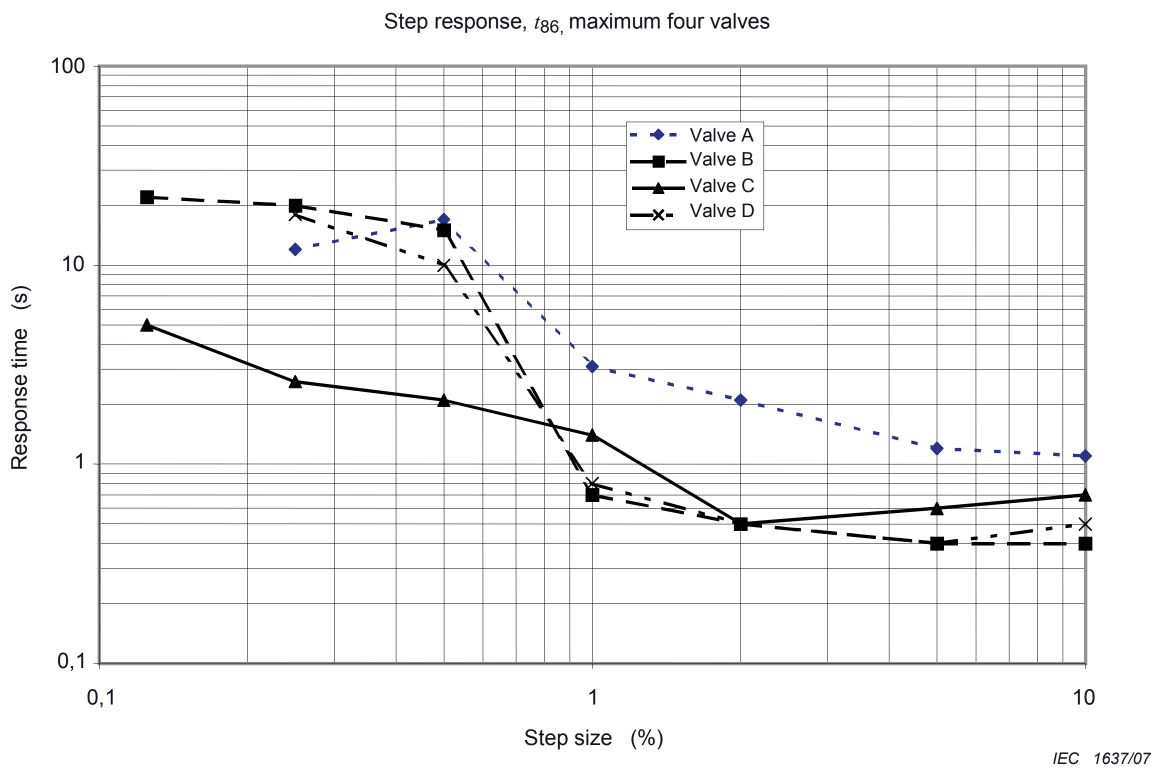


Figure 8 – Sample plot showing step response, t_{86}, versus step size for four different valves

Annex A
(informative)

Sliding friction measurement

The procedure below can be used to measure sliding friction in a control valve system with a pneumatic actuator. Before performing the test, packing should be tightened using manufacturer-recommended procedures and the valve should be cycled the specified number of cycles. This method assumes that the friction and spring forces (or torques) at any particular position are the same whether stroking open or stroking closed.

The increase/decrease rate used in this test shall be

$\frac{\mathrm{d}h}{\mathrm{d}t} = \frac{86}{20 \cdot t_{86(100\,\%)}}$, where $\frac{\mathrm{d}h}{\mathrm{d}t}$ is the increase/decrease rate in % of full stroke/s

and $t_{86(100\ \%)}$ is the step response time at Δs = 100 %.

a) The input signal shall be continuously increased (or decreased) at a rate as defined above until the desired stroke is reached, while measuring the position and the pressures on the top and bottom of the piston or diaphragm as the actuator moves. Ordinarily, the control valve will be stroked from fully open to fully closed (or fully closed to fully open) in this step.

b) The valve shall be stroked in the opposite direction by decreasing (or increasing) the input signal at the same rate as above until the desired stroke is reached, while, again, measuring the same variables measured in a).

c) The friction force shall be calculated at any specified position for a linear valve using the formula

$$F_{\mathrm{f}} = \frac{(p_{\mathrm{b}}\,A_{\mathrm{b}} - p_{\mathrm{t}}\,A_{\mathrm{t}})_{\mathrm{incr}} - (p_{\mathrm{b}}\,A_{\mathrm{b}} - p_{\mathrm{t}}\,A_{\mathrm{t}})_{\mathrm{decr}}}{2} \qquad \text{(A.1)}$$

where

F_{t}	is the friction force;
A_{b}	is the effective area on the bottom of the piston or diaphragm;
A_{t}	is the effective area on the top of the piston or diaphragm;
P_{b}	is the measured pressure on the bottom of the piston or diaphragm at a specified position;
P_{t}	is the measured pressure on the top of the piston or diaphragm at a specified position;
incr, dec	are the subscripts meaning increasing and decreasing signal, respectively,or, for a rotary valve, use the formula

$$T_{\mathrm{f}} = \frac{L\left[(p_{\mathrm{b}}\,A_{\mathrm{b}} - p_{\mathrm{t}}\,A_{\mathrm{t}})_{\mathrm{incr}} - (p_{\mathrm{b}}\,A_{\mathrm{b}} - p_{\mathrm{t}}\,A_{\mathrm{t}})_{\mathrm{decr}}\right]}{2} \qquad \text{(A.2}$$

where

L	is the effective moment arm at the particular position;
T_{f}	is the torque due to friction,

and other variables are the same as defined above. (It should be noted that pressures can be absolute or gauge but should be consistent. It should also be noted that for single-acting actuators or if A_b equals A_t, equations (A.1) and (A.2) can be simplified significantly). No more than two significant figures on friction should be reported.

Bibliography

[1] Control Valve Dynamic Specification, Version 2.1, 3/94, published by EnTech Control Engineering Inc., Toronto

[2] Gibson, J. E. "Nonlinear Automatic Control" McGraw-Hill 1963, p.14

[3] Van De Vegte, J., "Feedback Control Systems", 2nd ed, Prentice Hall, 1990, p.14

[4] McGraw-Hill "Dictionary of Scientific and Technical Terms", fifth edition, 1994

[5] ISA-51.1-1979 (R1993), Process Instrumentation Terminology

[6] ANSI/ISA-TR75.25.02-2000, Control Valve Response Measurement from Step Inputs

[7] ANSI/ISA-TR75.25.01-2000, Test Procedure for Control Valve Response Measurement from Step Inputs

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Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60534-1	– [1)]	Industrial-process control valves - Part 1: Control valve terminology and general considerations	EN 60534-1	2005 [2)]
IEC 60534-4	– [1)]	Industrial process control valves - Part 4: Inspection and routine testing	EN 60534-4	2006 [2)]

[1)] Undated reference.

[2)] Valid edition at date of issue.

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