INTERNATIONAL STANDARD

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Industrial automation systems and integration — Physical device control — Data model for computerized numerical controllers — Part 10: General process data

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

Partie 10: Données des procédés généraux

Reference number
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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 14649-10 was prepared by Technical Committee ISO/TC 184, *Industrial automation systems and integration*, Subcommittee SC 1, *Physical device control*.

This second edition cancels and replaces the first edition (ISO 14649-10:2003), of which it constitutes a minor revision.

ISO 14649 consists of the following parts, under the general title *Industrial automation systems and integration — Physical device control — Data model for computerized numerical controllers*:

— *Part 1: Overview and fundamental principles*

— *Part 10: General process data*

— *Part 11: Process data for milling*

— *Part 12: Process data for turning*

— *Part 111: Tools for milling machines*

— *Part 121: Tools for turning*

Gaps in the numbering of parts were left to allow further additions. The future Parts 2 and 3 will be for language bindings according to ISO 10303 methods. Part 10 is the ISO 10303 Application Reference Model (ARM) for process-independent data. ISO 10303 ARMs for specific technologies are added after Part 10. The future Part 50 will be the ISO 10303 Application Interpreted Model (AIM) for process-independent data. ISO 10303 AIMs for specific technologies are added after Part 50.

ISO 14649 is harmonised with ISO 10303 in the common field of Product Data over the whole life cycle. Figure 1 of ISO 14649-1 shows the different fields of standardisation between ISO 14649, ISO 10303 and CNC manufacturers with respect to implementation and software development.

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 must 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 standardised 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. Programs are typically generated by computer-aided manufacturing (CAM) systems that use computer-aided design (CAD) information. However, ISO 6983 limits program portability for three reasons. First, the language focuses on programming the tool center path with respect to machine axes, rather than the machining process with respect to the part. Second, the standard defines the syntax of program statements, but in most cases leaves the semantics ambiguous. Third, 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 programs in ISO 6983 are to be used on such controllers, the corresponding interpreters shall be able to process the different NC program types in parallel.

ISO TC184/SC1/WG7 envisions a gradual evolution 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 programs, 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. Therefore, ISO 14649 does not include legacy program statements, which would otherwise dilute the effectiveness of the standard.

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

Part 10: **General process data**

1 Scope

This part of ISO 14649 specifies the process data which is generally needed for NC-programming within all machining technologies. These data elements describe the interface between a computerised numerical controller and the programming system (i.e. CAM system or shop-floor programming system). On the programming system, the programme for the numerical controller is created. This programme includes geometric and technological information. It can be described using this part of ISO 14649 together with the technology-specific parts (ISO 14649-11, etc.). This part of ISO 14649 provides the control structures for the sequence of programme execution, mainly the sequence of working steps and associated machine functions.

The "machining_schema" defined in this part of ISO 14649 contains the definition of data types which are generally relevant for different technologies (e.g. milling, turning, grinding). The features for non-milling technologies like turning, EDM, etc. will be introduced when the technology specific parts like ISO 14649-12 for turning, ISO 14649-13 for EDM, and ISO 14649-14 for contour cutting of wood and glass are published. It includes the definition of the workpiece, a feature catalogue containing features which might be referenced by several technologies, the general executables and the basis for an operation definition. Not included in this schema are geometric items and representations, which are referenced from ISO 10303's generic resources, and the technology-specific definitions, which are defined in separate parts of ISO 14649.

This part of ISO 14649 cannot stand alone. An implementation needs in addition at least one technology-specific part (e.g. ISO 14649-11 for milling, ISO 14649-12 for turning).

Additionally, the schema uses machining features similar to ISO 10303-224 and ISO 10303-214. The description of process data is done using the EXPRESS language as defined in ISO 10303-11. The encoding of the data is done using ISO 10303-21.

2 Normative references

The following referenced documents are indispensable for the application 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 286-1:1988, *ISO system of limits and fits — Part 1: Bases of tolerances, deviations and fits*

ISO 10303-11, *Industrial automation systems and integration — Product data representation and exchange — Part 11: Description methods: The EXPRESS language reference manual*

ISO 10303-21, *Industrial automation systems and integration — Product data representation and exchange — Part 21: Implementation methods: Clear text encoding of the exchange structure*

ISO 10303-41, *Industrial automation systems and integration — Product data representation and exchange — Part 41: Integrated generic resource: Fundamentals of product description and support*

ISO 10303-42, *Industrial automation systems and integration — Product data representation and exchange — Part 42: Integrated generic resource: Geometric and topological representation*

ISO 10303-43, *Industrial automation systems and integration — Product data representation and exchange — Part 43: Integrated generic resource: Representation structures*

ISO 10303-214, *Industrial automation systems and integration — Product data representation and exchange — Part 214: Application protocol: Core data for automotive mechanical design processes*

ISO 10303-224:2001, *Industrial automation systems and integration — Product data representation and exchange — Part 224: Application protocol: Mechanical product definition for process planning using machining features*

ISO 10303-514:1999, *Industrial automation systems and integration — Product data representation and exchange — Part 514: Application interpreted construct: Advanced boundary representation*

3 Terms and definitions

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

3.1
2D
Geometry in a xy-plane, where all the geometry's points have only x and y coordinates.

3.2
2½D machining
Machining of a prismatic part. Typically, the workpiece is processed in several layers which are located perpendicular to the tool axis. In the EXPRESS listing of ISO14649, the term "two5D" is used for entity and attribute names.

3.3
3D
Geometry in three-dimensional space, where all points have x, y, and z coordinates.

3.4
freeform machining
Machining of freeform surfaces. For this kind of machining, the tool has to move in at least three axes simultaneously while processing the workpiece. Sometimes five-axes milling machines are used to reach an optimised angle between the tool and the workpiece surface.

3.5
CAM
Computer Aided Manufacturing

3.6
CNC
Computer Numerical Control

3.7
EDM
Electrical Discharge Machining

3.8
EXPRESS
The language described in ISO10303-11

3.9
EXPRESS-G
The graphic representation of the EXPRESS language as described in ISO10303-11

3.10
Feature
A geometric entity of a workpiece which has semantic significance. In the context of ISO 14649, manufacturing features are used

3.11
SI
International system of units

4 General Process data

4.1 Header and references

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

```
SCHEMA machining_schema;
(*
Version of April 30, 2004
Author: ISO TC184/SC1/WG7
*)


REFERENCE FROM approval_schema              (*ISO 10303-41e3*)
  ( approval,
    approval_status);

REFERENCE FROM date_time_schema             (*ISO 10303-41e3*)
  ( date_and_time,
    date);
REFERENCE FROM person_organization_schema   (*ISO10303-41e3*)
  ( person,
    address);

REFERENCE FROM support_resource_schema      (*ISO10303-41e3*)
  ( bag_to_set,
    identifier,
    label,
    text);

REFERENCE FROM measure_schema               (*ISO10303-41e3*)
  ( length_measure,
    parameter_value,
    plane_angle_measure,
    positive_length_measure);

REFERENCE FROM product_property_representation_schema  (*ISO10303-41e3*)
  ( shape_representation);

REFERENCE FROM representation_schema        (*ISO10303-43e2*)
  ( definitional_representation);

REFERENCE FROM geometry_schema              (*ISO10303-42e3*)
  ( trimming_select,
    trimming_preference,
    transition_code,
       trimmed_curve,
       composite_curve,
       composite_curve_segment,
       axis2_placement_3d,
       bounded_curve,
       bounded_surface,
       cartesian_point,
       circle,
       conic,
       curve,
       direction,
       elementary_surface,
       plane,
       polyline
       );

  REFERENCE FROM topology_schema              (*ISO10303-42e3*)
     ( edge, edge_curve, edge_loop, face, loop);

  REFERENCE FROM geometric_model_schema       (*ISO10303-42e3*)
     ( block,
       right_circular_cylinder
      );

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

4.2 General types and definitions

4.2.1 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 then, the following units are assumed:

length_measure	millimetres [mm],
time_measure	seconds [s],
plane_angle_measure	degrees [°],
pressure_measure	Pascal [pa],
speed_measure	meters per second [m/sec],
rot_speed_measure	revolutions per second [1/sec].

4.2.1.1 Toleranced length measure

Length measure with tolerance.

```
  ENTITY toleranced_length_measure;                        (* m1 *)
    theoretical_size:       positive_length_measure;
    implicit_tolerance:     tolerance_select;
  END_ENTITY;
```

theoretical_size:	The theoretical length.
implicit_tolerance:	The type of tolerance to apply to theoretical_size.

Note that all geometric properties of the workpiece are specified using toleranced_length_measure. If the NC controller has the ability to generate toolpaths or to make decisions about the tool used, it is the controller's responsibility to meet these tolerance requirements. On the other hand, data provided to the NC controller for explicit specification of movements will have no tolerances as the controller cannot do more than try to follow the given theoretical values to the best of its abilities. The same is true for offsets and other data referring to already toleranced dimensions.

4.2.1.1.1 Tolerance select

Select type offering different etities to describe tolerances for scalar values.

```
TYPE tolerance_select = SELECT(plus_minus_value, limits_and_fits);
END_TYPE;
```

4.2.1.1.2 Plus minus value

The plus_minus_value describes the upper and lower limits valid for a scalar dimension referencing this entity.

```
ENTITY plus_minus_value;                                      (* m1 *)
  upper_limit:          positive_length_measure;
  lower_limit:          positive_length_measure;
  significant_digits:   INTEGER;
END_ENTITY;
```

upper_limit:	The value of the tolerance that shall be added to the exact value to establish the maximum allowed value.
lower_limit:	the value of the tolerance that shall be subtracted from the exact value to establish the minimum allowed value.
significant_digits:	The number of decimal digits indicating the accuracy of the lower_bound and upper_bound values.

4.2.1.1.3 Limits and fits

A limits_and_fits contains the necessary information to express a tolerance of the limits-and-fits system standardised by ISO 286.

```
ENTITY limits_and_fits;                                       (* m1 *)
  deviation:            length_measure;
  grade:                length_measure;
  its_fitting_type:     OPTIONAL fitting_type;
END_ENTITY;
```

deviation:	The difference between a measured actual size and the corresponding basic size as defined in ISO 286-1.
grade:	The grade specifies the quality or the accuracy grade of a tolerance. The grade is based on the international standard tolerance grades IT01 to IT18 as defined in ISO 286-1.
fitting_type:	Specification whether the tolerance declaration applies to a shaft or to a hole.

4.2.1.1.4 Fitting type

The enumeration used to specify the type of fitting.

```
TYPE fitting_type = ENUMERATION OF (shaft,hole);
END_TYPE;
```

4.2.1.2 Speed measure

A measure for a linear speed used for cutting speeds and feed rates.

```
TYPE speed_measure = REAL;
END_TYPE;
```

4.2.1.3 Rotational speed measure

A measure for a rotational speed. Positive values indicate rotation in the mathematical positive sense, i. e. counter-clockwise motion.

```
TYPE rot_speed_measure = REAL;
END_TYPE;
```

4.2.1.4 Pressure measure

A measure for pressure.

```
TYPE pressure_measure = REAL;
END_TYPE;
```

4.2.2 Other general types

4.2.2.1 Rotational direction

Enumeration used to identify the direction (sense) of the tool's rotation or of the direction of a circular movement. It should not be used in conjunction with rot_speed_measure which carries its own sense of rotation.

```
TYPE rot_direction = ENUMERATION OF (cw,ccw);
END_TYPE;
```

Note: cw means clockwise, ccw means counter-clockwise.

4.2.2.2 Shape tolerance

Type for definition of shape tolerance.

```
TYPE shape_tolerance = length_measure;
END_TYPE;
```

4.3 Where to start: Project

Each part programme, i.e. data model, based on ISO14649 must include exactly one top-level entity, called project. The project indicates the workplan to be executed upon interpretation of this model (as several workplans might be included), and it may also provide the workpiece(s) upon which actions are to be performed.

```
ENTITY project;                                                   (* m0 *)
  its_id:                identifier;
  main_workplan:         workplan;
  its_workpieces:        SET [0:?] OF workpiece;
  its_owner:             OPTIONAL person_and_address;
  its_release:           OPTIONAL date_and_time;
  its_status:            OPTIONAL approval;
  (* Informal proposition:
     its_id shall be unique within the part programme.
  *)
END_ENTITY;
```

its_id:	The project’s identifier. It shall be unique within the part programme.
main_workplan:	The top-level workplan in this model.
its_workpieces:	The workpieces upon which actions are to be performed.
its_owner:	Optional information on the owner of the project.
its_release:	Optional date and time reference of the project.
its_status:	Optional attribute to indicate the current status of the project.

4.3.1 Person and address

Entity includes data to name and reference a person, who for instance is responsible for creating a project.

```
ENTITY person_and_address;                                        (* m0 *)
  its_person:            person;
  its_address:           OPTIONAL address;
END_ENTITY;
```

4.4 What to machine: Workpiece and manufacturing feature

4.4.1 Workpiece

The workpiece entity contains the entire description of the workpiece, if available. This includes material, surface condition and geometric data. Each workpiece has only one surface condition and one material. Dependent on the conformance class the workpiece entity includes the raw part dimension only as an including box or cylinder, or, in a higher class, as a representation which can be a complete geometric model, e.g. the state after previous manufacturing operations.

```
ENTITY workpiece;                                                 (* m1 *)
  its_id:                identifier;
  its_material:          OPTIONAL material;
  global_tolerance:      OPTIONAL shape_tolerance;
  its_rawpiece:          OPTIONAL workpiece;
  its_geometry:          OPTIONAL advanced_brep_shape_representation;
  its_bounding_geometry: OPTIONAL bounding_geometry_select;
  clamping_positions:    SET [0:?] OF cartesian_point;
END_ENTITY;
```

its_id:	The unique identification of a workpiece.
its_material:	The material attribute identifies the workpiece material. This data shall be used for determining the technological process parameters for the manufacturing process. It can be done by the machine operator or by an automatic feed rate/cutting condition selection (from a table or a data base on the CNC).
global_tolerance:	Tolerance for the workpiece, valid where no other tolerances are specified.
its_rawpiece:	The rawpiece geometry of the workpiece may be described here. A recursive description is used, i.e. the rawpiece is of type workpiece itself.
its_geometry:	An exact description of the final workpiece geometry according to ISO 10303-514.
its_bounding_geometry:	By this attribute the workpiece´s bounding geometry might be defined as a box, a cylinder or a geometry according to the definition of the entity advanced_brep_shape_representation (ISO 10303--514).
clamping_positions:	Positions of the clamping device on the workpiece's surface.

All attribute's locations, directions and geometrical information are defined relatively to the workpiece's coordinate system.

4.4.1.1 Material

This entity is for identifying the workpiece material.

```
ENTITY material;                                              (* m1 *)
  standard_identifier:    label;
  material_identifier:    label;
  material_property:      SET [0:?] OF property_parameter;
END_ENTITY;
```

standard_identifier:	The standard used for identifying the material. This can be a national standard or one used internally in the company.
material_identifier:	The name which identifies the material.
material_property:	The parameter which describes the properties of material. Since the demand for material properties varies, a generic type „property parameter" is used.

4.4.1.2 Property parameter

Generic property parameter which may be used to characterise any kind of property any kind of parameter might have. Subtypes are descriptive parameters (strings) and numeric parameters.

```
  ENTITY property_parameter                                    (* m0 *)
    SUPERTYPE OF (ONEOF (descriptive_parameter,numeric_parameter));
    parameter_name:          label;
  END_ENTITY;
```

parameter_name:	The name of the parameter to be described.

4.4.1.2.1 Descriptive parameter

A parameter description using a string to characterise the parameter.

```
  ENTITY descriptive_parameter                                 (* m0 *)
    SUBTYPE OF (property_parameter);
    descriptive_string:      text;
  END_ENTITY;
```

descriptive_string:	String value which describes the parameter.

4.4.1.2.2 Numeric parameter

A parameter description using a numeric value. Both the number and the unit shall be given.

```
  ENTITY numeric_parameter                                     (* m0 *)
    SUBTYPE OF (Property_parameter);
    its_parameter_value:     parameter_value;
    its_parameter_unit:      label;
  END_ENTITY;
```

its_parameter_value:	The value which describes the parameter.
its_parameter_unit:	The units associated with the value.

4.4.1.3 Bounding geometry select

This type offers three different entities to describe the bounding geometry of a workpiece. Depending on the conformance class the bounding geometry is described as a block or a cylinder using the geometric items of ISO 10303-42 or as a complex shape conformable to ISO 10303-514. All coordinates and directions given in bounding_geometry are defined in the given workpiece's coordinate system.

```
  TYPE bounding_geometry_select =
    SELECT (block, right_circular_cylinder,                    (* m1 *)
    advanced_brep_shape_representation);                       (* t1 *)
  END_TYPE;
```

4.4.2 Manufacturing feature

This entity is the supertype of all manufacturing features. When considering 2½D-manufacturing, features are of type two5D_manufacturing_feature and may be holes, pockets, etc. When considering freeform manufacturing, regions are used in the same sense.

The manufacturing feature describes the feature as such, e.g. by its geometric properties. It does not give any instruction on how the workpiece is manufactured. Such process related information is contained only in the operations and depends on the manufacturing method. The methods are described in the technology specific parts of ISO 14649. For example, plunging into a pocket, roughing the pocket and finishing the pocket bottom may all be individual operations, as well as the finishing of a portion of a freeform surface. For the concept of operations, please refer to section 4.7.1.

```
ENTITY manufacturing_feature                                  (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF(region, two5D_manufacturing_feature,
  transition_feature));
  its_id:                  identifier;
  its_workpiece:           workpiece;
  its_operations:          SET [0:?] OF machining_operation;
END_ENTITY;
```

its_id:	Each feature has an unique identifier.
its_workpiece:	The workpiece which the feature is part of.
its_operations:	A set of all operations associated with the feature required for the manufacturing of the feature. Note that the operations are not necessarily executed immediately after each other. Only the workplan determines the final order of operations of all operations included in a given programme, and manufacturing will typically not occur feature by feature but rather according to technological criteria like minimised tool change. However, it should be guaranteed by the CAM system (or by the controller, if the order of execution is determined by an intelligent CNC) that the order given in this attribute is never violated.

4.5 Catalogue of manufacturing features

4.5.1 Region

The region is the equivalent of a feature in freeform machining. It describes a bounded area of the final workpiece surface to which the associated operations will be applied. Note that for freeform surfaces the regions for different operations (e.g. roughing, finishing) may have different shapes based upon technological decisions.

```
ENTITY region                                                 (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF (region_surface_list, region_projection,
  topological_region))
  SUBTYPE OF (manufacturing_feature);
  feature_placement:       OPTIONAL axis2_placement_3d;
END_ENTITY;
```

feature_placement:	The placement of the feature relative to the workpiece co-ordinate system. The placement is a translation and/or a rotation which transforms the origin of the workpiece co-ordinate system origin into the origin of the feature's local co-ordinate system. If no feature_placement is given, the region will use workpiece co-ordinates. Regarding coordinate systems see also Section 4.6.4.1.2.

4.5.1.1 Region projection

A type of bounded region generated by projecting a closed curve on a surface. Thus, a region can easily be defined on an existing surface description. The region projection applies to any workpiece surface it hits when moving in space along proj_dir. This is a very simplistic region definition for situations where the use of topology is not desired.

```
ENTITY region_projection                                    (* m1 *)
  SUBTYPE OF (region);
  proj_curve:             bounded_curve;
  proj_dir:               direction;
  depth:                  toleranced_length_measure;
END_ENTITY;
```

proj_curve:	A curve in space, used for specifying the boundary for a surface through its projection on the surface. It must be a closed curve and will usually be in one plane.
proj_dir:	Direction used for projecting the above curve on the surface.
depth:	The depth is a positive scalar value. It describes the distance of material removal into negative z-direction of the region's local coordinate system. The depth is measured from the raw piece's surface, onto which the proj_curve has been projected, to the bottom to be machined. The depth is equal for the whole region. In case the bottom's shape shall not be equal to the raw piece's surface, the entity pocket and its subtypes have to be used.

4.5.1.2 Region surface list

A type of region specified by a list of surfaces. This allows for the most general description of regions. The region is bounded by the borders of the surfaces it encloses.

```
ENTITY region_surface_list                                  (* m1 *)
  SUBTYPE OF (region);
  surface_list:           LIST [1:?] OF bounded_surface;
END_ENTITY;
```

surface_list:	List of general surfaces, allowing for various descriptions.

4.5.1.3 Topological region

A type of region specified by a topological representation. Only faces of type advanced_face are allowed as they are certain to carry their own geometric representation.

```
ENTITY topological_region                                   (* t0 t1 *)
  SUBTYPE OF (region, open_shell);
WHERE
  WR1: SIZEOF(QUERY(it <* SELF.cfs_faces |
  NOT('MACHINING_SCHEMA.ADVANCED_FACE' IN TYPEOF(it)))) = 0;
END_ENTITY;
```

4.5.2 Two5D manufacturing feature

The entity two5D_manufacturing_feature is the abstract supertype of all 2½D features. This structure is defined in close resemblance to ISO 10303-224.

```
ENTITY two5D_manufacturing_feature                                  (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF(machining_feature, replicate_feature,
  compound_feature))
  SUBTYPE OF (manufacturing_feature);
  feature_placement:      axis2_placement_3d;
END_ENTITY;
```

feature_placement:	The placement of the feature relative to the workpiece co-ordinate system. The placement is a translation and/or a rotation which transforms the origin of the workpiece co-ordinate system origin into the origin of the feature's local co-ordinate system. For information on coordinate systems refer to Section 4.6.4.1.2. If the manufacturing feature is part of a compound_feature, then its placement is defined relative to the compound_feature´s origin.

4.5.3 Machining feature

The entity machining_feature is the abstract supertype of all features used for feature based 2½D machining. In this part the following features are foreseen as they are used in different technology specific parts of ISO 14649: planar face, pocket, slot, step, hole, generic feature, and compound feature. The features are defined in close resemblance to ISO 10303-224.

2½D machining is characterised by the fact that most tool movements occur only in the xy plane while the z axis is preset to a certain depth in order to remove a layer of material. For this reason, all machining features have a depth.

All feature geometry, e.g. the contour describing the outline of a pocket, is described in a local xyz co-ordinate system. The definition of the coordinate system's orientation is given in the machining method specific parts. The surrounding surface of the workpiece and the definition of the planar contour of the feature are assumed to lie in the xy plane (z = 0). The material is assumed to be in negative z direction of the xy-plane. In other words, a positive depth within a machining operation requires the tool to advance in negative z direction into the material's direction.

As ISO 14649 allows for a 3D description of the overall workpiece geometry, the inherited attribute feature_placement specifies the actual location of the feature within the workpiece co-ordinate system.

```
ENTITY machining_feature                                            (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF(planar_face, pocket, slot, step, round_hole,
  toolpath_feature, profile_feature, boss, spherical_cap, rounded_end,
  thread))
  SUBTYPE OF (two5D_manufacturing_feature);
  depth:                  elementary_surface;
END_ENTITY;
```

depth:	The depth of the feature is described by a plane which includes the lowest points of the feature (z<0) measured in the feature's local cartesian-coordinate system. If the depth is not an orthogonal plane to the z-axis this implies, that the bottom of the feature is inclined. Depending on the explicit features there can be described more complex bottom shapes.

4.5.4 Planar face

The planar face is used to describe machining of the outer face of a workpiece. The geometry of the planar face is given through the boundary and the depth (defined by the supertype). The depth denotes the bottom of the material that needs to be taken away from the workpiece to reach the final shape of the feature. The elementary surface describing the depth can be inclined or orthogonal to the feature’s local z-axis. The planar face may also have one or more bosses where no cutting will be done.

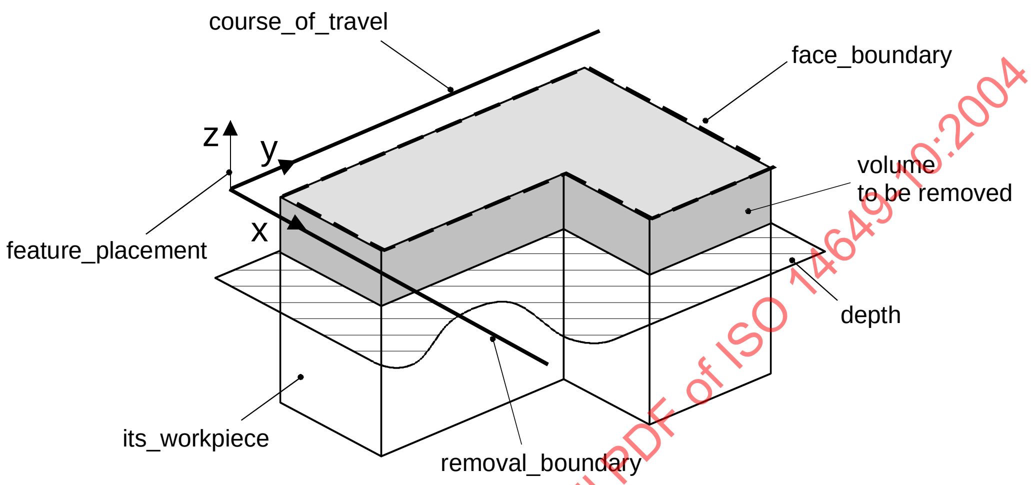


Figure 1 — Planar face

```
   ENTITY planar_face                                            (* m1 *)
     SUBTYPE OF (machining_feature);
     course_of_travel:        linear_path;
     removal_boundary:        linear_profile;
     face_boundary:           OPTIONAL closed_profile;
     its_boss:                SET [0:?] OF boss;
     (*Informal propositions:
       - The entire profile lies in the local xy plane.
       - The profile is not self-intersecting.
     *)
   END_ENTITY;
```

removal_direction:	The direction of material removal.
course_of_travel:	A straight line with magnitude and direction.
removal_boundary:	A line with direction and magnitude that when swept along a path defines the area on a workpiece for volume removal.
face_boundary:	The complete or partial outside final shape of the workpiece after the planar cut has been applied.
its_boss:	An optional list of entities which describe one or more bosses. A boss of a planar_face defines a part of the planar_face which is not cut during manufacturing of the planar_face.

4.5.5 Pocket

This is the abstract supertype for different implicit and explicit pockets. Open and closed pockets are derived from this supertype. The geometry of the pocket is defined by its contour on the outer face of the workpiece and its depth. A pocket may possess one or more bosses.

```
ENTITY pocket                                              (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF(closed_pocket, open_pocket))
  SUBTYPE OF (machining_feature);
  its_boss:                 SET [0:?] OF boss;
  slope:                    OPTIONAL plane_angle_measure;
  bottom_condition:         pocket_bottom_condition;
  planar_radius:            OPTIONAL toleranced_length_measure;
  orthogonal_radius:        OPTIONAL toleranced_length_measure;
END_ENTITY;
```

its_boss:	Optional list of bosses. This defines one or more parts of the pocket which are not cut during manufacturing of the pocket. With the cutting of the pocket, the boss is cut simultaneously.
slope:	Optional angle of the border of the pocket measured against the local z axis. Default is 0 degrees.
bottom_condition:	Possible bottom conditions of the pocket.
planar_radius:	The planar radius of a fillet, if existing within a pocket. This may be used to check against the radius of the tool tip.
orthogonal_radius:	The orthogonal radius of a fillet, if existing within a pocket. This may be used to check against the radius of the tool.

4.5.5.1 Closed pocket

Derived from the class pocket. A closed pocket is a pocket which is surrounded by material everywhere along its circumference. Its feature boundary is given by a closed profile.

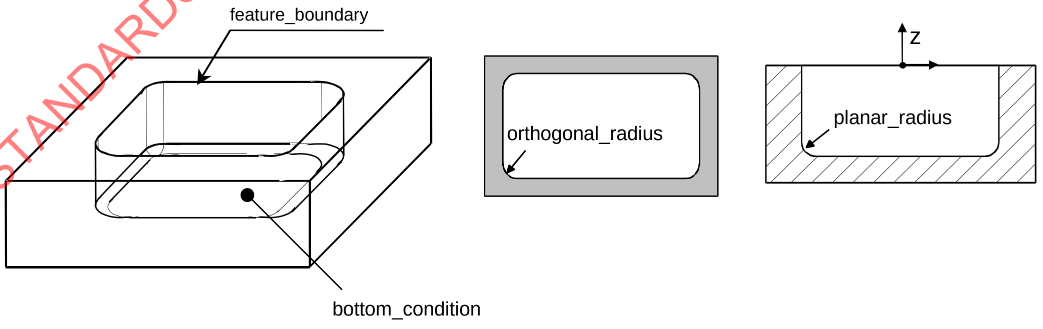


Figure 2 — Closed pocket

```
ENTITY closed_pocket                                         (* m1 *)
   SUBTYPE OF (pocket);
   feature_boundary:            closed_profile;
   (*Informal propositions:
     - The entire profile lies in the feature's local xy plane.
     - The profile is closed and not self-intersecting.
   *)
END_ENTITY;
```

feature_boundary:	The shape or outline that describes the upper edge of the pocket. It is an enclosed area that has a completely closed profile. The profile specifies the area required by a closed pocket.

4.5.5.2 Open pocket

Derived from the class pocket. An open pocket is a pocket which is not a closed pocket. Its feature boundary is given by a wall contour.

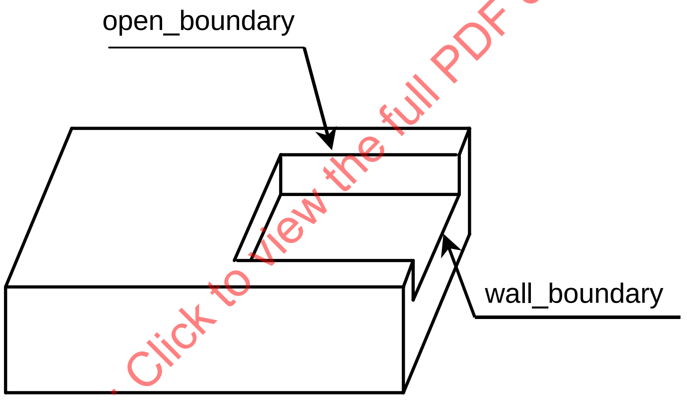


Figure 3 — Open pocket

```
ENTITY open_pocket                                           (* m1 *)
   SUBTYPE OF (pocket);
   open_boundary:           open_profile;
   wall_boundary:           OPTIONAL open_profile;
   (*Informal propositions:
     - The entire open_boundary profile lies in the local xy plane.
     - The profile are is not self-intersecting.
     - Together the two open_profiles form a closed profile.
     - wall_boundary is for information only.
   *)
END_ENTITY;
```

open_boundary:	The outline or shape that forms the upper edge of the open_pocket. The profile specifies the area required by open pocket. When travelling along the profile based as defined by its sense, the material lies on the left side of the profile. The open_boundary lies within the features xy-plane (z=0).
wall_boundary:	The outline or shape that forms the side edge of the open_pocket. It forms a closed profile together with open_boundary. Note that this contour will be most likely defined implicitly by the selected tool and the fillet options inherited from machining_feature. If given, it will be informative only.

4.5.5.3 Pocket bottom condition

This entity describes the shape of the bottom of a pocket.

