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General requirements for cyber-physically controlled smart machine tool systems (CPSMT) —

Part 1: Overview and fundamental principles

Exigences générales relatives aux systèmes de machines-outils intelligents à commandes cyber-physiques (CPSMT) —

Partie 1: Vue d'ensemble et principaux fondamentaux

Reference number
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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 184 *Automation systems and integration*, Subcommittee SC 1, *Industrial cyber and physical device control*.

A list of all parts in the ISO 23704 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

A machine tool is a key device in manufacturing since it is used indispensably in the production of machine parts used in various industrial areas. Many institutions have long been devoted to technological development from the viewpoint of reducing downtime and defects and are considering smart technologies such as the Internet-of-Things (IoT) as a new means to achieve this.

From the market perspective, there is a variety of so-called smart machine tools incorporating smart technologies based on their own concepts using, e.g. local terminologies by machine tool builders (MTBs), machine tool control, e.g. computerized numerical control (CNC) vendors, solution vendors and service providers, which can be confusing to stakeholders, including end-users. For this and other reasons, standards and substantial modelling for smart machine tool systems are needed.

From the standards perspective, RAMI 4.0 (IEC PAS 63088) and IEC TR 63319[1)] TR-SMRM provide a reference model for Industry 4.0 and smart manufacturing on a high level. The ISO 23247 series defines a generic framework to support the creation of a digital twin of observable manufacturing elements. Furthermore, although some existing standards deal with Industry 4.0 enabling technologies, e.g. OPC-UA (IEC/TR 62541-1), MTConnect (ANSI/MTC1.4-2018), ISO/IEC 30141, the IEC 62769 series, and many machine tool standards from ISO TC39, no standard yet exists for smart machine tools for realizing smart manufacturing / Industry 4.0 in the shop floor via cyber-physical systems (CPSs).

The ISO 23704 series specifies general requirements on smart machine tools for supporting smart manufacturing in the shop floor via cyber-physical system control scheme, namely cyber-physically controlled smart machine tool systems (CPSMT).

Figure 1 shows the overall structure of the ISO 23704 series, including:

— Overview and fundamental principles of a CPSMT in ISO 23704-1,

— Reference architecture of a CPSMT for subtractive manufacturing in ISO 23704-2, and

— Reference architecture of a CPSMT for additive manufacturing in ISO 23704-3[2)].

Other related parts such as implementation guidelines or reference architectures for other types of manufacturing will be added if and when necessary.

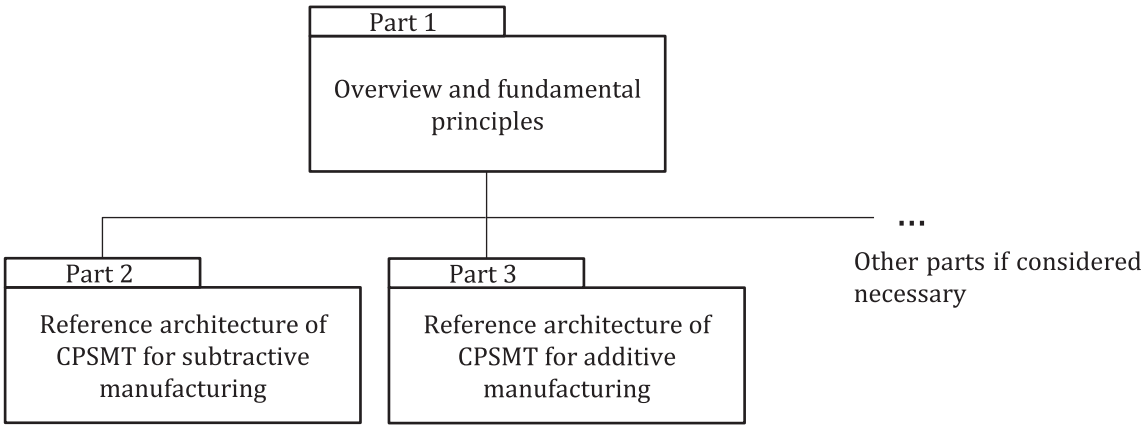

Figure 1 — Overall structure of the ISO 23704 series on general requirements for cyber-physically controlled smart machine tool systems (CPSMT)

This document can be used as a reference and guidelines for users such as, but not limited to:

a) Design engineers in the area of smart machine tools,

1) Under development. Stage at the time of publication: IEC/DTR 63319.

