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INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Controllers with analogue signals for use in industrial-process control systems –
Part 1: Methods of evaluating the performance**

**Régulateurs à signaux analogiques utilisés pour les systèmes de conduite des processus industriels –
Partie 1: Méthodes d'évaluation des performances**

IEC 60546-1:2010

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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CONTROLLERS WITH ANALOGUE SIGNALS FOR USE IN INDUSTRIAL-PROCESS CONTROL SYSTEMS –

Part 1: Methods of evaluating the performance

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 60546-1 has been prepared by subcommittee 65B: Devices and process analysis, of IEC technical committee 65: Industrial-process measurement, control and automation.

This third edition cancels and replaces the second edition, published in 1987. This third edition constitutes a minor technical revision made to bring terms, measurement units and references up to date.

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

CDV	Report on voting
65B/659A/CDV	65B/717A/RVC

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.

A list of all parts of the IEC 60546 series, under the general title: *Controllers with analogue signals for use in industrial-process control systems,* can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability 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.

INTRODUCTION

The methods of evaluation given in this International Standard are intended for use by manufacturers to determine the performance of their products and by users, or independent testing establishments, to verify manufacturers' performance specifications.

Part 2 of IEC 60546 describes a limited series of tests which may be used as acceptance tests.

The tests specified in this standard are not necessarily sufficient for instruments specifically designed for unusually arduous duties. Conversely, a restricted series of tests may be suitable for instruments designed to perform within a limited range of conditions.

It will be appreciated that the closest liaison should be maintained between an evaluating body and the manufacturer. Note is taken of the manufacturer's specifications for the instrument when the test program is being decided, and the manufacturer should be invited to comment on both the test program and the results. His comments on the results should be included in any report produced by the testing organization.

CONTROLLERS WITH ANALOGUE SIGNALS FOR USE IN INDUSTRIAL-PROCESS CONTROL SYSTEMS –

Part 1: Methods of evaluating the performance

1 Scope

This International Standard applies to proportional-integral-derivative (PID) pneumatic and electric industrial-process controllers using analogue continuous input and output signals which are in accordance with current international standards.

It should be noted that while the tests specified herein cover controllers having such signals, they can be applied in principle to controllers having different but continuous signals. It should be also noted that this standard has been written for pneumatic and electric industrial-process controllers with only analogue components and is not necessarily to be used for controllers with microprocessors.

This standard is intended to specify uniform methods of test for evaluating the performance of industrial-process PID controllers with analogue input and output signals[1)].

The test conditions specified in this standard, for example the range of ambient temperatures, power supply, etc., are used when no other values are agreed upon by the manufacturer and the user.

When a full evaluation in accordance with this standard is not required, those tests which are required shall be performed and the results reported in accordance with those parts of the standard which are relevant. The testing program should be subject to an agreement between manufacturer and user, depending on the nature and the extent of the equipment under consideration.

2 Normative references

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.

IEC 60068-2-6, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-30, *Environmental testing – Part 2-30: Tests – Test Db: Damp heat, cyclic (12 h + 12 h cycle*

IEC 60068-2-31, *Environmental testing – Part 2-31: Tests – Test Ec: Rough handling shocks, primarily for equipment-type specimens*

IEC 61000-4-2, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test*

IEC 61000-4-3, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*

[1)] See IEC 60381 and IEC 60382.

IEC 61010-1, *Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 1: General requirements*

IEC 61298-1, *Process measurement and control devices – General methods and procedures for evaluating performance – Part 1: General considerations*

IEC 61298-3, *Process measurement and control devices – General methods and procedures for evaluating performance – Part 3: Tests for the effects of influence quantities*

IEC 61298-4, *Process measurement and control devices – General methods and procedures for evaluating performance – Part 4: Evaluation report content*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
proportional band
proportional band X_p of a linear controller, expressed in per cent, given by the expression:

$$X_p = \frac{100}{K_p} \tag{1}$$

3.2
direct acting
controller output, which increases with an increase in the measured value

3.3
reverse acting
controller output, which decreases with an increase in the measured value

3.4
offset
steady-state deviation between measured value and set point

3.5
controller, proportional
P
controller which produces proportional control action only