```
ENTITY pocket_bottom_condition                                (* m1 *)
  ABSTRACT SUPERTYPE OF
  (ONEOF (through_pocket_bottom_condition, planar_pocket_bottom_condition,
  radiused_pocket_bottom_condition, general_pocket_bottom_condition));
END_ENTITY;
```

4.5.5.3.1 Through pocket bottom condition

The pocket extends fully through the workpiece.

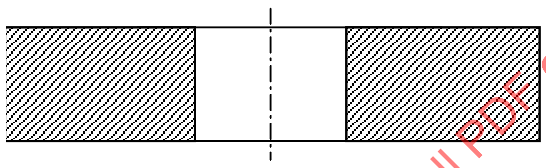


Figure 4 — Through pocket bottom condition

```
ENTITY through_pocket_bottom_condition                        (* m1 *)
  SUBTYPE OF (pocket_bottom_condition);
END_ENTITY;
```

4.5.5.3.2 Planar pocket bottom condition

The pocket has a plane bottom.

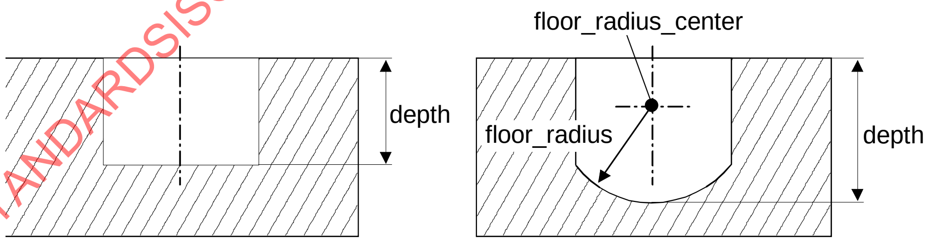


Figure 5 — Planar (left) and radiused (right) pocket bottom condition

```
ENTITY planar_pocket_bottom_condition                         (* m1 *)
  SUBTYPE OF (pocket_bottom_condition);
END_ENTITY;
```

4.5.5.3.3 Radiused pocket bottom condition

The pocket has a radiused bottom. As opposed to the use of the attribute planar_radius of the machining feature, which may be used to specify a fillet, the entire bottom surface will be continuously curved.

```
ENTITY radiused_pocket_bottom_condition                         (* m1 *)
  SUBTYPE OF (pocket_bottom_condition);
  floor_radius_center:       cartesian_point;
  floor_radius:              toleranced_length_measure;
END_ENTITY;
```

floor_radius_center:	Centre of the radius of the pocket floor. It is defined within the features coordinate system.
floor_radius:	Radius of the pocket floor. The radius creates a portion of a sphere on the pocket floor. Concave or convex behaviour depends upon the position of floor_radius_center. Note that the diameter of the sphere must span at least the perimeter of the pocket floor, or the result will be undefined.

Note that the depth of the pocket is determined by the combination of floor_radius_center and floor_radius

4.5.5.3.4 General pocket bottom condition

Any bottom condition not covered by planar_bottom_condition or through_bottom_condition. General pocket bottom condition defines a free-form surface at the bottom of a pocket.

Similar to the compound feature, the region referenced by the attribute shape is not allowed to be associated with machining operations of its own. All machining operations to manufacture the pocket must be defined by the attribute its_operations of the pocket itself.

```
ENTITY general_pocket_bottom_condition                          (* m1 *)
  SUBTYPE OF (pocket_bottom_condition);
  shape:                     region;
WHERE
  WR1: SIZEOF(shape\manufacturing_feature.its_operations) = 0;
END_ENTITY;
```

shape:	Description of the pocket floor as 3D surface in local xyz co-ordinates. Note that the feature_placement attribute of shape will specify its position relative to the local co-ordinate system of the pocket, not relative to the workpiece co-ordinates.

The pocket's attribute depth should specify the maximum depth of the pocket. Note that the actual depth of the pocket will be determined by the shape of the surface which is defined in 3D space. It will override any conflicting data given in the attribute depth.

4.5.6 Slot

The entity slot is closely related to the entity pocket. Generally speaking, a slot is a special kind of pocket. ISO 10303-224 lists slot as a separate entity. To be compatible, the entity slot is also included in this schema. The attribute course_of_travel describes the location and extension of the slot. Typically, the slot will be manufactured by a single sweep of a tool along the course of travel. In this case, the width of the slot equals the shape of the tool. In case of a milling operation the shape is given by the tool's diameter. If a workingstep which manufactures this slot calls for a smaller tool, more than one cut will have to be made.

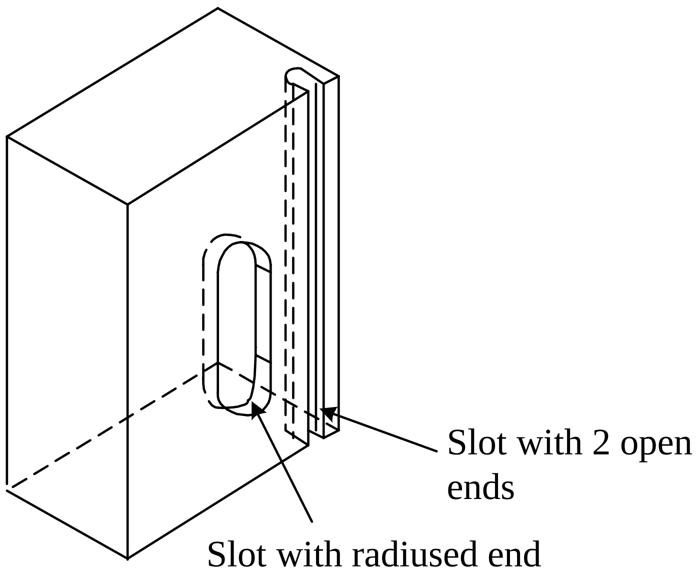


Figure 6 — Different examples of slots

```
ENTITY slot                 (* m1 *)
  SUBTYPE OF (machining_feature);
  course_of_travel:            travel_path;
  swept_shape:                 open_profile;
  end_conditions:              LIST[0:2] OF slot_end_type;
WHERE
  WR1: ( ( SIZEOF(QUERY (it <* SELF.end_conditions |
         ('MACHINING_SCHEMA.LOOP_SLOT_END_TYPE' IN TYPEOF(it)) )) = 1)
         AND
         (SIZEOF(end_conditions) = 1) )
         OR
         (SIZEOF(end_conditions) <> 1);
  (*
  Informal propositions:
  - The entire travel_path lies in the local xy plane.
  - The travel_path is not self-intersecting.
  *)
END_ENTITY;
```

course_of_travel:	Center line of the slot. The tool is moved along this path to achieve the manufacturing of the slot. As with the entity pocket, the upper edge is given.
swept_shape:	The (contoured) cross-section generated by a the tool, required for the selection of the proper tool For simple rectangular slot profiles, a square_u_profile should be specified giving only the width of the slot.
end_conditions:	For a slot closed on one side, end conditions may be given here. The sequence is oriented conformable to the direction of the course_of_travel.

4.5.6.1 Slot end type

Supertype of slot end types.

```
ENTITY slot_end_type                                                (* m1 *)
 ABSTRACT SUPERTYPE OF (ONEOF (woodruff_slot_end_type, radiused_slot_end_type,
  flat_slot_end_type, loop_slot_end_type, open_slot_end_type));
END_ENTITY;
```

4.5.6.1.1 Woodruff slot end type

The end of slot shall be a radius tangent to the slot bottom and curved upward about an axis.

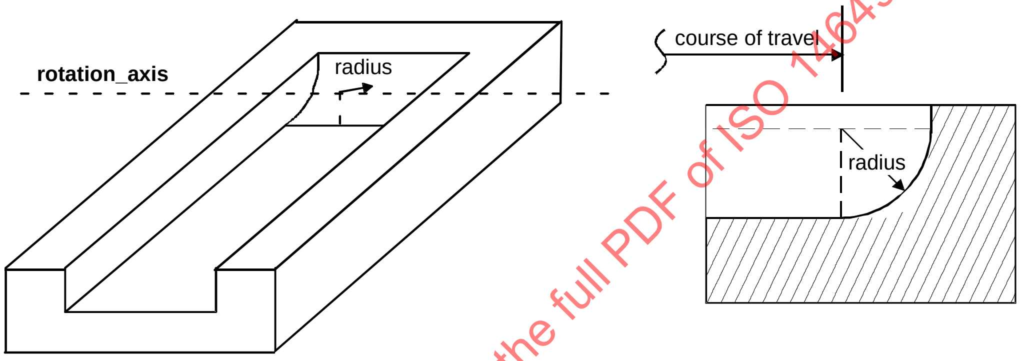


Figure 7 — Woodruff type slot end type

```
ENTITY woodruff_slot_end_type                                       (* m1 *)
  SUBTYPE OF (slot_end_type);
  radius:                       toleranced_length_measure;
END_ENTITY;
```

radius:	Radius of the slot end type. The radius continues tangential from the bottom of the slot. It starts at the bottom of the slot where the course_of_travel ends. The radius does not necessarily equal to the depth of the slot.

4.5.6.1.2 Radiused slot end type

The end of the slot consists of an arc. The diameter equals the width of the slot. The centre of the arc is identical with the end point of course_of_travel.

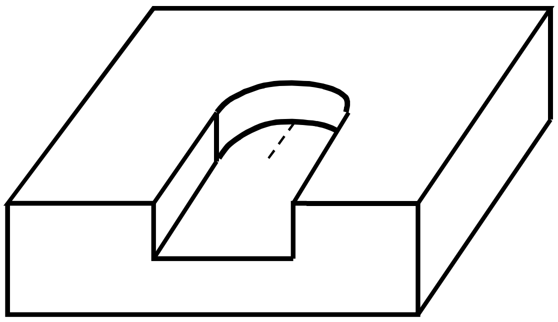


Figure 8 — Radiused slot end type

```
ENTITY radiused_slot_end_type                                    (* m1 *)
  SUBTYPE OF (slot_end_type);
END_ENTITY;
```

4.5.6.1.3 Flat slot end type

The end of the slot consists of a flat line with two arcs connecting the end to the sides of the slot. The radii of the two arcs are given. When traversing the slot along its centre line from start to finish, the radius on the left side of the centre line is corner_radius1, the radius on the right side of the centre line is corner_radius2. The end point of course_of_travel is in the flat end of the slot.

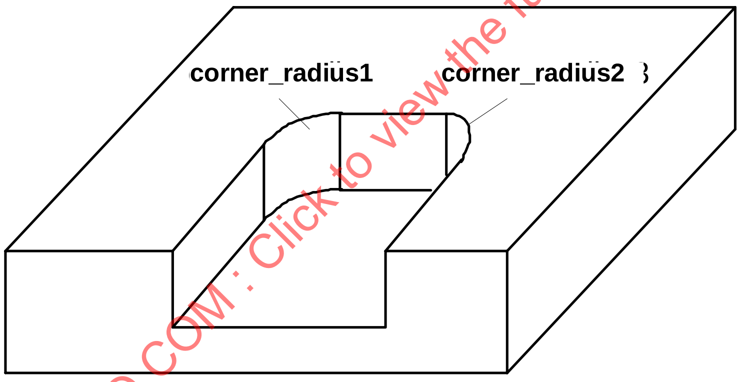


Figure 9 — Flat slot end type

```
ENTITY flat_slot_end_type                                        (* m1 *)
  SUBTYPE OF (slot_end_type);
  corner_radius1:          toleranced_length_measure;
  corner_radius2:          toleranced_length_measure;
END_ENTITY;
```

corner_radius1:	Radius of the first arc.
corner_radius2:	Radius of the second arc.

4.5.6.1.4 Loop slot end type

The slot forms a loop. The attribute depth is used to determine the scalar profoundness of the slot. The profoundness is equal to the smallest distance between the course_of_travel and the planar face described by the feature's attribute "depth".

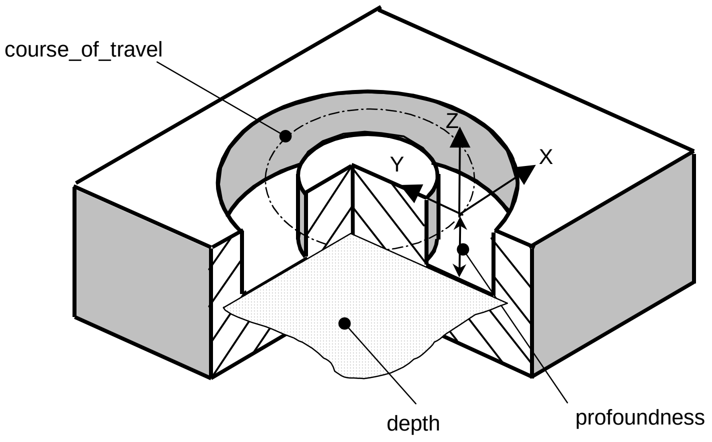


Figure 10 — Loop slot end type

```
ENTITY loop_slot_end_type  (* m1 *)
  SUBTYPE OF (slot_end_type);
END_ENTITY;
```

4.5.6.1.5 Open slot end type

The end of the slot is open.

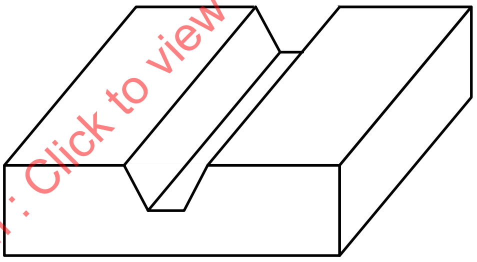


Figure 11 — Open slot end condition

```
ENTITY open_slot_end_type                                 (* m1 *)
  SUBTYPE OF (slot_end_type);
END_ENTITY;
```

4.5.7 Step

A step (or shoulder) is a volume of material removed from the top and the sides of the workpiece. Like an open pocket, its contour is open to its sides. The part of the V-profile describing the step's bottom lies in the elementary surface defined by the feature's attribute depth. The step may have one or more bosses as given by the optional attribute.

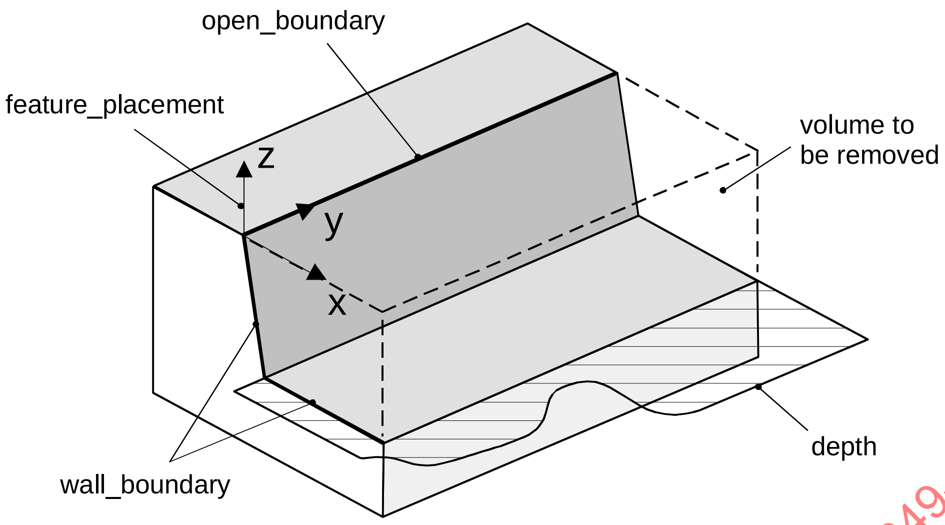


Figure 12 — Step

```
ENTITY step                                                     (* m1 *)
  SUBTYPE OF (machining_feature);
  open_boundary:          linear_path;
  wall_boundary:          OPTIONAL vee_profile;
  its_boss:               SET[0:?] OF boss;
  (*
  Informal propositions:
  - The entire linear_path lies in the same plane.
  *)
END_ENTITY;
```

open_boundary:	The outline or shape that forms the upper edge of the step. When travelling along the curve based as defined by its sense, the material is to the left of the curve.
wall_boundary:	The outline or shape that forms the side edge of the step, i. e. the “profile” of the cut.
its_boss:	A step may have one or more bosses..

4.5.8 Profile feature

A profile feature is a volume of material removed from the boundary shape of a workpiece. This is an abstract supertype of general outside profile and shape profile.

```
ENTITY profile_feature                                          (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(general_outside_profile, shape_profile))
  SUBTYPE OF (machining_feature);
  profile_swept_shape:    linear_path;
END_ENTITY;
```

profile_swept_shape:	An 2D line, when combined with a profile, which creates the shape of the profile feature. The placement of the linear path shall be the same as the profile feature. The direction of linear shall be with the Z-axis toward the direction of travel of the profile boundary.

4.5.8.1 General outside profile

A general outside profile is the removal volume of arbitrary shape from the outside shape of a workpiece. It may remove material from the entire outside shape or some portion of the shape. The contour of the shape is given by the attribute feature_boundary.

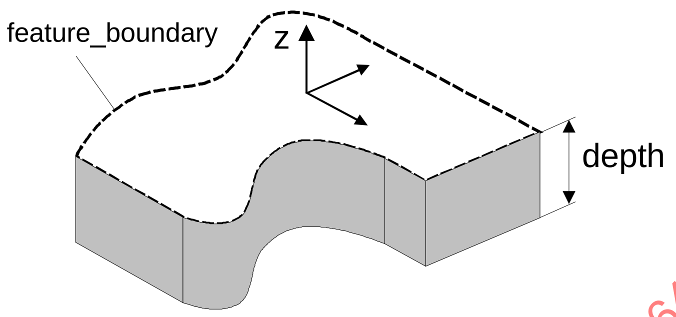


Figure 13 — General outside profile

```
ENTITY general_outside_profile                               (* m1 *)
  SUBTYPE OF (profile_feature);
  feature_boundary:       profile;
  (*
  Informal propositions:
  - The entire profile lies in the local xy plane.
  - The profile is not self-intersecting.
  *)
END_ENTITY;
```

feature_boundary:	The contour of the profile to be followed by the tool. Note that this attribute describes the profile itself, not the tool path. When travelling along the profile based as defined by its sense, the material lies to the left of the profile.

4.5.8.2 Shape profile

A shape profile is the removal volume of shaped profile from the boundary shape of a workpiece. The bottom of the boundary shape is limited by a floor condition. This is an abstract supertype of general shape profile, partial circular shape profile, circular closed shape profile, rectangular open shape profile, and rectangular closed shape profile.

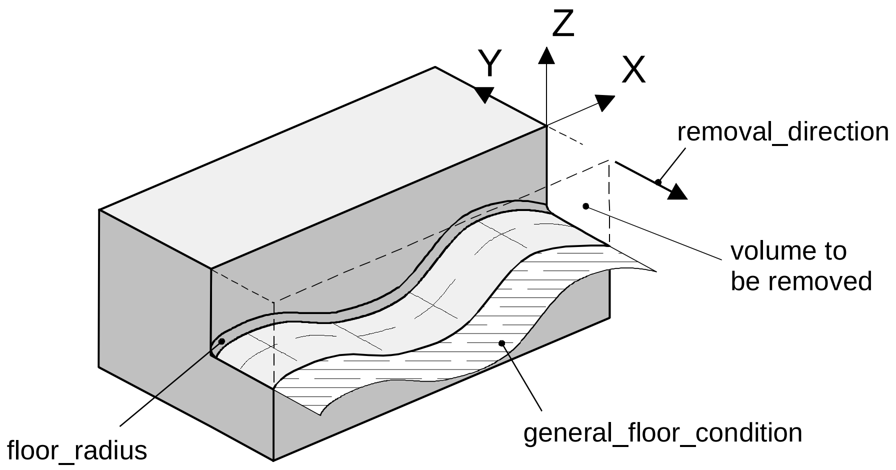


Figure 14 — Shape Profile

```
ENTITY shape_profile                                          (* m1 *)
  ABSTRACT SUPERTYPE
  OF(ONEOF(general_shape_profile,partial_circular_shape_profile,
  circular_closed_shape_profile,rectangular_open_shape_profile,
  rectangular_closed_shape_profile))
  SUBTYPE OF (profile_feature);
  floor_condition:        profile_select;
  removal_direction:      direction;
END_ENTITY;
```

floor_condition:	Specification of the shape of the bottom.
removal_direction:	A vector that points in the general direction away from the material.

4.5.8.2.1 Profile select

The floor condition of shape profile is either a through profile floor or a through profile floor.

```
TYPE profile_select =
  SELECT (through_profile_floor, profile_floor);
END_TYPE;
```

4.5.8.2.2 Through profile floor

A through profile floor describes the bottom condition of a shape profile which is open.

```
ENTITY through_profile_floor;                                 (* m1 *)
END_ENTITY;
```

4.5.8.2.3 Profile floor

A profile floor describes the bottom condition of a shape profile which may be flat or any arbitrary shape.

```
ENTITY profile_floor                                        (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(general_profile_floor, planar_profile_floor));
  floor_radius:          OPTIONAL numeric_parameter;
  start_or_end:          BOOLEAN;
END_ENTITY;
```

floor_radius:	The radius of curvature for an arc between the bottom and the sides.
start_or_end:	If true, the profile_floor is positioned at the end of a shape_profile. If false, its is at the start of the shape_profile.

4.5.8.2.4 General profile floor

A general_profile_floor is a type of profile_floor that specifies an enclosed area bounded by an arbitrary shape.

```
ENTITY general_profile_floor                                (* m1 *)
  SUBTYPE OF (profile_floor);
  floor:                 face;
END_ENTITY;
```

floor:	Specification of the face at the bottom of a shape_profile, adjacent to all the shape_profile walls.

4.5.8.2.5 Planar profile floor

A planar_profile_floor is a type of a profile_floor that characterises the bottom of a shape_profile which is flat.

```
ENTITY planar_profile_floor                                 (* m1 *)
  SUBTYPE OF (profile_floor);
  floor:                 plane;
END_ENTITY;
```

floor:	Specification of a planar face at the bottom of a shape_profile.

4.5.8.2.6 General shape profile

A general_shape_profile is a type of shape_profile that is a volume of arbitrary shape which defines a portion of the workpiece.

```
ENTITY general_shape_profile                                (* m1 *)
  SUBTYPE OF (shape_profile);
  profile_boundary:      profile;
END_ENTITY;
```

profile_boundary:	Specification of the outline of the shape_profile feature. It defines an area that may or may not be entirely enclosed.

4.5.8.2.7 Partial circular shape profile

A partial_circular_shape_profile is a type of shape_profile that defines a volume that is not enclosed on all sides.

```
ENTITY partial_circular_shape_profile                        (* m1 *)
  SUBTYPE OF (shape_profile);
  open_boundary:          partial_circular_profile;
END_ENTITY;
```

open_boundary:	Specification of the outline of the shape_profile feature. It defines an area that shall be circular and shall not be enclosed.

4.5.8.2.8 Circular closed shape profile

A circular_closed_shape_profile is a type of shape_profile that defines a completely enclosed volume. This may have a thread.

```
ENTITY circular_closed_shape_profile                         (* m1 *)
  SUBTYPE OF (shape_profile);
  closed_boundary:        circular_closed_profile;
END_ENTITY;
```

closed_boundary:	Specification of the outline of the shape_profile feature. It defines an area that shall be enclosed and circular.

4.5.8.2.9 Rectangular open shape profile

A rectangular_open_shape_profile is a type of shape_profile that is an open profile with opposite sides that are of equal length and with one side that does not make contact with the workpiece.

```
ENTITY rectangular_open_shape_profile                        (* m1 *)
  SUBTYPE OF (shape_profile);
  open_boundary:          square_u_profile;
END_ENTITY;
```

open_boundary:	Specification of the outline or shape that is an enclosed area that is open on one side.

4.5.8.2.10 Rectangular closed shape profile

A rectangular_closed_shape_profile is a type of shape_profile that is an enclosed volume with opposite sides that are equal in length.

```
ENTITY rectangular_closed_shape_profile                      (* m1 *)
  SUBTYPE OF (shape_profile);
  closed_boundary:        rectangular_closed_profile;
END_ENTITY;
```

closed_boundary:	Specification of the outline or shape that is an enclosed area that has a completely closed profile.

4.5.9 Round hole

This entity defines both holes and threaded holes. The feature_placement of a hole is the centre point at the surface, i. e. the hole is located at x = y = 0 in the local co-ordinate system. The specified (positive) depth causes the tool to advance into the hole in negative z direction.

Note that the bottom of the hole is not considered in the hole's depth.

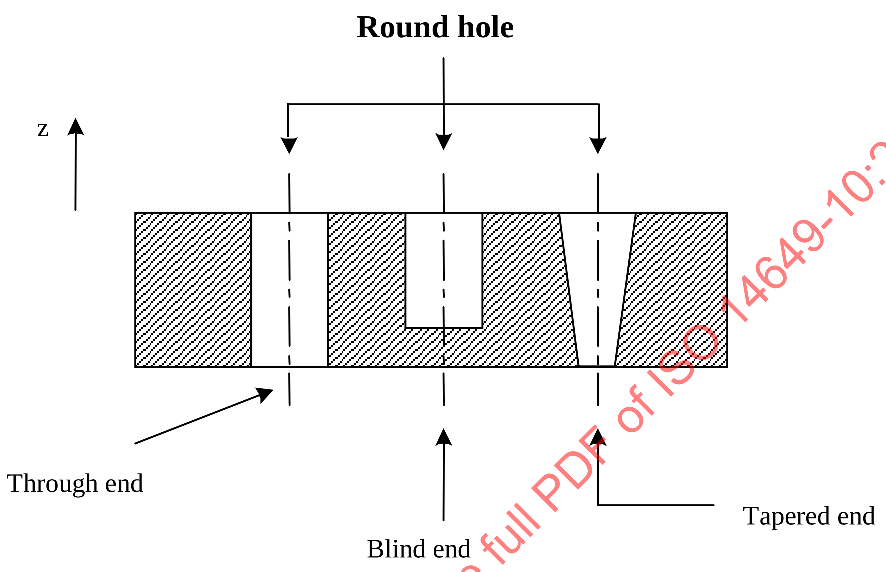


Figure 15 — Hole types

```
ENTITY round_hole                                              (* m1 *)
  SUBTYPE OF (machining_feature);
  diameter:                 toleranced_length_measure;
  change_in_diameter:       OPTIONAL taper_select;
  bottom_condition:         hole_bottom_condition;
END_ENTITY;
```

diameter:	The diameter of the hole. The diameter is measured in the xy-plane where z = 0.
change_in_diameter:	An optional parameter used to specify holes with a taper.
bottom_condition:	Specification of the bottom of a hole.

4.5.9.1 Taper select

The taper select indicates the manner by which a taper is described. A taper may be described either by diameter or by angle.

```
TYPE taper_select =
  SELECT (diameter_taper, angle_taper);
END_TYPE;
```

4.5.9.1.1 Diameter taper

Entity to describe a taper by its final diameter.

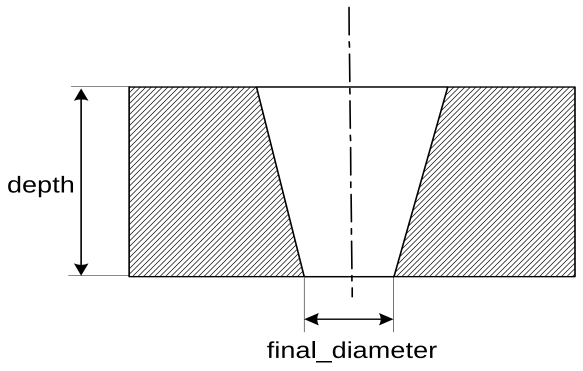


Figure 16 — Diameter taper

```
ENTITY diameter_taper;                                        (* m1 *)
  final_diameter: toleranced_length_measure;
END_ENTITY;
```

final_diameter:	The final diameter of the tapered hole at the indicated depth.

4.5.9.1.2 Angle taper

Entity to describe a taper by its half angle.

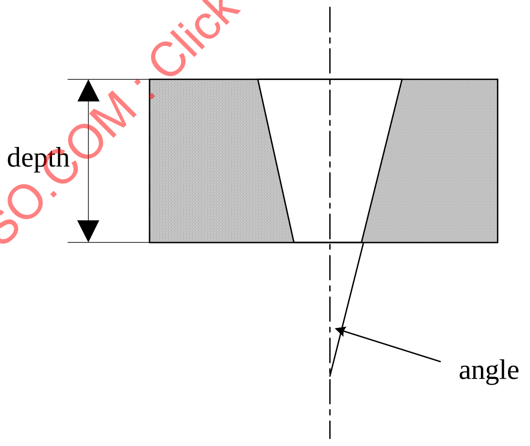


Figure 17 — Angle taper

```
ENTITY angle_taper;                                           (* m1 *)
  angle:                  plane_angle_measure;
END_ENTITY;
```

angle:	The angle of the tapered hole.

4.5.9.2 Hole bottom condition

Abstract supertype for the description of a bottom of a hole.

```
ENTITY hole_bottom_condition                                     (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF (blind_bottom_condition,
  through_bottom_condition));
END_ENTITY;
```

4.5.9.2.1 Through bottom condition

Entity which describes a hole bottom which is open.

```
ENTITY through_bottom_condition                                  (* m1 *)
  SUBTYPE OF (hole_bottom_condition);
END_ENTITY;
```

4.5.9.2.2 Blind bottom condition

Supertype to describe different types of blind bottom conditions. The bottom may break through the bottom of the workpiece, but is not entirely open. The depth of the hole is the length of the cylindrical section of the hole.

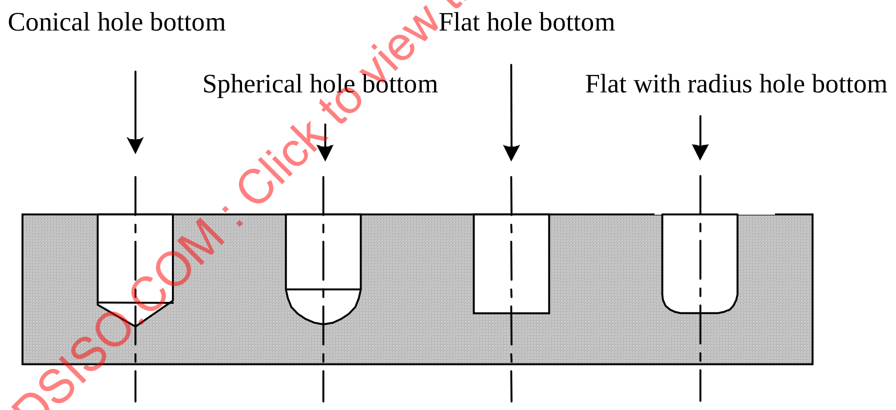


Figure 18 — Bottom conditions of holes

```
ENTITY blind_bottom_condition                                    (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF(flat_hole_bottom, flat_with_radius_hole_bottom,
  spherical_hole_bottom, conical_hole_bottom))
  SUBTYPE OF (hole_bottom_condition);
END_ENTITY;
```

4.5.9.2.2.1 Flat hole bottom

A hole with a flat bottom.

```
ENTITY flat_hole_bottom    (* m1 *)
  SUBTYPE OF (blind_bottom_condition);
END_ENTITY;
```

4.5.9.2.2.2 Flat with radius hole bottom

A hole with a flat bottom which has a radius.

```
ENTITY flat_with_radius_hole_bottom                            (* m1 *)
  SUBTYPE OF (blind_bottom_condition);
  corner_radius:          toleranced_length_measure;
END_ENTITY;
```

corner_radius:	The radius of the corner in the bottom.

4.5.9.2.2.3 Spherical hole bottom

A hole with a spherical bottom.

```
ENTITY spherical_hole_bottom                                   (* m1 *)
  SUBTYPE OF (blind_bottom_condition);
  radius:                 toleranced_length_measure;
END_ENTITY;
```

radius:	The radius of the spherical hole bottom.

Conical hole bottom

A hole with a conical bottom, as manufactured with a standard drill. A conical bottom is a constant decrease in diameter until the diameter is 'zero', or until it becomes tangent to a tip radius.

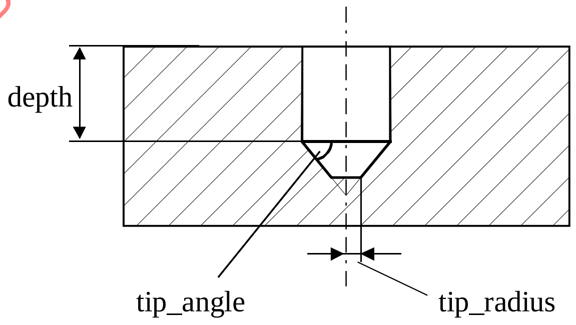


Figure 19 — Conical hole bottom

```
  ENTITY conical_hole_bottom                                   (* m1 *)
    SUBTYPE OF (blind_bottom_condition);
    tip_angle:              plane_angle_measure;
    tip_radius:             OPTIONAL toleranced_length_measure;
  END_ENTITY;
```

tip_angle:	The angle of the tip.
tip_radius:	Optional attribute for specification of a tip radius. Default is zero.

4.5.10 Toolpath feature

To enable the definition of tool movements not covered by the previously listed features, the toolpath_ feature has been introduced. Explicit toolpaths shall be assigned to the operations associated with this feature.