2) Under development. Stage at the time of publication: ISO/DIS 23704-3.

b) System architects in the area of smart machine tools,

c) Software engineers at the MTBs in the area of smart machine tools,

d) Machine tool control vendors in the area of smart machine tools,

e) Solution and service providers in the area of smart machine tools, and

f) End users, such as factory operators working with smart machine tools.

General requirements for cyber-physically controlled smart machine tool systems (CPSMT) —

Part 1: Overview and fundamental principles

1 Scope

This document specifies the concept and fundamental principles of cyber-physically controlled smart machine tool systems (CPSMT) and requirements, including

— the reference architecture of a CPSMT,

— the key components and interfaces which together make up the reference architecture of a CPSMT, and

— the capabilities of a CPSMT.

This document also provides:

— the background for a CPSMT,

— the concept of a shop floor device system (SFDS), and

— example use cases of the reference architecture of a CPSMT.

This document does not specify physical or implementation architecture.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms and definitions

3.1.1
abnormality
deviation from a standard condition

EXAMPLE Chatter, tool wear above prescribed limits, geometric inaccuracy, energy over-consumption.

[SOURCE: ISO 13372:2012, 4.1, modified — EXAMPLES added.]

3.1.2
additive manufacturing
process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to *subtractive manufacturing* (3.1.29) and formative manufacturing methodologies,

[SOURCE: ISO/ASTM 52900:2015, 2.1.2, modified — Notes 1 and 2 to entry deleted.]

3.1.3
administration shell
virtual digital and active representation of an *Industry 4.0 component* (3.1.18) in the Industry 4.0 system (3.1.19)

[SOURCE: Industrie 4.0 – Begriffe/Terms VDI Status report Industrie 4.0 (April 2017) modified — Notes 1 and 2 to entry deleted.]

3.1.4
computerized numerical control
CNC
automatic control of a process performed by a device that makes use of numerical data introduced while the operation is in progress

[SOURCE: ISO 2806:1994, 2.1.1]

3.1.5
cyber-physically controlled smart machine tool systems (CPSMT) associated system
CPSMT associated system
set of *CPSMT* (3.1.10) components to interface with the *CPSMT primary system* (3.1.6), including *shop floor device system (SFDS)* (3.1.24), *shop floor control system (SFCS)* (3.1.23), and *unified interface system (UIS)* (3.1.30)

3.1.6
cyber-physically controlled smart machine tool systems (CPSMT) primary system
CPSMT primary system
set of *cyber-physically controlled machine tool (CPSMT)* (3.1.10) components including *cyber-physically controlled machine tool (CPCM)* (3.1.9) and *cyber-supporting system for machine tool (CSSM)* (3.1.12)

3.1.7
cyber-physical manufacturing system
CPMS
manufacturing system based on an analogy of RAMI 4.0 from a cyber-physical perspective, comprised of a) a physical manufacturing system, composed of an office floor and shop floor, and b) the *cyber-supporting system (CSS)* (3.1.11), supporting the physical manufacturing system via monitoring, analysis, planning, and execution based on big data analytics / artificial intelligence, and *digital twin* (3.1.14) (MAPE / BD).

Note 1 to entry: The definition is based on reference [33].

Note 2 to entry: More details on the MAPE/BD concept are given in reference [36].

3.1.8
cyber-physical system
CPS
physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core

Note 1 to entry: The definition is taken from Rajkumar et al.[30]

3.1.9
cyber-physically controlled machine tool
CPCM
physical machine tool system, controlled by a cyber-physical control scheme, providing a more advanced control function via *cyber-physical system (CPS)* (3.1.8) unit in addition to the conventional machine control

Note 1 to entry: The CPS unit is the part of the reference architecture for different technologies responsible for performing the CPS function

3.1.10
cyber-physically controlled smart machine tool system
CPSMT
smart machine tool system, supporting smart manufacturing and Industry 4.0 on the shop floor via a *cyber-physical system* (3.1.8) control scheme

