IEC 60534-9

Edition 1.0 2007-09

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Industrial-process control valves –
Part 9: Test procedure for response measurements from step inputs

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

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FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

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International Standard IEC 60534-9 has been prepared by subcommittee 65B: Devices, of IEC technical committee 65: Industrial-process measurement and control.

The text of this standard is based on the following documents:

FDIS	Report on voting
65B/632/FDIS	65B/639/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The list of all the parts of the IEC 60634 series, under the general title *Industrial-process control valves*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

The contents of the corrigendum of June 2008 have been included in this copy.

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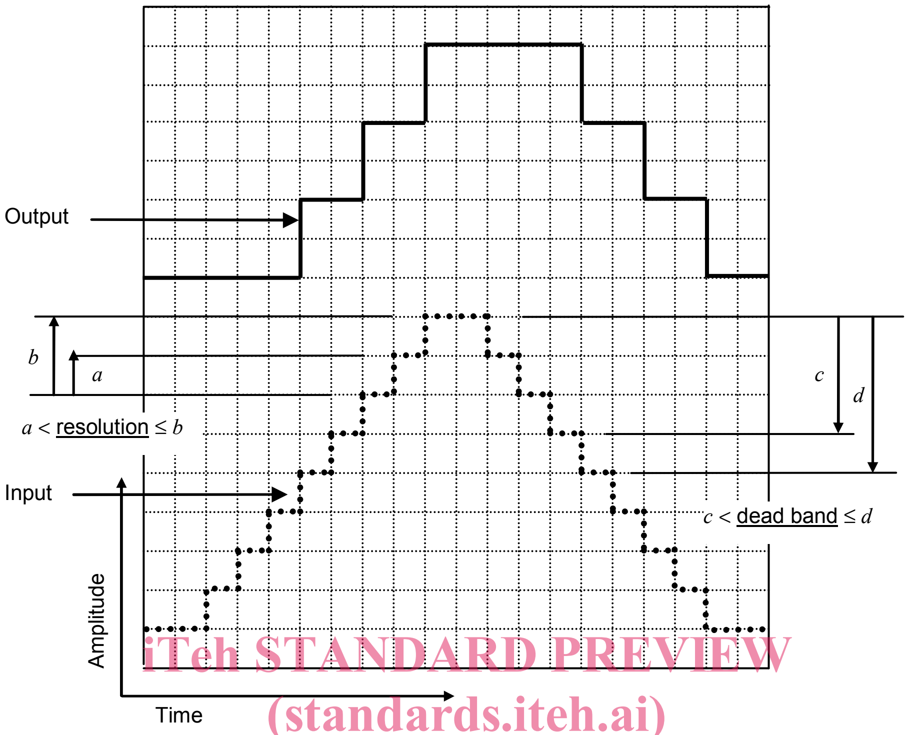
[1] Figures in square brackets refer to the Bibliography.

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.



Dynamics are not shown

IEC 1630/07

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

G_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

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

$\boldsymbol{C}_{\mathrm{R}}$

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:

$$\frac{K_{\mathrm{v}}}{C_{\mathrm{v}}} = 0{,}865$$

3.14

response gain

$\boldsymbol{G}_{\mathrm{Z}}$

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}

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

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

3.15

sampling interval

$\boldsymbol{\Delta t}_{\mathbf{s}}$

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

$\Delta t_{\mathrm{S}} = 1/f_0$

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

$\boldsymbol{f}_0$

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

3.17

sliding friction

$\boldsymbol{F}_{\mathrm{R}}$ **or** $\boldsymbol{T}_{\mathrm{R}}$

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

$G_X = \Delta X / \Delta s$

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
$G_{\mathrm{z}02}$	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.

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

$$\Delta t_{sc} \leq \frac{t_{86}}{20} \qquad (2)$$

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.

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

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

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,

$$C_R = \frac{W}{N_6 Y \sqrt{x p_1 \rho_1}} \tag{4}$$

where

W is the mass flow rate;

p_1 is the upstream absolute pressure in bar;

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

$\mathrm{Y} = 1 - \dfrac{x}{3F_\gamma x_T}$, 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.