```
  ENTITY toolpath_feature    (* m1 *)
    SUBTYPE OF (machining_feature);
  END_ENTITY;
```

This feature shall only be used if instead of a geometry like an explicit feature, a region, etc. there is only to be described a toolpath. Regular manufacturing features should be used whenever possible. Note that **all** manufacturing features and **all** operations offer the possibility to assign manually programmed toolpaths to them. Such toolpaths will always override any automatic generation of tool movements by the machine controller and offer the CAM system complete control over the machine.

So even if some special tool movement is needed it is preferred to use a regular manufacturing feature with the associated workingsteps and attach explicit tool paths to the workingsteps.

4.5.11 Boss

A boss is a feature which has to be related to an other feature. No separate workingstep can be assigned to manufacture a boss (i.e. it is not possible to first cut the feature and then cut the boss). Instead, the boss is the material which remains unworked after the machining of a feature with a boss. For this reason, boss is not an independent machining feature but exists only as an attribute.

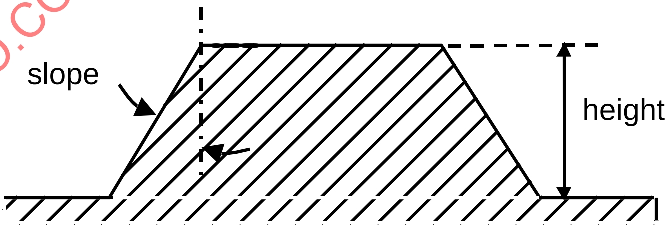


Figure 20 — Boss

```
  ENTITY boss                                                  (* m1 *)
    SUBTYPE OF(machining_feature);
    its_boundary:           closed_profile;
    slope:                  OPTIONAL plane_angle_measure;
    (*
    Informal propositions:
    - The entire profile lies in the same plane.
    - The profile is not self-intersecting.
    *)
  END_ENTITY;
```

its_boundary:	The contour of the boss at the top of the boss. The contour at the bottom may be calculated by traversing the slope along the contour. Also, for the boss to have a well-defined height, its_boundary should be parallel to the bottom of the parent feature. When travelling along the profile based as defined by its sense, the material is to the left of the profile.
slope:	The slope of the contour of the boss relative to the local z axis of the parent feature. The default is 0 degrees.

4.5.12 Spherical cap

This feature is circular about an axis of rotation. It consists of all points at a given distance from a point constituting its centre. The centre is defined by it's placement, that is not located in the feature's highest point, but in the sphere's centre.

```
ENTITY spherical_cap                                         (* m1 *)
  SUBTYPE OF (machining_feature);
  internal_angle:          numeric_parameter;
  radius:                  numeric_parameter;
END_ENTITY;
```

internal_angle:	The size of an angle from an axis for defining a portion of a sphere.
radius:	The constant distance from a point for defining a sphere.

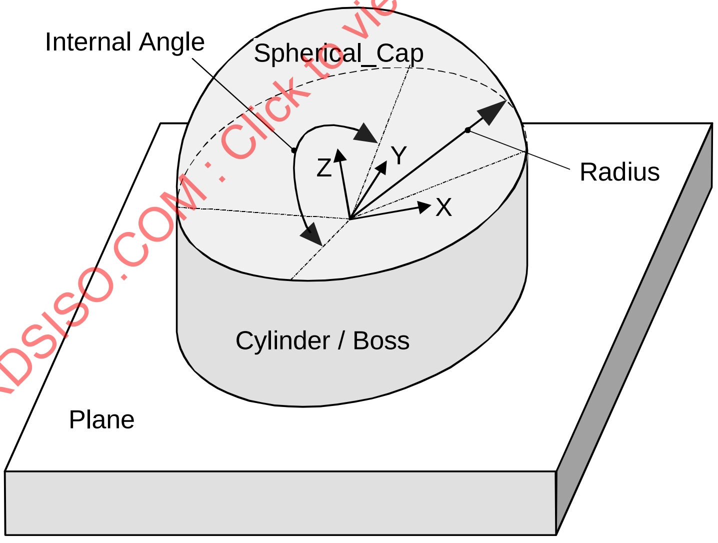


Figure 21 — Spherical cap

4.5.13 Rounded end

A rounded end is a partially circular shape passed along a linear path.

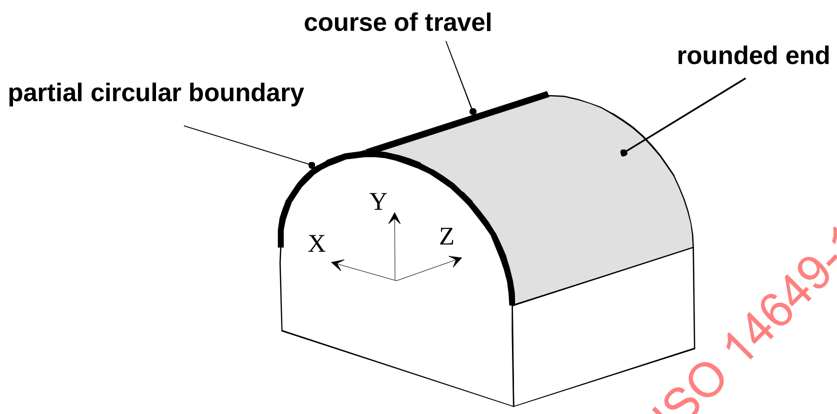


Figure 22 — Rounded end

```
ENTITY rounded_end                                              (* m1 *)
  SUBTYPE OF (machining_feature);
  course_of_travel:       linear_path;
  partial_circular_boundary: partial_circular_profile;
END_ENTITY;
```

course_of_travel:	A straight line with magnitude and direction.
partial_circular_boundary:	The arc that when swept along a path defines the area on a workpiece for volume removal.

4.5.14 Compound feature

A compound feature is a feature composed of two or more features. As opposed to the replicate feature, there is no regular spacing between the elements of the compound feature. In general, they will also not be of the same type.

The volume of removed material of the compound feature is the union of all volumes of the elements of the compound feature. It is illegal to create a compound feature where the volumes of the elements are not connected in such a way that their union can be machined.

Note that the individual elements of the compound feature are associated with machining operation. In addition the compound feature includes by the attribute its_operations all operations of its minor elements.

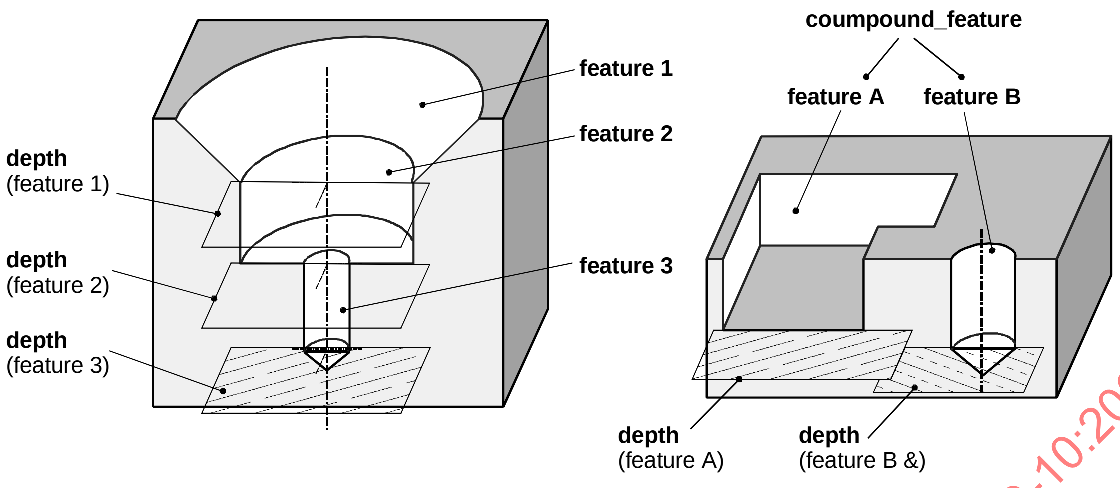


Figure 23 — Compound feature

```
ENTITY compound_feature                                         (* m1 *)
  SUPERTYPE OF (ONEOF(counterbore_hole, countersunk_hole))
  SUBTYPE OF (two5D_manufacturing_feature);
  elements: SET [2:?] OF compound_feature_select;
WHERE
  WR1: SIZEOF(QUERY(e <* elements |
  SIZEOF(e\manufacturing_feature.its_operations) <> 0)) = 0;
END_ENTITY;
```

elements:	Set of features composing the compound feature. Note that the feature_placement attribute of the elements will specify their position relative to the local co-ordinate system of the compound feature, not relative to the workpiece co-ordinates.

4.5.14.1 Compound feature select

Selection of the elements of compound_feature.

```
TYPE compound_feature_select = SELECT(
  machining_feature, transition_feature
  );
END_TYPE;
```

4.5.14.2 Counterbore hole

The counterbore hole is a type of compound feature that consists of two round_holes. The round hole closer to the counterbore's placement has to have a larger diameter than the one more inside of the material. The bottom of the former round_hole shall mate with the top of the latter round_hole. The orientation of counterbore_hole shall be the same as the orientation of the latter round_hole. Both round_holes shall be co-axial.

```
ENTITY counterbore_hole                                         (* m1 *)
  SUBTYPE OF (compound_feature);
WHERE
  WR1: SIZEOF(elements) =2;
  WR2: (SIZEOF(QUERY ( it <* SELF.elements |
       (('MACHINING_SCHEMA.ROUND_HOLE' IN TYPEOF(it))) )) = 2);
```

```
   WR3: SELF.elements[1].diameter.theoretical_size <>
        SELF.elements[2].diameter.theoretical_size;
END_ENTITY;
```

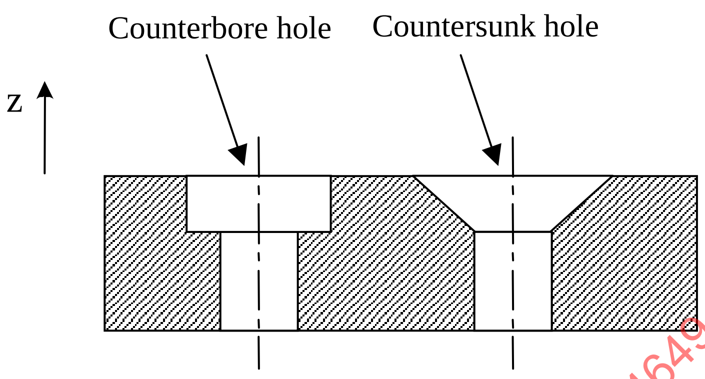


Figure 24 — Counterbore and countersunk hole

4.5.14.2.1 Countersunk hole

The countersunk hole is a type of compound feature that consists of two round_holes. The bottom of the round_hole closer to the countersunk's placement shall mate with the top of the round_hole more inside of material. The taper of the former round_hole shall be larger than the diameter of the latter round_hole, decreasing to the same diameter at the point where the two holes join. The orientation of countersunk_hole shall be the same as the orientation of the latter round_hole. Both round_holes shall be co-axial.

```
ENTITY countersunk_hole                                   (* m1 *)
   SUBTYPE OF (compound_feature);
WHERE
   WR1: SIZEOF(elements) =2;
   WR2: (SIZEOF(QUERY ( it <* SELF.elements |
        (('MACHINING_SCHEMA.ROUND_HOLE' IN TYPEOF(it))) )) = 2);
   WR3: SELF.elements[1].diameter.theoretical_size <>
        SELF.elements[2].diameter.theoretical_size;
   WR4: NOT EXISTS(SELF.elements[1].change_in_diameter) AND
        EXISTS(SELF.elements[2].change_in_diameter);
END_ENTITY;
```

4.5.15 Replicate feature

A replicate is an assembly of a number of similar features, e.g. a circle of holes or a mesh of holes. The feature is described only once and the number and spacing of the feature is described. Note that the attribute feature_placement of replicate_base_feature will describe the location of the feature relative to its position in the replication pattern as specified by the subtypes of replicate_feature.

```
ENTITY replicate_feature                                  (* m1 *)
   ABSTRACT SUPERTYPE OF (ONEOF(rectangular_pattern, circular_pattern,
   general_pattern))
   SUBTYPE OF (two5D_manufacturing_feature);
   replicate_base_feature: two5D_manufacturing_feature;
END_ENTITY;
```

replicate_base_feature:	The feature which forms the basis of the replicate feature.

4.5.15.1 Circular pattern

A circular pattern of features. A complete circle of features is a special case of circular pattern.

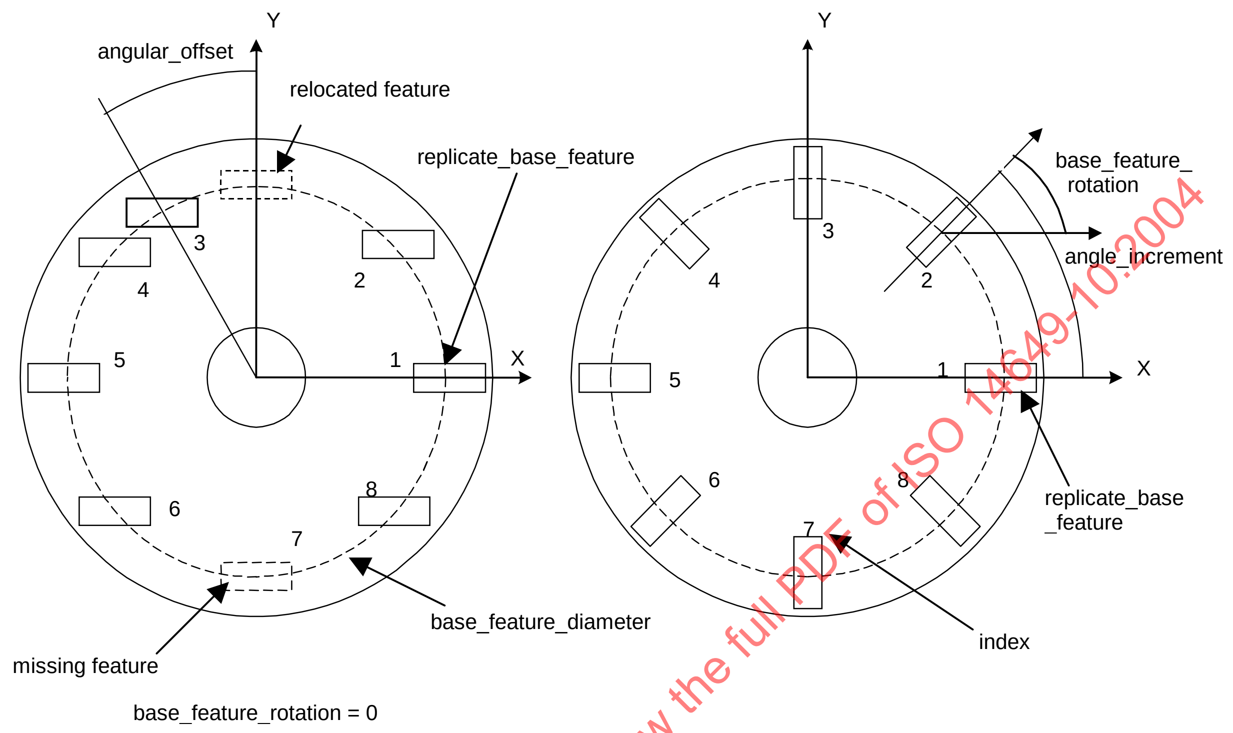


Figure 25 — Circular Pattern

```
ENTITY circular_pattern                                   (* m1 *)
  SUBTYPE OF(replicate_feature);
  angle_increment:          plane_angle_measure;
  number_of_feature:        INTEGER;
  relocated_base_feature:   SET[0:?] OF circular_offset;
  missing_base_feature:     SET[0:?] OF circular_omit;
  base_feature_diameter:    OPTIONAL toleranced_length_measure;
  base_feature_rotation:    plane_angle_measure;
END_ENTITY;
```

angle_increment:	Angle between two elements of the pattern. A positive angle means a counter-clockwise increment when looking towards the plane in negative z direction.
number_of_feature:	The total number of features in the replicate_feature. The maximum index of the circular pattern is calculated from number_of_feature plus the number of elements in the missing_base_feature set. The maximum index times angle_increment should not exceed 360° or the behaviour will be undefined.
relocated_base_feature:	Optional description of relocated features.
missing_base_feature:	Optional description of omitted features.
base_feature_diameter:	The diameter of the circular pattern. It has to be specified if rotate_feature is "false". If it is "true", the diameter can be calculated from the feature position and the location of the centre.

base_feature_rotation	Specification of the angle to rotate one element in regard to the orientation of the previous element. The previous element is located in mathematical negative direction (counter-clockwise) to the current element.

4.5.15.1.1 Circular offset

Definition of elements offset from the circle of elements.

```
ENTITY circular_offset;                                        (* m1 *)
  angular_offset:           plane_angle_measure;
  index:                    INTEGER;
END_ENTITY;
```

angular_offset:	Offset of angle of the relocated element.
index:	Number of the relocated element.

4.5.15.1.2 Circular omit

Definition of elements omitted from the circle of elements.

```
ENTITY circular_omit;                                          (* m1 *)
  index:                    INTEGER;
END_ENTITY;
```

index:	Number of the element to be omitted.

4.5.15.2 Rectangular pattern

The description of elements arranged in a rectangular pattern. This may be either a grid of elements with n rows and m columns and a total number of n x m elements or a single line of m elements (n=1).

```
ENTITY rectangular_pattern                                     (* m1 *)
  SUBTYPE OF(replicate_feature);
  spacing:                  toleranced_length_measure;
  its_direction:            direction;
  number_of_rows:           OPTIONAL INTEGER;
  number_of_columns:        INTEGER;
  row_spacing:              OPTIONAL toleranced_length_measure;
  row_layout_direction:     OPTIONAL direction;
  relocated_base_feature:   SET[0:?] OF rectangular_offset;
  missing_base_feature:     SET[0:?] OF rectangular_omit;
WHERE
  WR1: (
         (SELF.number_of_rows > 1 )
         AND EXISTS(SELF.row_spacing)
         AND EXISTS(SELF.row_layout_direction)
       );
END_ENTITY;
```

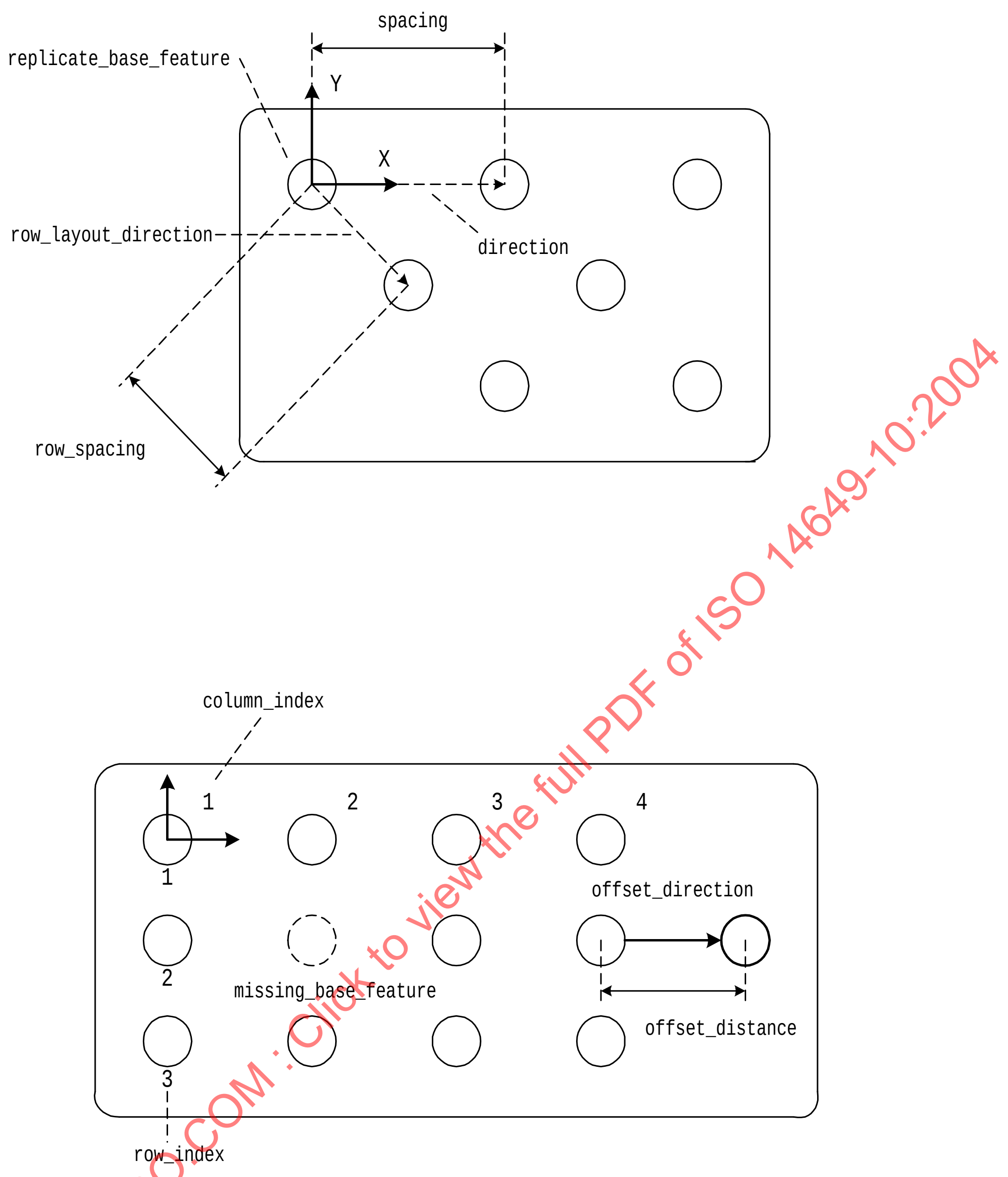


Figure 26 — Rectangular pattern

spacing:	The spacing of the columns of the pattern. If there is only one row, this is also the spacing between the elements.
its_direction:	Direction of the first row measured from the direction given in feature_placement. It points into the direction of the row, describing the order to manufacture the replicated feature.
number_of_rows:	The number of rows. Default is one, i. e. the rectangular pattern is a line of features. If number_of_rows is larger than one, the attributes row_spacing and row_layout_direction need to be specified.
number_of_columns:	The number of columns.

row_spacing:	The spacing of the rows (optional, needed if number_of_rows is larger than one).
row_layout_direction:	Optional description of the direction of the first column measured from the direction given in feature_placement. It points into the direction of the next row.
relocated_base_feature:	Optional description of relocated features.
missing_base_feature:	Optional description of missing features.

Note that the number of features can be calculated from the number_of_rows, number_of_columns, missing_base_feature, and relocated_base_feature.

4.5.15.2.1 Rectangular offset

Entity to describe the position of a single relocated element within a rectangular pattern of elements.

```
ENTITY rectangular_offset;                                    (* m1 *)
  offset_direction:         direction;
  offset_distance:          length_measure;
  row_index:                INTEGER;
  column_index:             INTEGER;
END_ENTITY;
```

offset_direction:	Direction of the offset of the element.
offset_distance:	Amount of offset of the element.
row_index:	Row of the offset element.
column_index:	Column of the offset element.

4.5.15.2.2 Rectangular omit

Entity to omit one or more elements of a rectangular pattern of elements.

```
ENTITY rectangular_omit;                                      (* m1 *)
  row_index:                INTEGER;
  column_index:             INTEGER;
END_ENTITY;
```

row_index:	Row of the omitted element.
column_index:	Column of the omitted element.

4.5.15.3 General pattern

Definition of a general list of identical elements (used i.e. for identical holes positioned arbitrarily).

```
ENTITY general_pattern                                    (* m1 *)
  SUBTYPE OF(replicate_feature);
  replicate_locations:    LIST [2:?] OF axis2_placement_3d;
END_ENTITY;
```

replicate_locations:	List of the placement of the features relative to the local co-ordinate system of general_pattern. The order of the features to be machined is given by the sequence of the features' placements within the list.

4.5.16 Transition feature

A transition feature may be added at the border of two features. Example: An edge round or a chamfer between two planar faces or between a planar face and a pocket. Unlike in ISO 10303-224, only those transition features which are generated using additional tool movements are considered here. Example: An edge round between a pocket and a planar face needs an additional manufacturing operation (workingstep). On the contrary, a fillet between the sides and the bottom of a pocket results from the geometry of the tool and thus needs no additional tool movement. It is therefore not considered in this context.

```
ENTITY transition_feature                                 (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF(chamfer, edge_round))
  SUBTYPE OF (manufacturing_feature);
  first_feature:          machining_feature;
  second_feature:         machining_feature;
END_ENTITY;
```

first_feature:	The first of the two features connected by the transition feature.
second_feature:	The second of the two features connected by the transition feature.

4.5.16.1 Chamfer

A chamfer is one of the two defined transition features for 2½D-machining This chamfer is always an *outer* chamfer as only this can be generated in a separate manufacturing operation.

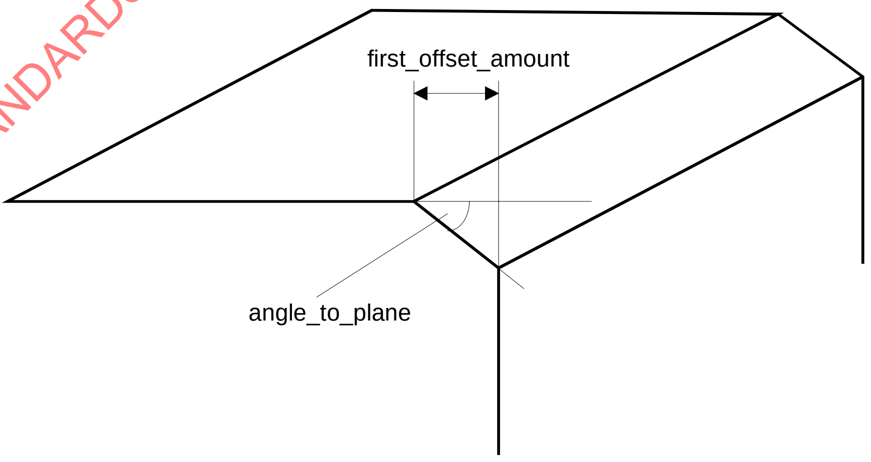


Figure 27 — Chamfer

```
  ENTITY chamfer                                          (* m1 *)
    SUBTYPE OF (transition_feature);
    angle_to_plane:          plane_angle_measure;
    first_offset_amount:     toleranced_length_measure;
  END_ENTITY;
```

angle_to_plane:	Angle between the first feature and the chamfer face measured from the first feature.
first_offset_amount:	The offset of the chamfer measure from the edge of the first feature.

4.5.16.2 Edge round (fillet)

An edge round is the other of the two defined transition features. In 2½D-machining, it is generated using a contoured tool which has to be selected according to the given fillet radius. The edge_round is always an **outer** fillet, since only this type of fillet can be manufactured in an extra manufacturing operation.

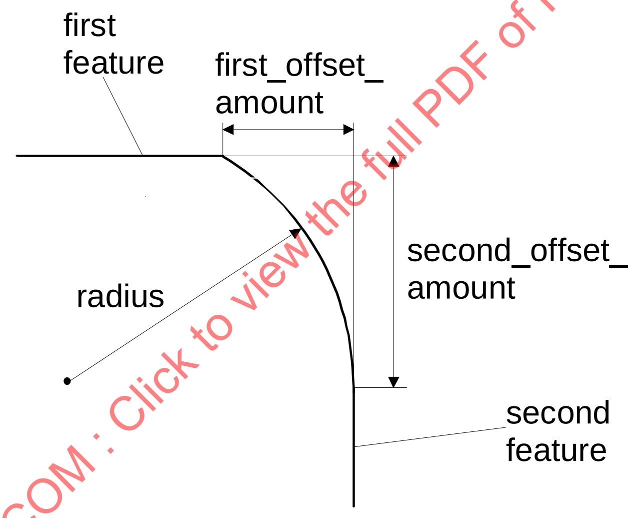


Figure 28 — Edge round

```
  ENTITY edge_round                                       (* m1 *)
    SUBTYPE OF (transition_feature);
    radius:                  toleranced_length_measure;
    first_offset_amount:     OPTIONAL toleranced_length_measure;
    second_offset_amount:    OPTIONAL toleranced_length_measure;
  END_ENTITY;
```

radius:	Radius of the edge round.
first_offset_amount:	The edge_round may or may not be tangent to the two features, this attribute specifies the location of the edge round (see figure).
second_offset_amount:	A non-tangent edge_round may or may not be symmetrical to the two features. If it is not symmetrical, this feature specifies the location of the edge round (see figure).

4.5.17 Thread

A thread is a ridge of a uniform section on the form of a helix on the external or internal surface of a cylinder. Each thread is either a catalogue_thread or a defined_thread.

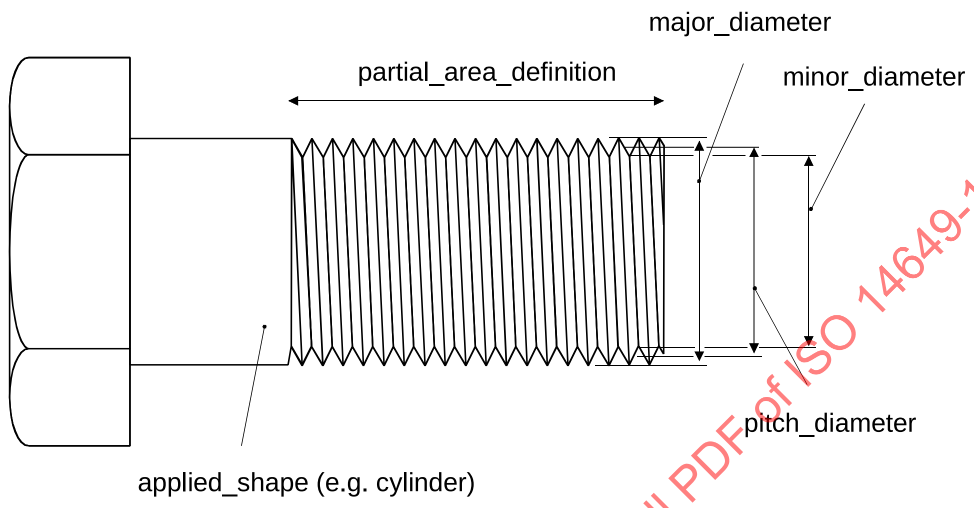


Figure 29 — Thread

```
ENTITY thread                                                (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(catalogue_thread, defined_thread))
  SUBTYPE OF(machining_feature);
  partial_profile:         partial_area_definition;
  applied_shape:           SET[1:?] OF machining_feature;
  inner_or_outer_thread:   BOOLEAN;
  qualifier:               OPTIONAL descriptive_parameter;
  fit_class:               descriptive_parameter;
  form:                    descriptive_parameter;
  major_diameter:          length_measure;
  number_of_threads:       numeric_parameter;
  thread_hand:             descriptive_parameter;
WHERE
  WR1: ('MACHINING_SCHEMA.ROUND_HOLE' IN TYPEOF(applied_shape))
   OR ('MACHINING_SCHEMA.CIRCULAR_CLOSED_SHAPE_PROFILE' IN
  TYPEOF(applied_shape))
   OR ('MACHINING_SCHEMA.BOSS' IN TYPEOF(applied_shape));
END_ENTITY;
```

partial_profile:	Specification of limitations of a surface to be applied on the thread.
applied_shape:	Physical shape of the workpiece that will define where the thread will be applied.
inner_or_outer_thread:	A flag specifies whether or not a thread is applied as an internal thread or an external thread.
qualifier:	Additional text information that describes a thread.

fit_class:	The value for the type of fit specification. These types are distinguished from each other by the amount of the tolerance and allowance.
form:	The definition of the shape of the thread. Various forms of threads are used to hold parts together, to adjust parts with reference to each other, or to transmit power.
major_diameter:	The dimension of the largest diameter of the thread and is applied to both an internal and external thread.
number_of_threads:	The thread pitch when used with metric unit of measure and the density of threads per inch when used with English unit of measure.
thread_hand:	A description of whether the thread is right or left handed. When viewed toward an end, a right hand winds in a clockwise direction and a left hand winds in a counter clockwise direction.

4.5.17.1.1 Partial area definition

A partial_area_definition includes the limitations of a surface for applying a thread. It places a limitation on how much and where to apply the thread on the cylindrical shape.

