INTERNATIONAL STANDARD

ISO 14649-17

First edition
2020-03

Industrial automation systems and integration — Physical device control — Data model for computerized numerical controllers —

Part 17: **Process data for additive manufacturing**

Systèmes d'automatisation industrielle et intégration — Commande des dispositifs physiques — Modèle de données pour les contrôleurs numériques informatisés —

Partie 17: Données de processus pour la fabrication additive

Reference number
ISO 14649-17:2020(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

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, *Physical device control*.

A list of all parts in the ISO 14649 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

Modern manufacturing enterprises are built from facilities spread around the globe, which contain equipment from hundreds of different manufacturers. Immense volumes of product information need to be transferred between the various facilities and machines. Today's digital communications standards have solved the problem of reliably transferring information across global networks. For mechanical parts, the description of product data has been standardized by ISO 10303. This leads to the possibility of using standard data throughout the entire process chain in the manufacturing enterprise. Impediments to realising this principle are the data formats used at the machine level. Most computer numerical control (CNC) machines are programmed in the ISO 6983 "G and M code" language. Programmes are typically generated by computer-aided manufacturing (CAM) systems that use computer-aided design (CAD) information. However, ISO 6983 limits programme portability for three reasons. Firstly, the language focuses on programming the tool centre path with respect to machine axes, rather than the machining process with respect to the part. Secondly, ISO 6983 defines the syntax of programme statements, but in most cases leaves the semantics ambiguous. Thirdly, vendors usually supplement the language with extensions that are not covered in the limited scope of ISO 6983.

ISO 14649 is a new model of data transfer between CAD/CAM systems and CNC machines, which replaces ISO 6983. It remedies the shortcomings of ISO 6983 by specifying machining processes rather than machine tool motion, using the object-oriented concept of workingsteps. Workingsteps correspond to high-level machining features and associated process parameters. CNCs are responsible for translating workingsteps to axis motion and tool operation. A major benefit of ISO 14649 is its use of existing data models from ISO 10303. As ISO 14649 provides a comprehensive model of the manufacturing process, it can also be used as the basis for a bi- and multi-directional data exchange between all other information technology systems.

ISO 14649 represents an object-oriented, information- and context-preserving approach for NC-programming that supersedes data reduction to simple switching instructions or linear and circular movements. As it is object- and feature-oriented and describes the machining operations executed on the workpiece, and not machine-dependent axis motions, it will be running on different machine tools or controllers. This compatibility will spare all data adaptations by postprocessors, if the new data model is correctly implemented on the NC-controllers. If old NC programmes in ISO 6983 are to be used on such controllers, the corresponding interpreters need to be able to process the different NC programme types in parallel.

A gradual evolution is envisioned from ISO 6983 programming to portable feature-based programming. Early adopters of ISO 14649 will certainly support data input of legacy "G and M codes" manually or through programmes, just as modern controllers support both command-line interfaces and graphical user interfaces. This will likely be made easier as open-architecture controllers become more prevalent. ISO 14649 does not include legacy programme statements, which would otherwise dilute its effectiveness.

This document extends the suite of processes covered by ISO 14649 for physical device control. The data model focuses on device control and expression of requirements for the results of the additive process rather than technology specific constructs. For the shape of the manufactured part, ISO 14649 takes the exact geometry to be made and avoids the necessity of the user having to decide on an approximation without necessarily knowing the precision and details of the process. The exact geometry is also important when additive manufacturing is used together with other processes in order to avoid having multiple representations of the same shape.

This document differentiates between explicit data and derived data. Support structures, for example, depend on the shape and process and need to be derived when the process and the machine are chosen in order to achieve maximum flexibility. The workingstep structure is sufficiently flexible to allow support structures to be added explicitly, if they are required. Assemblies can be described with different elements, with different materials, in different workingsteps. Additive manufacturing can be sequential or parallel and there is the possibility to define explicit parallel features.

Industrial automation systems and integration — Physical device control — Data model for computerized numerical controllers —

Part 17: Process data for additive manufacturing

1 Scope

This document specifies the process data for additive manufacturing. This document describes additive manufacturing at the micro process plan level without making a commitment to particular machines, processes or technologies.

