

Controllers with analogue signals for use in industrial-process control systems —

Part 1: Methods of evaluating the performance

The European Standard EN 60546-1:1993 has the status of a
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The preparation of this British Standard was entrusted by the Industrial-process Measurement and Control Standards Committee (PCL/-) to Technical Committee PCL/1, upon which the following bodies were represented:

- British Coal Corporation
- British Gas plc
- British Pressure Gauge Manufacturers' Association
- Department of Energy, Gas and Oil Measurement Branch
- Department of Trade and Industry, National Weights and Measures Laboratory
- Energy Industries' Council
- Engineering Equipment and Materials Users' Association
- GAMBICA (BEAMA Ltd.)
- Health and Safety Executive
- Institute of Gas Engineers

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

- British Steel Corporation
- British Valve Manufacturers' Association Ltd.
- Department of Trade and Industry, National Engineering Laboratory
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- Electricity Supply Industry in England and Wales
- Engineering Industries' Association
- Institute of Metals
- Sira Ltd.

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Contents

	Page
Committees responsible	Inside front cover
National foreword	ii
Foreword	2
Introduction	3
1 Scope	3
2 Object	3
3 Basic relations	4
4 Definitions	6
5 General test conditions	7
6 Offset	8
7 Dial markings and scale values	9
8 Effect of influence quantities	11
9 Output characteristics and power consumption	16
10 Frequency response	17
11 Miscellaneous tests	18
12 Documentary information	19
13 Technical examination	19
14 Test report	19
15 Summary of tests	20
Annex ZA (normative) Other international publications quoted in this standard with the references of the relevant European publications	32
Figure 1 — Basic signals to/from an idealized controller	4
Figure 2a — Arrangement for open loop or closed loop tests	23
Figure 2b — Arrangement for measuring air flow	24
Figure 3 — Characteristic of a controller with proportional action only	25
Figure 4 — Recorded characteristics of proportional action	26
Figure 5 — Recorded characteristics of integral action	27
Figure 6 — Recorded characteristics of derivative action	28
Figure 7 — Arrangement for common mode interference test (a.c. generator)	29
Figure 8a — Arrangement for series mode interference test (voltage input)	29
Figure 8b — Arrangement for series mode interference test (current input)	30
Figure 9 — Flow characteristic of a pneumatic controller	31
Figure 10 — Frequency response test results	31
Publications referred to	Inside back cover

National foreword

This Part of BS 5558 has been prepared under the direction of the Industrial-process Measurement and Control Standards Committee. It is identical with IEC Publication 546-1:1987 “*Controllers with analogue signals for use in industrial-process control systems — Part 1: Methods of evaluating the performance*” published by the International Electrotechnical Commission (IEC). This British Standard supersedes BS 5558:1978 which is withdrawn. BS 5558-2 has been published simultaneously with this Part and is a guide to inspection and routine testing. This Part of BS 5558 implements HD 530.1 S1 published by the European Committee for Electrotechnical Standardization (CENELEC). HD 530.1 S1 also corrects the textual error as detailed below.

In 1993 the European Committee for Electrotechnical Standardization (CENELEC) accepted IEC 546-1:1987 as European Standard EN 60546-1:1993. As a consequence of implementing the European Standard this British Standard is renumbered as BS EN 60546-1 and any reference to BS 5558-1 should be read as a reference to BS EN 60546-1. EN 60546-1:1993 supersedes HD 530.1 S1:1989. EN 60546-1 also corrects the textual error as detailed below.

Terminology and conventions. The text of the International Standard has been approved as suitable for publication as a British Standard without deviation. Some terminology and certain conventions are not identical with those used in British Standards; attention is drawn especially to the following.

Cross-references

International Standard	Corresponding British Standard
	BS 2011 <i>Basic environmental testing procedures</i>
IEC 68-2-1:1974	Part 2.1A:1977 <i>Tests A. Cold</i> (Identical)
IEC 68-2-3:1969	Part 2.1Ca:1977 <i>Test Ca. Damp heat, steady state</i> (Identical)
IEC 68-2-6:1982	Part 2.1Fc:1983 <i>Test Fc. Vibration (sinusoidal)</i> (Identical)
IEC 68-2-31:1969	Part 2.1Ec:1977 <i>Test Ec. Drop and topple, primarily for equipment-type specimens</i> (Identical)
IEC 348:1978	BS 4743:1979 <i>Specification for safety requirements for electronic measuring apparatus</i> (Identical)
IEC 381	BS 5863 <i>Analogue signals for process control systems</i> (Identical)
IEC 546-2:1987	BS 5558 <i>Controllers with analogue signals for use in industrial-process control systems</i> Part 2:1989 <i>Guide to inspection and routine testing</i> (Identical)
	BS 6667 <i>Electromagnetic compatibility for industrial-process measurement and control equipment</i>
IEC 801-3:1984	Part 3:1985 <i>Method of evaluating susceptibility to radiated electromagnetic energy</i> (Identical)