```
  ENTITY partial_area_definition;                             (* m1 *)
    effective_length:        length_measure;
    placement:               axis2_placement_3D;
    maximum_length:          OPTIONAL length_measure;
  END_ENTITY;
```

effective_length	The length of the thread which is usable.
placement:	The location and direction of the partial_area_definition.
maximum_length:	The dimension along a surface to apply a thread. It limits The dimensional distance limits the length along the surface axis for defining a thread.

4.5.17.2 Catalogue thread

A catalogue thread is a type of thread that is defined by a document containing the information to create threads on a workpiece.

```
  ENTITY catalogue_thread                                     (* m1 *)
    SUBTYPE OF (thread);
    documentation:           specification;
  END_ENTITY;
```

documentation:	Specification of the document that defines information pertaining to a thread.

4.5.17.3 Specification

A specification is a document that defines information pertaining to properties or processes for a workpiece or an aspect of a workpiece.

```
ENTITY specification;                                                (* m1 *)
  constraint:              SET [0:?] OF specification_usage_constraint;
  specification_id:        text;
  specification_description: OPTIONAL text;
  specification_class:     OPTIONAL text;
END_ENTITY;
```

constraint:	A set of the restrictions on the specification.
specification_id:	A unique identifier of the document.
specification_description:	A description of the content of the specification and any notes in human interpretable prose.
specification_class:	A section within a specification that is divided into classes.

4.5.17.3.1 Specification usage constraint

A specification_usage_constraint is a restriction on the application of information defined within a specification.

```
ENTITY specification_usage_constraint;                               (* m1 *)
  element:                 text;
  class_id:                text;
END_ENTITY;
```

element:	The particular piece or area of information that is being restricted within the specification.
class_id:	The data or range of data with respect to the element that defines the restriction imposed on the usage of the specification.

4.5.17.4 Defined thread

A defined_thread is a type of thread that is specified explicitly.

```
ENTITY defined_thread                                                (* m1 *)
  SUBTYPE OF (thread);
  pitch_diameter:          length_measure;
  minor_diameter:          OPTIONAL length_measure;
  crest:                   OPTIONAL length_measure;
END_ENTITY;
```

pitch_diameter:	The dimension of an imaginary cylinder passing through the thread so as to make equal the widths of the threads and the widths of the spaces cut by the cylinder.
minor_diamter:	The dimension of the smallest diameter of the defined_thread and is applied to both an internal and external thread.

crest:	The distance between the opposing points of the thread. It is formed by the intersection of the sides of the thread if extended, if necessary, beyond the top of the thread.

4.5.18 Profile

A profile is a planar outline used in the definition of a feature. A profile may be either open or closed. A profile shall be in the X-Y plane and may have an orientation that will position it in reference to the local coordinate system of a manufacturing_feature, which may require a profile as a part of its definition.

```
ENTITY profile                                                    (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(closed_profile, open_profile));
  placement:               OPTIONAL axis2_placement_3d;
END_ENTITY;
```

placement:	Specification where to locate the profile in reference to the orientation of the manufacturing_feature. If not given, the orientation is at the zero point of the manufacturing_feature.

4.5.18.1 Open profile

An open_profile is a type of profile that is an outline or shape with no enclosing or confining bounds. The open ends of the profile may extend infinitely.

```
ENTITY open_profile                                               (* m1 *)
  ABSTRACT SUPERTYPE OF
  (ONEOF (linear_profile, square_u_profile, rounded_u_profile, tee_profile,
  vee_profile, partial_circular_profile, general_profile))
  SUBTYPE OF(profile);
END_ENTITY;
```

4.5.18.1.1 Linear profile

A linear_profile is a type of open_profile that is a straight line of a specified length. The linear_profile shall have orientation parallel to the X-axis.

```
ENTITY linear_profile                                             (* m1 *)
  SUBTYPE OF (open_profile);
  profile_length:          numeric_parameter;
END_ENTITY;
```

profile_length:	The length of the profile.

4.5.18.1.2 Square U profile

A square U profile is a type of open profile that is bounded by three lines. One is the base line and has a defined length. The other two lines begin at the ends of the base line, and extend infinitely at any obtuse or acute angle that is equal to or larger than a right angle. The corners of the square U profile need not be blended by a radius.

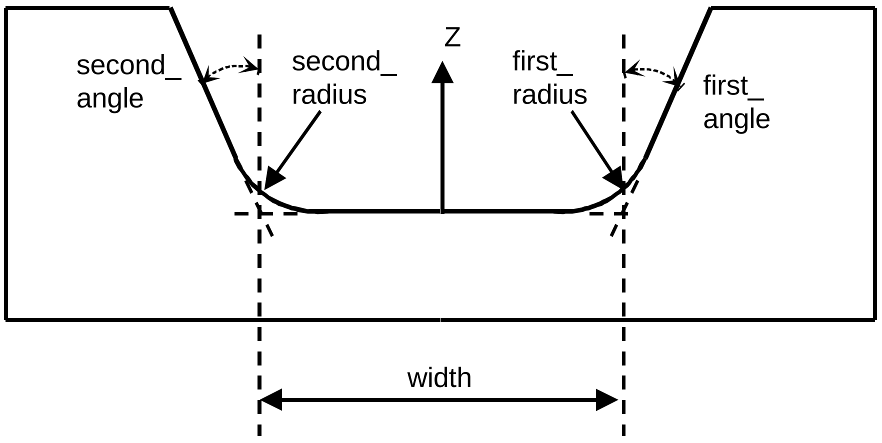


Figure 30 — Square U profile

For a rectangular slot, all values except for the width shall be zero.

```
ENTITY square_u_profile                                        (* m1 *)
  SUBTYPE OF (open_profile);
  width:                    toleranced_length_measure;
  first_radius:             toleranced_length_measure;
  first_angle:              plane_angle_measure;
  second_radius:            toleranced_length_measure;
  second_angle:             plane_angle_measure;
END_ENTITY;
```

width:	The size of the base line for a square U profile.
first_radius:	The radius shape blend between one side of the profile and the base.
first_angle:	The angle of the one side of the profile measured against the local z axis.
second_radius:	The radius shape blend between the second side of the profile and the base.
second_angle:	The angle of the another side of the profile measured against the local z axis.

4.5.18.1.3 Rounded U profile

A rounded U profile is a type of open profile that is a shape bounded by two parallel lines and a semicircle.

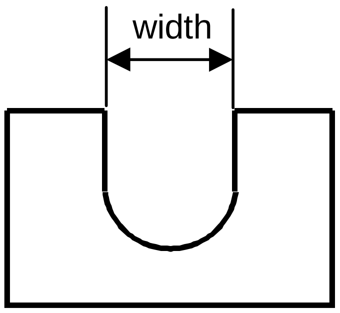


Figure 31 — Rounded U profile

```
ENTITY rounded_u_profile                                         (* m1 *)
  SUBTYPE OF (open_profile);
  width:                    toleranced_length_measure;
END_ENTITY;
```

width:	Distance across the rounded u profile.

4.5.18.1.4 T profile

A T profile is a type of open profile the cross-section of which has the shape of the letter "T". The attributes are explained in the figure.

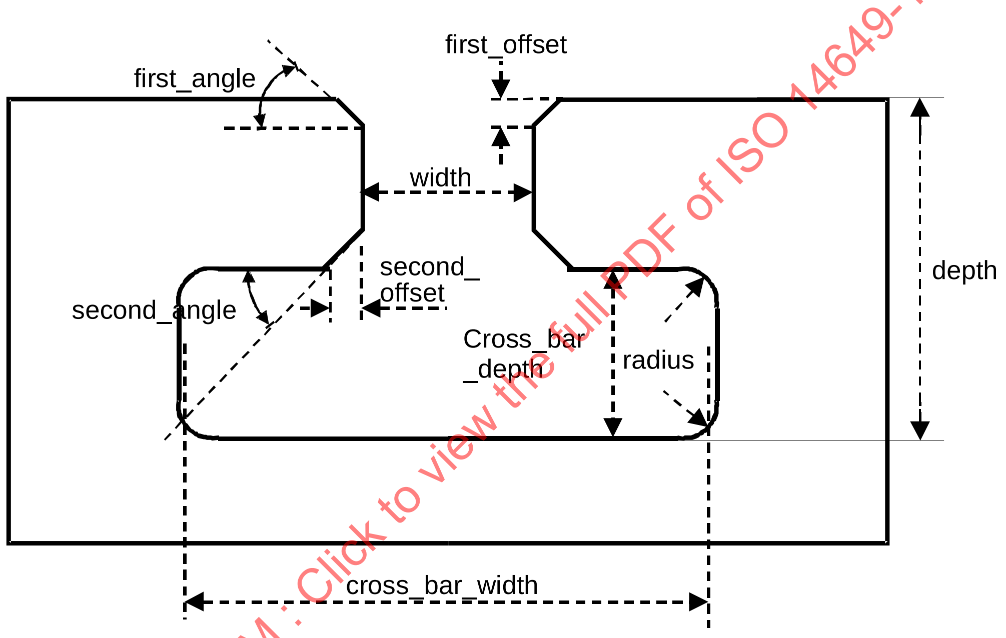


Figure 32 — T profile

```
ENTITY tee_profile                                               (* m1 *)
  SUBTYPE OF (open_profile);
  first_angle:              plane_angle_measure;
  second_angle:             plane_angle_measure;
  cross_bar_width:          toleranced_length_measure;
  cross_bar_depth:          toleranced_length_measure;
  radius:                   toleranced_length_measure;
  width:                    toleranced_length_measure;
  first_offset:             toleranced_length_measure;
  second_offset:            toleranced_length_measure;
END_ENTITY;
```

first_angle:	Angular measurement for creating a chamfer on the open end.
second_angle:	Angular measurement for creating a chamfer between the stem and the cross bar parts of a T profile.
cross_bar_width:	Width of the T cross bar.
cross_bar_depth:	Depth of the T cross bar.

radius:	Arc size for blending the sides of a tee cross bar.
width:	Width of the T stem.
first_offset:	Distance from the edge of the T stem to create a chamfer on the open end.
second_offset:	Distance from the edge of the T stem to create a chamfer a distance from the edge of a surface to the finish of a chamfer.

4.5.18.1.5 V profile

A V profile is a type of open profile that is a shape bounded by two lines that connect at a point and extend infinitely. The enclosed angle is less than 180 degrees.

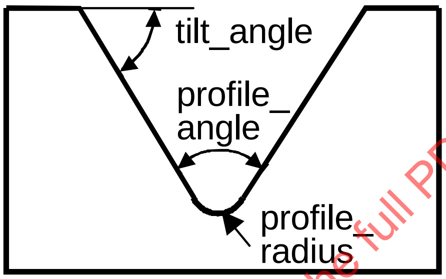


Figure 33 — V profile

```
ENTITY vee_profile                                              (* m1 *)
  SUBTYPE OF (open_profile);
  profile_radius:        toleranced_length_measure;
  profile_angle:         plane_angle_measure;
  tilt_angle:            plane_angle_measure;
END_ENTITY;
```

profile_radius:	Size of the blend radius at the point of the V or where the two sides come together.
profile_angle:	The size of the angle between the two sides of the V profile.
tilt_angle:	The size of the angle between one side of the V profile and the surrounding workpiece surface.

4.5.18.1.6 Partial circular profile

A partial circular profile is a type of open_profile that is specified by an arc. The arc shall be a constant radius swept about a point. The orientation of the profile shall be positioned at the origin of the are, with one end point of the arc on the X-axis.

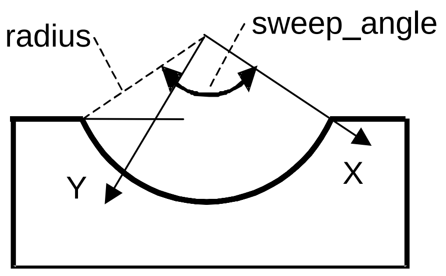


Figure 34 — Partial circular profile

```
ENTITY partial_circular_profile                                    (* m1 *)
  SUBTYPE OF (open_profile);
  radius:                  toleranced_length_measure;
  sweep_angle:             plane_angle_measure;
END_ENTITY;
```

radius:	The size of the arc to define a partial circular profile.
sweep_angle:	The size of the angle to define a circular shaped profile.

4.5.18.1.7 General profile

Any profile as defined by an arbitrary contour.

```
ENTITY general_profile                                             (* m1 *)
  SUBTYPE OF (open_profile);
  its_profile:             bounded_curve;
  (*
  Informal propositions:
  - The entire profile lies in the local yz plane.
  - The profile is not self-intersecting.
  *)
END_ENTITY;
```

its_profile:	A contour describing the general profile.

4.5.18.2 Closed profile

A closed_profile is a type of profile that is an outline or shape that bounds an enclosed area with no opening.

```
ENTITY closed_profile                                              (* m1 *)
  ABSTRACT SUPERTYPE OF
  (ONEOF (rectangular_closed_profile, circular_closed_profile, ngon_profile,
  general_closed_profile))
  SUBTYPE OF(profile);
END_ENTITY;
```

4.5.18.2.1 Rectangular closed profile

A rectangular_closed_profile is a type of closed_profile that is an enclosed area bounded by four sides with opposite sides equal in length and corners at 90 degrees. The orientation is at the center of the rectangle, the X-axis is parallel to the length of the rectangle and the Y-axis is parallel to the width.

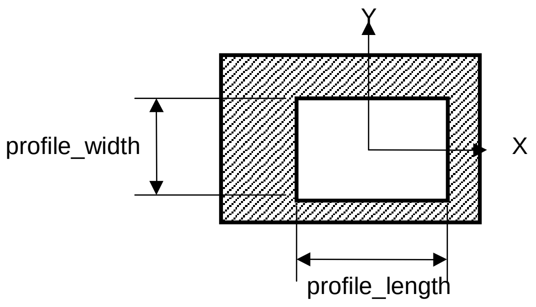


Figure 35 — Rectangular closed profile

```
ENTITY rectangular_closed_profile                                 (* m1 *)
  SUBTYPE OF(closed_profile);
  profile_width:          toleranced_length_measure;
  profile_length:         toleranced_length_measure;
END_ENTITY;
```

profile_width:	The size of the shortest side of the rectangular_profile.
profile_length:	The size of the longest side of the rectangular_profile.

4.5.18.2.2 Circular closed profile

A circular_closed_profile is a type of closed_profile that is an enclosed area bounded by a circle. The orientation is at the center of the circle.

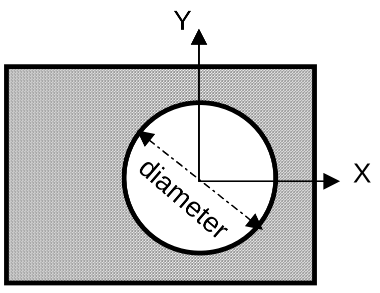


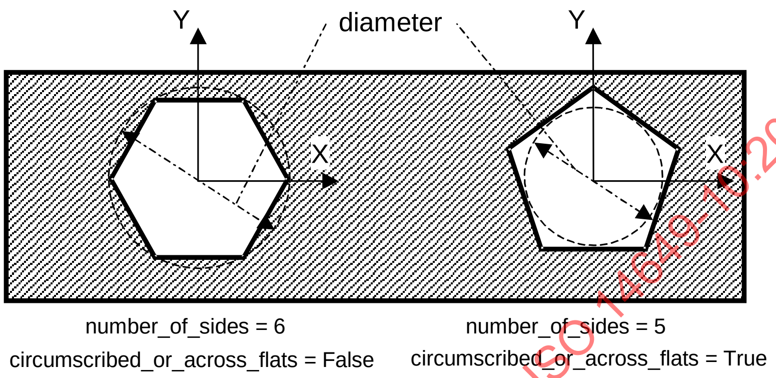
Figure 36 — Circular closed profile

```
ENTITY circular_closed_profile                                    (* m1 *)
  SUBTYPE OF(closed_profile);
  diameter:               toleranced_length_measure;
END_ENTITY;
```

diameter:	The distance across the circular_closed_profile.

4.5.18.2.3 Ngon profile

An ngon_ profile is a type of closed_profile that is an enclosed area bounded by three or more connected straight line sides. The orientation is at the center of the profile with one side of the ngon parallel to the X-axis


Y
diameter
Y
X
X
number_of_sides = 6
circumscribed_or_across_flats = False
number_of_sides = 5
circumscribed_or_across_flats = True

crossing the Y-axis at a negative value.

Figure 37 — Ngon profile

```
ENTITY ngon_profile                                          (* m1 *)
  SUBTYPE OF(closed_profile);
  diameter:                 toleranced_length_measure;
  number_of_sides:          INTEGER;
  circumscribed_or_across_flats: BOOLEAN;
END_ENTITY;
```

diameter:	The size of the circle which surrounds the ngon or is surrounded by the ngon. It depends on the flag of circumscribed_or_across_flats.
number_of_sides:	Number of sides needed for the ngon.
circumscribed_or_across_flats:	If false, the ngon is surrounded by a circle with the specified diameter. If true, the ngon surrounds a circle with the specified diameter.

4.5.18.2.4 General closed profile

A general_closed_profile is a type of closed_profile that is an enclosed area bounded by a arbitrary shape. The orientation is defined by the explicit geometry of the shape.

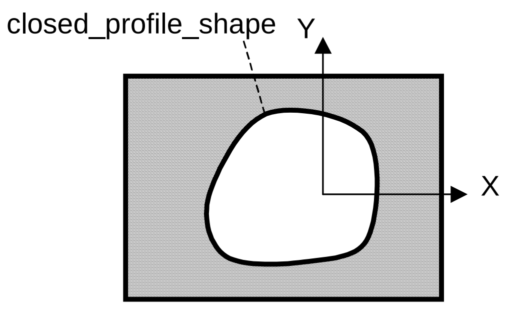


Figure 38 — General closed profile

```
ENTITY general_closed_profile                                 (* m1 *)
  SUBTYPE OF(closed_profile);
  closed_profile_shape:    bounded_curve;
END_ENTITY;
```

closed_profile_shape:	A bounded curve that defines the arbitrary shape of the profile.

4.5.19 Travel path

A travel_path is a continuous set of curves that define a direction of travel. These curves do not intersect or duplicate themselves. A travel_path may have its own orientation in reference to the local coordinate system of the machining_feature which requires it as a part of a feature definition.

```
ENTITY travel_path                                            (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(general_path, linear_path, circular_path));
  placement:               OPTIONAL axis2_placement_3d;
END_ENTITY;
```

placement:	Specification where to locate the travel_path in reference to the orientation of the manufacturing_feature. If not given, the orientation is at the zero point of the manufacturing_feature.

4.5.19.1 General path

A General_path is a type of path that is a direction of travel along an arbitrary curve.

```
ENTITY general_path                                           (* m1 *)
  SUBTYPE OF(travel_path);
  swept_path:              bounded_curve;
END_ENTITY;
```

swept_path:	A continuous set of curves that define an arbitrary direction of travel.

4.5.19.2 Linear path

A linear_path is a type of path that is a direction of travel along a line.

```
  ENTITY linear_path                                         (* m1 *)
    SUBTYPE OF(travel_path);
    distance:                toleranced_length_measure;
    its_direction:           direction;
  END_ENTITY;
```

distance:	The length of the path.
its_direction:	A vector which indicates the direction of the path starting from the path placement.

4.5.19.3 Circular path

The cicular_path is a type of path that is a direction of travel along an arc of constant radius around the Z-axis of the feature.

```
  ENTITY circular_path                                       (* m1 *)
    ABSTRACT SUPERTYPE OF(ONEOF(complete_circular_path, partial_circular_path))
    SUBTYPE OF(travel_path);
    radius:                  toleranced_length_measure;
  END_ENTITY;
```

radius:	The constant distance from an axis for the circular_path

4.5.19.3.1 Complete circular path

A complete_circular_path is a type of circular_path that is a direction of travel that begins and ends the same point on the arc.

```
  ENTITY complete_circular_path                              (* m1 *)
    SUBTYPE OF(circular_path);
  END_ENTITY;
```

4.5.19.3.2 Partial circular path

A partical_circular_path is a type of circular_path that is a direction of travel along an arc of constant radius around an axis. The path shall begin and end at different points on the arc.

```
  ENTITY partial_circular_path                               (* m1 *)
    SUBTYPE OF(circular_path);
    sweep_angle:             plane_angle_measure;
  END_ENTITY;
```

sweep_angle:	The size of the angle to define an arc shaped path.

4.5.20 Surface texture parameter

A Surface_texture_parameter is a combination of a parameter name and possibly indices describing one particular parameter of a surface texture such as roughness or waviness

```
ENTITY surface_texture_parameter;                          (* m1 *)
   its_value:              parameter_value;
   parameter_name:         label;
   measuring_method:       identifier;
   parameter_index:        OPTIONAL identifier;
   applied_surfaces:       SET [1:?] OF machined_surface;
 END_ENTITY;
```

its_value:	The value of the surface_texture_parameter.
parameter_name:	The name of the surface_texture_parameter. For example, a typical Surface_texture_parameter according to ISO 4287 is Ra; in this case, the parameter name is 'R' and the index is 'a'.
measuring_method:	The measuring_method specifies the method or standard that describes the method used to characterize the Surface_texture. Where applicable the following values shall be used: 'ISO 4287': The used surface texture parameters are defined in ISO 4287; 'ISO 12085': The used surface texture parameters are defined in ISO 12085; 'ISO 13565': The used surface texture parameters are defined in ISO 13565.
parameter_index:	An index that specifies the name of the measuring_method further.
applied_surfaces:	Physical surface of machining_feature that will define where the surface_texture_parameter will be applied.

4.5.20.1 Machined surface

The physical surface of machining_feature where the surface_texture_parameter will be applied.

```
ENTITY machined_surface;                                   (* m1 *)
   its_machining_feature:  machining_feature;
   surface_element:        bottom_or_side;
END_ENTITY;
```

its_machining_feature:	The physical shape of the workpiece where the machined_surface belongs.
surface_element:	The selection of the location of the machined_surface in reference to its_machining_feature

4.5.20.1.1 Bottom or side

Selection of the location of a surface in reference to the machining_feature.

```
TYPE bottom_or_side =
   ENUMERATION OF (bottom, side, bottom_and_side);
END_TYPE;
```

4.6 To make things happen: Executables

4.6.1 Executable

Executable is the base entity of all executable objects. They initiate actions on a machine and shall be arranged in a defined order. There are three types of executable objects: workplans, nc_function, and workingstep.

```
ENTITY executable                                          (* m0 *)
  ABSTRACT SUPERTYPE OF (ONEOF( workingstep, nc_function,program_structure));
  its_id:                identifier;
  (*
  Informal proposition:
  its_id shall be unique within the part programme.
  *)
END_ENTITY;
```

its_id: The executable's identifier. It shall be unique within the part programme.

Workingsteps (Section 4.6.2) describe manufacturing or handling operations which involve interpolating axes, i.e. whose execution normally spans a certain period of time and which can only be executed in conjunction with a workpiece. They have attributes which describe the state of the machine during their execution.

NC functions on the other hand describe switching operations or other non-interpolating machine functionality, i.e. typically singular events. The current NC functions are listed in section 4.6.3.

Program structures (Section 4.6.4) are used to build logical blocks for structured programming of the manufacturing operation The program structures, not the list of manufacturing features, have the authority over the actual manufacturing sequence. The most important structure is the workplan which provides linear sequence of executables. To arrange the manufacturing sequence in an arbitrary manner, structures for parallel processing, loops and conditional execution can be used.

4.6.2 Workingstep

The workingsteps represent the essential building blocks of an ISO 14649 NC programme. They can either be technology-independent actions, like rapid movements or probing operations, or machining workingsteps which relate to the different technologies like milling, drilling, turning etc.

The actual content of the workingsteps is specified in the entity operation and its subtypes. The reason for this design is the possibility to re-use the information specified for an operation for several features of the workpiece. An operation can be associated with multiple features and can be used in different locations. A workingstep, on the other hand, is unique. Duplicating a workingstep in a workplan will replicate the exact same physical machine action. For more information on operations see Section 4.7.1.

Workingsteps describe manufacturing or handling operations which involve interpolating axes. They do not describe a sequence of events in time but rather the conditions under which the operation has to be performed. For example, the workingstep calls for a specific tool which is required for an operation, and may specify the use of coolant. It does not, however, specify at exactly which moment the tool needs to be changed and whether the tool change or the activation of the coolant comes first. These decisions are left to the programmer or in real time to the NC controller. If in this example the requested tool is already in the spindle during the previous workingstep, the NC controller will decide not to perform any tool change.

At the lowest level of information provided by ISO 14649, the operations can also contain an explicit and exact description of the toolpath if this is required by the CAM system or the NC controller. For the explicit definition of tool movements, see Section 4.8.1.

```
ENTITY workingstep                                         (* m0 *)
  ABSTRACT SUPERTYPE OF (ONEOF (machining_workingstep, rapid_movement,
  touch_probing))
  SUBTYPE OF (executable);
  its_secplane:          elementary_surface;
END_ENTITY;
```

its_secplane:	The security plane for the workingstep. On or above this plane, i. e. for z values greater than those of the elementary_surface, a safe movement of the tool without danger of collision is possible. The dimensions given are relative coordinates as measured from the workpiece co-ordinate system or, if this workingstep is associated with a manufacturing_feature, in the local co-ordinate system of the feature.

4.6.2.1 Machining workingsteps

Machining workingsteps represent the machining process for a specified area of the workpiece. As opposed to the other workingsteps, machining workingsteps cannot exist independent of a feature. Rather, they specify the association between a distinct feature and an operation to be performed on the feature. This removes the ambiguity of the n:1 relation between features and operations, thus creating an unambiguous specification which can be executed by the machine.

As the underlying operation, the machining workingstep is characterised by the use of a single tool and a set of technological parameters which normally remain constant during the reign of this machining workingstep. Upon the execution of a machining workingstep the first operation will be, if necessary, a tool change. During the machining workingstep, no tool change is possible.

The machine is instructed to reach the operating conditions specified by its_operation (attributes its_tool and its_technology) before the operation of the workingstep commences. If the machine is unable to reach these conditions during the preceding workingstep (e.g. during a preceding rapid movement) a halt will occur before the execution of the workingstep until all parameters are stable.

See the technology specific parts of ISO 14649 for details on operations, especially on how the association between the feature and the operation will change the interpretation of the operation.

```
ENTITY machining_workingstep                                 (* m0 *)
  SUBTYPE OF (workingstep);
  its_feature:            manufacturing_feature;
  its_operation:          machining_operation;
  its_effect:             OPTIONAL in_process_geometry;
END_ENTITY;
```

its_feature:	The manufacturing_feature upon which the workingstep operates.
its_operation:	The operation which will be performed upon the manufacturing_feature. The operation must be a member of the manufacturing_feature's list of operations.
its_effect:	The change to the geometry of the workpiece effected by the operation. A CAM system can use this attribute to describe the predicted effect of this operation on the geometry of the workpiece. If given the controller can compare the geometry change described by this attribute with the geometry change predicted by its internal algorithm. ISO 14649 does not describe how closely the two geometries must match in order for the controller to be considered to be in conformance.

Based on the interpretation of the underlying operation a machining workingstep typically has a well-defined start and end point of the tool motion. Thus it will not generally be possible that two subsequent elements in a workplan are machining workingsteps. A gap between the end point of the predecessor and the start point of the successor shall cause the machine to stop.

There are three exceptions to this rule:

(a) the respective end and start points of two subsequent workingsteps happen to coincide,

(b) a tool change is required between the two workingsteps in which case the controller has to calculate the respective toolpaths to and from the tool change position,

(c) the start point of the workingstep is not well-defined and left to the NC controllers discretion, e.g. a pocket finishing operation following a roughing operation where the finishing may start at either boundary of the pocket. However, if an operation contains an explicit toolpath, start and end point are always well-defined.

So often a rapid movement will be used between two machining workingsteps in order to bridge the gap, see Section 4.6.2.1.1.

4.6.2.1.1 In_process_geometry

Entity to represent in-process geometry for additional checking routines. A CAM system can use this information to describe the predicted effect of an operation on one feature. The controller can compare the geometry given in this entity with the geometry change predicted by its internal algorithm. ISO 14649 does not describe how closely the two geometries must match in order for the controller to be considered to be in conformance.

```
ENTITY in_process_geometry;                            (* m1 *)
  as_is:                 OPTIONAL advanced_brep_shape_representation;
  to_be:                 OPTIONAL advanced_brep_shape_representation;
  removal:               OPTIONAL advanced_brep_shape_representation;
WHERE
  WR1: EXISTS (as_is) OR EXISTS (to_be) OR EXISTS (removal);
END_ENTITY;
```

as_is:	Attribute to describe the geometry before an operation is executed.
to_be:	Attribute to describe the desired effect of an operation.
removal:	Volume removed by an operation.

4.6.2.2 Rapid movement

For rapid movements between two workingsteps the entity rapid_movement is used. If no toolpath is given, i. e. the inherited attribute its_toolpath is not set, the NC controller will move the tool in rapid motion from the current position to the beginning of the next workingstep which needs to have a defined starting point. The connection will be done via the security plane.

If a toolpath is specified, this toolpath will be executed in rapid motion. Note that a toolpath of type parameterised path can be used so as to avoid an explicit toolpath definition in cartesian space. This will provide greater flexibility in case of changing start and/or end points of the neighbouring workingsteps.

Unlike a machining workingstep, the rapid movement by itself has no well-defined start and end point unless an explicit toolpath is specified in cartesian space.

If rapid_movement is used during a five-axis machining operation, it will interpolate the tool direction between the previous and the next workingstep. In this case, the tool will retract in the tool direction from the last point of the previous workingstep. On the security plane the tool will rotate to the new tool direction, and then it will move down in the tool direction for the first point of the next workingstep. No change of the tool direction takes place during the lift and approach to and from the security plane.

However, if a toolpath is specified and the toolpath contains an explicit definition of the toolaxis then this definition will prevail.

```
ENTITY rapid_movement                                          (* m0 *)
  SUPERTYPE OF (return_home)
  SUBTYPE OF (workingstep, operation);
END_ENTITY;
```

Note that the first element in a workplan needs to be a rapid movement without explicit toolpath in order to move the tool from its unknown start position to the start point of the first machining operation.

4.6.2.2.1 Return home

This workingstep positions all machine axes to the machine-defined home position in the absolute machine coordinate system with a pre-defined sequence. This should normally be the last operation in a workplan.

```
ENTITY return_home                                             (* m0 *)
  SUBTYPE OF (rapid_movement);
END_ENTITY;
```

4.6.2.3 Touch probing

This is the supertype of touch probe workingsteps. Unlike other workingsteps, touch_probing returns a value for further consideration by the NC programme.

In future releases of this part of ISO 14649, touch_probing may be moved to a separate part specifying operations for measurement equipment. In this case it will become a subtype of machining_operation and needs to be associated with an appropriate measurement feature.