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 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.

ISO 14649-1:2003, *Industrial automation systems and integration — Physical device control — Data model for computerized numerical controllers — Part 1: Overview and fundamental principles*

ISO 14649-10:2004, *Industrial automation systems and integration — Physical device control — Data model for computerized numerical controllers — Part 10: General process data*

ISO 14649-11:2004, *Industrial automation systems and integration — Physical device control — Data model for computerized numerical controllers — Part 11: Process data for milling*

ISO 10303-242, *Industrial automation systems and integration — Product data representation and exchange — Part 242: Application protocol: Managed model-based 3D engineering*

ISO/ASTM 52900, *Additive manufacturing — General principles — Terminology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14649-1, ISO 14649-10, ISO 14649-11, ISO 10303-242, ISO/ASTM 52900 and the following apply.

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

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

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

3.1
feature
geometric entity of a workpiece which has semantic significance

Note 1 to entry: In the context of ISO 14649, manufacturing features are used.

4 General process data

4.1 General

The full schema is given in EXPRESS format in Annex A.

4.2 Header and references

The following listing gives the header and the list of entities which are referenced within this schema.

```
SCHEMA additive_manufacturing_schema;

REFERENCE FROM geometry_schema (*ISO10303-42e3*)
(axis2_placement_3d, direction, elementary_surface);

REFERENCE FROM aic_advanced_brep (*ISO10303-514*)
(advanced_brep_shape_representation);

REFERENCE FROM mathematical_function_schema (*ISO10303-50*)
(function_application);

REFERENCE FROM measure_schema (* ISO10303-41e3 *)
(length_measure);

REFERENCE FROM presentation_resource_schema (*ISO10303-46e3*)
(colour);

REFERENCE FROM machining_schema (* ISO 14649-10 *)
(in_process_geometry, machine_functions, manufacturing_feature, material, operation,
property_parameter, workpiece, workingstep);

REFERENCE FROM milling_schema (* ISO 14649-11 *)
(approach_retract_strategy);
```

4.3 General types and definitions

4.3.1 Measure units

The types of units supported by ISO 14649 are SI units as well as derived or conversion-based units as defined in ISO 10303-41. If no units are given, the following units are assumed:

length_measure millimetres [mm].

4.4 Additive manufacturing entities

The additive manufacturing entities were developed to support both users and machine operators by providing information at a high level. Additive manufacturing is defined in ISO/ASTM 52900. The additive processes include both processes which make a part or parts from nothing and those processes, such as cladding, which can be used to add to existing parts. The information model caters for single, graded and heterogenous materials and colours and an arbitrary base geometry on which the part is built. The entities in the descriptions define what is to be made so that the detailed control information for the processes can be derived from that. In this way, both legacy machines and new machines are supported.

4.4.1 AM workpiece

The AM workpiece is a description of a volumetric element to be made. The AM workpiece structure can be quite complex depending on the shape of this element. With some processes there can also be a base part onto which material is added. It is also possible that AM workpieces are added onto other AM workpieces (using the inherited its_raw_piece attribute), creating a manufacturing hierarchy.


```
ENTITY am_workpiece                                                      (* m1 *)
SUBTYPE OF (workpiece);
END_ENTITY;
```

4.4.2 AM workingstep

In order to incorporate additive operations within a workplan and also to enable hybrid manufacturing, the entity AM_workingstep is defined as a subtype of workingstep to contain the information required for an atomic transformation in the additive build process. Using the workpiece geometry allows the exact geometry of the part to be defined, with no approximations like those in ISO/ASTM 52915 being necessary.

```
ENTITY am_workingstep                                                    (* m1 *)
SUBTYPE OF (workingstep);
its_effect:                   OPTIONAL in_process_geometry;
its_operation:                am_operation;
its_feature:                  am_feature;
its_resulting_part:           am_workpiece
END_ENTITY;
```

Its_effect: allows the changes in the geometry that result from successful execution of the atomic additive workingstep to be modelled.

