BS ISO 23704-3:2023

BSI Standards Publication

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

Part 3: Reference architecture of CPSMT for additive manufacturing

Documents
Document Sharing Hub

Full document details: BS ISO 23704-3:2023

National foreword

This British Standard is the UK implementation of ISO 23704-3:2023.

The UK participation in its preparation was entrusted to Technical Committee AMT/4, Industrial data and manufacturing interfaces.

A list of organizations represented on this committee can be obtained on request to its committee manager.

Contractual and legal considerations

This publication has been prepared in good faith, however no representation, warranty, assurance or undertaking (express or implied) is or will be made, and no responsibility or liability is or will be accepted by BSI in relation to the adequacy, accuracy, completeness or reasonableness of this publication. All and any such responsibility and liability is expressly disclaimed to the full extent permitted by the law.

This publication is provided as is, and is to be used at the recipient's own risk.

The recipient is advised to consider seeking professional guidance with respect to its use of this publication.

This publication is not intended to constitute a contract. Users are responsible for its correct application.

© The British Standards Institution 2023
Published by BSI Standards Limited 2023

ISBN 978 0 539 15989 9

ICS 25.040.20

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 March 2023.

Amendments/corrigenda issued since publication

Date	Text affected

Documents
Document Sharing Hub

Full document details: BS ISO 23704-3:2023

INTERNATIONAL STANDARD

ISO 23704-3

First edition
2023-03

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

Part 3: Reference architecture of CPSMT for additive manufacturing

Reference number
ISO 23704-3:2023(E)

Documents
Document Sharing Hub

© ISO 2023

Full document details: BS ISO 23704-3:2023

COPYRIGHT PROTECTED DOCUMENT

© ISO 2023

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

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

Published in Switzerland

© ISO 2023 – All rights reserved

Documents
Document Sharing Hub

Full document details: BS ISO 23704-3:2023

Contents

Page

Foreword ... **v**

Introduction ... **vi**

1 Scope ... **1**

2 Normative references ... **1**

3 Terms, definitions and abbreviated terms ... **1**
3.1 Terms, definitions and abbreviations ... 2
3.2 Symbols and abbreviated terms ... 4

4 Conformance with the CPSMT reference architecture for additive manufacturing (AM) ... **4**

5 Goals and objectives of the CPSMT reference architecture for AM ... **4**

6 Technical requirements of a smart additive manufacturing system (SAMS) from the CPSMT perspective ... **6**
6.1 General ... 6
6.2 Technical requirements of autonomously dealing with abnormalities ... 7
6.2.1 General ... 7
6.2.2 Dealing with hard real-time scale abnormalities during an AM process ... 7
6.2.3 Dealing with soft real-time scale abnormalities during an AM process ... 8
6.2.4 Acquisition of data related to an AM process ... 8
6.2.5 Data processing related to an AM process ... 8
6.2.6 Extraction of value-added data ... 8
6.2.7 AM process monitoring ... 9
6.2.8 AM process status prediction ... 9
6.2.9 AM process status diagnosis ... 9
6.2.10 Making decisions about the AM system to enhance AM process performance ... 10
6.2.11 Update of the AM workflow data ... 10
6.2.12 Dealing with abnormalities ... 10
6.3 Technical requirements of autonomous coordination with shop floor devices ... 11
6.3.1 General ... 11
6.3.2 Coordination among shop floor devices ... 11
6.4 Technical requirements of autonomous collaboration with a shop floor control system ... 12
6.4.1 General ... 12
6.4.2 Receiving a coordinated process plan ... 12
6.4.3 Providing the AM process data for shop floor operation ... 12
6.4.4 Interoperability for the data interface ... 12
6.5 Technical requirements of interface with AM workflow ... 13
6.5.1 General ... 13
6.5.2 Interface with AM workflow ... 13
6.5.3 Interoperability for interface with AM workflow ... 13
6.6 Technical requirement of interface with hierarchy levels ... 13
6.6.1 General ... 13
6.6.2 Interface with a hierarchy level ... 13
6.6.3 Interoperability for interface with hierarchy level ... 14
6.7 Technical requirement of interface with humans ... 14
6.7.1 General ... 14
6.7.2 Interface with humans ... 14
6.7.3 Interoperability for interface with humans ... 14

7 Reference architecture of a CPSMT for AM ... **14**

8 Functional view of a CPCM for additive manufacturing (AM) ... **17**
8.1 General ... 17
8.2 AM machine unit (AMU) of a CPCM ... 17