```
ENTITY touch_probing                                           (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF (workpiece_probing, workpiece_complete_probing,
  tool_probing))
  SUBTYPE OF (workingstep, operation);
  measured_offset:        nc_variable;
END_ENTITY;
```

measured_offset:	The measured value of probing.

4.6.2.3.1 Workpiece probing

Probing of a dimension with one axis movement. Probing tool movement starts at start_position in the direction "direction" towards the workpiece. When the probe tool touches the workpiece, the machine stops and the difference of expected_value and tool position is stored in the inherited attribute measured_offset.

Like machining_workingstep, workpiece_probing has a well defined start point and cannot be the first element in a workplan.

```
ENTITY workpiece_probing                                       (* m1 *)
  SUBTYPE OF (touch_probing);
  start_position:         axis2_placement_3d;
  its_workpiece:          workpiece;
  its_direction:          direction;
  expected_value:         toleranced_length_measure;
  its_probe:              touch_probe;
END_ENTITY;
```

start_position:	The starting position for the probing operation.
its_workpiece:	The workpiece to be probed.
its_direction:	The direction of the probing movement.
expected_value:	The approximate value for probing.
its_probe:	The identification of the probe which has to be used.

4.6.2.3.1.1 Touch probe

This gives an identification of touch probe which has to be used for workpiece probing.

```
ENTITY touch_probe;                                                  (* m1 *)
  its_id:                  identifier;
END_ENTITY;
```

its_id:	The identification of touch probe used.

4.6.2.3.2 Workpiece_complete_probing

This entity is similar to workpiece probing only that a complete measurement cycle at six locations of the given workpiece is automatically performed and the translation and rotational offset of the detected workpiece position compared to the given workpiece is computed. The locations of probing are automatically determined by the NC controller based on the geometry of the workpiece. The offset vector is returned in computed_offset while the inherited attributed measured_offset will hold the average of all (six) measured offsets.

Based on the automatic determination of the probing locations, workpiece_complete_probing does *not* have a well defined start point.

```
ENTITY workpiece_complete_probing
  SUBTYPE OF (touch_probing);
  its_workpiece:           workpiece;
  probing_distance:        toleranced_length_measure;
  its_probe:               touch_probe;
  computed_offset:         offset_vector;
END_ENTITY;
```

its_workpiece:	The workpiece to be probed.
probing_distance:	The distance between the probe's tip and the workpiece normal to its surface at the beginning of each probing movement. This value should be well above the maximum expected deviation between the actual position and the workpiece position specified by its_workpiece.
its_probe:	The identification of the probe which has to be used.

computed_offset: The attributes 'translation' and 'rotate' describe the actual workpiece position compared to the position specified by the respective setup. It is computed as a result of the (six) measurements performed by this workingstep.

4.6.2.3.2.1 Offset vector

This entity is used to store the offset resulting from a workpiece probing operation. For entity nc_variable, see section 4.6.4.9. All variables must have initial values, most likely zeros.

```
ENTITY offset_vector;                                         (* m1 *)
  translate:              LIST [3:3] OF nc_variable;
  rotate:                 OPTIONAL LIST [3:3] OF nc_variable;
WHERE
  WR1: (SIZEOF(QUERY(i <* translate | NOT EXISTS(i.initial_value))) = 0)
       AND (NOT EXISTS(rotate) OR (SIZEOF(QUERY(i <* rotate |
       NOT EXISTS(i.initial_value))) = 0));
END_ENTITY;
```

translate:	Variables to store the translation required in each co-ordinate direction (x-, y-, z-axis) in order to move from the theoretical position to the actual position, measured in millimetres.
rotate:	Variables to store the rotation around the x-, y-, and z-axis, respectively, in order to move from the theoretical position to the actual position, measured in degrees. If omitted, only the translational offset will be considered.

4.6.2.3.3 Tool probing

Probing of the length and width/diameter of a tool. The selected tool starts its movement at a machine dependent start position. From that position the tool position is shifted to a fixed sensor position by the offset. Then the tool is moved in direction to the sensor until contact. This is done in longitudinal and perpendicular direction of the tool-axis.

The result of probing is stored in the inherited attribute measured_offset and the NC controllers tool database is automatically updated. NC controllers providing tool correction algorithms are expected to use the updated information of its_tool from the moment the tool_probing workingstep has been completed.

```
ENTITY tool_probing                                           (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF (tool_length_probing, tool_radius_probing))
  SUBTYPE OF (touch_probing);
  offset:                 cartesian_point;
  max_wear:               length_measure;
  its_tool:               machining_tool;
END_ENTITY;
```

offset:	location of the sensor.
max_wear:	maximum permissible wear in length direction.
its_tool:	The tool which has to be probed.

4.6.2.3.4 Machining tool

This is the supertype for all tools which are needed for machining. They are to be specified in the technology-specific parts of ISO 14649 or future standards might be referenced.

```
ENTITY machining_tool                                          (* m0 *)
  ABSTRACT SUPERTYPE;
  its_id:                    label;
END_ENTITY;
```

its_id :	An unique label to exactly identify the tool.

4.6.2.3.5 Tool length probing

The entity can be used for probing the tool length.

```
ENTITY tool_length_probing                                     (* m1 *)
  SUBTYPE OF (tool_probing);
END_ENTITY;
```

4.6.2.3.6 Tool radius probing

The entity can be used for probing the tool radius.

```
ENTITY tool_radius_probing
  SUBTYPE OF (tool_probing);
END_ENTITY;
```

4.6.3 NC function

A NC function is an executable object. It describes manufacturing or handling operations which do not involve interpolation of axes. It shall be switching operations or other singular-event machine functionality.

```
ENTITY nc_function                                             (* m0 *)
  ABSTRACT SUPERTYPE SUBTYPE OF (executable);
END_ENTITY;
```

4.6.3.1 Display message

This function is used to display a message on the operator's screen.

```
ENTITY display_message                                         (* m0 *)
  SUBTYPE OF (nc_function);
  its_text:                  text;
END_ENTITY;
```

its_text:	The message to be displayed on the operator's screen, until the next message is sent. To clear the screen, send an empty message.

4.6.3.2 Optional stop

This function is used to stop executing the NC program until the operator presses the start button. The optional stop permits the user to guide the tool. The controller has to consider the changed axis positions etc.

after the optional stop is released. However, it is only effective under the condition that the operating mode “optional stop” is enabled on the NC controllers operating panel.

```
ENTITY optional_stop                                        (* m0 *)
  SUBTYPE OF (nc_function);
END_ENTITY;
```

4.6.3.3 Program stop

This function is used to stop executing the NC program until the operator presses the start button.

```
ENTITY program_stop                                         (* m0 *)
  SUBTYPE OF (nc_function);
END_ENTITY;
```

4.6.3.4 Set mark

This function is used to synchronize the multiple channel operation. When it is invoked in the channel specified by the attribute its_channel of the entity wait_for_mark, the operation in that channel is started.,

```
ENTITY set_mark                                             (* m0 *)
  SUBTYPE OF (nc_function);
END_ENTITY;
```

4.6.3.5 Wait for mark

This function is used to synchronize the multiple channel operation. When it is invoked, the specified channel start to wait until the mark is read from another channel's program or from the main program.

```
ENTITY wait_for_mark                                        (* m0 *)
  SUBTYPE OF (nc_function);
  its_channel:              channel;
END_ENTITY;
```

its_channel:	The identification of the channel engaged in a synchronized operation.

4.6.4 Program structure

A program structure is an executable object which includes other executables. The included executables can be executed depending on conditions or in manners determined by the program structure object.

```
ENTITY program_structure                                    (* m0 *)
  ABSTRACT SUPERTYPE OF (ONEOF(workplan, parallel, non_sequential, selective,
  if_statement, while_statement, assignment))
  SUBTYPE OF (executable);
END_ENTITY;
```

4.6.4.1 Workplan

The entity workplan allows to combine several workingsteps and NC functions in a linear order. It also serves as an attribute of the top level entity project which has to be provided in each ISO 14649 data model exactly once. The recursive definition of workplan as subtype of executable allows to group manufacturing operations into larger units, e.g. to summarise all turning operations and all grinding operations if a workpiece is to undergo several different processes.

```
ENTITY workplan                                              (* m0 *)
  SUBTYPE OF (program_structure);
  its_elements: LIST[0:?] OF executable;
  its_channel:           OPTIONAL channel;
  its_setup:             OPTIONAL setup;
  its_effect:            OPTIONAL in_process_geometry;
WHERE
  WR1: SIZEOF(QUERY(it <* its_elements | it = SELF)) = 0;
END_ENTITY;
```

its_elements:	An ordered sequence of executable objects. The workplan cannot contain itself as element. It can only contain itself indirectly within a control structure which allows to skip this workplan in order to prevent an infinite loop.
its_channel:	The identifier of the channel used for the execution of workplan. This is only for machine control systems which support multiple channel operation.
its_setup:	The setup includes the workplan's global security plane and a zero offset where all feature placements are referred to.
its_effect:	The change to the geometry of the workpiece effected by the operation. A CAM system can use this attribute to describe the predicted effect of this operation on the geometry of the workpiece. If given the controller can compare the geometry change described by this attribute with the geometry change predicted by its internal algorithm. ISO 14649 does not describe how closely the two geometries must match in order for the controller to be considered to be in conformance.

4.6.4.1.1 Channel

This entity is used to identify the channel when multiple channel operation is engaged. It is currently a primitive implementation and cannot be used for machine independent programs. Further attributes, like special kinematical descriptions, can be added to this entity in the future. For simple synchronisation, the NC functions set_mark and wait_for_mark can be used.

```
ENTITY channel;                                              (* m0 *)
  its_id: identifier;
END_ENTITY;
```

its_id:	The identification of the channel.

4.6.4.1.2 Setup

This entity includes information concerning the location of the workpieces' coordinate systems. As one setup might include several workpieces of which each one might have its own coordinate system there is one more hierarchical level of frame of reference:

By the setup's attribute its_origin a cartesian coordinate system is defined relative to the machine coordinate system. It is the frame of reference for the location of each workpiece related to the setup.

The setup's origin is only valid within this particular setup and is not referenced by any other setup.

```
ENTITY setup;                                              (* m0 *)
  its_id:                 identifier;
  its_origin:             OPTIONAL axis2_placement_3d;
  its_secplane:           elementary_surface;
  its_workpiece_setup:    LIST [0:?] OF workpiece_setup;
  (*
  Informal proposition:
  If its_origin is not set, the default for the origin
  of the setup is identical with the machine origin.
  *)
END_ENTITY;
```

its_id:	The identification of the setup.
its_origin:	Position and orientation of the setup's cartesian coordinate system relative to the machine coordinate system.
its_secplane:	The security plane for the whole setup. On or above this plane, i. e. for z values greater than those of the elementary_surface, a safe movement of the tool without danger of collision is possible. The dimensions given are relative coordinates as measured from the origin of the setup.
its_workpiece_setup:	Each workpiece which is included within the setup and which will be machined within the respective workplan is listed with its placement and additional informations for its setup.

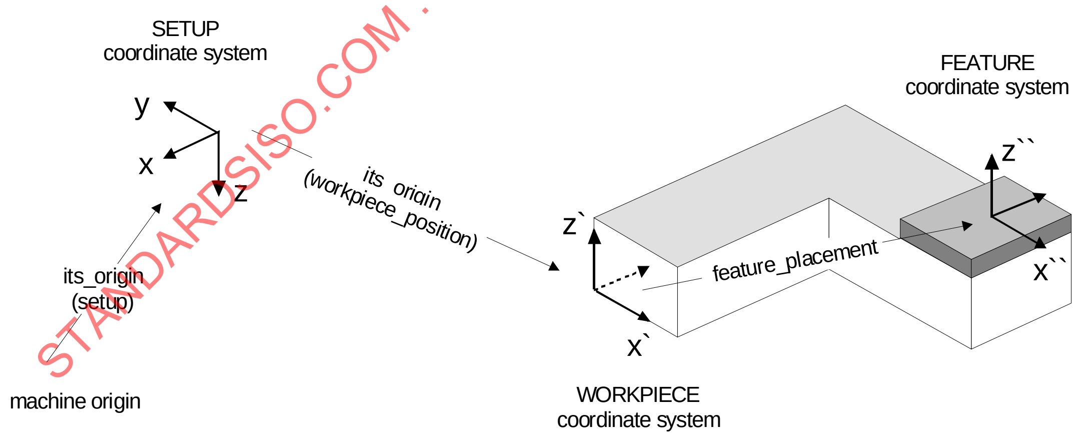


Figure 39 — Coordinate systems

4.6.4.1.3 Workpiece_setup

This entity allows to specify for a workpiece its placement relative to the setup's origin.

```
ENTITY workpiece_setup;                                          (* m0 *)
  its_workpiece:          workpiece;
  its_origin:             axis2_placement_3d;
  its_offset:             OPTIONAL offset_vector;
  its_restricted_area:    OPTIONAL restricted_area_select;
  its_instructions:       LIST [0:?] OF setup_instruction;
END_ENTITY;
```

its_workpiece:	affected workpiece
its_origin:	the workpiece's cartesian system relative to the setup's cartesian system.
its_offset:	The translational and rotational offset of the actual workpiece compared to the position specified by its_origin. It is used to adjust the positions due to a measurement operation. The offset can be changed by a measurement operation (e.g.4.6.2.3).
its_restricted_area:	Area or volume within which tool-movements are forbidden due to possible collisions. Generally used to avoid collisions with fixtures or machine parts.
its_instructions:	Contains optional setup instructions such as description or external documents reference etc.

4.6.4.1.4 Restricted_area_select

This select type offers different optional geometric elements to describe areas or volumes in which due to fixtures, machine elements, etc. there might occur collisions. (Tool-) Movements within this area are forbidden.

If the restricted area is of type bounded_surface movements below the surface risc collisions. By the bounding geometry a volume can be described. Within this volume might occur collisions.

```
TYPE restricted_area_select = SELECT (
  bounded_surface,          (* ISO 10303-42 *)
  bounding_geometry_select);
END_TYPE;
```

Note: The directions mentioned are considered to be positive in positive z-direction of the its_origin. "Below" therefore means a decreasing z-value within the local coordinate system defined by its_origin of the workpiece position.

4.6.4.2 Setup_Instruction

The Setup_instruction includes operator instructions for the setup of its workpiece.

```
ENTITY setup_instruction;                                        (* m1 *)
  description:            OPTIONAL text;
  external_document:      OPTIONAL identifier;
WHERE
  WR1: EXISTS (description) OR EXISTS (external_document);
END_ENTITY;
```

internal:	Description of the setup instruction
external:	Identifier used to identify external document reference such as tables, guidelines etc.

4.6.4.3 Parallel

The parallel entity allows to run several executables in parallel. All branches are started at the same time; the execution of the parallel entity ends when the last branch has finished. If the NC controller determines that the branches cannot be executed in parallel the machine will stop with an error condition. Note that normally parallel execution will require the use of different channels in each branch. NC functions can be used to synchronise events across different channels.

```
ENTITY parallel                                                (* m1 *)
  SUBTYPE OF (program_structure);
  branches:                SET [2:?] OF executable;
END_ENTITY;
```

branch:	Executables to be executed in parallel.

NOTE The parallel entity allows to define the general processing of execuables in parallel. To define the delay of single executalbes etc. we concede that there have to be defined more detailed subtypes of parallel.

4.6.4.4 Non_sequential

The non_sequential entity allows to define a set of executables which all shall be executed but which's order is not prescribed. In contrast to the workplan entity the non_sequential does not define a sequence.

```
ENTITY non_sequential                                          (* m1 *)
  SUBTYPE OF (program_structure);
  its_elements:            SET[2:?] OF executable;
END_ENTITY;
```

its_elements:	An set of executable objects. The non_sequential cannot contain itself as element. It can only contain itself indirectly within a control structure which allows to skip itself in order to prevent an infinite loop.

NOTE This is the minimum requirement for controller determined sequencing. Additional attributes providing the controller extra information for sequencing will be defined by future work.

4.6.4.5 Selective

The selective entity contains a set of executables from which only "one" will be executed. The other executables are to be omitted.

```
ENTITY selective                                               (* m1 *)
  SUBTYPE OF (program_structure);
  its_elements:            SET[2:?] OF executable;
END_ENTITY;
```

its_elements:	A set of executable objects of which exactly one has to be selected and executed by the controller of the machine tool.

NOTE This is the minimum requirement for controller determined selection. Additional attributes providing the controller extra information for selection will be defined by future work.

4.6.4.6 If statement

The if statement runs an executable if a given condition is fulfilled; it may include an alternative option.

```
ENTITY if_statement                                             (* m1 *)
  SUBTYPE OF (program_structure);
  condition:                boolean_expression;
  true_branch:              executable;
  false_branch:             OPTIONAL executable;
END_ENTITY;
```

condition:	Expression to be tested based on the rules given below.
true_branch:	Executable to be executed if the condition evaluates to be true.
false_branch:	Executable to be executed if the condition evaluates to be false.

4.6.4.7 While statement

The while statement runs and repeats an executable as long a given condition is fulfilled. Note that all executables are defined statically so the operation in the body of the while statement cannot be modified during the execution of the loop.

```
ENTITY while_statement                                          (* m1 *)
  SUBTYPE OF (program_structure);
  condition:                boolean_expression;
  body:                     executable;
END_ENTITY;
```

condition:	Expression to be tested based on the rules given below. It is tested before attempting the first execution of the body and then each time after the execution of body has been completed.
body:	Executable to be executed as long as the condition is true. If the condition is not true upon the initial encounter of the while statement, no action occurs at all.

4.6.4.8 Assignment

Assigns a value to a nc_variable.

```
   ENTITY assignment                                        (* m1 *)
     SUBTYPE OF (program_structure);
     its_lvalue:               nc_variable;
     its_rvalue:               rvalue;
   END_ENTITY;
```

its_lvalue:	The nc_variable which will be assigned a value.
its_rvalue:	The value to be assigned to its_lvalue. This is either a numeric constant or a reference to another nc_variable.

4.6.4.9 NC variable

The variable concept introduced here is primitive. Only numeric variables are allowed. The NC controller will map the variable name given by this entity to an internal storage. The attribute its_name must therefore be unique throughout the entire model supplied by an ISO 14649 physical file. Not that several nc_variable entities using the same name will actually refer to the same storage location.

Accessing nc_variables in a program_structure entity may take place only after the previous program_structure has been completely executed by the machine. Note that due to the pipeline concept of most NC controllers there can be a significant time gap between the interpretation of the program and the actual execution. It is there the responsibility of the NC controller to halt interpretation until the value of the nc_variable(s) used are available. This is especially true for the lvalue in an assignment operation because the premature execution of the assignment would allow an ongoing NC process to overwrite the assigned nc_variable before it is used, leading to unexpected and possibly fatal results.

Note also that there is no guarantee at which time a certain value from any parallel branch would be available. If timing matters, a synchronising NC function has to be inserted before the use of a nc_variable.

Variables can be used to access controller-internal information, like sensor readings. This, however, would be controller-dependent and implemented by the use of reserved names as specified by the control vendor.

```
   ENTITY nc_variable;                                      (* m1 *)
     its_name:                 LABEL;
     initial_value:            OPTIONAL NUMBER;
   END_ENTITY;
```

its_name:	The unique reference to an internal storage provided by the NC controller. All characters in LABEL are significant. The number of different nc_variable names allowed is controller dependent.
initial_value:	The value of the nc_variable before it is accessed the first time. If omitted, the initial value is undefined.

4.6.4.10 NC_constant

The nc_constant is used to assign a constant value to an attribute. Its value is determined by the NC-Program and cannot be modified within the process.

```
ENTITY nc_constant;                                       (* m1 *)
  its_name:               LABEL;
  its_value:              OPTIONAL NUMBER;
END_ENTITY;
```

its_name:	Name of the constant. It shall be unique within the program.
its_value:	The value of the nc_constant.

4.6.4.11 Rvalue

In assignment and comparison operations, the rvalue can be used to specify either a numeric constant or a reference to a nc_variable.

```
TYPE rvalue = SELECT(nc_constant, nc_variable);
END_TYPE;
```

4.6.4.12 Boolean expression

The Boolean expression entity is used to determine whether a given condition is met. At this time, it can either be a numeric comparison or a composition of several other Boolean expressions.

```
ENTITY boolean_expression                                 (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(unary_boolean_expression,
  binary_boolean_expression, multiple_arity_boolean_expression,
  comparison_expression));
END_ENTITY;
```

4.6.4.12.1 Unary_boolean_expression

Unary operators perform Boolean algebra on one arguments and produce a false or true value.

```
ENTITY unary_boolean_expression                           (* m1 *)
  ABSTRACT SUPERTYPE OF(not_expression)
  SUBTYPE OF (boolean_expression);
  operand:                boolean_expression;
END_ENTITY;
```

4.6.4.12.2 Not expression

Logical negation 'NOT': NOT 0 = 1 and NOT 1 = 0.

```
ENTITY not_expression                                     (* m1 *)
  SUBTYPE OF (unary_boolean_expression);
END_ENTITY;
```

4.6.4.12.3 Binary_boolean_expression

Binary operators perform Boolean algebra on two arguments and produce a false or true value.

```
ENTITY binary_boolean_expression                             (* m1 *)
  ABSTRACT SUPERTYPE OF(xor_expression)
  SUBTYPE OF (boolean_expression);
  operand1:                boolean_expression;
  operand2:                boolean_expression;
END_ENTITY;
```

4.6.4.12.4 Xor expression

Logical "not equal to" function: 0 XOR 0 = 0, 0 XOR 1 = 1, 1 XOR 0 = 1, and 1 XOR 1 = 0.

```
ENTITY xor_expression                                        (* m1 *)
  SUBTYPE OF (binary_boolean_expression);
END_ENTITY;
```

4.6.4.12.5 Multiple_arity_boolean_expression

Binary operators perform Boolean algebra on multiple arguments and produce a false or true value: AND(a,b,c, ...) is true if a,b,c,etc are all true and OR(a,b,c, ...) true if one of a,b,c,etc is true.

```
ENTITY multiple_arity_boolean_expression                     (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(and_expression, or_expression))
  SUBTYPE OF (boolean_expression);
  operands:                LIST [2:?] OF boolean_expression;
END_ENTITY;
```

4.6.4.12.6 And expression

Logical conjunction: 0 AND 0 = 0, 0 AND 1 = 0, 1 AND 0 = 0, 1 AND 1 = 1.

```
ENTITY and_expression                                        (* m1 *)
  SUBTYPE OF (multiple_arity_boolean_expression);
END_ENTITY;
```

4.6.4.12.7 Or expression

Logical disjunction: 0 OR 0 = 0, 0 OR 1 = 1, 1 OR 0 = 1, 1 OR 1 = 1.

```
ENTITY or_expression                                         (* m1 *)
  SUBTYPE OF (multiple_arity_boolean_expression);
END_ENTITY;
```

4.6.4.12.8 Comparison_expression

The comparison establishes a relationship between the values of two operands.. Carefully observe the note on the time-critical behaviour of variables.

```
ENTITY comparison_expression                                 (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(comparison_equal, comparison_not_equal,
  comparison_greater, comparison_greater_equal, comparison_less,
  comparison_less_equal))
  SUBTYPE OF (boolean_expression);
  operand1:                nc_variable;
  operand2:                rvalue;
END_ENTITY;
```

operand1:	Designation of a nc_variable which is the first of two values to compare.
operand2:	Designation of an rvalue which may either be a nc_variable of a numeric constant.

The result of a comparison is a Boolean depending whether the relationship is true or false. The comparison operators are: 'equal' (==), 'not_equal' (!=), 'greater_equal' (>=), 'greater' (>), 'less_equal' (<=), 'less' (<):

Comparison equal:

```
  ENTITY comparison_equal                                        (* m1 *)
    SUBTYPE OF (comparison_expression);
  END_ENTITY;

  ENTITY comparison_not_equal                                    (* m1 *)
    SUBTYPE OF (comparison_expression);
  END_ENTITY;

  ENTITY comparison_greater  (* m1 *)
    SUBTYPE OF (comparison_expression);
  END_ENTITY;

  ENTITY comparison_greater_equal                                (* m1 *)
    SUBTYPE OF (comparison_expression);
  END_ENTITY;

  ENTITY comparison_less                                         (* m1 *)
    SUBTYPE OF (comparison_expression);
  END_ENTITY;

  ENTITY comparison_less_equal                                   (* m1 *)
    SUBTYPE OF (comparison_expression);
  END_ENTITY;
```

4.7 How to machine: Operations

Operations are used to specify the content of a workingstep. Unlike a workingstep, an operation cannot be executed by itself – unless it is also a workingstep by means of multiple inheritance, like rapid_movement or touch_probing. The latter do not require the presence of a feature for unambiguous interpretation.

However, the most typical operation, machining operation, needs an association with a manufacturing feature in order to be interpreted. It relies on the geometric information provided by the feature, namely its placement in the workpiece co-ordinate system. Such association can either be established through a reference from a manufacturing_feature or through a reference from a machining_workingstep which references in turn a manufacturing_feature.

The important difference between a workingstep and an operation is in the number of associated features. The workingstep is associated with zero or one features. So at the time of execution the NC controller will know unambiguously which feature to use for geometric placement (or to use workpiece co-ordinates if no feature is associated). A workingstep is thus unique. Duplicating a workingstep in a workplan will replicate the exact same physical machine action.

The operation on the other hand can be associated with zero or multiple features. The same operation can thus be used in different locations. The NC controller would be unable to decide on which of the associated features to execute the operation, so an execution of a "naked" operation is not possible.

The reason for this design is the possible re-use of operation data for several manufacturing features. Consider ten identical holes in different positions around the workpiece. They can all share the operation data, but they can not share the workingsteps which represent an operation at a certain instance in time and space. As the “heavyweight” operation entities can be shared, this may reduce the volume of data to be exchanged.

4.7.1 Operation

The supertype operation specifies the generic data required by all operations.

All operations have the option of specifying an explicit toolpath. For 2½D machining operations, many numerical controls will specify cycles for generating their own toolpaths. However, for older controls which are not able to generate toolpaths or if technological reasons require the communication of exactly prescribed toolpaths, the attribute its_toolpath may be used. Also, the 3- to 5-axis milling of freeform surfaces will typically require the explicit specification of toolpaths by a CAM system.

```
ENTITY operation                                            (* m0 *)
  ABSTRACT SUPERTYPE OF (ONEOF (machining_operation, rapid_movement,
  touch_probing));
  its_toolpath:           OPTIONAL toolpath_list;
  its_tool_direction:     OPTIONAL tool_direction;
END_ENTITY;
```

its_toolpath:	Its_toolpath defines a list of all toolpaths in this operation. Note: If its_toolpath exists, the attribute its_machining_strategy in the subtype machining_operation is for information only. Also, all semantics or parameters provided by the operation will be overridden by its_toolpath. The toolpaths are given in coordinates as measured from the workpiece co-ordinate system or, if this operation is associated with a manufacturing_feature, in the local co-ordinate system of the feature.
its_tool_direction:	Specification of the type of tool orientation used. If none is given, a technology specific default is assumed. Therefore refer to the technology specific parts of ISO 14649.

Note that the operation is geometrically linked with the associated manufacturing_feature, if such an association exists. If the feature has a feature_placement attribute, this transformation will also apply to all geometry specified here, i. e. its_toolpath and to all other geometric information like directions or orientations which may be used in subtypes of operation. In other words, all geometry and parameters of the machining_operation are defined in the local co-ordinate system of the feature. As the operation may be associated with multiple manufacturing_features it can only be interpreted in the context of such feature.

For features without a feature_placement attribute or for operations without an associated feature, all data is to be interpreted in workpiece co-ordinates as specified by the attribute its_origin of the workplan which uses this operation.

4.7.1.1 Toolpath list

The entity toolpath_list contains a list of toolpaths (trajectories) which will be executed by the CNC one after the other.

```
ENTITY toolpath_list;                                       (* m0 *)
  its_list:               LIST [1:?] OF toolpath;
END_ENTITY;
```

its_list:	A list of toolpaths. These toolpaths shall be executed in the defined order. See Section 4.8.1 for details about the toolpath definition.

4.7.1.2 Tool direction

The following entities define the tool direction for freeform machining.

```
ENTITY tool_direction                                        (* m0 *)
  ABSTRACT SUPERTYPE OF (ONEOF (two_axes, three_axes));
END_ENTITY;
```

4.7.1.2.1 Two axes

Only two axes can be simultaneously active.

```
ENTITY two_axes                                              (* m0 *)
  SUBTYPE OF (tool_direction);
END_ENTITY;
```

4.7.1.2.2 Three axes

Simultaneous tool movements in three axes are used for machining. The tool orientation is always parallel to the third axis (generally, the z axis) in the machine co-ordinate system. Therefore the tool direction will not be affected by any workpiece placements or workingstep transformation.

```
ENTITY three_axes                                            (* m0 *)
  SUBTYPE OF (tool_direction);
END_ENTITY;
```

4.7.2 Machining operation

Machining operations define the machining process for a limited area of the workpiece, i. e. the contents of a machining workingstep. For the feature to which they refer they specify, at a minimum, the tool to be used, and a set of technological parameters. This data forms an integral part of the operation and cannot be normally changed during its scope.

However, for special operations, and if an explicit toolpath is provided in the inherited attribute its_toolpath, it is also possible to specify certain deviating parameters along portions of the toolpath. In this case, the data given in machining_operation serves as default data in case no specific technological information for a toolpath is provided. Note that any parameters or semantics specified by this operation or the associated feature will be overridden by the toolpath definition, even if the actions defined by the toolpath contradict the intuitive notion of this operation of the associated feature. In other words, you can even use a pocket operation to bore a hole.

The first tool movement within a machining_operation will typically be an approach movement to the defined start point, allowing the machine to reach its operating speed. This can be either be defined explicitly in a toolpath, or by means of a parameterised path, or it can be defined within the strategy for the operation where the exact definition of the path is left to the NC controller. The last tool movement will typically be a retract or lift movement.

The tool movement within the machining_operation, unless defined by an explicit toolpath, will be determined by the technology-dependent strategy and additional parameters as defined by subtypes of machining_operation.

Machining_operation is the supertype for all technologies included in ISO 14649. For each of these technologies, specific machining strategies are defined in separate, technology depending parts. They may be used to instruct the NC controller on how to generate toolpaths if no toolpath is explicitly specified for this operation.