3.6
controller, proportional plus derivative (rate)
PD
controller which produces proportional plus derivative control action

3.7
controller, proportional plus integral (reset)
PI
controller which produces proportional plus integral control action

3.8
controller PID
controller with compound action which produces proportional, plus integral, plus derivative actions

3.9
dead band
finite range of values within which variation of the input variable does not produce any measurable change in the output variable

3.10
average upscale error
arithmetic mean of the errors at each point of measurement for the upscale readings of each measurement cycle

3.11
average downscale error
arithmetic mean of the errors at each point of measurement for the downscale readings of each measurement cycle

3.12
average error
arithmetic mean of all upscale and downscale errors at each point of measurement

3.13
hysteresis
difference between the average upscale error and the average downscale error at each point of measurement

4 Basic relationships

4.1 Input/output relations of idealized controllers

In its simplest form, the relationship may be given by an equation generally presented in one of the following forms:

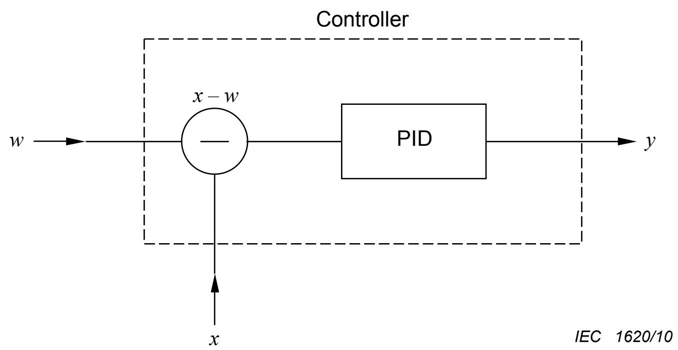

Figure 1 – Basic signals to/from an idealized controller

$$y - y_0 = K_p (x - w) + K_I \int_0^t (x - w) \mathrm{d}t + K_D \frac{\mathrm{d}(x - w)}{\mathrm{d}t} \tag{2}$$

$$y - y_0 = K_p \left[(x - w) + \frac{1}{T_I} \int_0^t (x - w) \mathrm{d}t + T_D \frac{\mathrm{d}(x - w)}{\mathrm{d}t} \right] \tag{3}$$

or in the frequency domain:

$$F(\mathrm{j}\omega) = K_p \left[1 + \frac{1}{\mathrm{j}\omega T_I} \right] + \mathrm{j}\omega T_D \tag{4}$$

These equations are valid for controllers with no interaction between factors K_p, K_1 and K_D. The equation for idealized controllers with interaction taken into account may be written as:

$$y - y_0 = K'_p A \left[(x - w) + \frac{1}{A T'_I} \int_0^t (x - w) \mathrm{d}t + \frac{T'_D \, \mathrm{d}(x - w)}{A \, \mathrm{d}t} \right] \tag{5}$$

In this equation, A is the interaction factor that depends on the structure of the controller. It can often be written as:

$$A = 1 + \frac{T'_D}{T'_I} \quad \text{(6a)}; \qquad K'_p = \frac{K_p}{A} \tag{6b}$$

$$T'_I = 1 + \frac{T_1}{A} \quad \text{(6c)}; \qquad T'_D = A \, T_D \tag{6d}$$

where

t is the time;

y is the output signal (correcting variable);

y_0 is the output signal at time t = 0 (controller output balance);

x is the measured value (controlled variable);

w is the set point value (reference input variable);

K_p is the proportional action factor (proportional action coefficient (see Note 1);

K_1 is the integral action factor (integral action coefficient (see Note 1);

K_D is the derivative action factor (derivative action coefficient (see Note 1);

T_I is the reset time;

T_D is the rate time;

x and w, and consequently also y can be functions of time t, and:

e is the error or controller off-set, i.e.: $x - w$;

ω is the angular velocity.

NOTE 1 For the definition of this term, see IEC 60050-351.

NOTE 2 This standard is limited to P, PI, PD or PID controllers.

NOTE 3 The factors K_p, K_1 and K_D may have the sign “plus” or “minus”; it is usual to associate “direct action” with the positive sign and “reverse action” with the negative sign.