The Technical Committee has reviewed the provisions of IEC 382:1971, referred to in clause 1, IEC 27-2A:1975 and IEC 50 (351):1975, referred to in clause 3, and IEC 160:1963, referred to in clause 5, and has decided that they are acceptable for use in conjunction with this standard.

NOTE *Textual error.* In clause 3, equation (3) is incorrect and should read as follows:

$$y - y_0 = K_p A \left[(x - w) + \frac{1}{AT_1} \int_0^t (x - w) dt + \frac{T_D d(x - w)}{A dt} \right]$$

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, the EN title page, pages 2 to 32, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Descriptors: Controller, controller with analogue signals, control system, industrial-process, performance evaluation

English version

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

(IEC 546-1:1987)

Régulateurs à signaux analogiques utilisés
pour les systèmes de conduite des processus
industriels
Première partie: Méthodes d'évaluation des
performances
(CEI 546-1:1987)

Regler mit analogen Signalen für die
Anwendung in Systemen der industriellen
Prozeßtechnik
Teil 1: Methoden der Beurteilung des
Betriebsverhaltens
(IEC 546-1:1987)

This European Standard was approved by CENELEC on 1993-03-09. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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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

Foreword

At the request of CENELEC Reporting Secretariat SR 65B, HD 530.1 S1:1989 (IEC 546-1:1987) was submitted to the CENELEC voting procedure for conversion into a European Standard.

The text of the International Standard was approved by CENELEC as EN 60546-1 on 9 March 1993.

The following dates were fixed:

- latest date of publication of an identical national standard (dop) 1994-03-01
- latest date of withdrawal of conflicting national standards (dow) —

Annexes designated “normative” are part of the body of the standard. In this standard, Annex ZA is normative.

Editorial modification to IEC 546-1:1987

In 3.1, the equation (3) shall read as follows:

$$y - y_0 = K_p A \left[(x - w) + \frac{1}{AT_1} \int_0^t (x - w) dt + \frac{T_D d(x - w)}{A dt} \right]$$

Introduction

The methods of evaluation given in this 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 the standard, IEC Publication 546-2, describes a limited series of tests which may be used as acceptance tests.

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

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 shall be 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.

1 Scope

This standard applies to pneumatic and electric industrial-process controllers using analogue continuous input and output signals which are in accordance with current International Standards.¹⁾

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. These methods of evaluation may also be employed on devices which internally use digital concepts and elements provided the input and output signals are conventional analogue signals.

2 Object

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

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.

¹⁾ IEC Publications 381 and 382.