Its_operation: defines the additive operation that is carried out within the workingstep.

Its_feature: defines the feature that is built in the workingstep.

Its_resulting_part: defines the part that results from completing the workingstep.

4.4.3 AM feature

The feature allows the additive workpiece to be linked with a workingstep and an operation. It also allows heterogenous materials and gradients to be defined in the additive manufactured part.

```
ENTITY am_feature                                                        (* m1 *)
ABSTRACT SUPERTYPE OF (ONEOF (am_compound_feature, am_simple_feature, am_gradient_feature,
am_heterogenous_feature))
SUBTYPE OF (manufacturing_feature);
   primary_colour:           OPTIONAL colour;
END_ENTITY;
```

primary_colour: defines the main colour of the feature.

4.4.4 AM compound feature

The compound additive manufacturing feature allows multiple added features to be linked together in a compound information structure.

```
ENTITY am_compound_feature                                               (* m1 *)
SUBTYPE OF (am_feature);
its_am_features:              SET [2:?] OF am_feature;
END_ENTITY;
```

its_am_feature: The constituent features of the compound additive manufacturing feature.

4.4.5 AM simple feature

This entity allows simple additive geometries with a single material and colour to be defined. The assumption is that the feature is built with a skin and a core where the thickness of the skin is uniform.

```
ENTITY am_simple_feature                                                 (* m1 *)
SUBTYPE OF (am_feature);
```

```
skin_thickness:              OPTIONAL length_measure;
skin_construction:           OPTIONAL am_construction;
core_construction:           OPTIONAL am_construction;
END_ENTITY;
```

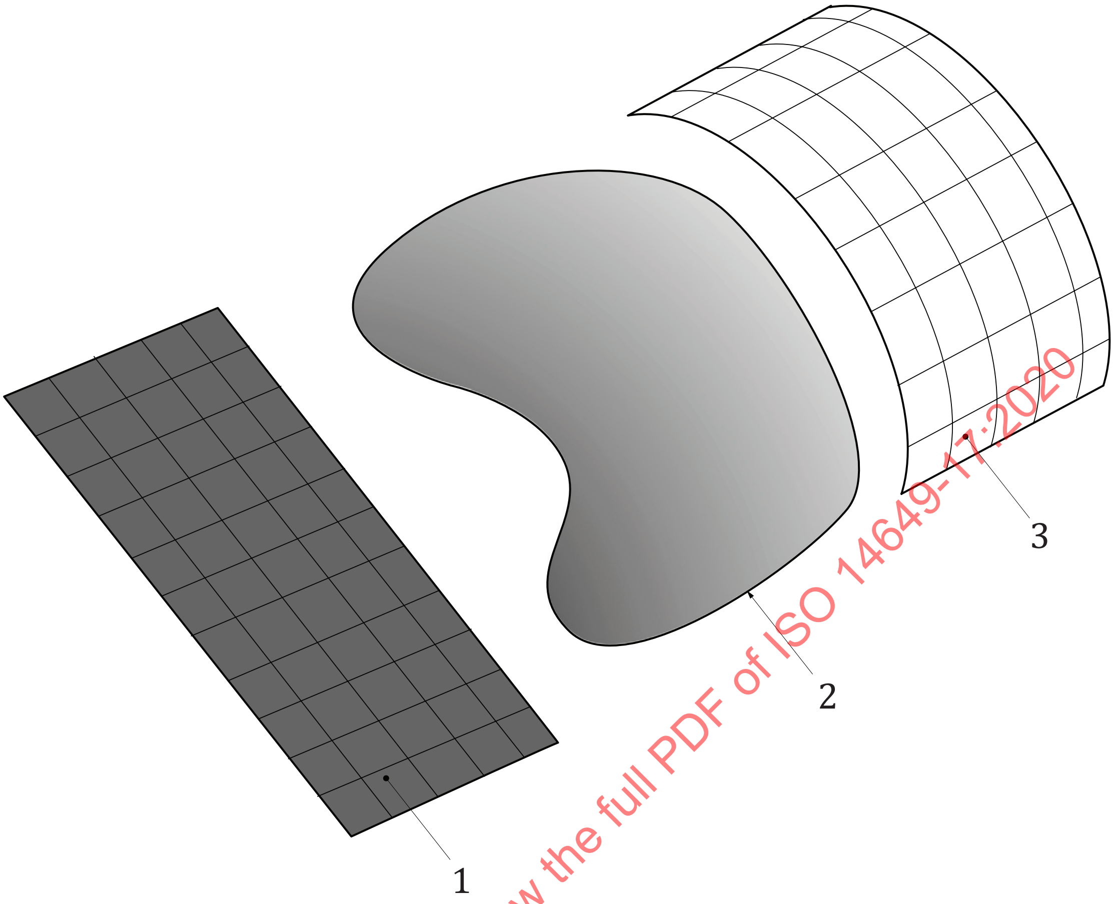
skin_thickness: The uniform thickness of the skin layer in the geometry.

