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Vesoljska tehnika - Zmogljivost krmiljenja

Space engineering - Control performances

Raumfahrttechnik - Steuerungsleistung

Ingénierie spatiale - Performance de systèmes de contôle

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Space engineering - Control performances

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Raumfahrttechnik - Steuerungsleistung

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Foreword

This document (EN 16603-60-10:2014) has been prepared by Technical Committee CEN/CLC/TC 5 “Space”, the secretariat of which is held by DIN.

This standard (EN 16603-60-10:2014) originates from ECSS-E-ST-60-10C.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2015, and conflicting national standards shall be withdrawn at the latest by March 2015.

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This document has been developed to cover specifically space systems and has therefore precedence over any EN covering the same scope but with a wider domain of applicability (e.g. : aerospace).

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Introduction

This standard focuses on the specific issues raised by managing performance aspects of control systems in the frame of space projects. It provides a set of normative definitions, budget rules, and specification templates applicable when developing general control systems.

The standard is split up in two main clauses, respectively dealing with:

- Performance error indices and analysis methods.
- Stability and robustness specification and verification for linear systems.

This document constitutes the normative substance of the more general and informative handbook on control performance, issued in the frame of the E-60-10 ECSS working group. If clarifications are necessary (on the concepts, the technical background, the rationales for the rules for example) the readers should refer to the handbook.

NOTE It is not intended to substitute to textbook material on automatic control theory, neither in this standard nor in the associated handbook. The readers and the users are assumed to possess general knowledge of control system engineering and its applications to space missions.

1 Scope

This standard deals with control systems developed as part of a space project. It is applicable to all the elements of a space system, including the space segment, the ground segment and the launch service segment.

It addresses the issue of control performance, in terms of definition, specification, verification and validation methods and processes.

The standard defines a general framework for handling performance indicators, which applies to all disciplines involving control engineering, and which can be applied as well at different levels ranging from equipment to system level. It also focuses on the specific performance indicators applicable to the case of closed-loop control systems – mainly stability and robustness.

Rules are provided for combining different error sources in order to build up a performance error budget and use this to assess the compliance with a requirement.

NOTE 1 Although designed to be general, one of the major application field for this Standard is spacecraft pointing. This justifies why most of the examples and illustrations are related to AOCS problems.

NOTE 2 Indeed the definitions and the normative clauses of this Standard apply to pointing performance; nevertheless fully specific pointing issues are not addressed here in detail (spinning spacecraft cases for example). Complementary material for pointing error budgets can be found in ECSS-E-HB-60-10.

NOTE 3 For their own specific purpose, each entity (ESA, national agencies, primes) can further elaborate internal documents, deriving appropriate guidelines and summation rules based on the top level clauses gathered in this ECSS-E-ST-60-10 standard.

This standard may be tailored for the specific characteristic and constrains of a space project in conformance with ECSS-S-ST-00.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revision of any of these publications do not apply, However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

EN reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS System – Glossary of terms

3 Terms, definitions and abbreviated terms

3.1 Terms from other standards

For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply, in particular for the following terms:

error

performance

uncertainty

3.2 Terms specific to the present standard[1]

3.2.1 absolute knowledge error (AKE)

instantaneous value of the knowledge error at any given time

NOTE 1 This is expressed by:

$$AKE(t)=e_K(t)$$

NOTE 2 See annex A.1.3 for defining requirements on the knowledge error.

3.2.2 absolute performance error (APE)

instantaneous value of the performance error at any given time

NOTE This is expressed by:

$$APE(t)=e_P(t)$$

3.2.3 error index

parameter isolating a particular aspect of the time variation of a **performance error** or **knowledge error**

NOTE 1 A performance error index is applied to the difference between the target (desired) output of the system and the actual system output.

[1] As a preliminary note, the error signals introduced in clause 3.2 are very general. They represent any type of physical quantity (e.g. attitude, temperature, pressure, position). According to the situation and to the nature of the control system, they are scalar or multi-dimensional.

NOTE 2 A knowledge error index is applied to the difference between the actual output of the system and the known (estimated) system output.

NOTE 3 The most commonly used indices are defined in this chapter (APE, RPE, AKE etc.). The list is not limitative.

3.2.4 individual error source

elementary physical characteristic or process originating from a well-defined source which contributes to a **performance error** or a performance **knowledge error**

NOTE For example sensor noise, sensor bias, actuator noise, actuator bias, disturbance forces and torques (e.g. microvibrations, manoeuvres, external or internal subsystem motions), friction forces and torques, misalignments, thermal distortions, assembly distortions, digital quantization, control law performance (steady state error), jitter, etc.

3.2.5 knowledge error

difference between the known (estimated) output of the system and the actual achieved output

NOTE 1 It is denoted by e_K.

NOTE 2 Usually this is time dependent.

NOTE 3 Sometimes confusingly referred to as “measurement error”, though in fact the concept is more general than direct measurement.

NOTE 4 Depending upon the system, different quantities can be relevant for parameterising the knowledge error, in the same way as for the performance error. A degree of judgement is used to decide which is most appropriate.

NOTE 5 For example: the difference between the actual and the known orientation of a frame can be parameterised using the Euler angles for the frame transformation or the angle between the actual and known orientation of a particular vector within that frame.

3.2.6 mean knowledge error (MKE)

mean value of the knowledge error over a specified time interval

NOTE 1 This is expressed by:

$$MKE(\Delta t) = \overline{e_K}(\Delta t) = \frac{1}{\Delta t}\int_{\Delta t} e_K(t)\,dt$$

NOTE 2 See annex A.1.4 for discussion of how to specify the interval Δt, and annex A.1.3 for defining requirements on the knowledge error.