3.1.11
cyber-supporting system
CSS
cyber-system that supports a physical system for the enhancement of performance of a physical system via monitoring, analysis, planning, and execution based on big data analytics / artificial intelligence, and *digital twin* (3.1.14) (MAPE / BD)

3.1.12
cyber-supporting system for machine tool
CSSM
cyber-supporting system (3.1.11) for *cyber-physically controlled machine tools (CPCMs)* (3.1.9) that provides decisions from the viewpoint of *abnormality* (3.1.1) resolution, and provides CPCM abnormality data to a *shop floor control system (SFCS)* (3.1.23) and external systems including humans, life cycle aspects, and hierarchy level

3.1.13
data
reinterpretable representation of information in a formalized manner suitable for communication, interpretation, or processing

Note 1 to entry: Data can be processed by humans or by automatic means.

[SOURCE: ISO/IEC 2382-1:1993, 2121272, modified — Notes 2 and 3 to entry were deleted.]

3.1.14
digital twin
digital replica of physical assets (physical twin), processes and systems that can be used for various purposes or a fit-for-purpose digital representation of something outside its own context with data connections that enable convergence between the physical and virtual states at an appropriate rate of synchronization

Note 1 to entry: The definition is from the ISO TC184 Ad Hoc Group on the digital twin.

Note 2 to entry: The digital twin is used by the cyber supporting system for the machine tool (CSSM) as an interrogable cyber model of the machine tool for analysis and planning stages of the MAPE.

3.1.15
event
noteworthy occurrence that happens at a point in time or during a temporal interval

[SOURCE: ISO/IEC 15938-5:2003, 3.3.2.14.]

3.1.16
event-driven
methodology that focuses on *events* (3.1.15) and their dependency

3.1.17
hard-real time
time based operational characteristic in which processing of data by a computer in connection with another process outside the computer is incorrect if results are not produced according to specified timing requirements

Note 1 to entry: The hard-real time definition is based on reference [12].

3.1.18
Industry 4.0 component
globally uniquely identifiable participant with communication capability consisting of an *administration shell* (3.1.3) and an asset (corresponds to classification of Communication and Presentation (CP) 24, CP34 or CP44) within an *Industry 4.0 system* (3.1.19) which offers services with defined quality of service characteristics

Note 1 to entry: CP24, CP34 and CP44 are classifications of Communication and Presentation for Industry 4.0. The first digit indicates the communication capability and the second the degree of familiarity. CP24 means "capable of passive communication" and "managed as an entity". CP34 means "capable of active communication" and "managed as an entity". CP44 means "capable of I4.0 conformal communication" and "managed as an entity".

[SOURCE: Industrie 4.0 — Begriffe/Terms VDI Statusreport Industrie 4.0 (April 2017), modified: Notes 1 and 2 to entry deleted, Communication and Presentation (CP) added.]

3.1.19
Industry 4.0 system
system, consisting of *Industry 4.0 components* (3.1.18) and components of a lower Communication and Presentation (CP) classification, which serves a specific purpose, has defined properties and supports standardized services and states

[SOURCE: Industrie 4.0 — Begriffe/Terms VDI Statusreport Industrie 4.0 (April 2017), modified: CP expanded to "Communication and Presentation (CP)", Notes 1, 2 and 3 to entry deleted]

3.1.20
key performance indicator
KPI
quantifiable level of achieving a critical objective

Note 1 to entry: The KPIs are derived directly from or through an aggregation function of physical measurements, data and / or other KPIs.

[SOURCE: ISO 22400-1:2014, 2.1.5]

3.1.21
machine tool
mechanical device that is fixed (i.e. not mobile) and powered (typically by electricity and compressed air), typically used to process workpieces by selective removal / addition of material or mechanical deformation

Note 1 to entry: Machine tool operation can be mechanical, controlled by humans, or by computers. Machine tools may have a number of peripherals used for machine tool cooling / heating, process conditioning, workpiece and tool handling (workpiece feeding excluded), recyclables and waste handling, and other tasks connected to their main activities.

[SOURCE: ISO 14955-1:2017, 3.16]

3.1.22
reference architecture
core architecture that captures the high-level architecture concept of domain architecture

[SOURCE: ISO/IEC 26552:2019, 3.9, modified — “and application architecture” deleted.]