Documents
Document Sharing Hub

© ISO 2023 – All rights reserved

Full document details: BS ISO 23704-3:2023

8.2.1 General 17
8.2.2 AM function perspective 17
8.2.3 AM process perspective 17
8.2.4 AM component perspective 18
8.2.5 Abnormalities of an AM machine unit (AMU) 19
8.3 Cyber-physical system (CPS) unit 19
8.3.1 General 19
8.3.2 Inner-loop element 20
8.3.3 Intra-loop element 22
8.3.4 Inter-loop element 23

9 Functional view of a CSSM for AM 23
9.1 General 23
9.2 Data processing unit (DPU) 24
9.2.1 General 24
9.2.2 CPCM interface element 24
9.2.3 UIS interface element 24
9.2.4 Data fusion element 25
9.2.5 Data storage element 25
9.2.6 Data transformer for external entities element 25
9.3 Digital thread unit 26
9.3.1 General 26
9.3.2 AM workflow data model 26
9.3.3 AM workflow data management 30
9.3.4 AM behaviour model 30
9.3.5 Behaviour model engine 30
9.4 MAPE unit 31
9.4.1 General 31
9.4.2 Monitoring element 31
9.4.3 Analysis element 31
9.4.4 Planning element 32
9.4.5 Execution element 32
9.5 External interface unit 32
9.5.1 General 32
9.5.2 Interface schema element 33
9.5.3 Interface manager element 33

10 Interface view of a CPSMT for AM 33
10.1 General 33
10.2 CPCM interface 34
10.2.1 General 34
10.2.2 External interface with a CPCM 34
10.2.3 Internal interface with a CPCM 35
10.3 CSSM interface 35
10.3.1 General 35
10.3.2 External interface with a CSSM 36
10.3.3 Internal interface with a CSSM 36

Annex A (informative) **Collected stakeholder requirements on smart additive manufacturing system (SAMS) 38**

Annex B (informative) **Concept of the digital thread in AM 40**

Annex C (informative) **Types of abnormality in AM 41**

Annex D (informative) **Example use cases of reference architecture of a CPSMT for additive manufacturing (AM) 43**

Bibliography 49

© ISO 2023 – All rights reserved

Documents
Document Sharing Hub
Full document details: BS ISO 23704-3:2023

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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.

© ISO 2023 – All rights reserved

Documents
Document Sharing Hub
Full document details: BS ISO 23704-3:2023

Introduction

According to ISO/ASTM 52900, additive manufacturing (AM) is the process of joining materials to make a part from 3D model data usually layer by layer. With the advancement of various feedstocks, process technologies, and product design methodologies, AM contributes to realizing customized production, which is the key objective of Industry 4.0. Also, AM allows construction of complex geometry and other features that were previously impossible or impractical to manufacture.

Many institutions have long been devoted to technological development from the viewpoint of reducing downtime and defects and are considering smart technologies such as Internet-of-Things (IoT) as a new means to achieve this.

From the market perspective, many institutions have released various smart additive manufacturing systems (SAMS) based on their own concepts and local terminologies. This makes stakeholders confused about the common concept of SAMS, including end-users. For this reason, standards and substantial modelling for a SAMS are needed.

From the standards perspective, for standards on contemporary AM technology, there is a set of standards and a roadmap from ISO TC261/ASTM F42. For standards on smart manufacturing, RAMI 4.0 (IEC/PAS 63088) and IEC TR 63319 TR-SMRM provide a reference model for smart manufacturing on a high level. Even though some standards deal with Industry 4.0 enabling technologies, e.g. OPC-UA (IEC/TR 62541-1 and Reference [67]), MTConnect (ANSI/MTC1.4-2018), ISO/IEC 30141, IEC 62769, there are no standards specifying the SAMS.

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 CPSMT in ISO 23704-1;

— Reference architecture of CPSMT for subtractive manufacturing in ISO 23704-2;

— Reference architecture of CPSMT for AM in ISO 23704-3.