Skin_construction: The construction type of the skin.

Core_construction: The construction type of the core.

4.4.6 AM gradient feature

Figure 1 illustrates the AM gradient feature. This entity allows graded materials and colours to be defined within the additive feature. The boundaries of the geometry are specified in the workpiece attributes. The gradient is formed between two elementary surfaces that are defined. Each elementary surface will have a colour and material and a linear gradient between the two are formed. To form the gradient, for every point inside the boundary of the workpiece the distance to the primary surface, d_1 , and secondary surface, d_2, are calculated. The colour for the point will be assigned as $\frac{d_2 c_1 + c_2 d_1}{d_1 + d_2}$ if c_1 is the colour of the primary elementary surface and c_2 is the colour of the secondary elementary surface. For material, at a given point, $\frac{d_2}{d_1 + d_2}$ of material 1 and $\frac{d_1}{d_1 + d_2}$ of material 2 will be mixed.



Key

1 primary gradient surface
material 1, colour 1

2 boundary specified in workpiece

3 secondary gradient surface
material 2, colour 2

Figure 1 — AM gradient feature


```
ENTITY am_gradient_feature                                      (* m1 *)
SUBTYPE OF (am_feature);
primary_surface:            elementary_surface;
secondary_surface:          elementary_surface;
its_construction:           OPTIONAL am_construction;
secondary_colour:           OPTIONAL colour;
secondary_material:         OPTIONAL material;
END_ENTITY;
```

primary_surface:	The surface at which the gradient starts. On every point on this surface the material and colour are the primary material and colours.
Secondary_surface:	The surface at which the gradient ends. On every point on this surface the material and colour are the primary materials and colours.
Its_construction:	Specifies the additive construction of the feature.
Secondary_colour:	Is the colour at the secondary elementary surface.
Secondary_material:	Is the material at the secondary elementary surface.

4.4.7 AM heterogeneous feature

Figure 2 illustrates the AM heterogeneous feature. The most flexible way of defining heterogenous materials and colours is by defining these using a mathematical function. The heterogeneous additive feature allows multiple atoms to be defined and the material is blended using a freeform mathematical equation across the different atoms.

The AM heterogenous feature specifies how many different materials or colours are involved in constructing a feature by specifying their quantity and the set of materials that construct the heterogeneous feature. The proportion of each material for each point in space is defined using a mathematical function of coordinates.

```
ENTITY am_heterogenuous_feature                              (* m1 *)
SUBTYPE OF (am_feature);
items:                      SET [1:?] OF am_heterogenuous_atom;
END_ENTITY;
```

no_of_elements: The number of different materials and colours that are used in the construction of the feature.

Items: The various heterogeneous materials and colours that are used in the construction of the feature.

EXAMPLE Assume that a rectangular box is to be manufactured from two materials (m_1, m_2) with the gradient shown in Figure 2. The two elements e_1 and e_2 represent the two materials m_1 and m_2. Hence the number of elements is two. Defining R as $\sqrt{L^2+H^2+W^2}$ at any given point in the box, the proportion of m_1 for any coordinate is $\frac{x^2+y^2+z^2}{R^2}$ and the proportion of m_2 is $1-\frac{x^2+y^2+z^2}{R^2}$.