NOTE 4 Symbols with prime (K'_p, T'_I T'_D) represent nominal values, in contrast to effective values.

NOTE 5 Integral-action time constant and derivative-action time constant refer only to pure integral or derivative-action controllers (IEC 60050-351)).

There are controllers with still other structures, for example where the differentiation is applied only to the measured value x, not to $(x - w)$.

Equation (5) therefore becomes:

$$y - y_0 = K_p' A \left[(x - w) + \frac{1}{A\,T_I'} \int_0^t (x - w)\,\mathrm{d}t + \frac{T_D'}{A} \frac{\mathrm{d}}{\mathrm{d}t}(x) \right] \qquad (7)$$

4.2 Limitations

The equations describing the performance of an actual controller are usually different from equations (2) to (7) because they include time constants and limitations.

Two commonly encountered deviations from the idealized controller equations can be expressed as follows:

a) Maximum integral gain V_I

Because of the finite integral gain of actual controllers, the integral part of equations (2) and (3) is an approximation of the actual response only for sufficiently high frequencies. For low frequencies, a controller may have an integral action [integral term of equation (4)] expressed in the frequency domain as follows:

$$F(\mathrm{j}\omega) = K_p \frac{V_I}{1 + \mathrm{j}\omega T_I V_1} \qquad (8)$$

b) Maximum derivative gain V_D

Because of the limited derivative gain of actual controllers, the derivative terms of equations (2) and (3) are an approximation of the actual response only for sufficiently low frequencies. In the most simple case, there may be additional time constant and proportional terms. The derivative term of equation (4) may then be expressed, in the frequency domain, as follows:

Derivative action and time constant

$$F(\mathrm{j}\omega) = K_p \frac{\mathrm{j}\omega T_D}{1 + \mathrm{j}\omega T} \qquad (9)$$

or

proportional action, derivative action and time constant

$$F(\mathrm{j}\omega) = K_p \frac{1 + \mathrm{j}\omega T_D}{1 + \mathrm{j}\omega T} \qquad (10)$$

where

T is the time constant of a first order time delay.

The ratio $\frac{T_D}{T}$ may be constant for all adjustable values of T_D (depending upon the design of the controller). The ratio $\frac{T_D}{T}$ is then called maximum derivative gain or V_D.

4.3 Dial graduation of controllers

The action factors and action times as used in the equations shown above give an idealized description of the performance of a controller. Their values may differ from the values which are the graduations marked on the dials of the controller. The relationship between the dial graduations and the effective values, i.e. the “interaction formula”, shall be provided by the manufacturer. The relationship may be expressed in algebraic form or by graphs, tables, diagrams, etc.

5 General test conditions

5.1 Environmental conditions

As per IEC 61298-1:

5.1.1 Recommended range of ambient conditions for test measurements

Temperature range	15 °C to 35 °C
Relative humidity	45 % to 75 %
Atmospheric pressure	86 kPa to 106 kPa
Electromagnetic field	value to be stated, if relevant

The maximum rate of ambient temperature change permissible during any test shall be 1 °C in 10 min. These conditions may be equivalent to normal operating conditions.

5.1.2 Standard reference atmosphere

Temperature	20 °C
Relative humidity	65 %
Atmospheric pressure	101,3 kPa

This standard reference atmosphere is the atmosphere to which values measured under any other atmospheric conditions are corrected by calculation. It is recognized, however, that in many cases a correction factor for humidity is not possible. In such cases, the standard reference atmosphere takes account of temperature and pressure only.

This atmosphere is equivalent to the normal reference operating conditions usually identified by the manufacturer.

5.1.3 Standard atmosphere for referee measurements

When correction factors to adjust atmospheric-condition-sensitive parameters to their standard reference atmosphere value are unknown, and measurements under the recommended range of ambient atmospheric conditions are unsatisfactory, repeated measurements under closely controlled atmospheric conditions may be conducted.

For the purpose of this standard, the following atmospheric conditions are given for referee measurements.

	Nominal value	Tolerance
Temperature	20 °C	±2 °C
Relative humidity	65 %	±5 %
Atmospheric pressure	86 kPa to 106 kPa	–

For tropical, sub-tropical or other special requirements, alternate referee atmospheres may be used.