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

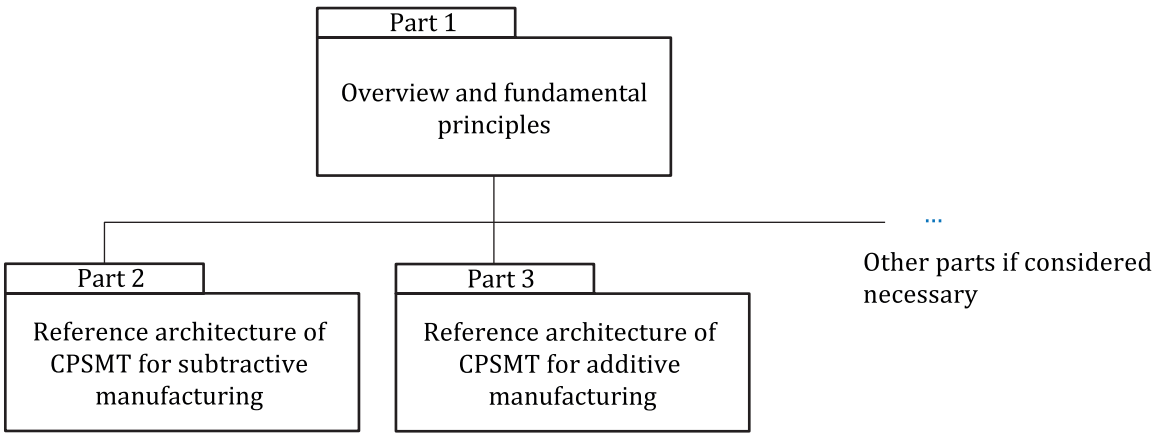

Figure 1 — Overall structure of the ISO 23704 series on general requirements for cyber-physically controlled smart machine tool systems (CPSMT)

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

— Design engineers in the area of SAMS,

© ISO 2023 – All rights reserved
Documents
Document Sharing Hub
Full document details: BS ISO 23704-3:2023

— System architects in the area of SAMS,

— Software engineers working with the AM machine builders in the area of SAMS,

— Machine tool control vendors in the area of SAMS,

— Solution and service providers in the area of SAMS, and

— End users such as factory operators working with SAMS.

© ISO 2023 – All rights reserved

Documents
Document Sharing Hub
Full document details: BS ISO 23704-3:2023

Documents
Document Sharing Hub

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

Part 3: Reference architecture of CPSMT for additive manufacturing

1 Scope

This document specifies a reference architecture of cyber-physically controlled smart machine tool systems (CPSMT) for additive manufacturing (AM) based on the reference architecture of CPSMT as provided in ISO 23704-1 and the requirements for cyber-physically controlled smart additive manufacturing system.

The reference architecture of a CPSMT for AM includes:

— the technical requirements for the smart additive manufacturing system (SAMS),

— the reference architecture of the cyber-physically controlled machine tools (CPCM) for AM,

— the reference architecture of the cyber-supporting system for machine tools (CSSM) for AM, and

— the interface view of the CPSMT for AM.

This document also provides:

— stakeholder requirements for the SAMS,

— the concept of the digital thread,

— types of abnormality in AM, and

— use cases of reference architecture of a CPSMT for AM.

This document does not specify physical or implementation architecture.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements for this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 23704-1, *General requirements for cyber-physically controlled smart machine tool systems (CPSMT) — Part 1: Overview and fundamental principles*

ISO 23704-2, *General requirements for cyber-physically controlled smart machine tool systems (CPSMT) — Part 2: Reference architecture of CPSMT for subtractive manufacturing*

ISO/ASTM 52900, *Additive manufacturing — General principles — Fundamentals and vocabulary*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 23704-1, ISO 23704-2, ISO/ASTM 52900, and the following apply.

© ISO 2023 – All rights reserved

AVA Documents Document Sharing Hub
Full document details: BS ISO 23704-3:2023

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, definitions and abbreviations

3.1.1
additive manufacturing component
AM component
single piece or group of pieces forming a functional unit within an additive manufacturing (AM) machine *unit* (3.1.15)

3.1.2
additive manufacturing function
AM function
function performed by an additive manufacturing (AM) machine *unit* (3.1.15) instance

3.1.3
additive manufacturing machine unit
AM machine unit
AMU
instance of a cyber-physically controlled machine tool (CPCM) for additive manufacturing (AM) in the reference architecture of cyber-physically controlled smart machine tool systems (CPSMT) for AM

3.1.4
additive manufacturing process
AM process
process of joining materials to make a part from a 3D model data layer by layer in the reference architecture of a cyber-physically controlled machine tool (CPCM) for additive manufacturing (AM)

Note 1 to entry: Definition is based on the ISO/ASTM 52900 definition of single-step AM process in Annex B.

3.1.5
additive manufacturing workflow
AM workflow
sequence of process steps involved in producing a physical part using additive manufacturing

Note 1 to entry: The AM workflow consists of a) product design, b) feedstock, c) build preparation, d) process control, e) post-processing, f) quality control, and g) part.