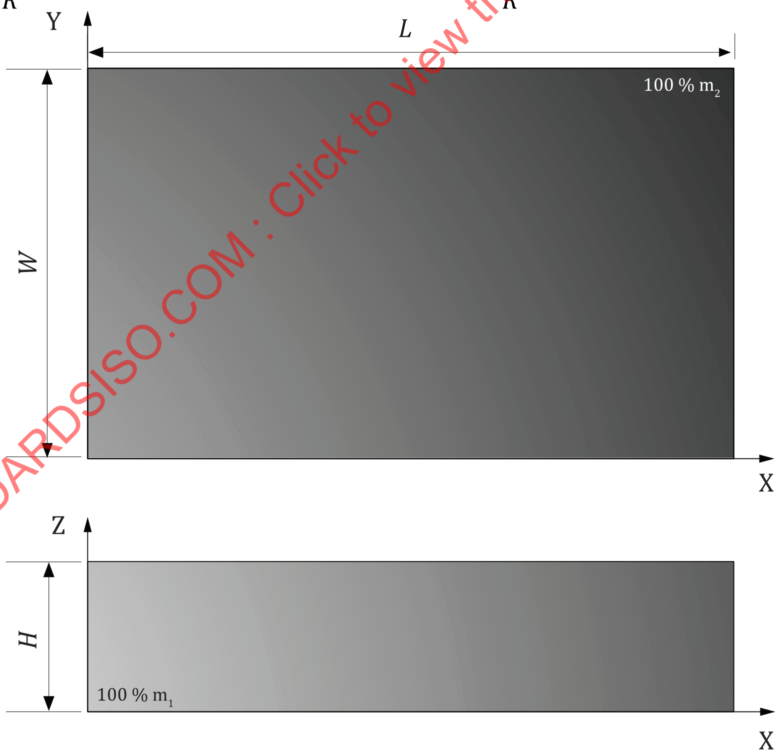


Figure 2 — AM heterogeneous feature

4.4.8 AM heterogeneous atom

Each material atom is specified by describing a local coordinate system (with the feature coordinate system as the base), the material, colour and optionally the construction, together with a governing function which relates the proportion of this atom with the location in space.

```
ENTITY am_heterogenuous_atom;                                    (* m1 *)
local_coord_axes:            axis2_placement_3d;
its_material:                material;
its_colour:                  colour;
its_construction:            OPTIONAL am_construction;
governing_function:          function_application;
END_ENTITY;
```

local_coord_axes: Defines the local coordinate system to be used in the function as an axis placement based on the feature coordinate system.

Its_material: Defines the material associated with this atom.

Its_colour: Defines the colour associated with this atom.

Its_construction: Is the construction associated with this atom.

Governing_function: Specifies the proportion of this atom as a function of coordinates in space based on the local coordinate system. The use of the governing functions uses the approach proposed in Reference [17].

4.4.9 AM machine functions

The AM machine functions allow specification of the manufacturing environment needed to make a part. Different materials and machines have different requirements for making parts. For example, a neutral atmosphere or a vacuum may be needed to make a metal part so as to avoid oxidation during building. Titanium parts also need special atmosphere to avoid burning. For some plastic processes, such as polymer powder bed fusion processes as categorized in ISO 17296-2, it is necessary to heat the chamber to close to the powder melting point in order to minimize thermic expansion when the powder is melted. These and other similar parameters can be specified using the functions attribute of this entity.

```
ENTITY am_machine_functions
SUBTYPE OF (machine_functions);
functions:              OPTIONAL SET [1:?] OF property_parameter;
END_ENTITY;
```

functions: An optional specification of functions that might be needed for building a part.

4.4.10 AM operation

The AM operation specifies the attributes of the process for manufacturing the additive feature.