```
ENTITY machining_operation (* m0 *)
  ABSTRACT SUPERTYPE
  SUBTYPE OF (OPERATION);
  its_id:                 identifier;
  retract_plane:          OPTIONAL length_measure;
  start_point:            OPTIONAL cartesian_point;
  its_tool:               machining_tool;
  its_technology:         technology;
  its_machine_functions:  machine_functions;
  (*
  Informal proposition:
  If attribute SELF\operation.its_toolpath exists, then attributes
  its_machining_strategy, retract_plane and start_point, if present, are for
  information only.
  *)
END_ENTITY;
```

its_id:	A unique identifier of the operation.
retract_plane:	The height of a retract plane associated with this operation. This is not the security plane. The start and the end point of the operation – as discussed in Section 4.6.2.1 – shall be within z-direction at the length given by the attribute retract_plane. It is guaranteed that the approach movement from the retract plane to the first cut and the lift movement from the last cut to the retract plane are executed in cutting feed as specified for the operation. A change to rapid feed, e.g. to reach the security plane, can only occur above this plane, and only in the context of a new operation which should be of type rapid_movement. If not given, and if the inherited attribute its_toolpath is not given, the NC controller will determine an appropriate retract plane which may be the security plane. If its_toolpath is given, or if approach or retract strategies are given which do not make use of a retract plane, this attribute will be ignored. Depending on the type of operation, the attribute will be interpreted as follows:

For plane milling or drilling operations, retract_plane is the z coordinate of the retract plane from which the tool starts (for approach) and to which it is retracted (for retract movements).

For side milling, retract_plane indicates a distance perpendicular to the manufacutred surface.

For freeform milling, retract_plane is the distance between the workpiece surface and the retract plane which is oriented perpendicular to the surface normal in the first cutting point (for approach) or the last cutting point (for lift).

start_point:	Optional starting point of the cutting process specified as tool centre point in the local xy plane. The z co-ordinate of start_point is determined depending on the type of operation:

For milling, the z co-ordinate is the depth of the first cut, excluding any plunge or approach movements. If an approach or plunge movement is used, the actual start point of the operation will be the start point of that approach or plunge movement which can be calculated based on this attribute. The start_point will be reached at the end of such approach or plunge. Thus the x and y co-ordinates of start_point not necessarily coincide with those of the start point of the operation, depending on the type of approach or plunge.

For drilling, the start_point is identical with the start point of the operation as no approach or plunge is foreseen here. Therefore, the z co-ordinate is given by the attribute retract_plane.

If this attribute is given, the operation has a defined start point as discussed in Section 4.6.2.1, otherwise not. In the latter case, the NC controller will determine a reasonable default.

If its_toolpath is given, or if start_point specifies a point violating the feature's boundary or otherwise incompatible with the machining strategy, this attribute will be ignored.

its_tool:	The tool which has to be used for this workingstep. For the definition of machining_tool, please refer to technology-specific parts of ISO 14649. It is important to understand that the tool data given describes the *ideal required tool*. If this attribute calls for a tool with diameter 10.0 mm, the NC controller may select a tool with diameter 9.983 mm provided that it has the ability for on-line tool correction and has the actual value of the tool stored in its tool memory data, and provided that the result of the operation remains within the given tolerances of the feature. (In other words, the NC controller is not allowed to select a 9.983 mm drill if the hole has the toleranced dimension $10.0_{-0.01}$ mm.) The possibility to find a suitable tool in the machine's tool magazine is reduced the more details for the tool are specified. So only the technologically necessary parameters should be given. (In other words, do not specify a tool length if only the diameter is of importance.) If a tool id is specified, only an exact match can be selected.
its_technology:	The technological parameters of the machining operation, like spindle speed and feed of the tool.
its_machine_functions:	Indicates the state of various machine functions, like coolant, chip removal, etc. to be applied during the time span of this operation.

Please observe carefully the note about the geometric relation with the associated feature in Section 4.7.1. Keep in mind that in the local co-ordinate system the planar contour of the feature lies in the xy plane (z = 0), and material is assumed to be in negative z direction, as defined in 4.5.2.

4.7.2.1 Technology

This entity is the supertype for the technologies defined in the following parts of ISO 14649.

```
ENTITY technology                                          (* m0 *)
  ABSTRACT SUPERTYPE;
  feedrate:              OPTIONAL speed_measure;
  feedrate_reference:    tool_reference_point;
END_ENTITY;
```

feedrate :	Feed of the tool expressed as a linear speed. The feed rate specified applies to the motion of the tool center point.
feedrate_reference:	Specifies whether the feed rate given above is to be calculated with regard to the tool center point or the cutter contact point.

4.7.2.1.1 Tool reference point

This type can be used to select a tool reference point.

```
TYPE tool_reference_point = ENUMERATION OF (tcp, ccp);
END_TYPE;
```

tcp:	Tool center point, i. e. the point where the rotational axis of the tool leaves the tip.
ccp:	Cutter contact point, i. e. the point where the tool tip, modelled as an ideal cylinder, would touch the ideal surface of the finished workpiece.

4.7.2.2 Machine functions

Each technology has its specific machine functions. This entity is their abstract supertype.

```
ENTITY machine_functions                                         (* m0 *)
  ABSTRACT SUPERTYPE;
END_ENTITY;
```

4.8 To be in full control: Explicit toolpath definition

The toolpath entities generally describe the movement of the tool or of the axis of a machine. They represent the lowest level of information within ISO 14649 which actually allows to re-create all the information given in today's ISO 6983 G codes. However, even the low-level definition of the toolpaths in ISO 14649 still has an advantage over the legacy programmes. By connecting this information with the high-level operation and feature data, the toolpaths can always be interpreted within their semantic context. They are provided in a structure which allows to identify the individual toolpath rather than to search through thousands of lines of unstructured code for axis movements.

And, of course, the mathematical representation of the toolpaths in ISO 14649 fulfils modern CNC standards. The use of splines for toolpaths is supported as well as the definition of cutter-contact paths for controllers which allow on-line tool correction and kinematic transformation. This is required, among others, for today's new parallel kinematics.

Because the definition of the conformance classes has been done according to the interpolating requirements of a CNC, several subtypes of toolpaths have been defined. Two general classes of toolpaths are available, trajectories and parameterised paths. A trajectory is a precalculated movement and can reference as underlying element either a polyline or a spline. A parameterised path describes approach- ,lift - and connector-movements by the definition of type and parameters of the movement (e.g. tangential approach). The exact movement itself has to be calculated by the CNC.

4.8.1 Toolpath

This is the supertype for all explicit toolpaths. If needed, the toolpaths can have technological parameters and the machine functions which override the default value specified at the operation level.

If the attributes its_technology and/or its_machine_functions are given, the machine is instructed to reach the specified operating conditions before entering the toolpath. Unlike the similar case for workingsteps, no halt is allowed between toolpaths in an operation's toolpath list. So the previous toolpath may be adversely affected if a significant change of parameters occurs and the controller tries to provide run up to these parameters prior to the current toolpath. Also, if the time span of the previous toolpath is insufficient to reach stable parameters, there is no guarantee that the new toolpath will be using these parameters from the start.

Caution is therefore advised when using technological parameters at the toolpath level. If required, e.g. for special operations requiring a reversing of the spindle rotation, a feedstop toolpath should be inserted in order to grant the machine sufficient time for changing the parameters.

```
ENTITY toolpath                                               (* m0 *)
  ABSTRACT SUPERTYPE OF (ONEOF(feedstop, trajectory, parameterised_path));
  its_priority:           BOOLEAN;
  its_type:               toolpath_type;
  its_speed:              OPTIONAL toolpath_speedprofile;
  its_technology:         OPTIONAL technology;
  its_machine_functions: OPTIONAL machine_functions;
END_ENTITY;
```

its_priority:	As a toolpath may contain all necessary movements to manufacture a feature the priority of execution between the toolpath and the feature has to be determined. In case there is a toolpath of higher priority (true) than the geometry of the path generation based on the manufacturing feature is subordinated to this toolpath.
its_type:	Type of the toolpath.
its_speed:	A means to influence the feed rate. This factor will be multiplied into the feed rate defined in the operation. It can be either a fixed value or a curve specifying a velocity profile along the toolpath.
its_technology:	The technology defines the spindle and the feed of the tool.
its_machine_functions:	Various machine functions, like coolant, chip removal, etc.

4.8.1.1 Toolpath type

Enumerator describing the type of the trajectory. This can be used by the controller e.g. to identify whether rapid motion may be allowed or not.

```
TYPE toolpath_type = ENUMERATION OF (
  approach,
  lift,
  connect,
  non_contact,
  contact,
  trajectory_path
  );
END_TYPE;
```

The following values are used:

approach:	The movement towards the workpiece.
lift:	The movement away from the workpiece.

connect:	The connecting movement (usually in rapid speed) between the lift and the approach movement.
non_contact:	A movement without contact with the workpiece.
contact:	A movement with contact of the workpiece.
trajectory_path:	A movement described by a trajectory.

Note that any toolpath can be tagged with any of these types. For example, it is not necessary to use specialised toolpath elements like approach_lift_path in order to build an approach movement. This can just as well done through a pre-calculated cutter location path using the approach toolpath_type.

4.8.1.2 Toolpath speedprofile

Select type of the speed profile to influence the feed rate given by the attribute technology of either the operation or the toolpath itself.

```
TYPE toolpath_speedprofile = SELECT (
   toolpath_speed,
   positive_ratio_measure,
   speed_name
   );
END_TYPE;
```

4.8.1.2.1 Toolpath speed

This is a one-dimensional curve specifying the speed profile as defined by type positive_ratio_measure. If the attribute basiccurve of the toolpath exists, the parameterisation of speed must be the same as basiccurve. Otherwise, speed must be parameterised by the path length of the underlying toolpath, i. e. the first parameter is 0, the last parameter equals the length of the underlying toolpath as defined by type length_measure.

```
ENTITY toolpath_speed;                                         (* m1 *)
   speed:                  b_spline_curve;
WHERE
   WR1: speed\geometric_representation_item.dim = 1;
   (*
   Informal proposition:
   - speed shall have only values greater than zero.
   *)
END_ENTITY;
```

4.8.1.2.2 Speed name

Enumerator to specify rapid speed. It can be extended in the future to include other named speeds.

```
TYPE speed_name = ENUMERATION OF(RAPID);
END_TYPE;
```

4.8.2 Feedstop

Feedstop is a toolpath element with no feed motion. The spindle remains in the selected speed while the execution of the subsequent toolpath is delayed for the specified time.

```
ENTITY feedstop                                              (* m0 *)
  SUBTYPE OF (toolpath);
  dwell:                   time_measure;
END_ENTITY;
```

dwell:	The time to stop the feed axis.

4.8.3 Trajectory

Supertype for all explicit trajectories.

```
ENTITY trajectory                                            (* m0 *)
  ABSTRACT SUPERTYPE OF (ONEOF(cutter_location_trajectory,
  cutter_contact_trajectory, axis_trajectory))
  SUBTYPE OF (toolpath);
  its_direction:           OPTIONAL BOOLEAN;
END_ENTITY;
```

its_direction:	If true or omitted, the tool has to be moved from the beginning to the end of the referenced geometric curve. Otherwise, it will be moved from the end point to the start point of the referenced geometric curve.

4.8.4 Cutter location trajectory

Cutter location paths define a tool movement with respect to the tool center point. This is the point where the rotational axis of the tool leaves the tool tip.

```
ENTITY cutter_location_trajectory                            (* m0 *)
  SUBTYPE OF (trajectory);
  basiccurve:              bounded_curve;
  its_toolaxis:            OPTIONAL bounded_curve;
  surface_normal:          OPTIONAL bounded_curve;
  (*
  Information proposition:
  its_toolaxis must have the same must have the same parameter range as
  basiccurve.
  *)
END_ENTITY;
```

basiccurve:	A 3D curve defining the cartesian co-ordinates of the cutter location point in the workpiece co-ordinate system or the local co-ordinate system of the feature, respectively.
its_toolaxis:	A 3D curve defining the toolaxis of the tool. The three co-ordinates of the curve represent the three components of the vector in the workpiece co-ordinate system or the local co-ordinate system of the feature, respectively. If given, the parameterisation of the toolaxis curve must correspond to that of the basiccurve. Note that this attribute will override any information about the tool orientation given by the its_tool_direction attribute of the workingstep.

surface_normal:	A curve in space defining the surface normal. It has to be of the same type and has to have the same parameterisation than the basiccurve.

4.8.5 Cutter contact trajectory

Cutter contact paths define a tool movement with respect to the cutter contact point.

```
ENTITY cutter_contact_trajectory                            (* m1 *)
  SUBTYPE OF (trajectory);
  basiccurve:              curve_with_surface_normal;
  its_toolaxis:            OPTIONAL bounded_curve;
  its_contact_type:        OPTIONAL contact_type;
  (*
  Informal proposition:
  its_toolaxis must have the same must have the same parameter range as
  basiccurve.
  *)
END_ENTITY;
```

basiccurve:	A 3D curve defining the cartesian co-ordinates of the cutter contact point in the workpiece co-ordinate system or the local co-ordinate system of the feature, respectively.
its_toolaxis:	A 3D curve defining the toolaxis of the tool. The first co-ordinate represents the yaw angle, the second co-ordinate the tilt angle in degrees. For the definition of tilt and yaw angles, see Section 5.2.2.3 of ISO 14649-11. If given, the parameterisation of the toolaxis curve must correspond to that of the basiccurve. Note that this attribute will override any information about the tool orientation given by the its_tool_direction attribute of the workingstep.

4.8.5.1 Curve with surface normal

Select type for definition of a curve with surface normal. The bounded_pcurve is taken from AP42 and the curve_with_normal_vector is defined in this part of ISO 14649.

```
TYPE curve_with_surface_normal = SELECT (
  bounded_pcurve, curve_with_normal_vector
  );
END_TYPE;
```

4.8.5.2 Curve with normal vector

A bounded curve which has a second curve defining the surface normal.

```
ENTITY curve_with_normal_vector;                            (* m1 *)
  basiccurve:              bounded_curve;
  surface_normal:          bounded_curve;
  (*
  Informal proposition:
  basiccurve and surface_normal must have the same parameter range
  *)
END_ENTITY;
```

basiccurve:	The reference to the geometric curve in the geometry description.
surface_normal:	A 3D curve in space defining the surface normal. The three co-ordinates of the curve represent the three components of the surface normal vector in the co-ordinate system of the basiccurve. It has to be of the same type and has to have the same parameterisation than the basiccurve.

4.8.5.3 Contact type

Contact type specifies how the cutter contact point is determined. Depending on the mode of milling – plane milling, side milling or freeform milling – the cutter contact is desired at different locations of the tool, relative to its motion.

```
  TYPE contact_type = ENUMERATION OF (side, front);
  END_TYPE;
```

According to Figure 40 the interpretation of contact type is as follows:

side:	Side milling. The cutter contact point is located at the circumference of the tool, perpendicular to the cutting direction. Whether the material can be found on the left-hand or right-hand side of the cutter depends on the direction of the surface normal specified by the toolpath's attribute basiccurve.
front:	End milling as used for plane or freeform milling. The cutter contact point is a point at the bottom of the cutter. Note that such point is only properly defined when the cutter is inclined against the normal of the surface which it passes. If this is not the case, as for most two5D milling operations, the tool's forward-most contact point in the direction of the cut shall be regarded as cutter-contact point.

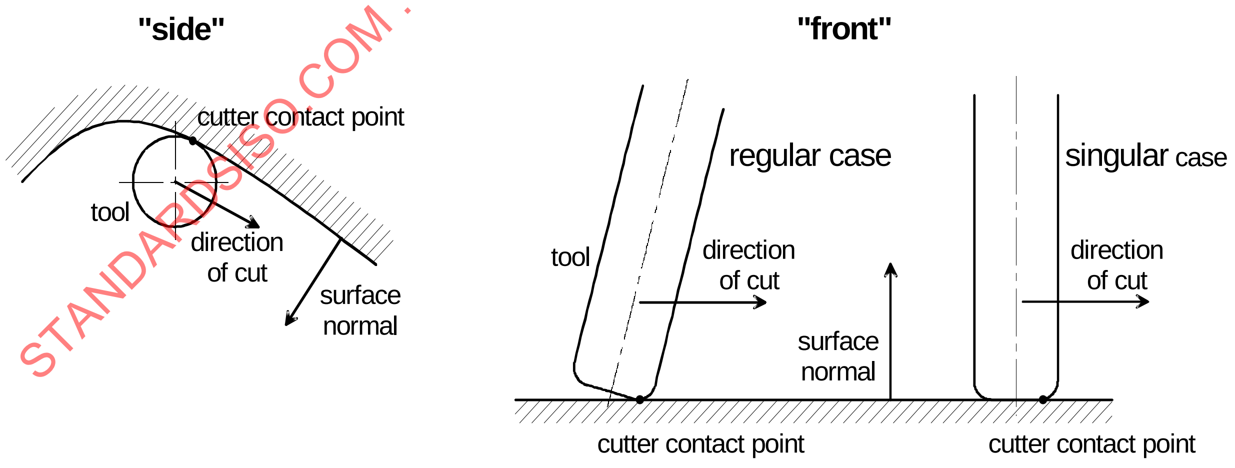


Figure 40 — Contact type

4.8.6 Axis trajectory

Axis trajectories do not directly define a tool movement, but rather the movement of the machine axis. They are comparable to the G00/G01 commands of ISO 6983.

They should not be used because the resulting NC programme will no longer be machine independent.

```
ENTITY axis_trajectory                                      (* m0 *)
   SUBTYPE OF (trajectory);
   axis_list:                  LIST [1:?] OF identifier;
   commands:                   LIST [1:?] OF bounded_curve;
WHERE
   WR1: SIZEOF(QUERY(cmd <* commands |
   cmd\geometric_representation_item.dim <> 1)) = 0;
END_ENTITY;
```

axis_list:	A list with axis names defining these axes which will be moved by the trajectory.
commands:	A list of one-dimensional curves. The array contains one curve per axis whose name is given by the respective index in the axis_list. The values represent axis positions in units as defined for length_measure (for linear axes) or planar_angle_measure (for rotary axes).

4.8.7 Parameterised path

This subtype of the toolpath entity is used to define help movements like connectors, approach and lift movements without giving the actual tool path. The movement is rather described by a movement type and its parameters. The CNC itself then has to calculate the resulting toolpath for the actual tool.

This concept is especially useful when working with cutter contact trajectories for the milling operations. As cutter contact trajectories can only be used for motions on the workpiece surface itself there is a need for defining the connecting movements between the individual toolpaths in an indirect way. Also, the parameterised paths given here can be used to connect cutter contact and cutter location trajectories.

Note that even though the parameterised paths are named for their most frequent use they can be used for any portion of a toolpath description just as any other form of toolpath. Their actual use is not indicated by the entity names but rather by the inherited its_type attribute.

```
ENTITY parameterised_path                                   (* m0 *)
   ABSTRACT SUPERTYPE OF (ONEOF (approach_lift_path, connector))
   SUBTYPE OF (toolpath);
END_ENTITY;
```

4.8.8 Connector

The connector entity defines a connection path between a lift and a following approach movement. This path type if typically needed to implement a rapid_movement operation but can also be used within a machining operation for connecting several cutting paths.

```
ENTITY connector                                            (* m1 *)
   ABSTRACT SUPERTYPE OF (ONEOF(connect_secplane, connect_direct))
   SUBTYPE OF (parameterised_path);
END_ENTITY;
```

4.8.8.1 Connect two points via the security plane

The security plane connector moves the tool up to the security plane until the cutter location point reaches the security plane, then linear to the projected starting point of the following movement and again from the security plane down to this starting point. This type of connection may be needed for unidirectional machining of freeform surface. For bidirectional machining, a connect_direct between the preceding lift and the following approach movement will be more efficient.

```
ENTITY connect_secplane                                    (* m1 *)
  SUBTYPE OF (connector);
  up_dir:                    OPTIONAL direction;
  down_dir:                  OPTIONAL direction;
END_ENTITY;
```

up_dir:	specification of the direction of the upward movement. If none is given, the motion will be in tool direction.
down_dir:	specification of the direction of the downward movement. If none is given, the motion will be in tool direction.

Note: If this connector is used during a five-axis milling operation, it will interpolate the tool direction between the previous and the next cut. In this case, the tool will retract in the tool direction from the last point of the previous cut (unless overridden by up_dir). On the security the tool will rotate to the new tool direction, and then it will move down in the tool direction (unless overridden by down_dir) for the first point of the next cut. No change of the tool direction takes place during the lift and approach to and from the security plane.

4.8.8.2 Connect two points directly

The direct connector moves the tool in a straight line from the end point of the previous toolpath to the starting point of the next toolpath.

```
ENTITY connect_direct                                      (* m1 *)
  SUBTYPE OF (connector);
END_ENTITY;
```

Note: If this connector is used during a five-axis milling operation, the connector may be used to adjust the tool direction between the previous and the next cut. The tool will rotate to the new tool direction during the linear motion.

4.8.9 Approach and lift path

This subtype of parameterised path describes the lift and approach movement in terms of angles or tangential movements. See also Section 4.8.1. The strategy will initiate the generation of toolpath based on the surrounding feature. This entity, on the other hand, specifies a distinct path in cartesian space. It can be the result of a path generation based on an air strategy in which case the fix_point would lie in the retract_plane of the associated operation.

```
ENTITY approach_lift_path                                  (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF (ap_lift_path_angle, ap_lift_path_tangent))
  SUBTYPE OF (parameterised_path);
  fix_point:                 cartesian_point;
  fix_point_dir:             OPTIONAL direction;
END_ENTITY;
```

fix_point:	The starting point for the approach movement or the destination for the lift movement in the workpiece co-ordinate system, or the feature's local co-ordinate system, respectively. The reference point on the tool is the tool center point (tcp), which is the point where the rotational axis of the tool leaves the tip.

fix_point_dir:	The tool direction in fix_point as 3D vector in the workpiece co-ordinate system, or the feature's local co-ordinate system, respectively. If given, the machine will attempt to interpolate between the tool direction in the fix point and the tool direction in the start (approach) or end (lift) point of the connecting toolpath during the approach/lift movement. If not given, the tool direction will not be changed during the approach/lift movement.

4.8.9.1 Approach lift angle

Approach or lift at an angle to the path using a linear approach (see figure).

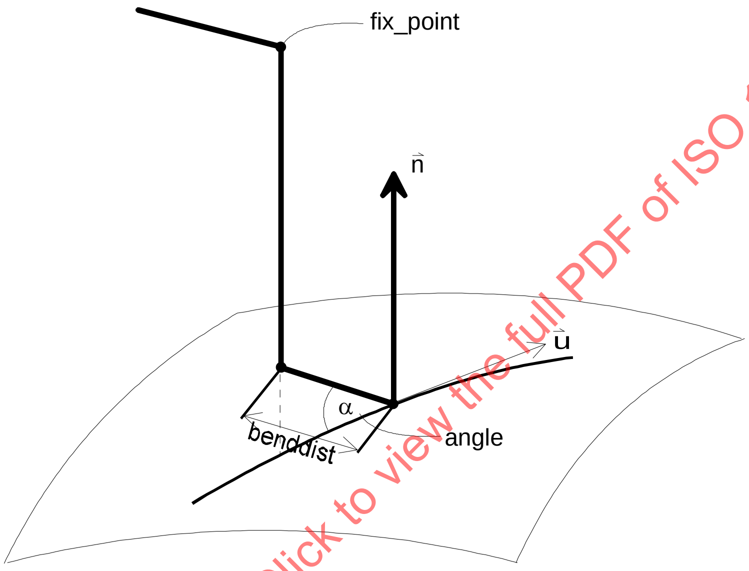


Figure 41 — Linear approach with angle

```
  ENTITY ap_lift_path_angle                                     (* m1 *)
    SUBTYPE OF (approach_lift_path);
    angle:                  plane_angle_measure;
    benddist:               positive_length_measure;
  END_ENTITY;
```

angle:	Approach or lift angle.
benddist:	The length of the angular approach angle.

4.8.9.2 Approach lift tangent

Approach or lift to the path using a tangential approach (see figure).

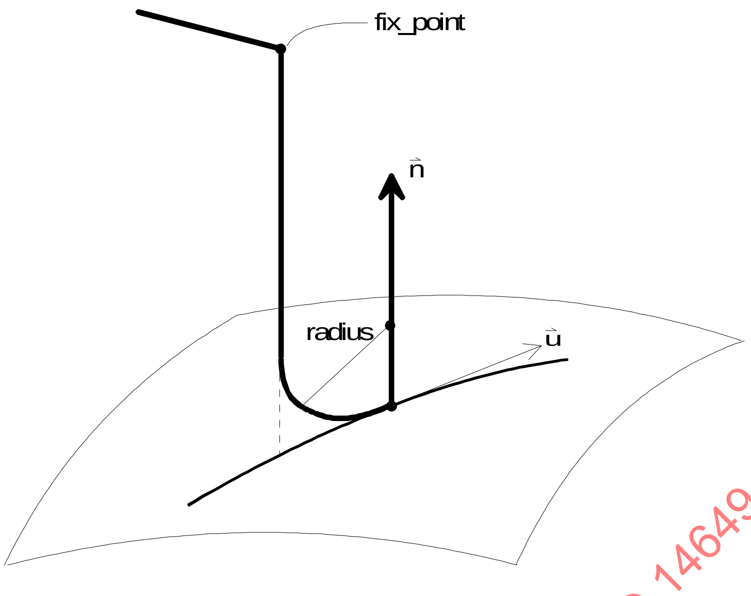


Figure 42 — Tangential approach

```
ENTITY ap_lift_path_tangent                                  (* m1 *)
  SUBTYPE OF (approach_lift_path);
  radius:                    positive_length_measure;
END_ENTITY;
```

radius: The radius of the approach movement.

4.9 Rules

The following rules are needed to ensure the consistency of the geometric, topological and technological model.

4.9.1 dependent_instantiable_representation_item

The dependent_instantiable_representation_item rule specifies that all instances of representation_item are dependent on the usage to define another entity.

```
RULE dependent_instantiable_representation_item FOR (representation_item);
WHERE
  WR1: SIZEOF (QUERY (ri <* representation_item |
     NOT (SIZEOF (USEDIN (ri, '')) >= 1))) = 0;
END_RULE;
```

4.9.2 dependent_instantiable_shape_representation

The dependent_instantiable_shape_representation rule specifies that all instances of shape_representation are dependent on the usage to define another entity.

```
RULE dependent_instantiable_shape_representation FOR (shape_representation);
WHERE
  WR1: SIZEOF (QUERY (sr <* shape_representation |
       NOT (SIZEOF(USEDIN(sr, '')) >= 1))) = 0;
END_RULE;
```

4.9.3 geometric_representation_item_3d

The geometric_representation_item_3d rule specifies that every geometric_representation_item must be founded within a geometric_representation_context that has a dimensionality of 3 except for use in defining the pcurve entity. This rule constrains all geometry to be three dimensional. The pcurve entity is an exception because it must be founded in a 2 dimensional context which is the parameter space of a surface.

```
RULE geometric_representation_item_3d FOR (geometric_representation_item);
WHERE
  WR1: SIZEOF (QUERY (gri <* geometric_representation_item |
       NOT( (dimension_of (gri) = 3)  OR
       (SIZEOF (bag_to_set (USEDIN (gri, ''))  - bag_to_set (USEDIN
       (gri,'REPRESENTATION_SCHEMA.'+  = 0)))) = 0;
END_RULE;
```

4.10 End of schema

```
END_SCHEMA; (* machining_schema *)
```

5 Conformance requirements

Conformance to this part of ISO 14649 includes satisfying the requirements stated in this part, the requirements of the implementation methods supported, and the relevant requirements of the normative references.

For requirements with respect to implementation methods see Annex C.

This part of ISO 14649 provides a number of options that may be supported by an implementation. These options shall all be supported by six classes of conformance.

These conformance classes are characterized as follows:

• conformance class 1 –	c0m0:	Minimum set of curve geometry and minimum set of manufacturing data;
• conformance class 2 –	c0m0m1:	Class 1 plus full set of manufacturing data, especially manufacturing features;
• conformance class 3 –	s0c0m0m1:	Class 2 plus minimum set of surface geometry;
• conformance class 4 –	s0s1c0c1m0m1:	Class 3 plus full curve and surface geometry;
• conformance class 5 –	t0t1s0c0m0m1:	Class 3 plus topological information;
• conformance class 6 –	t0t1s0s1c0c1m0m1:	Class 4 plus topological information.

The identifiers for the respective data sets (m0/m1, c0/c1, s0/s1, t0/t1) can be found in the expanded EXPRESS listing in Appendix A for each member of the data set in order to facilitate implementation.

5.1 Conformance class 1 entities

An implementation of conformance class 1 of this part of ISO 14649 shall support the following entities and related constructs:

```
address
approval
approval_status
axis_trajectory
axis2_placement_3d
b_spline_curve
b_spline_curve_with_knots
bounded_curve
calendar_date
cartesian_point
channel
composite_curve
composite_curve_segment
coordinated_universal_time_offset
curve
cutter_location_trajectory
date
date_and_time
descriptive_parameter
direction
display_message
elementary_surface
executable
feedstop
geometric_representation_context
geometric_representation_item
local_time
machine_functions
machining_operation
machining_tool
machining_workingstep
nc_function
numeric_parameter
operation
optional_stop
ordinal_date
parameterised_path
person
person_and_address
placement
plane
point
polyline
program_stop
program_structure
project
property_parameter
rapid_movement
rational_b_spline_curve
representation_item
return_home
set_mark
setup
surface
technology
three_axes
tool_direction
toolpath
toolpath_list
trajectory
trimmed_curve
two_axes
wait_for_mark
week_of_year_and_day_date
workingstep
workpiece_setup
```

5.2 Conformance class 2 entities

An implementation of conformance class 2 of this part of ISO 14649 shall support the following entities and related constructs:

```
address
and_expression
angle_taper
ap_lift_path_angle
ap_lift_path_tangent
approach_lift_path
approval
approval_status
assignment
axis_trajectory
axis2_placement_3d
b_spline_curve
b_spline_curve_with_knots
binary_boolean_expression
blind_bottom_condition
block
boolean_expression
boss
bounded_curve
calendar_date
cartesian_point
catalogue_thread
chamfer
channel
circular_closed_profile
circular_closed_shape_profile
circular_offset
circular_omit
circular_path
circular_pattern
```

closed_pocket
closed_profile
comparison_equal
comparison_expression
comparison_greater
comparison_greater_equal
comparison_less
comparison_less_equal
comparison_not_equal
complete_circular_path
composite_curve
composite_curve_segment
compound_feature
conical_hole_bottom
connect_direct
connect_secplane
connector
coordinated_universal_time_offset
counterbore_hole
countersunk_hole
curve
curve_with_normal_vector
cutter_contact_trajectory
cutter_location_trajectory
date
date_and_time
defined_thread
descriptive_parameter
diameter_taper
direction
display_message
edge_round
elementary_surface
executable
feedstop
flat_hole_bottom
flat_slot_end_type
flat_with_radius_hole_bottom
general_closed_profile
general_outside_profile
general_path
general_pattern
general_pocket_bottom_condition
general_profile
general_profile_floor
general_shape_profile
geometric_representation_context
geometric_representation_item
hole_bottom_condition
if_statement
in_process_geometry
limits_and_fits
linear_path
linear_profile
local_time
loop_slot_end_type
machine_functions
machined_surface
machining_feature
machining_operation
machining_tool
machining_workingstep
manufacturing_feature
material
multiple_arity_boolean_expression
nc_constant
nc_function
nc_variable
ngon_profile
non_sequential
not_expression
numeric_parameter
offset_vector
open_pocket
open_profile
open_slot_end_type
operation
optional_stop
or_expression
ordinal_date
parallel
parameterised_path
partial_area_definition
partial_circular_path
partial_circular_profile
partial_circular_shape_profile
person
person_and_address
placement
planar_face
planar_pocket_bottom_condition
planar_profile_floor
plane
plus_minus_value
pocket
pocket_bottom_condition
point
polyline
profile
profile_feature
profile_floor
program_stop
program_structure
project
property_parameter
radiused_pocket_bottom_condition
radiused_slot_end_type
rapid_movement
rational_b_spline_curve
rectangular_closed_profile
rectangular_closed_shape_profile
rectangular_offset
rectangular_omit
rectangular_open_shape_profile
rectangular_pattern
region
region_projection
region_surface_list
replicate_feature
representation_item
return_home
right_circular_cylinder

```
round_hole
rounded_end
rounded_u_profile
selective
set_mark
setup
setup_instruction
shape_profile
slot
slot_end_type
specification
specification_usage_constraint
spherical_cap
spherical_hole_bottom
square_u_profile
step
surface
surface_texture_parameter
technology
tee_profile
thread
three_axes
through_bottom_condition
through_pocket_bottom_condition
through_profile_floor
toleranced_length_measure
tool_direction
tool_length_probing
tool_probing
tool_radius_probing
toolpath
toolpath_feature
toolpath_list
toolpath_speed
touch_probe
touch_probing
trajectory
transition_feature
travel_path
trimmed_curve
two_axes
two5D_manufacturing_feature
unary_boolean_expression
vee_profile
wait_for_mark
week_of_year_and_day_date
while_statement
woodruff_slot_end_type
workingstep
workpiece
workpiece_complete_probing
workpiece_probing
workpiece_setup
workplan
xor_expression
```

5.3 Conformance class 3 entities

An implementation of conformance class 3 of this part of ISO 14649 shall support the following entities and related constructs:

```
address
and_expression
angle_taper
ap_lift_path_angle
ap_lift_path_tangent
approach_lift_path
approval
approval_status
assignment
axis_trajectory
axis2_placement_3d
b_spline_curve
b_spline_curve_with_knots
b_spline_surface
b_spline_surface_with_knots
binary_boolean_expression
blind_bottom_condition
block
boolean_expression
boss
bounded_curve
bounded_pcurve
bounded_surface
calendar_date
cartesian_point
catalogue_thread
chamfer
channel
circular_closed_profile
circular_closed_shape_profile
circular_offset
circular_omit
circular_path
circular_pattern
closed_pocket
closed_profile
comparison_equal
comparison_expression
comparison_greater
comparison_greater_equal
comparison_less
comparison_less_equal
comparison_not_equal
complete_circular_path
composite_curve
composite_curve_segment
compound_feature
conical_hole_bottom
connect_direct
connect_secplane
```

```
connector
coordinated_universal_time_offset
counterbore_hole
countersunk_hole
curve
curve_with_normal_vector
cutter_contact_trajectory
cutter_location_trajectory
date
date_and_time
defined_thread
definitional_representation
descriptive_parameter
diameter_taper
direction
display_message
edge_round
elementary_surface
executable
feedstop
flat_hole_bottom
flat_slot_end_type
flat_with_radius_hole_bottom
general_closed_profile
general_outside_profile
general_path
general_pattern
general_pocket_bottom_condition
general_profile
general_profile_floor
general_shape_profile
geometric_representation_context
geometric_representation_item
hole_bottom_condition
if_statement
in_process_geometry
limits_and_fits
linear_path
linear_profile
local_time
loop_slot_end_type
machine_functions
machined_surface
machining_feature
machining_operation
machining_tool
machining_workingstep
manufacturing_feature
material
multiple_arity_boolean_expression
nc_constant
nc_function
nc_variable
ngon_profile
non_sequential
not_expression
numeric_parameter
offset_vector
open_pocket
open_profile
open_slot_end_type
operation
optional_stop
or_expression
ordinal_date
parallel
parameterised_path
partial_area_definition
partial_circular_path
partial_circular_profile
partial_circular_shape_profile
pcurve
person
person_and_address
placement
planar_face
planar_pocket_bottom_condition
planar_profile_floor
plane
plus_minus_value
pocket
pocket_bottom_condition
point
polyline
profile
profile_feature
profile_floor
program_stop
program_structure
project
property_parameter
radiused_pocket_bottom_condition
radiused_slot_end_type
rapid_movement
rational_b_spline_curve
rational_b_spline_surface
rectangular_closed_profile
rectangular_closed_shape_profile
rectangular_offset
rectangular_omit
rectangular_open_shape_profile
rectangular_pattern
region
region_projection
region_surface_list
replicate_feature
representation_item
return_home
right_circular_cylinder
round_hole
rounded_end
rounded_u_profile
selective
set_mark
setup
setup_instruction
shape_profile
slot
slot_end_type
specification
specification_usage_constraint
spherical_cap
```

```
spherical_hole_bottom
square_u_profile
step
surface
surface_texture_parameter
technology
tee_profile
thread
three_axes
through_bottom_condition
through_pocket_bottom_condition
through_profile_floor
toleranced_length_measure
tool_direction
tool_length_probing
tool_probing
tool_radius_probing
toolpath
toolpath_feature
toolpath_list
toolpath_speed
touch_probe
touch_probing
trajectory
transition_feature
travel_path
trimmed_curve
two_axes
two5D_manufacturing_feature
unary_boolean_expression
vee_profile
wait_for_mark
week_of_year_and_day_date
while_statement
woodruff_slot_end_type
workingstep
workpiece
workpiece_complete_probing
workpiece_probing
workpiece_setup
workplan
xor_expression
```

5.4 Conformance class 4 entities

An implementation of conformance class 4 of this part of ISO 14649 shall support the following entities and related constructs:

```
address
and_expression
angle_taper
ap_lift_path_angle
ap_lift_path_tangent
approach_lift_path
approval
approval_status
assignment
axis_trajectory
axis1_placement
axis2_placement_3d
b_spline_curve
b_spline_curve_with_knots
b_spline_surface
b_spline_surface_with_knots
bezier_curve
bezier_surface
binary_boolean_expression
blind_bottom_condition
block
boolean_expression
boss
bounded_curve
bounded_pcurve
bounded_surface
calendar_date
cartesian_point
catalogue_thread
chamfer
channel
circle
circular_closed_profile
circular_closed_shape_profile
circular_offset
circular_omit
circular_path
circular_pattern
closed_pocket
closed_profile
comparison_equal
comparison_expression
comparison_greater
comparison_greater_equal
comparison_less
comparison_less_equal
comparison_not_equal
complete_circular_path
composite_curve
composite_curve_segment
compound_feature
conic
conical_hole_bottom
connect_direct
connect_secplane
connector
coordinated_universal_time_offset
counterbore_hole
countersunk_hole
curve
curve_with_normal_vector
cutter_contact_trajectory
cutter_location_trajectory
date
date_and_time
defined_thread
```

```
definitional_representation
descriptive_parameter
diameter_taper
direction
display_message
edge_round
elementary_surface
ellipse
executable
feedstop
flat_hole_bottom
flat_slot_end_type
flat_with_radius_hole_bottom
general_closed_profile
general_outside_profile
general_path
general_pattern
general_pocket_bottom_condition
general_profile
general_profile_floor
general_shape_profile
geometric_representation_context
geometric_representation_item
hole_bottom_condition
hyperbola
if_statement
in_process_geometry
limits_and_fits
line
linear_path
linear_profile
local_time
loop_slot_end_type
machine_functions
machined_surface
machining_feature
machining_operation
machining_tool
machining_workingstep
manufacturing_feature
material
multiple_arity_boolean_expression
nc_constant
nc_function
nc_variable
ngon_profile
non_sequential
not_expression
numeric_parameter
offset_vector
open_pocket
open_profile
open_slot_end_type
operation
optional_stop
or_expression
ordinal_date
oriented_surface
parabola
parallel
parameterised_path
partial_area_definition
partial_circular_path
partial_circular_profile
partial_circular_shape_profile
pcurve
person
person_and_address
placement
planar_face
planar_pocket_bottom_condition
planar_profile_floor
plane
plus_minus_value
pocket
pocket_bottom_condition
point
polyline
profile
profile_feature
profile_floor
program_stop
program_structure
project
property_parameter
quasi_uniform_curve
quasi_uniform_surface
radiused_pocket_bottom_condition
radiused_slot_end_type
rapid_movement
rational_b_spline_curve
rational_b_spline_surface
rectangular_closed_profile
rectangular_closed_shape_profile
rectangular_offset
rectangular_omit
rectangular_open_shape_profile
rectangular_pattern
region
region_projection
region_surface_list
replicate_feature
representation_item
return_home
right_circular_cylinder
round_hole
rounded_end
rounded_u_profile
selective
set_mark
setup
setup_instruction
shape_profile
slot
slot_end_type
specification
specification_usage_constraint
spherical_cap
spherical_hole_bottom
spherical_surface
square_u_profile
step
```

surface
surface_of_linear_extrusion
surface_of_revolution
surface_texture_parameter
swept_surface
technology
tee_profile
thread
three_axes
through_bottom_condition
through_pocket_bottom_condition
through_profile_floor
toleranced_length_measure
tool_direction
tool_length_probing
tool_probing
tool_radius_probing
toolpath
toolpath_feature
toolpath_list
toolpath_speed
touch_probe
touch_probing
trajectory
transition_feature
travel_path
trimmed_curve
two_axes
two5D_manufacturing_feature
unary_boolean_expression
uniform_curve
uniform_surface
vector
vee_profile
wait_for_mark
week_of_year_and_day_date
while_statement
woodruff_slot_end_type
workingstep
workpiece
workpiece_complete_probing
workpiece_probing
workpiece_setup
workplan
xor_expression

5.5 Conformance class 5 entities

An implementation of conformance class 5 of this part of ISO 14649 shall support the following entities and related constructs:

address
advanced_brep_shape_representatio
n
advanced_face
and_expression
angle_taper
ap_lift_path_angle
ap_lift_path_tangent
approach_lift_path
approval
approval_status
assignment
axis_trajectory
axis2_placement_3d
b_spline_curve
b_spline_curve_with_knots
b_spline_surface
b_spline_surface_with_knots
binary_boolean_expression
blind_bottom_condition
block
boolean_expression
boss
bounded_curve
bounded_pcurve
bounded_surface
calendar_date
cartesian_point
catalogue_thread
chamfer
channel
circular_closed_profile
circular_closed_shape_profile
circular_offset
circular_omit
circular_path
circular_pattern
closed_pocket
closed_profile
closed_shell
comparison_equal
comparison_expression
comparison_greater
comparison_greater_equal
comparison_less
comparison_less_equal
comparison_not_equal
complete_circular_path
composite_curve
composite_curve_segment
compound_feature
conical_hole_bottom
connect_direct
connect_secplane
connected_face_set
connector
coordinated_universal_time_offset
counterbore_hole
countersunk_hole
curve
curve_with_normal_vector
cutter_contact_trajectory

cutter_location_trajectory
date
date_and_time
defined_thread
definitional_representation
descriptive_parameter
diameter_taper
direction
display_message
edge
edge_curve
edge_loop
edge_round
elementary_surface
executable
face
face_bound
face_outer_bound
face_surface
faceted_brep
feedstop
flat_hole_bottom
flat_slot_end_type
flat_with_radius_hole_bottom
founded_item
general_closed_profile
general_outside_profile
general_path
general_pattern
general_pocket_bottom_condition
general_profile
general_profile_floor
general_shape_profile
geometric_representation_context
geometric_representation_item
hole_bottom_condition
if_statement
in_process_geometry
limits_and_fits
linear_path
linear_profile
local_time
loop
loop_slot_end_type
machine_functions
machined_surface
machining_feature
machining_operation
machining_tool
machining_workingstep
manifold_solid_brep
manufacturing_feature
mapped_item
material
multiple_arity_boolean_expression
nc_constant
nc_function
nc_variable
ngon_profile
non_sequential
not_expression
numeric_parameter
offset_vector
open_pocket
open_profile
open_shell
open_slot_end_type
operation
optional_stop
or_expression
ordinal_date
oriented_closed_shell
oriented_edge
oriented_face
orineted_open_shell
oriented_path
parallel
parameterised_path
partial_area_definition
partial_circular_path
partial_circular_profile
partial_circular_shape_profile
path
pcurve
person
person_and_address
placement
planar_face
planar_pocket_bottom_condition
planar_profile_floor
plane
plus_minus_value
pocket
pocket_bottom_condition
point
polyline
poly_loop
profile
profile_feature
profile_floor
program_stop
program_structure
project
property_parameter
radiused_pocket_bottom_condition
radiused_slot_end_type
rapid_movement
rational_b_spline_curve
rational_b_spline_surface
rectangular_closed_profile
rectangular_closed_shape_profile
rectangular_offset
rectangular_omit
rectangular_open_shape_profile
rectangular_pattern
region
region_projection
region_surface_list
replicate_feature
representation_context
representation_item
representation_map

```
return_home
right_circular_cylinder
round_hole
rounded_end
rounded_u_profile
selective
set_mark
setup
setup_instruction
shape_profile
shape_representation
slot
slot_end_type
solid_model
specification
specification_usage_constraint
spherical_cap
spherical_hole_bottom
square_u_profile
step
surface
surface_texture_parameter
technology
tee_profile
thread
three_axes
through_bottom_condition
through_pocket_bottom_condition
through_profile_floor
toleranced_length_measure
tool_direction
tool_length_probing
tool_probing
tool_radius_probing
toolpath
toolpath_feature
toolpath_list
toolpath_speed
topological_region
topological_representation_item
touch_probe
touch_probing
trajectory
transition_feature
travel_path
trimmed_curve
two_axes
two5D_manufacturing_feature
unary_boolean_expression
vee_profile
vertex
vertex_loop
vertex_point
wait_for_mark
week_of_year_and_day_date
while_statement
woodruff_slot_end_type
workingstep
workpiece
workpiece_complete_probing
workpiece_probing
workpiece_setup
workplan
xor_expression
```

5.6 Conformance class 6 entities

An implementation of conformance class 6 of this part of ISO 14649 shall support the following entities and related constructs:

```
address
advanced_brep_shape_representatio
  n
advanced_face
and_expression
angle_taper
ap_lift_path_angle
ap_lift_path_tangent
approach_lift_path
approval
approval_status
assignment
axis_trajectory
axis1_placement
axis2_placement_3d
b_spline_curve
b_spline_curve_with_knots
b_spline_surface
b_spline_surface_with_knots
bezier_curve
bezier_surface
binary_boolean_expression
blind_bottom_condition
block
boolean_expression
boss
bounded_curve
bounded_pcurve
bounded_surface
calendar_date
cartesian_point
catalogue_thread
chamfer
channel
circle
circular_closed_profile
circular_closed_shape_profile
circular_offset
circular_omit
circular_path
circular_pattern
closed_pocket
closed_profile
closed_shell
comparison_equal
comparison_expression
comparison_greater
comparison_greater_equal
comparison_less
comparison_less_equal
comparison_not_equal
complete_circular_path
composite_curve
composite_curve_segment
compound_feature
conic
conical_hole_bottom
connect_direct
connect_secplane
connected_face_set
connector
coordinated_universal_time_offset
counterbore_hole
countersunk_hole
curve
curve_with_normal_vector
cutter_contact_trajectory
cutter_location_trajectory
date
date_and_time
defined_thread
definitional_representation
descriptive_parameter
diameter_taper
direction
display_message
edge
edge_curve
edge_loop
edge_round
elementary_surface
ellipse
executable
face
face_bound
face_outer_bound
face_surface
faceted_brep
feedstop
flat_hole_bottom
flat_slot_end_type
flat_with_radius_hole_bottom
founded_item
general_closed_profile
general_outside_profile
general_path
general_pattern
general_pocket_bottom_condition
general_profile
general_profile_floor
general_shape_profile
geometric_representation_context
geometric_representation_item
hole_bottom_condition
hyperbola
if_statement
in_process_geometry
limits_and_fits
line
linear_path
```

linear_profile
local_time
loop
loop_slot_end_type
machine_functions
machined_surface
machining_feature
machining_operation
machining_tool
machining_workingstep
manifold_solid_brep
manufacturing_feature
mapped_item
material
multiple_arity_boolean_expression
nc_constant
nc_function
nc_variable
ngon_profile
non_sequential
not_expression
numeric_parameter
offset_vector
open_pocket
open_profile
open_shell
open_slot_end_type
operation
optional_stop
or_expression
ordinal_date
oriented_closed_shell
oriented_edge
oriented_face
orineted_open_shell
oriented_path
oriented_surface
parabola
parallel
parameterised_path
partial_area_definition
partial_circular_path
partial_circular_profile
partial_circular_shape_profile
path
pcurve
person
person_and_address
placement
planar_face
planar_pocket_bottom_condition
planar_profile_floor
plane
plus_minus_value
pocket
pocket_bottom_condition
point
polyline
poly_loop
profile
profile_feature
profile_floor
program_stop
program_structure
project
property_parameter
quasi_uniform_curve
quasi_uniform_surface
radiused_pocket_bottom_condition
radiused_slot_end_type
rapid_movement
rational_b_spline_curve
rational_b_spline_surface
rectangular_closed_profile
rectangular_closed_shape_profile
rectangular_offset
rectangular_omit
rectangular_open_shape_profile
rectangular_pattern
region
region_projection
region_surface_list
replicate_feature
representation_context
representation_item
representation_map
return_home
right_circular_cylinder
round_hole
rounded_end
rounded_u_profile
selective
set_mark
setup
setup_instruction
shape_profile
shape_representation
slot
slot_end_type
solid_model
specification
specification_usage_constraint
spherical_cap
spherical_hole_bottom
spherical_surface
square_u_profile
step
surface
surface_of_linear_extrusion
surface_of_revolution
surface_texture_parameter
swept_surface
technology
tee_profile
thread
three_axes
through_bottom_condition
through_pocket_bottom_condition
through_profile_floor
toleranced_length_measure
tool_direction
tool_length_probing

```
tool_probing
tool_radius_probing
toolpath
toolpath_feature
toolpath_list
toolpath_speed
topological_region
topological_representation_item
touch_probe
touch_probing
trajectory
transition_feature
travel_path
trimmed_curve
two_axes
two5D_manufacturing_feature
unary_boolean_expression
uniform_curve
uniform
_surface
vector
vee_profile
vertex
vertex_loop
vertex_point
wait_for_mark
week_of_year_and_day_date
while_statement
woodruff_slot_end_type
workingstep
workpiece
workpiece_complete_probing
workpiece_probing
workpiece_setup
workplan
xor_expression
```

Annex A
(normative)

EXPRESS expanded listing

The following EXPRESS is the whole schema given in clause 5. In the event of any discrepancy between the short form and this expanded listing, the expanded listing shall be used. The two-character labels used for each entity indicate to which conformance class an entity belongs; please refer to Chapter 5.

```
SCHEMA machining_schema;
(*
Version of April 30, 2004
Author: ISO TC184/SC1/WG7
*)

REFERENCE FROM approval_schema                  (*ISO 10303-41e3*)
  ( approval,
    approval_status);

REFERENCE FROM date_time_schema                 (*ISO 10303-41e3*)
  ( date_and_time,
    date);
REFERENCE FROM person_organization_schema      (*ISO10303-41e3*)
  ( person,
    address);

REFERENCE FROM support_resource_schema         (*ISO10303-41e3*)
  ( bag_to_set,
    identifier,
    label,
    text);

REFERENCE FROM measure_schema                   (*ISO10303-41e3*)
  ( length_measure,
    parameter_value,
    plane_angle_measure,
    positive_length_measure);

REFERENCE FROM product_property_representation_schema  (*ISO10303-41e3*)
  ( shape_representation);

REFERENCE FROM representation_schema            (*ISO10303-43e2*)
  ( definitional_representation);

REFERENCE FROM geometry_schema                  (*ISO10303-42e3*)
  ( trimming_select,
    trimming_preference,
    transition_code,
    trimmed_curve,
    composite_curve,
    composite_curve_segment,
    axis2_placement_3d,
    bounded_curve,
      bounded_surface,
      cartesian_point,
      circle,
      conic,
      curve,
      direction,
      elementary_surface,
      plane,
      polyline
      );

REFERENCE FROM topology_schema              (*ISO10303-42e3*)
  ( edge, edge_curve, edge_loop, face, loop);

REFERENCE FROM geometric_model_schema       (*ISO10303-42e3*)
  ( block,
    right_circular_cylinder
   );

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

(* ************************************************************ *)
(* ************************************************************ *)
(*                                                              *)
(* General types and definitions                                *)
(*                                                              *)
(* ************************************************************ *)
(* ************************************************************ *)

(* ************************************************************ *)
(* Measure units                                                *)
(* ************************************************************ *)

ENTITY toleranced_length_measure;                  (* m1 *)
  theoretical_size:       positive_length_measure;
  implicit_tolerance:     tolerance_select;
END_ENTITY;

TYPE tolerance_select = SELECT(plus_minus_value, limits_and_fits);
END_TYPE;

ENTITY plus_minus_value;                           (* m1 *)
  upper_limit:            positive_length_measure;
  lower_limit:            positive_length_measure;
  significant_digits:     INTEGER;
END_ENTITY;

ENTITY limits_and_fits;                            (* m1 *)
  deviation:              length_measure;
  grade:                  length_measure;
  its_fitting_type:       OPTIONAL fitting_type;
END_ENTITY;

TYPE fitting_type = ENUMERATION OF (shaft,hole);
END_TYPE;
TYPE speed_measure = REAL;
END_TYPE;

TYPE rot_speed_measure = REAL;
END_TYPE;
```

```
TYPE pressure_measure = REAL;
END_TYPE;

(* ************************************************************ *)
(* Other general types                                          *)
(* ************************************************************ *)

TYPE rot_direction = ENUMERATION OF (cw,ccw);
END_TYPE;

TYPE shape_tolerance = length_measure;
END_TYPE;

(* ************************************************************ *)
(* ************************************************************ *)
(*                                                              *)
(*  PROJECT                                                     *)
(*                                                              *)
(* ************************************************************ *)
(* ************************************************************ *)

ENTITY project;                                                     (* m0 *)
  its_id:                  identifier;
  main_workplan:           workplan;
  its_workpieces:          SET [0:?] OF workpiece;
  its_owner:               OPTIONAL person_and_address;
  its_release:             OPTIONAL date_and_time;
  its_status:              OPTIONAL approval;
  (* Informal proposition:
     its_id shall be unique within the part programme.
  *)
END_ENTITY;

ENTITY person_and_address;                                          (* m0 *)
  its_person:              person;
  its_address:             OPTIONAL address;
END_ENTITY;

(* ************************************************************ *)
(* ************************************************************ *)
(*                                                              *)
(* Workpiece and manufacturing feature                          *)
(*                                                              *)
(* ************************************************************ *)
(* ************************************************************ *)

ENTITY workpiece;                                                   (* m1 *)
  its_id:                  identifier;
  its_material:            OPTIONAL material;
  global_tolerance:        OPTIONAL shape_tolerance;
  its_rawpiece:            OPTIONAL workpiece;
  its_geometry:            OPTIONAL advanced_brep_shape_representation;
  its_bounding_geometry:   OPTIONAL bounding_geometry_select;
  clamping_positions:      SET [0:?] OF cartesian_point;
END_ENTITY;

(* ************************************************************ *)
(* Material                                                     *)
(* ************************************************************ *)
```

```
ENTITY material;                                           (* m1 *)
  standard_identifier:    label;
  material_identifier:    label;
  material_property:      SET [0:?] OF property_parameter;
END_ENTITY;

(* ************************************************************ *)
(* Property parameter                                           *)
(* ************************************************************ *)

ENTITY property_parameter                                  (* m0 *)
  SUPERTYPE OF (ONEOF (descriptive_parameter,numeric_parameter));
  parameter_name:         label;
END_ENTITY;

ENTITY descriptive_parameter                               (* m0 *)
  SUBTYPE OF (property_parameter);
  descriptive_string:     text;
END_ENTITY;

ENTITY numeric_parameter                                   (* m0 *)
  SUBTYPE OF (Property_parameter);
  its_parameter_value:    parameter_value;
  its_parameter_unit:     label;
END_ENTITY;

(* ************************************************************ *)
(* Bounding geometry                                            *)
(* ************************************************************ *)

TYPE bounding_geometry_select =
  SELECT (block, right_circular_cylinder,                  (* m1 *)
  advanced_brep_shape_representation);                     (* t1 *)
END_TYPE;

(* ************************************************************ *)
(* Manufacturing feature                                        *)
(* ************************************************************ *)

ENTITY manufacturing_feature                               (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF(region, two5D_manufacturing_feature,
  transition_feature));
  its_id:                 identifier;
  its_workpiece:          workpiece;
  its_operations:         SET [0:?] OF machining_operation;
END_ENTITY;

(* ************************************************************ *)
(* ************************************************************ *)
(*                                                              *)
(* Catalogue of manufacturing feature                           *)
(*                                                              *)
(* ************************************************************ *)
(* ************************************************************ *)


(* ************************************************************ *)
(* Region                                                       *)
(* ************************************************************ *)
```

```
ENTITY region                                            (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF (region_surface_list, region_projection,
  topological_region))
  SUBTYPE OF (manufacturing_feature);
  feature_placement:      OPTIONAL axis2_placement_3d;
END_ENTITY;

ENTITY region_projection                                 (* m1 *)
  SUBTYPE OF (region);
  proj_curve:             bounded_curve;
  proj_dir:               direction;
  depth:                  toleranced_length_measure;
END_ENTITY;

ENTITY region_surface_list                               (* m1 *)
  SUBTYPE OF (region);
  surface_list:           LIST [1:?] OF bounded_surface;
END_ENTITY;

ENTITY topological_region                                (* t0 t1 *)
  SUBTYPE OF (region, open_shell);
WHERE
  WR1: SIZEOF(QUERY(it <* SELF.cfs_faces |
  NOT('MACHINING_SCHEMA.ADVANCED_FACE' IN TYPEOF(it)))) = 0;
END_ENTITY;

(* ************************************************************ *)
(* 2.5D manufacturing feature                                   *)
(* ************************************************************ *)

ENTITY two5D_manufacturing_feature                       (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF(machining_feature, replicate_feature,
  compound_feature))
  SUBTYPE OF (manufacturing_feature);
  feature_placement:      axis2_placement_3d;
END_ENTITY;

(* ************************************************************ *)
(* Machining feature                                            *)
(* ************************************************************ *)

ENTITY machining_feature                                 (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF(planar_face, pocket, slot, step, round_hole,
  toolpath_feature, profile_feature, boss, spherical_cap, rounded_end,
  thread))
  SUBTYPE OF (two5D_manufacturing_feature);
  depth:                  elementary_surface;
END_ENTITY;

(* ************************************************************ *)
(* Planer face                                                  *)
(* ************************************************************ *)

ENTITY planar_face                                       (* m1 *)
  SUBTYPE OF (machining_feature);
  course_of_travel:       linear_path;
  removal_boundary:       linear_profile;
  face_boundary:          OPTIONAL closed_profile;
  its_boss:               SET [0:?] OF boss;
  (*Informal propositions:
    - The entire profile lies in the local xy plane.
    - The profile is not self-intersecting.
  *)
END_ENTITY;

(* ************************************************************ *)
(* Pocket                                                       *)
(* ************************************************************ *)

ENTITY pocket                                               (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF(closed_pocket, open_pocket))
  SUBTYPE OF (machining_feature);
  its_boss:                 SET [0:?] OF boss;
  slope:                    OPTIONAL plane_angle_measure;
  bottom_condition:         pocket_bottom_condition;
  planar_radius:            OPTIONAL toleranced_length_measure;
  orthogonal_radius:        OPTIONAL toleranced_length_measure;
END_ENTITY;

ENTITY closed_pocket                                        (* m1 *)
  SUBTYPE OF (pocket);
  feature_boundary:             closed_profile;
  (*Informal propositions:
    - The entire profile lies in the feature's local xy plane.
    - The profile is closed and not self-intersecting.
  *)
END_ENTITY;

ENTITY open_pocket                                          (* m1 *)
  SUBTYPE OF (pocket);
  open_boundary:            open_profile;
  wall_boundary:            OPTIONAL open_profile;
  (*Informal propositions:
    - The entire open_boundary profile lies in the local xy plane.
    - The profile are is not self-intersecting.
    - Together the two open_profiles form a closed profile.
    - wall_boundary is for information only.
  *)
END_ENTITY;

ENTITY pocket_bottom_condition                              (* m1 *)
  ABSTRACT SUPERTYPE OF
  (ONEOF (through_pocket_bottom_condition, planar_pocket_bottom_condition,
  radiused_pocket_bottom_condition, general_pocket_bottom_condition));
END_ENTITY;

ENTITY through_pocket_bottom_condition                      (* m1 *)
  SUBTYPE OF (pocket_bottom_condition);
END_ENTITY;

ENTITY planar_pocket_bottom_condition                       (* m1 *)
  SUBTYPE OF (pocket_bottom_condition);
END_ENTITY;

ENTITY radiused_pocket_bottom_condition                     (* m1 *)
  SUBTYPE OF (pocket_bottom_condition);
  floor_radius_center:          cartesian_point;
  floor_radius:                 toleranced_length_measure;
END_ENTITY;

ENTITY general_pocket_bottom_condition                      (* m1 *)
  SUBTYPE OF (pocket_bottom_condition);
  shape:                      region;
WHERE
  WR1: SIZEOF(shape\manufacturing_feature.its_operations) = 0;
END_ENTITY;

(* ************************************************************** *)
(* Slot                                                             *)
(* ************************************************************** *)

ENTITY slot                (* m1 *)
  SUBTYPE OF (machining_feature);
  course_of_travel:           travel_path;
  swept_shape:                open_profile;
  end_conditions:             LIST[0:2] OF slot_end_type;
WHERE
  WR1: ( ( SIZEOF(QUERY (it <* SELF.end_conditions |
         ('MACHINING_SCHEMA.LOOP_SLOT_END_TYPE' IN TYPEOF(it)) )) = 1)
         AND
         (SIZEOF(end_conditions) = 1) )
         OR
         (SIZEOF(end_conditions) <> 1);
  (*
  Informal propositions:
  - The entire travel_path lies in the local xy plane.
  - The travel_path is not self-intersecting.
  *)
END_ENTITY;

ENTITY slot_end_type                                        (* m1 *)
 ABSTRACT SUPERTYPE OF (ONEOF (woodruff_slot_end_type, radiused_slot_end_type,
  flat_slot_end_type, loop_slot_end_type, open_slot_end_type));
END_ENTITY;

ENTITY woodruff_slot_end_type                               (* m1 *)
  SUBTYPE OF (slot_end_type);
  radius:                    toleranced_length_measure;
END_ENTITY;

ENTITY radiused_slot_end_type                               (* m1 *)
  SUBTYPE OF (slot_end_type);
END_ENTITY;

ENTITY flat_slot_end_type                                   (* m1 *)
  SUBTYPE OF (slot_end_type);
  corner_radius1:            toleranced_length_measure;
  corner_radius2:            toleranced_length_measure;
END_ENTITY;

ENTITY loop_slot_end_type  (* m1 *)
  SUBTYPE OF (slot_end_type);
END_ENTITY;

ENTITY open_slot_end_type                                   (* m1 *)
  SUBTYPE OF (slot_end_type);
END_ENTITY;

(* ************************************************************** *)
(* Step                                                             *)
(* ************************************************************** *)

ENTITY step                                                 (* m1 *)
```

```
   SUBTYPE OF (machining_feature);
   open_boundary:          linear_path;
   wall_boundary:          OPTIONAL vee_profile;
   its_boss:               SET[0:?] OF boss;
   (*
   Informal propositions:
   - The entire linear_path lies in the same plane.
   *)
END_ENTITY;

(* ************************************************************ *)
(* Profile_feature                                              *)
(* ************************************************************ *)

ENTITY profile_feature                                         (* m1 *)
   ABSTRACT SUPERTYPE OF(ONEOF(general_outside_profile, shape_profile))
   SUBTYPE OF (machining_feature);
   profile_swept_shape:    linear_path;
END_ENTITY;

ENTITY general_outside_profile                                 (* m1 *)
   SUBTYPE OF (profile_feature);
   feature_boundary:       profile;
   (*
   Informal propositions:
   - The entire profile lies in the local xy plane.
   - The profile is not self-intersecting.
   *)
END_ENTITY;

ENTITY shape_profile                                           (* m1 *)
   ABSTRACT SUPERTYPE
   OF(ONEOF(general_shape_profile,partial_circular_shape_profile,
   circular_closed_shape_profile,rectangular_open_shape_profile,
   rectangular_closed_shape_profile))
   SUBTYPE OF (profile_feature);
   floor_condition:        profile_select;
   removal_direction:      direction;
END_ENTITY;

TYPE profile_select =
   SELECT (through_profile_floor, profile_floor);
END_TYPE;

ENTITY through_profile_floor;                                  (* m1 *)
END_ENTITY;

ENTITY profile_floor                                           (* m1 *)
   ABSTRACT SUPERTYPE OF(ONEOF(general_profile_floor, planar_profile_floor));
   floor_radius:           OPTIONAL numeric_parameter;
   start_or_end:           BOOLEAN;
END_ENTITY;