3.1.6
build motion
machine movements needed for creating a product with feedstock / support

Note 1 to entry: Feedstock and support are defined in ISO/ASTM 52900 in the context of additive manufacturing.

3.1.7
build process
realization of the material joining by providing a source of activation

Note 1 to entry: Joining means realization of consolidation of the raw material to create the final form using a material activation method.

Note 2 to entry: Example activation methods are binding mechanism, chemical reaction or heating.

© ISO 2023 – All rights reserved
Documents
Document Sharing Hub
Full document details: BS ISO 23704-3:2023

3.1.8
cyber physical system unit
CPS unit
collection of functional entities responsible for advanced cyber-physical control

Note 1 to entry: ISO 23704-1:2022, 3.1.8 defines a CPS (Cyber-Physical System) as a physical and engineered system whose operations are monitored, coordinated, controlled and integrated by a computing and communication core.

Note 2 to entry: The CPS unit provides advanced control functionalities for the *machine tool unit* (3.1.13), interfacing with data from sensors, numerical control kernel / programmable logic controller, the cyber-supporting system for machine tool (CSSM), shop floor control system (SFCS), and unified interface system (UIS).

3.1.9
cyber-physically controlled smart additive manufacturing system
CPSAM
smart additive manufacturing system (SAMS) (3.1.14) viewed from the capabilities of cyber-physically controlled smart machine tool systems (CPSMT)

Note 1 to entry: See ISO 23704-1:2022, Clause 10 for the capabilities of CPSMT.

3.1.10
digital thread
framework that provides an integrated view of all data throughout the *AM workflow* (3.1.5)

Note 1 to entry: The digital thread manages a record of a product from its creation to its removal. The CAx chain (CAD, CAPP, CAE, CAM, CNC, CMM) is a key enabler for this, based on Reference [104].

Note 2 to entry: The data are interconnected in a series of feedback and feedforward loops.

Note 3 to entry: For more details on digital thread including the difference between digital thread and digital twin, see Annex B.

3.1.11
digital thread unit
instance of a *digital thread* (3.1.10), focussed on the operation phase, in the reference architecture of cyber-physically controlled smart machine tool systems (CPSMT) for additive manufacturing (AM)

3.1.12
feedstock / support handling
delivery (feeding), storage and management of the remaining feedstock / support on the machine, e.g. recoating and surface levelling mechanism in vat photopolymerization, powder feeding system in binder jetting

3.1.13
machine tool unit
unit (3.1.15) consisting of hardware that performs a series of machine tool functions

Note 1 to entry: According to ISO 14955-1, the machine tool function consists of machine tool operations (machining process, motion and control), process conditioning, *workpiece* (3.1.16) handling, tool handling or die change, recyclables and waste handling and machine tool cooling / heating.

3.1.14
smart additive manufacturing system
SAMS
additive manufacturing system that supports the vision, characteristics, and capabilities of smart manufacturing

Note 1 to entry: Details of smart manufacturing are described in IEC TR 63319[51].

© ISO 2023 – All rights reserved

Documents
Document Sharing Hub
Full document details: BS ISO 23704-3:2023

3.1.15
unit
group of elements that constitutes part of the reference architecture of a cyber-physically controlled machine tool (CPCM) and a cyber-supporting system for machine tool (CSSM) for additive manufacturing

Note 1 to entry: The term "unit" here is used as an instance of a collection of elements.

3.1.16
workpiece
joined material forming a functional element that could constitute all or a section of an intended product

Note 1 to entry: The functional requirements for a workpiece are typically determined by the intended application.

[SOURCE: ISO/ASTM 52900:2021, 3.9.1, modified — term "part" changed to workpiece]

3.2 Symbols and abbreviated terms

For the purposes of this document, the abbreviated terms given in ISO 23704-1, ISO 23704-2, and the following apply.

AM	Additive Manufacturing
AMF	Additive Manufacturing File Format
CPCM	Cyber-Physically Controlled Machine tool system
CPS	Cyber-Physical System
CPSAM	Cyber-Physically controlled Smart Additive Manufacturing system
CPSMT	Cyber Physically controlled Smart Machine Tool system
CSSM	Cyber Supporting System for Machine tool
KPI	Key Performance Indicator
SAMS	Smart Additive Manufacturing System
SFCS	Shop Floor Control System
SFDS	Shop Floor Device System
STL	Standard Transformation Language
3MF	3D Manufacturing Format
UIS	Unified Interface System

4 Conformance with the CPSMT reference architecture for additive manufacturing (AM)

To claim conformance, a definition of specific system architecture 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 for AM

The CPSMT reference architecture for AM describes an architecture of smart machine tool systems for AM based on the generic reference architecture specified in ISO 23704-1. It provides guidance for designers developing smart machine tool systems for AM and aims to give a better understanding of smart machine tools to the stakeholders of such systems.