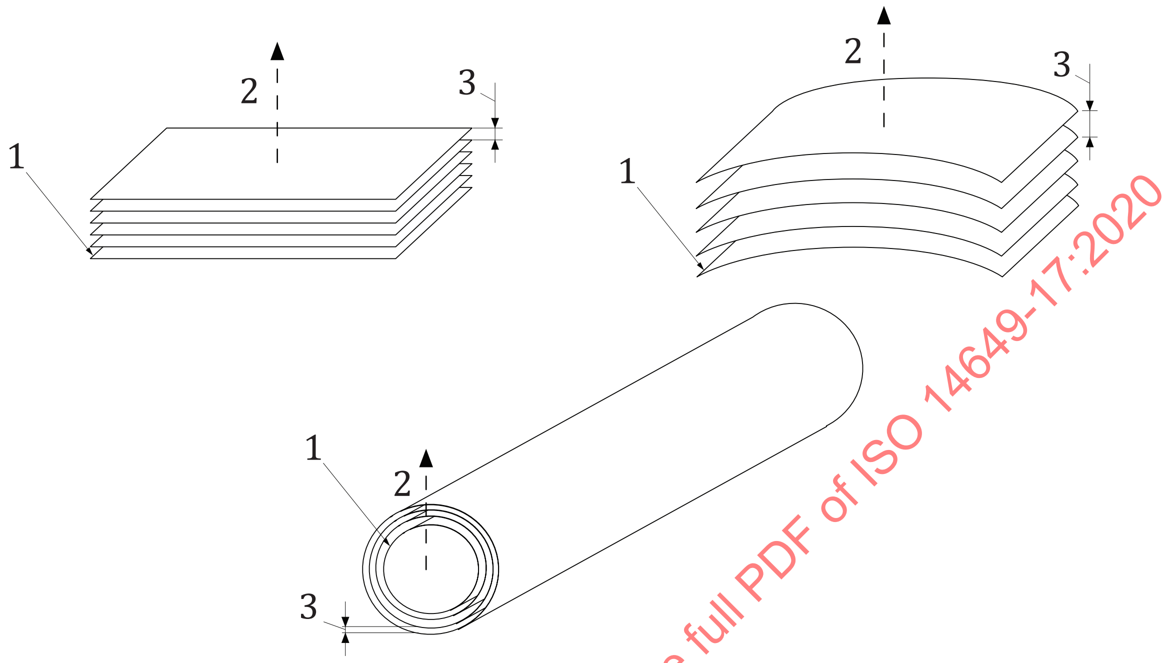
```
ENTITY am_operation
ABSTRACT SUPERTYPE OF (ONEOF (am_twod_operation, am_oned_operation))
SUBTYPE OF (operation);
   machine_functions:        am_machine_functions;
   its_support_geometry:     OPTIONAL advanced_brep_shape_representation;
END_ENTITY;
```

Machine_functions: Specifies the functions that the machine has to perform for this operation.

Its_support_geometry: Identifies the geometry of the support structure required for performing this operation.

4.4.11 AM twoD operation

Figure 3 illustrates the AM twoD operation. The AM_twoD_operation defines the attributes for additive operations that build a feature layer by layer. The layers are identified by the guiding geometry, the thickness of each layer and the normal vector for direction of layer stacking.



Key

1 base layer

2 normal direction

3 Thickness

Figure 3 — AM twoD operation


```
ENTITY am_twod_operation
SUBTYPE OF (am_operation);
   layer_thickness:      OPTIONAL length_measure;
   base_layer:           OPTIONAL elementary_surface;
   normal_direction:     OPTIONAL direction;
END_ENTITY;
```

layer_thickness: Specifies the thickness of each layer measured on the normal direction of the base layer.

Base_layer: An elementary surface that specifies the geometry of each layer.

Normal_direction: Specifies the direction in which the layers are added.

4.4.12 AM oneD operation

This entity allows the definition of particular additive depositions. In contrast to the layer-by-layer operation, the freeform operation only produces one filament of material and needs to be repeated as necessary to obtain the full geometry. The tool path, if necessary, can be specified using the its_toolpath attribute that is inherited by am_operation from operation in 14649-10.

```
ENTITY am_oned_operation
SUBTYPE OF (am_operation);
   approach:             approach_retract_strategy;
   retract:              approach_retract_strategy;
```



```
END_ENTITY;
```

approach: Defines how the additive manufacturing end effector approaches the build area.