3.1.23
shop floor control system
SFCS
system that controls a shop floor system including a *shop floor device system (SFDS)* (3.1.24) and a *cyber-physically controlled machine tool (CPCM)* (3.1.9) in a collaborative fashion for the enhancement of the performance of the shop floor

3.1.24
shop floor device system
SFDS
set of devices, including production facilities and material handlers, on the shop floor

Note 1 to entry: A shop floor device x with the controller is regarded as having its own cyber-physically controlled x (CPCx), and cyber-supporting system x (CSSx).

3.1.25
smart machine tool
machine tool (3.1.21) that supports the vision, characteristics, and capabilities of smart manufacturing

Note 1 to entry: Details of smart manufacturing are described in IEC TR 63319[24].

3.1.26
smart manufacturing
manufacturing that improves its performance aspects with integrated and intelligent use of processes and resources in 'cyber,' 'physical,' and 'human' spheres to create and deliver products and services, which also collaborate with other domains within enterprise value chains

Note 1 to entry: The definition is from IEC TR 63319[26]

3.1.27
smart manufacturing reference model
SMRM
framework for understanding significant relationships among the entities involved in smart manufacturing and for the development of consistent standards or specifications that support smart manufacturing

Note 1 to entry: The definition is from IEC TR 63319[26]

3.1.28
soft-real time
time-based operational characteristic in which processing of data by a computer in connection with another process outside the computer is degraded if results are not produced according to specified timing requirements

Note 1 to entry: The soft-real time definition is based on reference [12].

3.1.29
subtractive manufacturing
process of machining, grinding or reducing a larger bulk object to create a smaller detailed three-dimensional object using computer-aided design software and computer-aided manufacturing methods

[SOURCE: ISO 18739:2016, 3.1.37]

3.1.30
unified interface system
UIS
system that incorporates interfaces with: a) a *cyber-physically controlled machine tool (CPCM)* (3.1.9), b) a *cyber-supporting system for machine tool (CSSM)* (3.1.12), c) a shop floor device system (SFDS), d) a shop floor control system (SFCS), e) humans, f) life cycle aspects and g) hierarchy level

Note 1 to entry: The UIS is an advanced concept of human-machine interface incorporating a wide range of systems, including the life cycle aspect and hierarchy level.

3.2 Abbreviated terms

CNC	computerized numerical control
CP	communication and presentation
CPCM	cyber physically controlled machine tool
CPMS	cyber physical manufacturing system
CPS	cyber physical system
CPSMT	cyber-physically controlled smart machine tool
CRM	customer relationship management
CSS	cyber supporting system
CSSM	cyber supporting system for machine tool
ERP	enterprise resource planning
HMI	human machine interface
KPI	key performance indicator
MAPE/BD	monitoring, analysis, planning and execution based on big data and digital twin
MES	manufacturing execution system
MTB	machine tool builder
RAMI 4.0	reference architecture model industries 4.0
SCM	supply chain management
SFCS	shop floor control system
SFDS	shop floor device system
SMRM	smart manufacturing reference model
UIS	unified interface system

4 Conformance with the CPSMT reference architecture

To claim conformance, the definition of a specific system architecture, as provided by a vendor or system integrator, should use the terminology, architectural concepts, and have the capabilities defined in this document, within the scope of their specific use cases.

5 Goals and objectives of the CPSMT reference architecture

The CPSMT reference architecture describes generic smart machine tools to support Industry 4.0 and smart manufacturing via a cyber-physical system (CPS). It provides guidance for designers developing smart machine tool systems and aims to give a better understanding of smart machine tools to the stakeholders of such systems.

NOTE Examples of stakeholders are MTBs, computerized numerical control (CNC) and other machine control vendors, solution vendors, application developers, service providers, customers and end-users.

A CPSMT reference architecture supports the following standardization objectives:

a) To ensure clear and unambiguous communication between all interested parties of smart machine tools.

b) To ensure the interoperability of smart machine tools with related hardware devices, software, service and manufacturing systems.

c) To ensure the quality / capability of smart machine tools.

d) To ensure the use of smart machine tools.