NOTE Examples of stakeholders are machine tool builders, CNC vendors, solution vendors, service providers, customers and end-users.

© ISO 2023 – All rights reserved
Documents
Document Sharing Hub
Full document details: BS ISO 23704-3:2023

The CPSMT reference architecture for AM ensures the following important standardization objectives:

— transparent and unambiguous communication between all interested parties of an SAMS,

— the interoperability of an SAMS with related hardware devices, software, services, and manufacturing systems,

— the quality / capability of an SAMS,

— the use of an SAMS, and

— systematic development, modification of an SAMS.

Figure 2 illustrates the context of how the CPSMT reference architecture for AM is derived and viewed from various perspectives.

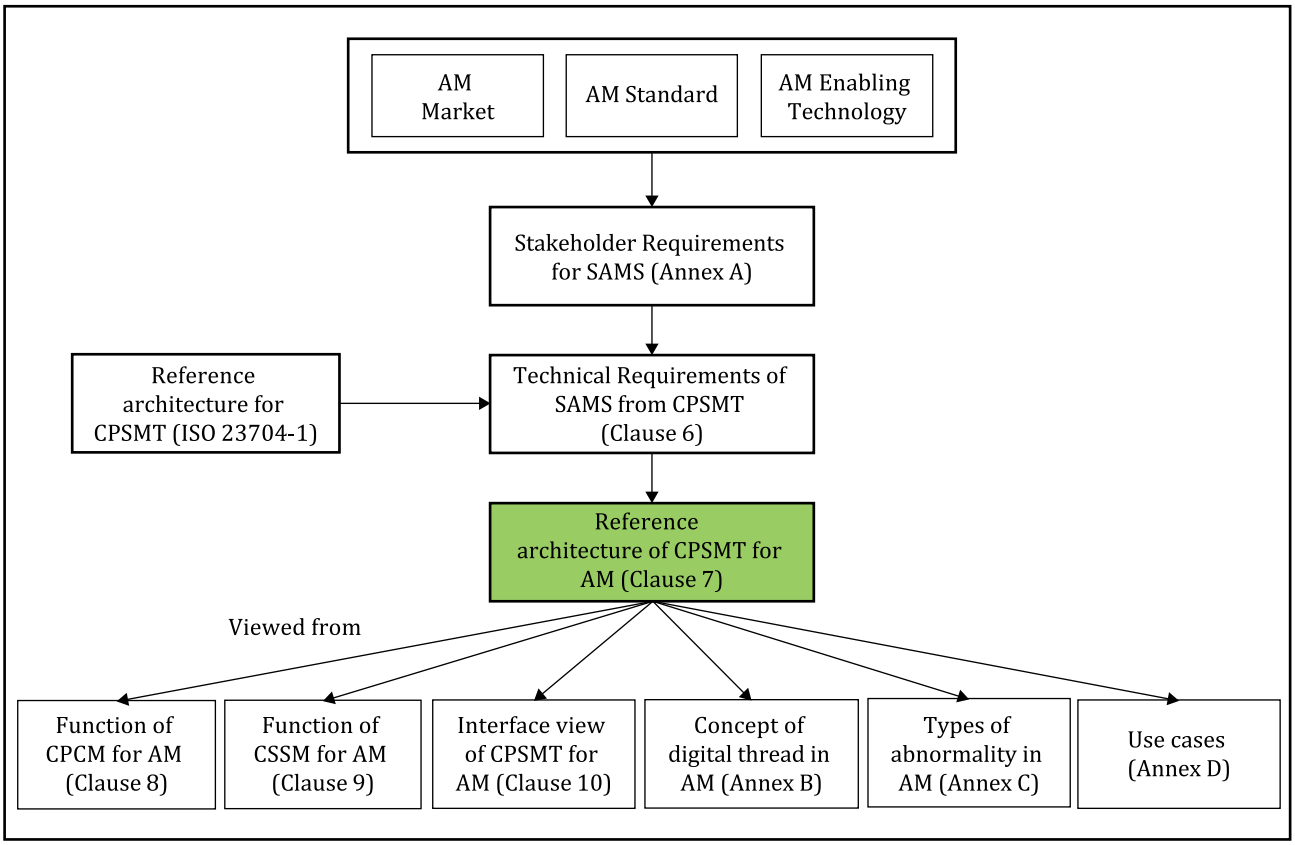

Figure 2 — Context of the CPSMT reference architecture for additive manufacturing (AM)