3 Basic relations

3.1 Input/output relations of idealized controllers

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

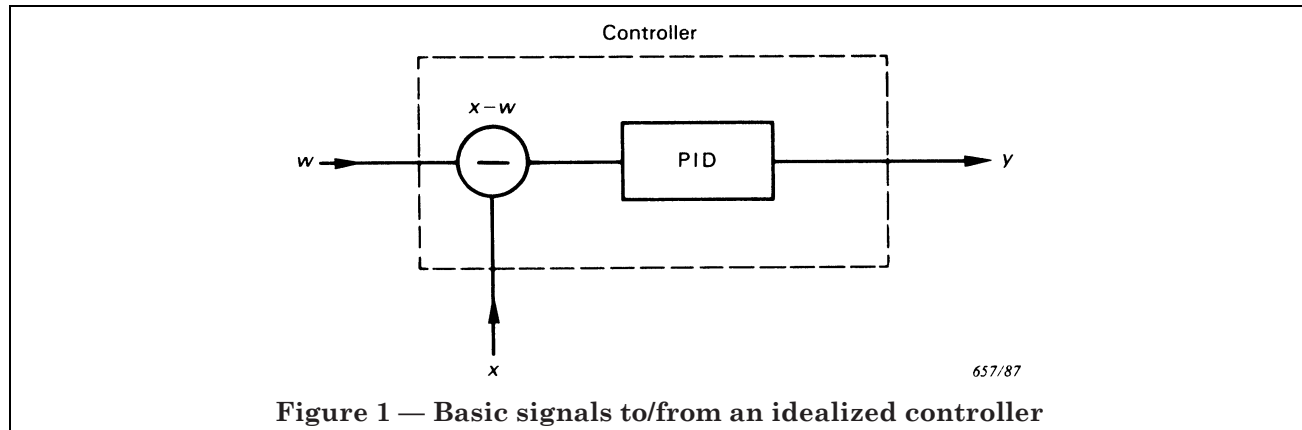


Figure 1 — Basic signals to/from an idealized controller

$$y - y_0 = K_p (x - w) + K_I \int_0^t (x - w) dt + K_D \frac{d(x - w)}{dt} \quad (1)$$

$$y - y_0 = K_p \left[(x - w) + \frac{1}{T_I} \int_0^t (x - w) dt + T_D \frac{d(x - w)}{dt} \right] \quad (2a)$$

or in the frequency domain:

$$F(j\omega) = K_p \left[1 + \frac{1}{j\omega T_I} + j\omega T_D \right] \quad (2b)$$

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

$$y - y_0 = K'_p A \left[(x - w) \frac{1}{A T'_I} \int_0^t (x - w) dt + \frac{T'_D d(x - w)}{A dt} \right] \quad (3)^a$$

^a See national foreword for details of textual error.

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

$$A = 1 + \frac{T'_D}{T'_I} \quad (4a); \quad K'_p = \frac{K_p}{A} \quad (4b);$$

$$T'_I = \frac{T_I}{A} \quad (4c); \quad T'_D = A T_D \quad (4d).$$

where:

- t = time
- y = output signal [correcting variable (see note 1)]
- y_0 = output signal at time $t = 0$ (controller output balance)
- x = measured value [controlled variable (see note 1)]

- w = set point value [reference input variable (see note 1)]
 K_p = proportional action factor [proportional-action coefficient (see note 2)]
 K_I = integral action factor [integral-action coefficient (see note 2)]
 K_D = derivative action factor [derivative-action coefficient (see note 2)]
 T_I = reset time
 T_D = rate time
 x and/or w and consequently also y can be functions of time t
 j = $\sqrt{-1}$
 ω = angular velocity
 $\frac{d}{dt}$ = differential operator

NOTE 1 Definitions of terms in parentheses are given in IEC Publication 27-2A.

NOTE 2 Definitions of terms in parentheses are given in IEC Publication 50 (351).

NOTE 3 This standard is limited to P, PI, PD or PID controllers.

NOTE 4 The factors K_p , K_I 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 5 Symbols with prime (K'_p , T'_I , T'_D) represent nominal values, in contrast to effective values.

NOTE 6 Integral-action time constant and derivative-action time constant refer only to pure integral or derivative-action controllers [IEC Publication 50 (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 (3) becomes thereby:

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

3.2 Limitations

The equations describing the performance of an actual controller are usually different from equations (1) to (5) 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 (1) and (2) 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 (2b)] expressed in the frequency domain as follows:

$$F(j\omega) = K_p \frac{V_I}{1 + j\omega T_I V_I} \quad (6)$$

b) Maximum derivative gain V_D

Because of the limited derivative gain of actual controllers, the derivative terms of equations (1) and (2) are an approximation of the actual response only for sufficiently high frequencies. In the most simple case, there may be additional time constant and proportional terms.

The derivative term of equation (2b) may then be expressed, in the frequency domain, as follows:
 derivative action and time constant

$$F(j\omega) = \frac{j\omega T_D}{1 + j\omega T} \quad (7)$$

or

proportional action, derivative action and time constant

$$F(j\omega) = K_p \frac{1 + j\omega T_D}{1 + j\omega T} \quad (8)$$

where:

T = 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 .

3.3 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.

4 Definitions

4.1

proportional band

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

$$X_p = \frac{100}{K_p} \quad (9)$$

4.2

direct acting

output y increases with increase in the measured value x

4.3

reverse acting

output y decreases with increase in the measured value x

4.4

offset

the steady-state deviation between measured value x and set point w

4.5

controller, proportional (P)

a controller which produces proportional control action only

4.6

controller, proportional plus derivative (rate) (PD)

a controller which produces proportional plus derivative control action

4.7

controller, proportional plus integral (reset) (PI)

a controller which produces proportional plus integral control action

4.8

controller PID

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