Retract: Defines how the additive manufacturing end effector retracts from the build area.

4.4.13 AM construction

The AM construction allows the construction of the part to be specified based on predefined patterns or a solid.

```
ENTITY am_construction
ABSTRACT SUPERTYPE OF (ONEOF(am_infill, am_solid));
END_ENTITY;
```

its_material An optional definition of the material of the structure.

4.4.14 AM solid

This entity when used as the construction of an AM feature indicates that it needs to be built as a solid.

```
ENTITY am_solid
SUBTYPE OF (am_construction);
END_ENTITY;
```

4.4.15 AM infill

This entity indicates that the AM feature should be built as infill and specifies the pattern, direction and density of the deposited material.

```
ENTITY am_infill
SUBTYPE OF (am_construction);
   infill_percentage:        OPTIONAL REAL;
   its_direction:            OPTIONAL direction;
   its_pattern:              OPTIONAL am_patterns;
END_ENTITY;
```

infill_percentage Indicates the density of the material used for creating the infill.

Its_direction Indicates the direction (based on feature coordinate system) to apply the infill pattern.

Its_pattern Indicates the pattern to be used.

4.4.16 AM patterns

This type provides a placeholder for the data model to capture patterns used for infills in additive manufacturing. It is expected that terms such as honeycomb, concentric, line, rectilinear, Hilbert curve, Archimedean chords, octagram spiral or any other terms that are interpretable for the controller of the Additive Machine to be used here.

```
TYPE am_patterns = STRING;
END_TYPE;
```

4.5 End of schema

```
END_SCHEMA; (* additive manufacturing schema *)
```

Annex A
(informative)

EXPRESS expanded listing

This annex contains the full listing of the schema introduced in Clause 4.

```
SCHEMA additive_manufacturing_schema;

REFERENCE FROM geometry_schema (*ISO10303-42e3*)
(axis2_placement_3d, direction, elementary_surface);

REFERENCE FROM aic_advanced_brep (*ISO10303-514*)
(advanced_brep_shape_representation);

REFERENCE FROM mathematical_function_schema (*ISO10303-50*)
(function_application);

REFERENCE FROM measure_schema (* ISO10303-41e3 *)
(length_measure);

REFERENCE FROM presentation_resource_schema (*ISO10303-46e3*)
(colour);

REFERENCE FROM machining_schema (* ISO 14649-10 *)
(in_process_geometry, machine_functions, manufacturing_feature, material, operation,
property_parameter, workpiece, workingstep);

REFERENCE FROM milling_schema (* ISO 14649-11 *)
(approach_retract_strategy);

ENTITY am_workpiece (* m1 *)
SUBTYPE OF (workpiece);
END_ENTITY;

ENTITY am_workingstep (* m1 *)
SUBTYPE OF (workingstep);
   its_effect: OPTIONAL in_process_geometry;
   its_operation: am_operation;
   its_feature: am_feature;
   its_resulting_part: am_workpiece;
END_ENTITY;

ENTITY am_feature (* m1 *)
ABSTRACT SUPERTYPE OF (ONEOF (am_compound_feature, am_simple_feature,am_gradient_feature,
am_heterogeneous_feature))
SUBTYPE OF (manufacturing_feature);
   primary_colour: OPTIONAL colour;
END_ENTITY;

ENTITY am_compound_feature (* m1 *)
SUBTYPE OF (am_feature);
   its_am_features: SET [2:?] OF am_feature;
END_ENTITY;

ENTITY am_simple_feature (* m1 *)
SUBTYPE OF (am_feature);
   skin_thickness: OPTIONAL length_measure;
   skin_construction: OPTIONAL am_construction;
   core_construction: OPTIONAL am_construction;
END_ENTITY;

ENTITY am_gradient_feature (* m1 *)
SUBTYPE OF (am_feature);
   primary_surface: elementary_surface;
```