Based on Figure 2, this document has the following descriptions:

— The technical requirements of an SAMS from the CPSMT perspective in Clause 6,

— The reference architecture of a CPSMT for AM in Clause 7,

— The reference architecture of a CPCM for AM viewed from a functionality perspective in Clause 8,

— The reference architecture of a CSSM for AM viewed from a functionality perspective in Clause 9,

— The reference architecture of a CPSMT for AM viewed from the interface perspective in Clause 10,

— The stakeholder requirements on an SAMS in Annex A,

— The concept of digital thread in AM in Annex B,

© ISO 2023 – All rights reserved

Documents
Document Sharing Hub
Full document details: BS ISO 23704-3:2023

— The types of abnormality in AM in Annex C, and

— Example use cases on the reference architecture of a CPSMT for AM in Annex D.

6 Technical requirements of a smart additive manufacturing system (SAMS) from the CPSMT perspective

6.1 General

This Clause describes the technical requirements of the SAMS mainly based on the AM stakeholder requirements described in Annex A from the perspective of a CPSMT as summarized in Table 1.

NOTE 1 In the view of 'systems engineering,' an advanced methodology for developing complex systems, the technical requirements described in Clause 6 correspond to 'system requirements,' the technical requirements to be satisfied by the reference (solution) architecture for the smart manufacturing system are specified in Clause 7.

NOTE 2 For details on systems engineering, see ISO/IEC/IEEE 15288, ISO/IEC/IEEE 12207, ISO/IEC/IEEE 42010.

In terms of the phase of the AM workflow, the technical requirements are functions to be fulfilled by the SAMS during the process control (operation) phase categorized into six capabilities of a CPSMT specified in ISO 23704-1:2022, Clause 10.

NOTE 3 The 'life cycle aspect' defined in ISO 23704-1 corresponds to 'AM workflow' in the AM domain.

The details of the technical requirements in each category are given in the following subclauses so that they can be used as the requirements to be satisfied by the reference architecture of a CPSMT for AM specified in Clause 7.

Table 1 — Technical requirements of Smart Additive Manufacturing System (SAMS) from the CPSMT capabilities

Categories based on the CPSMT capabilities (subclause number in this document)	Technical requirements (subclause number in this document)
Autonomous dealing with abnormalities (6.2)	6.2.2 Dealing with hard real-time scale abnormalities during an AM process
	6.2.3 Dealing with soft real-time scale abnormalities during an AM process
	6.2.4 Acquisition of data related to an AM process
	6.2.5 Data processing related to an AM process
	6.2.6 Extraction of value-added data
	6.2.7 AM process monitoring
	6.2.8 AM process status prediction
	6.2.9 AM process status diagnosis
	6.2.10 Making decisions about the AM system to enhance AM process performance
	6.2.11 Update of AM workflow data
	6.2.12 Dealing with abnormalities
Autonomous coordination with shop floor devices (6.3)	6.3.2 Coordination among shop floor devices
	6.3.2 Supporting the combination of finish cutting in subtractive manufacturing and AM process

© ISO 2023 – All rights reserved
Documents Document Sharing Hub
Full document details: BS ISO 23704-3:2023

Table 1 *(continued)*

Categories based on the CPSMT capabilities (subclause number in this document)	Technical requirements (subclause number in this document)
Autonomous collaboration with shop floor control system (6.4)	6.4.2 Receiving a coordinated process plan
	6.4.3 Providing the AM process data for shop floor operation
	6.4.4 Interoperability for the data interface
Interface with an AM workflow (6.5)	6.5.2 Interaction with AM workflow
	6.5.3 Interoperability for interface with AM workflow
Interface with hierarchy level (6.6)	6.6.2 Interaction with a hierarchy level
	6.6.3 Interoperability for interface with hierarchy level
Interface with humans (6.7)	6.7.2 Interaction with humans
	6.7.3 Interoperability for interface with humans

6.2 Technical requirements of autonomously dealing with abnormalities

6.2.1 General

This subclause describes the technical requirements of an SAMS from the "autonomously dealing with abnormalities" capability perspective.

NOTE 1 See ISO 23704-1:2022, 3.1.1 for the definition of abnormality.

NOTE 2 As noted in ISO 23704-1:2022, 10.1, the capability of dealing with abnormalities is emphasized due to the fact that:

— In principle, total optimization of the manufacturing process, in essence, is done by: a) off-line optimization (e.g. via CAx, DfAM), followed by b) on-line 'faithful' execution.