3.2.7 mean performance error (MPE)

mean value of the performance error over a specified time interval

NOTE 1 This is expressed by:

$$MPE(\Delta t) = \overline{e_P}(\Delta t) = \frac{1}{\Delta t}\int_{\Delta t} e_P(t)\,dt$$

NOTE 2 See annex A.1.4 for discussion of how to specify the interval Δt .

3.2.8 performance drift error (PDE)

difference between the means of the performance error taken over two time intervals within a single observation period

NOTE 1 This is expressed by:

$$PDE(\Delta t_1, \Delta t_2) = \overline{e_P}(\Delta t_2) - \overline{e_P}(\Delta t_1) = \frac{1}{\Delta t_2}\int_{\Delta t_2} e_P(t)\,dt - \frac{1}{\Delta t_1}\int_{\Delta t_1} e_P(t)\,dt$$

NOTE 2 Where the time intervals Δt_1 and Δt_2 are separated by a non-zero time interval Δt_{PDE}.

NOTE 3 The durations of Δt_1 and Δt_2 are sufficiently long to average out short term contributions. Ideally they have the same duration. See annex A.1.4 for further discussion of the choice of Δt_1 , Δt_2, Δt_{PDE}.

NOTE 4 The two intervals Δt_1 and Δt_2 are within a single observation period

3.2.9 performance error

difference between the target (desired) output of the system and the actual achieved output

NOTE 1 It is denoted by e_P.

NOTE 2 Usually this is time dependent.

NOTE 3 Depending upon the system, different quantities can be relevant for parameterising the performance error. A degree of judgement is used to decide which is most appropriate.

NOTE 4 For example: The difference between the target and actual orientation of a frame can be parameterised using the Euler angles for the frame transformation or the angle between the target and actual orientation of a particular vector within that frame.

3.2.10 performance reproducibility error (PRE)

difference between the means of the performance error taken over two time intervals within different observation periods

NOTE 1 This is expressed by:

$$PRE(\Delta t_1, \Delta t_2) = \overline{e_P}(\Delta t_2) - \overline{e_P}(\Delta t_1)$$
$$= \frac{1}{\Delta t_2} \int_{\Delta t_2} e_P(t)\, dt - \frac{1}{\Delta t_1} \int_{\Delta t_1} e_P(t)\, dt$$

NOTE 2 Where the time intervals Δt_1 and Δt_2 are separated by a time interval Δt_{PRE}.

NOTE 3 The durations of Δt_1 and Δt_2 are sufficiently long to average out short term contributions. Ideally they have the same duration. See annex A.1.4 for further discussion of the choice of Δt_1, Δt_2, Δt_{PRE}.

NOTE 4 The two intervals Δt_1 and Δt_2 are within different observation periods

NOTE 5 The mathematical definitions of the PDE and PRE indices are identical. The difference is in the use: PDE is used to quantify the drift in the performance error during a long observation, while PRE is used to quantify the accuracy to which it is possible to repeat an observation at a later time.

3.2.11 relative knowledge error (RKE)

difference between the instantaneous knowledge error at a given time, and its mean value over a time interval containing that time

NOTE 1 This is expressed by:

$$RKE(t, \Delta t) = e_K(t) - \overline{e_K}(\Delta t)$$
$$= e_K(t) - \frac{1}{\Delta t} \int_{\Delta t} e_K(t)\, dt \qquad t \in \Delta t$$

NOTE 2 As stated here the exact relationship between t and Δt is not well defined. Depending on the system it can be appropriate to specify it more precisely: e.g. t is randomly chosen within Δt, or t is at the end of Δt. See annex A.1.4 for discussion of how to specify the interval Δt, and annex A.1.3 for defining requirements on the knowledge error.

3.2.12 relative performance error (RPE)

difference between the instantaneous performance error at a given time, and its mean value over a time interval containing that time

NOTE 1 This is expressed by:

$$RPE(t, \Delta t) = e_P(t) - \overline{e_P}(\Delta t)$$
$$= e_P(t) - \frac{1}{\Delta t} \int_{\Delta t} e_P(t)\, dt \qquad t \in \Delta t$$

NOTE 2 As stated here the exact relationship between t and Δt is not well defined. Depending on the system it can be appropriate to specify it more precisely: e.g. t is randomly chosen within Δt, or t is at the end of Δt. See annex A.1.4 for further discussion

3.2.13 robustness

ability of a controlled system to maintain some performance or stability characteristics in the presence of plant, sensors, actuators and/or environmental uncertainties

NOTE 1 Performance robustness is the ability to maintain performance in the presence of defined bounded uncertainties.

NOTE 2 Stability robustness is the ability to maintain stability in the presence of defined bounded uncertainties.

3.2.14 stability

ability of a system submitted to bounded external disturbances to remain indefinitely in a bounded domain around an equilibrium position or around an equilibrium trajectory

3.2.15 stability margin

maximum excursion of some parameters describing a given control system for which the system remains stable

NOTE The most frequent **stability margins** defined in classical control design are the gain margin, the phase margin, the modulus margin, and – less frequently – the delay margins (see Clause 5 of this standard)

3.2.16 statistical ensemble

set of all physically possible combinations of values of parameters which describe a **control system**

NOTE For example: Considering the attitude dynamics of a spacecraft, these parameters include the mass, inertias, modal coupling factors, eigenfrequencies and damping ratios of the appendage modes, the standard deviation of the sensor noises etc., that means all physical parameters that potentially have a significant on the performance of the system.