— Faithful execution can be done by autonomously dealing with abnormalities; the deviations from the normal status optimally planned off-line.

6.2.2 Dealing with hard real-time scale abnormalities during an AM process

This technical requirement means dealing with abnormalities during the AM process in a hard real-time fashion. Hard real-time means the result of data handling is incorrect unless the measure meets the specified timing requirements.

NOTE 1 See ISO 23704-1:2022, 3.1.17 for the definition of hard real-time.

NOTE 2 Hard-real time does not mean the process itself, but the controller task, i.e. even a slow process is operational in real time.

There are abnormalities occurring abruptly during the build process, e.g. within a layer, between layers, immediately adversely affecting the AM system when measures are not taken within the time limit. In order to detect and take action for these abnormalities, the AM process needs to be checked and handled in hard real-time.

Explicitly, an SAMS should have a means for dealing with the abnormalities in a hard real-time scale.

NOTE 3 Example abnormalities to be dealt with in the hard real-time scale include inappropriate melt pool geometry and thermal distribution, servo disturbance, clogging.

© ISO 2023 – All rights reserved

Documents
Document Sharing Hub
Full document details: BS ISO 23704-3:2023

6.2.3 Dealing with soft real-time scale abnormalities during an AM process

This technical requirement means dealing with abnormalities during the AM process in a soft-real time fashion. Soft real-time means the result of data handling is degraded unless the measure meets the specified timing requirements.

NOTE 1 See ISO 23704-1:2022, 3.1.28 for the definition of soft-real time.

There are abnormalities occurring during the build process, e.g. within a layer, between layers, gradually adversely affecting the AM system. In order to detect and take action for the abnormalities, the AM process needs to be checked and handled in soft-real time.

Explicitly, an SAMS should have a means for dealing with the abnormalities in a soft-real time scale.

NOTE 2 Example abnormalities to be dealt with in the soft real-time scale include gradual energy overconsumption, gradual reduction of the remaining useful life of the motor in the nozzle.

6.2.4 Acquisition of data related to an AM process

This technical requirement means the process of collecting data related to the AM system to determine and to analyse its status.

All data in the AM domain are related to the AM workflow. The representative sources of data include, e.g. the AM machine (e.g. sensor, controller), office floor (e.g. order management system), a CAx system (e.g. CAD, CAM, CAE), human input. Those data are a valuable asset and have the potential for enhancement of the operational performance.

Explicitly, an SAMS should have a means for acquiring data related to the AM process.

NOTE 1 Example sensors include infrared camera, thermocouple, strain gauge.

NOTE 2 Example process parameters, in the case of powder bed fusion, include heat source energy, scanning feed, scanning spot size, chamber preheat temperature, chamber pressure.

NOTE 3 Example CAx data includes part program which conforms to the ISO 14649 series, ISO 6983-1, or 3D modelling format (e.g. AMF, 3MF, STL).

6.2.5 Data processing related to an AM process

This technical requirement involves the systematic performance of operations upon AM data.

NOTE 1 See Reference [1] for more details on data processing.

In practice, it is difficult to use the acquired data (See 6.2.4) immediately as they often include unorganized, inaccurate, and incorrect data. In order to make them usable, they need to be processed in some fashion. Data processing functions for supporting this include, e.g. cleansing, formatting, and grouping.

Explicitly, an SAMS should have a means for data processing related to the AM process.

NOTE 2 Examples of data cleansing include dealing with missing and noisy thermocouple values.

NOTE 3 Examples of data formatting include organizing the sensor, controller, and CAx data into pre-defined AM workflow data models.

NOTE 4 An example of data grouping is the insertion of formatted data into a group, e.g. porosity abnormality dataset.

6.2.6 Extraction of value-added data

This technical requirement means generating data of added value through data processing, which is described in 6.2.5.

© ISO 2023 – All rights reserved
Documents
Document Sharing Hub
Full document details: BS ISO 23704-3:2023

Data processing provides the foundation for further analysis and utilization of data with specific purpose. These value-added data, through further processing, can contribute not only to enhancing the complexity and predictability of the AM machine behaviour, but also to making accurate decisions and generating control inputs for an AM machine, entities such as humans, CAx system, office floor systems, and shop floor systems.

Explicitly, an SAMS should acquire and utilize extracted value-added data.

NOTE Example value-added data includes the amount of deviation of energy supply from activation source compared with the reference value and estimated amount of the melt-pool geometry with thermal distribution.

6.2.7 AM process monitoring

This technical requirement means assessing whether or not an abnormality is occurring during an AM process in the time span of control.

During the AM process, various types of abnormality can occur. Early detection of abnormalities helps to shorten the time for making decisions to maintain or enhance the operational performance of the AM process.

Explicitly, an SAMS should have an AM monitoring function.

NOTE Examples of AM process monitoring include detection of insufficient energy supply to the laser power source, detection of laser overheating, detection of energy overconsumption during the AM operation, detection of thermal distortion / warping, calculating the thermal distribution of the melt pool, detection of porosity inside the AM product.

6.2.8 AM process status prediction

This technical requirement means prediction of future signs of abnormalities.

Various types of abnormality can occur during the AM process. If the symptoms of abnormalities can be identified in advance it can contribute to the improvement of AM process performance by shortening the time for making decisions and increasing the chance of pre-emptive action.

Explicitly, an SAMS should have an AM process status prediction function.

NOTE Examples of AM process status prediction include predicting the energy consumption during the AM operation, predicting the thermal distribution of the AM product during the AM process, predicting the cycle time of the AM process.

6.2.9 AM process status diagnosis

This technical requirement involves the identification of the root causes of malfunctions and the appraisal of their relevance for the AM process.

NOTE 1 For more details on diagnosis, see ISO 20077-1[22].

Since the AM process is a new and dynamically changing process, establishing root cause analysis for the various abnormalities in a variety of states and contexts is crucial for sustainable controllability and reproducibility.

Explicitly, an SAMS should have a mechanism for the diagnosis for the enhancement of the reliability and reproducibility, of the AM process.

NOTE 2 Examples of AM process status diagnosis include finding out the cause of balling phenomena in the direct energy deposition process, root cause analysis on thermal distortion / warping of an AM product, finding out the cause of inconsistent microstructure on the AM product.

© ISO 2023 – All rights reserved

Documents
Document Sharing Hub
Full document details: BS ISO 23704-3:2023

6.2.10 Making decisions about the AM system to enhance AM process performance

This technical requirement involves: a) making decisions for dealing with abnormalities, and b) reflecting those decisions to the AM machine operation to alleviate the abnormalities and increase the AM operational performance.

Since the AM process is a new and dynamically changing process, making decisions on the AM system and reflection to it is crucial for a sustainable enhancement of AM process performance.

Explicitly, an SAMS should have a mechanism for the enhancement of the operational performance to realize the capability of autonomously dealing with abnormalities.

NOTE Examples of decision-making on the AM system include modifying parameters for reducing the chance of warp / distortion and verifying the changed parameter set, the transmission of modified parameter sets for reducing the chance of warp / distortion to the AM machine with the modification of path data of part program.

6.2.11 Update of the AM workflow data

This technical requirement involves updating the AM workflow data based on data processing (see 6.2.5), monitoring (see 6.2.7), prediction (see 6.2.8), diagnosis (see 6.2.9), and making decisions (see 6.2.10) on the AM process and AM system.

As a key enabler of personalized production, the AM process needs to be updated in a shorter cycle in conjunction with CAx activity compared with other types of manufacturing. To support more rapid updates, updating the AM workflow data based on the result of data handling (including data processing, monitoring, prediction, diagnosis and decision making) is necessary.

Explicitly, an SAMS should have a means to adapt to the change of the AM workflow data in a rapid and systematic fashion.

NOTE Examples of updating the AM workflow data include modifying parameters for reducing the chance of warp / distortion, changing the part orientation and support deployment in build preparation.

6.2.12 Dealing with abnormalities

6.2.12.1 General

This technical requirement involves a) monitoring abnormalities during operation, b) predicting abnormalities and diagnosing their cause, c) making decisions about appropriate countermeasures accordingly and d) reflecting these to the AM system.

Advanced data processing can be utilized for monitoring, diagnosis, prediction and making decisions on the various issues. Smart technologies such as the Internet-of-Things (IoT) can also be used to provide support by accessing data from other sources as well.

6.2.12.2 Abnormalities on an AM machine

During the AM process, according to stakeholder requirements in Annex A, there are issues on the AM machine components, including inappropriate feedstock / support delivery, path disturbance, insufficient energy supply from the activation source.

Explicitly, an SAMS should have a means for enhancing the operational performance of the AM process by dealing with abnormalities on the AM machine.

NOTE See C.2 for more details on the abnormalities of an AM machine.

© ISO 2023 – All rights reserved
Documents
Document Sharing Hub
Full document details: BS ISO 23704-3:2023