ENTITY general_profile_floor                                   (* m1 *)
   SUBTYPE OF (profile_floor);
   floor:                  face;
END_ENTITY;

ENTITY planar_profile_floor                                    (* m1 *)
   SUBTYPE OF (profile_floor);
   floor:                  plane;
END_ENTITY;
```

```
ENTITY general_shape_profile                                    (* m1 *)
  SUBTYPE OF (shape_profile);
  profile_boundary:       profile;
END_ENTITY;

ENTITY partial_circular_shape_profile                           (* m1 *)
  SUBTYPE OF (shape_profile);
  open_boundary:          partial_circular_profile;
END_ENTITY;

ENTITY circular_closed_shape_profile                            (* m1 *)
  SUBTYPE OF (shape_profile);
  closed_boundary:        circular_closed_profile;
END_ENTITY;

ENTITY rectangular_open_shape_profile                           (* m1 *)
  SUBTYPE OF (shape_profile);
  open_boundary:          square_u_profile;
END_ENTITY;

ENTITY rectangular_closed_shape_profile                         (* m1 *)
  SUBTYPE OF (shape_profile);
  closed_boundary:        rectangular_closed_profile;
END_ENTITY;

(* ************************************************************ *)
(* Round hole                                                   *)
(* ************************************************************ *)

ENTITY round_hole                                               (* m1 *)
  SUBTYPE OF (machining_feature);
  diameter:               toleranced_length_measure;
  change_in_diameter:     OPTIONAL taper_select;
  bottom_condition:       hole_bottom_condition;
END_ENTITY;

TYPE taper_select =
  SELECT (diameter_taper, angle_taper);
END_TYPE;

ENTITY diameter_taper;                                          (* m1 *)
  final_diameter: toleranced_length_measure;
END_ENTITY;

ENTITY angle_taper;                                             (* m1 *)
  angle:                  plane_angle_measure;
END_ENTITY;

ENTITY hole_bottom_condition                                    (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF (blind_bottom_condition,
  through_bottom_condition));
END_ENTITY;

ENTITY through_bottom_condition                                 (* m1 *)
  SUBTYPE OF (hole_bottom_condition);
END_ENTITY;
```

```
ENTITY blind_bottom_condition                                 (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF(flat_hole_bottom, flat_with_radius_hole_bottom,
  spherical_hole_bottom, conical_hole_bottom))
  SUBTYPE OF (hole_bottom_condition);
END_ENTITY;

ENTITY flat_hole_bottom    (* m1 *)
  SUBTYPE OF (blind_bottom_condition);
END_ENTITY;

ENTITY flat_with_radius_hole_bottom                           (* m1 *)
  SUBTYPE OF (blind_bottom_condition);
  corner_radius:          toleranced_length_measure;
END_ENTITY;

ENTITY spherical_hole_bottom                                  (* m1 *)
  SUBTYPE OF (blind_bottom_condition);
  radius:                 toleranced_length_measure;
END_ENTITY;

ENTITY conical_hole_bottom                                    (* m1 *)
  SUBTYPE OF (blind_bottom_condition);
  tip_angle:              plane_angle_measure;
  tip_radius:             OPTIONAL toleranced_length_measure;
END_ENTITY;

(* ************************************************************ *)
(* Toolpath feature                                            *)
(* ************************************************************ *)

ENTITY toolpath_feature    (* m1 *)
  SUBTYPE OF (machining_feature);
END_ENTITY;

(* ************************************************************ *)
(* Boss                                                         *)
(* ************************************************************ *)

ENTITY boss                                                   (* m1 *)
  SUBTYPE OF(machining_feature);
  its_boundary:           closed_profile;
  slope:                  OPTIONAL plane_angle_measure;
  (*
  Informal propositions:
  - The entire profile lies in the same plane.
  - The profile is not self-intersecting.
  *)
END_ENTITY;

(* ************************************************************ *)
(* Spherical_cap                                                *)
(* ************************************************************ *)

ENTITY spherical_cap                                          (* m1 *)
  SUBTYPE OF (machining_feature);
  internal_angle:         numeric_parameter;
  radius:                 numeric_parameter;
END_ENTITY;

(* ************************************************************ *)
(* Rounded_end                                                  *)
(* ************************************************************ *)
```

```
ENTITY rounded_end                                           (* m1 *)
  SUBTYPE OF (machining_feature);
  course_of_travel:       linear_path;
  partial_circular_boundary: partial_circular_profile;
END_ENTITY;

(* ************************************************************ *)
(* Compound feature                                             *)
(* ************************************************************ *)

ENTITY compound_feature                                      (* m1 *)
  SUPERTYPE OF (ONEOF(counterbore_hole, countersunk_hole))
  SUBTYPE OF (two5D_manufacturing_feature);
  elements: SET [2:?] OF compound_feature_select;
WHERE
  WR1: SIZEOF(QUERY(e <* elements |
  SIZEOF(e\manufacturing_feature.its_operations) <> 0)) = 0;
END_ENTITY;

TYPE compound_feature_select = SELECT(
  machining_feature, transition_feature
  );
END_TYPE;

ENTITY counterbore_hole                                      (* m1 *)
  SUBTYPE OF (compound_feature);
WHERE
  WR1: SIZEOF(elements) =2;
  WR2: (SIZEOF(QUERY ( it <* SELF.elements |
       (('MACHINING_SCHEMA.ROUND_HOLE' IN TYPEOF(it))) )) = 2);
  WR3: SELF.elements[1].diameter.theoretical_size <>
       SELF.elements[2].diameter.theoretical_size;
END_ENTITY;

ENTITY countersunk_hole                                      (* m1 *)
  SUBTYPE OF (compound_feature);
WHERE
  WR1: SIZEOF(elements) =2;
  WR2: (SIZEOF(QUERY ( it <* SELF.elements |
       (('MACHINING_SCHEMA.ROUND_HOLE' IN TYPEOF(it))) )) = 2);
  WR3: SELF.elements[1].diameter.theoretical_size <>
       SELF.elements[2].diameter.theoretical_size;
  WR4: NOT EXISTS(SELF.elements[1].change_in_diameter) AND
       EXISTS(SELF.elements[2].change_in_diameter);
END_ENTITY;

(* ************************************************************ *)
(* Replicate feature                                            *)
(* ************************************************************ *)

ENTITY replicate_feature                                     (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF(rectangular_pattern, circular_pattern,
  general_pattern))
  SUBTYPE OF (two5D_manufacturing_feature);
  replicate_base_feature: two5D_manufacturing_feature;
END_ENTITY;

ENTITY circular_pattern                                      (* m1 *)
  SUBTYPE OF(replicate_feature);
  angle_increment:        plane_angle_measure;
```

```
    number_of_feature:       INTEGER;
    relocated_base_feature:  SET[0:?] OF circular_offset;
    missing_base_feature:    SET[0:?] OF circular_omit;
    base_feature_diameter:   OPTIONAL toleranced_length_measure;
    base_feature_rotation:   plane_angle_measure;
  END_ENTITY;

  ENTITY circular_offset;                                   (* m1 *)
    angular_offset:          plane_angle_measure;
    index:                   INTEGER;
  END_ENTITY;

  ENTITY circular_omit;                                     (* m1 *)
    index:                   INTEGER;
  END_ENTITY;

  ENTITY rectangular_pattern                                (* m1 *)
    SUBTYPE OF(replicate_feature);
    spacing:                 toleranced_length_measure;
    its_direction:           direction;
    number_of_rows:          OPTIONAL INTEGER;
    number_of_columns:       INTEGER;
    row_spacing:             OPTIONAL toleranced_length_measure;
    row_layout_direction:    OPTIONAL direction;
    relocated_base_feature:  SET[0:?] OF rectangular_offset;
    missing_base_feature:    SET[0:?] OF rectangular_omit;
  WHERE
    WR1: (
          (SELF.number_of_rows > 1 )
          AND EXISTS(SELF.row_spacing)
          AND EXISTS(SELF.row_layout_direction)
         );
  END_ENTITY;

  ENTITY rectangular_offset;                                (* m1 *)
    offset_direction:        direction;
    offset_distance:         length_measure;
    row_index:               INTEGER;
    column_index:            INTEGER;
  END_ENTITY;

  ENTITY rectangular_omit;                                  (* m1 *)
    row_index:               INTEGER;
    column_index:            INTEGER;
  END_ENTITY;

  ENTITY general_pattern                                    (* m1 *)
    SUBTYPE OF(replicate_feature);
    replicate_locations:     LIST [2:?] OF axis2_placement_3d;
  END_ENTITY;

  (* ************************************************************ *)
  (* Transition feature                                            *)
  (* ************************************************************ *)

  ENTITY transition_feature                                 (* m1 *)
    ABSTRACT SUPERTYPE OF (ONEOF(chamfer, edge_round))
    SUBTYPE OF (manufacturing_feature);
    first_feature:           machining_feature;
    second_feature:          machining_feature;
  END_ENTITY;
```

```
ENTITY chamfer                                                (* m1 *)
  SUBTYPE OF (transition_feature);
  angle_to_plane:          plane_angle_measure;
  first_offset_amount:     toleranced_length_measure;
END_ENTITY;

ENTITY edge_round                                             (* m1 *)
  SUBTYPE OF (transition_feature);
  radius:                  toleranced_length_measure;
  first_offset_amount:     OPTIONAL toleranced_length_measure;
  second_offset_amount:    OPTIONAL toleranced_length_measure;
END_ENTITY;

(* ***************************************************** *)
(* Tread                                                  *)
(* ***************************************************** *)

ENTITY thread                                                 (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(catalogue_thread, defined_thread))
  SUBTYPE OF(machining_feature);
  partial_profile:         partial_area_definition;
  applied_shape:           SET[1:?] OF machining_feature;
  inner_or_outer_thread:   BOOLEAN;
  qualifier:               OPTIONAL descriptive_parameter;
  fit_class:               descriptive_parameter;
  form:                    descriptive_parameter;
  major_diameter:          length_measure;
  number_of_threads:       numeric_parameter;
  thread_hand:             descriptive_parameter;
WHERE
  WR1: ('MACHINING_SCHEMA.ROUND_HOLE' IN TYPEOF(applied_shape))
   OR ('MACHINING_SCHEMA.CIRCULAR_CLOSED_SHAPE_PROFILE' IN
  TYPEOF(applied_shape))
   OR ('MACHINING_SCHEMA.BOSS' IN TYPEOF(applied_shape));
END_ENTITY;

ENTITY partial_area_definition;                               (* m1 *)
  effective_length:        length_measure;
  placement:               axis2_placement_3D;
  maximum_length:          OPTIONAL length_measure;
END_ENTITY;

ENTITY catalogue_thread                                       (* m1 *)
  SUBTYPE OF (thread);
  documentation:           specification;
END_ENTITY;

ENTITY specification;                                         (* m1 *)
  constraint:              SET [0:?] OF specification_usage_constraint;
  specification_id:        text;
  specification_description: OPTIONAL text;
  specification_class:     OPTIONAL text;
END_ENTITY;

ENTITY specification_usage_constraint;                        (* m1 *)
  element:                 text;
  class_id:                text;
END_ENTITY;
```

```
ENTITY defined_thread                                        (* m1 *)
  SUBTYPE OF (thread);
  pitch_diameter:         length_measure;
  minor_diameter:         OPTIONAL length_measure;
  crest:                  OPTIONAL length_measure;
END_ENTITY;

(* ************************************************************ *)
(* Profile                                                       *)
(* ************************************************************ *)

ENTITY profile                                               (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(closed_profile, open_profile));
  placement:              OPTIONAL axis2_placement_3d;
END_ENTITY;

ENTITY open_profile                                          (* m1 *)
  ABSTRACT SUPERTYPE OF
  (ONEOF (linear_profile, square_u_profile, rounded_u_profile, tee_profile,
  vee_profile, partial_circular_profile, general_profile))
  SUBTYPE OF(profile);
END_ENTITY;

ENTITY linear_profile                                        (* m1 *)
  SUBTYPE OF (open_profile);
  profile_length:         numeric_parameter;
END_ENTITY;

ENTITY square_u_profile                                      (* m1 *)
  SUBTYPE OF (open_profile);
  width:                  toleranced_length_measure;
  first_radius:           toleranced_length_measure;
  first_angle:            plane_angle_measure;
  second_radius:          toleranced_length_measure;
  second_angle:           plane_angle_measure;
END_ENTITY;

ENTITY rounded_u_profile                                     (* m1 *)
  SUBTYPE OF (open_profile);
  width:                  toleranced_length_measure;
END_ENTITY;

ENTITY tee_profile                                           (* m1 *)
  SUBTYPE OF (open_profile);
  first_angle:            plane_angle_measure;
  second_angle:           plane_angle_measure;
  cross_bar_width:        toleranced_length_measure;
  cross_bar_depth:        toleranced_length_measure;
  radius:                 toleranced_length_measure;
  width:                  toleranced_length_measure;
  first_offset:           toleranced_length_measure;
  second_offset:          toleranced_length_measure;
END_ENTITY;

ENTITY vee_profile                                           (* m1 *)
  SUBTYPE OF (open_profile);
  profile_radius:         toleranced_length_measure;
  profile_angle:          plane_angle_measure;
  tilt_angle:             plane_angle_measure;
END_ENTITY;
```

```
ENTITY partial_circular_profile                              (* m1 *)
  SUBTYPE OF (open_profile);
  radius:                  toleranced_length_measure;
  sweep_angle:             plane_angle_measure;
END_ENTITY;

ENTITY general_profile                                       (* m1 *)
  SUBTYPE OF (open_profile);
  its_profile:             bounded_curve;
  (*
  Informal propositions:
  - The entire profile lies in the local yz plane.
  - The profile is not self-intersecting.
  *)
END_ENTITY;

ENTITY closed_profile                                        (* m1 *)
  ABSTRACT SUPERTYPE OF
  (ONEOF (rectangular_closed_profile, circular_closed_profile, ngon_profile,
  general_closed_profile))
  SUBTYPE OF(profile);
END_ENTITY;

ENTITY rectangular_closed_profile                            (* m1 *)
  SUBTYPE OF(closed_profile);
  profile_width:           toleranced_length_measure;
  profile_length:          toleranced_length_measure;
END_ENTITY;

ENTITY circular_closed_profile                               (* m1 *)
  SUBTYPE OF(closed_profile);
  diameter:                toleranced_length_measure;
END_ENTITY;

ENTITY ngon_profile                                          (* m1 *)
  SUBTYPE OF(closed_profile);
  diameter:                toleranced_length_measure;
  number_of_sides:         INTEGER;
  circumscribed_or_across_flats: BOOLEAN;
END_ENTITY;

ENTITY general_closed_profile                                (* m1 *)
  SUBTYPE OF(closed_profile);
  closed_profile_shape:    bounded_curve;
END_ENTITY;

(* ************************************************************ *)
(* Travel path                                                  *)
(* ************************************************************ *)

ENTITY travel_path                                           (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(general_path, linear_path, circular_path));
  placement:               OPTIONAL axis2_placement_3d;
END_ENTITY;

ENTITY general_path                                          (* m1 *)
  SUBTYPE OF(travel_path);
  swept_path:              bounded_curve;
END_ENTITY;

ENTITY linear_path                                           (* m1 *)
  SUBTYPE OF(travel_path);
```

```
    distance:                 toleranced_length_measure;
    its_direction:            direction;
  END_ENTITY;

  ENTITY circular_path                                          (* m1 *)
    ABSTRACT SUPERTYPE OF(ONEOF(complete_circular_path, partial_circular_path))
    SUBTYPE OF(travel_path);
    radius:                   toleranced_length_measure;
  END_ENTITY;

  ENTITY complete_circular_path                                 (* m1 *)
    SUBTYPE OF(circular_path);
  END_ENTITY;

  ENTITY partial_circular_path                                  (* m1 *)
    SUBTYPE OF(circular_path);
    sweep_angle:              plane_angle_measure;
  END_ENTITY;

  (* ************************************************************ *)
  (* Surface texture parameter                                    *)
  (* ************************************************************ *)

  ENTITY surface_texture_parameter;                             (* m1 *)
    its_value:                parameter_value;
    parameter_name:           label;
    measuring_method:         identifier;
    parameter_index:          OPTIONAL identifier;
    applied_surfaces:         SET [1:?] OF machined_surface;
  END_ENTITY;

  ENTITY machined_surface;                                      (* m1 *)
    its_machining_feature:    machining_feature;
    surface_element:          bottom_or_side;
  END_ENTITY;

  TYPE bottom_or_side =
    ENUMERATION OF (bottom, side, bottom_and_side);
  END_TYPE;

  (* ************************************************************ *)
  (* ************************************************************ *)
  (*                                                              *)
  (* Executable                                                   *)
  (*                                                              *)
  (* ************************************************************ *)
  (* ************************************************************ *)

  ENTITY executable                                             (* m0 *)
    ABSTRACT SUPERTYPE OF (ONEOF( workingstep, nc_function,program_structure));
    its_id:                   identifier;
    (*
    Informal proposition:
    its_id shall be unique within the part programme.
    *)
  END_ENTITY;

  (* ************************************************************ *)
  (* Workingstep                                                  *)
  (* ************************************************************ *)
```

```
ENTITY workingstep                                          (* m0 *)
  ABSTRACT SUPERTYPE OF (ONEOF (machining_workingstep, rapid_movement,
  touch_probing))
  SUBTYPE OF (executable);
  its_secplane:            elementary_surface;
END_ENTITY;

(* ************************************************************ *)
(* Machining workingstep                                        *)
(* ************************************************************ *)

ENTITY machining_workingstep                                (* m0 *)
  SUBTYPE OF (workingstep);
  its_feature:             manufacturing_feature;
  its_operation:           machining_operation;
  its_effect:              OPTIONAL in_process_geometry;
END_ENTITY;

ENTITY in_process_geometry;                                 (* m1 *)
  as_is:                   OPTIONAL advanced_brep_shape_representation;
  to_be:                   OPTIONAL advanced_brep_shape_representation;
  removal:                 OPTIONAL advanced_brep_shape_representation;
WHERE
  WR1: EXISTS (as_is) OR EXISTS (to_be) OR EXISTS (removal);
END_ENTITY;

(* ************************************************************ *)
(* Rapid movement                                               *)
(* ************************************************************ *)

ENTITY rapid_movement                                       (* m0 *)
  SUPERTYPE OF (return_home)
  SUBTYPE OF (workingstep, OPERATION);
END_ENTITY;

ENTITY return_home                                          (* m0 *)
  SUBTYPE OF (rapid_movement);
END_ENTITY;

(* ************************************************************ *)
(* Touch probing                                                *)
(* ************************************************************ *)

ENTITY touch_probing                                        (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF (workpiece_probing, workpiece_complete_probing,
  tool_probing))
  SUBTYPE OF (workingstep, OPERATION);
  measured_offset:         nc_variable;
END_ENTITY;

ENTITY workpiece_probing                                    (* m1 *)
  SUBTYPE OF (touch_probing);
  start_position:          axis2_placement_3d;
  its_workpiece:           workpiece;
  its_direction:           direction;
  expected_value:          toleranced_length_measure;
  its_probe:               touch_probe;
END_ENTITY;

ENTITY touch_probe;                                         (* m1 *)
  its_id:                  identifier;
END_ENTITY;
```

```
ENTITY workpiece_complete_probing
  SUBTYPE OF (touch_probing);
  its_workpiece:          workpiece;
  probing_distance:       toleranced_length_measure;
  its_probe:              touch_probe;
  computed_offset:        offset_vector;
END_ENTITY;

ENTITY offset_vector;                                      (* m1 *)
  translate:              LIST [3:3] OF nc_variable;
  rotate:                 OPTIONAL LIST [3:3] OF nc_variable;
WHERE
  WR1: (SIZEOF(QUERY(i <* translate | NOT EXISTS(i.initial_value))) = 0)
       AND (NOT EXISTS(rotate) OR (SIZEOF(QUERY(i <* rotate |
       NOT EXISTS(i.initial_value))) = 0));
END_ENTITY;

ENTITY tool_probing                                        (* m1 *)
  ABSTRACT SUPERTYPE OF (ONEOF (tool_length_probing, tool_radius_probing))
  SUBTYPE OF (touch_probing);
  offset:                 cartesian_point;
  max_wear:               length_measure;
  its_tool:               machining_tool;
END_ENTITY;

(* ************************************************************ *)
(* machining_tool                                                *)
(* ************************************************************ *)

ENTITY machining_tool                                      (* m0 *)
  ABSTRACT SUPERTYPE;
  its_id:                 label;
END_ENTITY;

ENTITY tool_length_probing                                 (* m1 *)
  SUBTYPE OF (tool_probing);
END_ENTITY;

ENTITY tool_radius_probing
  SUBTYPE OF (tool_probing);
END_ENTITY;

(* ************************************************************ *)
(* NC_function                                                  *)
(* ************************************************************ *)

ENTITY nc_function                                         (* m0 *)
  ABSTRACT SUPERTYPE SUBTYPE OF (executable);
END_ENTITY;

ENTITY display_message                                     (* m0 *)
  SUBTYPE OF (nc_function);
  its_text:               text;
END_ENTITY;

ENTITY optional_stop                                       (* m0 *)
  SUBTYPE OF (nc_function);
END_ENTITY;
```

```
ENTITY program_stop                                         (* m0 *)
  SUBTYPE OF (nc_function);
END_ENTITY;

ENTITY set_mark                                             (* m0 *)
  SUBTYPE OF (nc_function);
END_ENTITY;

ENTITY wait_for_mark                                        (* m0 *)
  SUBTYPE OF (nc_function);
  its_channel:            channel;
END_ENTITY;

(* ********************************************************** *)
(* Program structure                                          *)
(* ********************************************************** *)

ENTITY program_structure                                    (* m0 *)
  ABSTRACT SUPERTYPE OF (ONEOF(workplan, parallel, non_sequential, selective,
  if_statement, while_statement, assignment))
  SUBTYPE OF (executable);
END_ENTITY;

(* ********************************************************** *)
(* Workplan                                                   *)
(* ********************************************************** *)

ENTITY workplan                                             (* m0 *)
  SUBTYPE OF (program_structure);
  its_elements: LIST[0:?] OF executable;
  its_channel:            OPTIONAL channel;
  its_setup:              OPTIONAL setup;
  its_effect:             OPTIONAL in_process_geometry;
WHERE
  WR1: SIZEOF(QUERY(it <* its_elements | it = SELF)) = 0;
END_ENTITY;

ENTITY channel;                                             (* m0 *)
  its_id: identifier;
END_ENTITY;

ENTITY setup;                                               (* m0 *)
  its_id:                 identifier;
  its_origin:             OPTIONAL axis2_placement_3d;
  its_secplane:           elementary_surface;
  its_workpiece_setup:    LIST [0:?] OF workpiece_setup;
  (*
  Informal proposition:
  If its_origin is not set, the default for the origin
  of the setup is identical with the machine origin.
  *)
END_ENTITY;

ENTITY workpiece_setup;                                     (* m0 *)
  its_workpiece:          workpiece;
  its_origin:             axis2_placement_3d;
  its_offset:             OPTIONAL offset_vector;
  its_restricted_area:    OPTIONAL restricted_area_select;
  its_instructions:       LIST [0:?] OF setup_instruction;
END_ENTITY;
```

```
TYPE restricted_area_select = SELECT (
   bounded_surface,          (* ISO 10303-42 *)
   bounding_geometry_select);
END_TYPE;

ENTITY setup_instruction;                                       (* m1 *)
   description:              OPTIONAL text;
   external_document:        OPTIONAL identifier;
WHERE
   WR1: EXISTS (description) OR EXISTS (external_document);
END_ENTITY;

ENTITY parallel                                                 (* m1 *)
   SUBTYPE OF (program_structure);
   branches:                 SET [2:?] OF executable;
END_ENTITY;

ENTITY non_sequential                                           (* m1 *)
   SUBTYPE OF (program_structure);
   its_elements:             SET[2:?] OF executable;
END_ENTITY;

ENTITY selective                                                (* m1 *)
   SUBTYPE OF (program_structure);
   its_elements:             SET[2:?] OF executable;
END_ENTITY;

ENTITY if_statement                                             (* m1 *)
   SUBTYPE OF (program_structure);
   condition:                boolean_expression;
   true_branch:              executable;
   false_branch:             OPTIONAL executable;
END_ENTITY;

ENTITY while_statement                                          (* m1 *)
   SUBTYPE OF (program_structure);
   condition:                boolean_expression;
   body:                     executable;
END_ENTITY;

ENTITY assignment                                               (* m1 *)
   SUBTYPE OF (program_structure);
   its_lvalue:               nc_variable;
   its_rvalue:               rvalue;
END_ENTITY;

ENTITY nc_variable;                                             (* m1 *)
   its_name:                 LABEL;
   initial_value:            OPTIONAL NUMBER;
END_ENTITY;

ENTITY nc_constant;                                             (* m1 *)
   its_name:                 LABEL;
   its_value:                OPTIONAL NUMBER;
END_ENTITY;

TYPE rvalue = SELECT(nc_constant, nc_variable);
END_TYPE;
```

```
ENTITY boolean_expression                                   (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(unary_boolean_expression,
  binary_boolean_expression, multiple_arity_boolean_expression,
  comparison_expression));
END_ENTITY;

ENTITY unary_boolean_expression                             (* m1 *)
  ABSTRACT SUPERTYPE OF(not_expression)
  SUBTYPE OF (boolean_expression);
  operand:                 boolean_expression;
END_ENTITY;

ENTITY not_expression                                       (* m1 *)
  SUBTYPE OF (unary_boolean_expression);
END_ENTITY;

ENTITY binary_boolean_expression                            (* m1 *)
  ABSTRACT SUPERTYPE OF(xor_expression)
  SUBTYPE OF (boolean_expression);
  operand1:                boolean_expression;
  operand2:                boolean_expression;
END_ENTITY;

ENTITY xor_expression                                       (* m1 *)
  SUBTYPE OF (binary_boolean_expression);
END_ENTITY;

ENTITY multiple_arity_boolean_expression                    (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(and_expression, or_expression))
  SUBTYPE OF (boolean_expression);
  operands:                LIST [2:?] OF boolean_expression;
END_ENTITY;

ENTITY and_expression                                       (* m1 *)
  SUBTYPE OF (multiple_arity_boolean_expression);
END_ENTITY;

ENTITY or_expression                                        (* m1 *)
  SUBTYPE OF (multiple_arity_boolean_expression);
END_ENTITY;

ENTITY comparison_expression                                (* m1 *)
  ABSTRACT SUPERTYPE OF(ONEOF(comparison_equal, comparison_not_equal,
  comparison_greater, comparison_greater_equal, comparison_less,
  comparison_less_equal))
  SUBTYPE OF (boolean_expression);
  operand1:                nc_variable;
  operand2:                rvalue;
END_ENTITY;

ENTITY comparison_equal                                     (* m1 *)
  SUBTYPE OF (comparison_expression);
END_ENTITY;

ENTITY comparison_not_equal                                 (* m1 *)
  SUBTYPE OF (comparison_expression);
END_ENTITY;

ENTITY comparison_greater  (* m1 *)
  SUBTYPE OF (comparison_expression);
END_ENTITY;
```

```
ENTITY comparison_greater_equal                                  (* m1 *)
  SUBTYPE OF (comparison_expression);
END_ENTITY;

ENTITY comparison_less                                           (* m1 *)
  SUBTYPE OF (comparison_expression);
END_ENTITY;

ENTITY comparison_less_equal                                     (* m1 *)
  SUBTYPE OF (comparison_expression);
END_ENTITY;

(* ************************************************************ *)
(* ************************************************************ *)
(*                                                              *)
(* Operation                                                    *)
(*                                                              *)
(* ************************************************************ *)
(* ************************************************************ *)

ENTITY OPERATION                                                 (* m0 *)
  ABSTRACT SUPERTYPE OF (ONEOF (machining_operation, rapid_movement,
  touch_probing));
  its_toolpath:           OPTIONAL toolpath_list;
  its_tool_direction:     OPTIONAL tool_direction;
END_ENTITY;

ENTITY toolpath_list;                                            (* m0 *)
  its_list:               LIST [1:?] OF toolpath;
END_ENTITY;

ENTITY tool_direction                                            (* m0 *)
  ABSTRACT SUPERTYPE OF (ONEOF (two_axes, three_axes));
END_ENTITY;

ENTITY two_axes                                                  (* m0 *)
  SUBTYPE OF (tool_direction);
END_ENTITY;

ENTITY three_axes                                                (* m0 *)
  SUBTYPE OF (tool_direction);
END_ENTITY;

(* ************************************************************ *)
(* Machining operation                                          *)
(* ************************************************************ *)

ENTITY machining_operation (* m0 *)
  ABSTRACT SUPERTYPE
  SUBTYPE OF (OPERATION);
  its_id:                 identifier;
  retract_plane:          OPTIONAL length_measure;
  start_point:            OPTIONAL cartesian_point;
  its_tool:               machining_tool;
  its_technology:         technology;
  its_machine_functions:  machine_functions;
  (*
  Informal proposition:
  If attribute SELF\operation.its_toolpath exists, then attributes
  its_machining_strategy, retract_plane and start_point, if present, are for
  information only.
   *)
END_ENTITY;
```

```
(* ************************************************************ *)
(* Technology                                                   *)
(* ************************************************************ *)

ENTITY technology                                          (* m0 *)
  ABSTRACT SUPERTYPE;
  feedrate:                OPTIONAL speed_measure;
  feedrate_reference:      tool_reference_point;
END_ENTITY;

TYPE tool_reference_point = ENUMERATION OF (tcp, ccp);
END_TYPE;

(* ************************************************************ *)
(* Machine functions                                            *)
(* ************************************************************ *)

ENTITY machine_functions                                   (* m0 *)
  ABSTRACT SUPERTYPE;
END_ENTITY;

(* ************************************************************ *)
(* ************************************************************ *)
(*                                                              *)
(* Toolpath                                                     *)
(*                                                              *)
(* ************************************************************ *)
(* ************************************************************ *)

ENTITY toolpath                                            (* m0 *)
  ABSTRACT SUPERTYPE OF (ONEOF(feedstop, trajectory, parameterised_path));
  its_priority:            BOOLEAN;
  its_type:                toolpath_type;
  its_speed:               OPTIONAL toolpath_speedprofile;
  its_technology:          OPTIONAL technology;
  its_machine_functions: OPTIONAL machine_functions;
END_ENTITY;

(* ************************************************************ *)
(* Toolpath type                                                *)
(* ************************************************************ *)

TYPE toolpath_type = ENUMERATION OF (
  approach,
  lift,
  connect,
  non_contact,
  contact,
  trajectory_path
  );
END_TYPE;

(* ************************************************************ *)
(* Toolpath speedprofile                                        *)
(* ************************************************************ *)

TYPE toolpath_speedprofile = SELECT (
  toolpath_speed,
    positive_ratio_measure,
    speed_name
    );
  END_TYPE;

  ENTITY toolpath_speed;                                      (* m1 *)
    speed:                   b_spline_curve;
  WHERE
    WR1: speed\geometric_representation_item.dim = 1;
    (*
    Informal proposition:
    - speed shall have only values greater than zero.
    *)
  END_ENTITY;

  TYPE speed_name = ENUMERATION OF(RAPID);
  END_TYPE;

  (* ************************************************************ *)
  (* Feedstop                                                     *)
  (* ************************************************************ *)

  ENTITY feedstop                                             (* m0 *)
    SUBTYPE OF (toolpath);
    dwell:                   time_measure;
  END_ENTITY;

  (* ************************************************************ *)
  (* Trajectory                                                   *)
  (* ************************************************************ *)

  ENTITY trajectory                                           (* m0 *)
    ABSTRACT SUPERTYPE OF (ONEOF(cutter_location_trajectory,
    cutter_contact_trajectory, axis_trajectory))
    SUBTYPE OF (toolpath);
    its_direction:           OPTIONAL BOOLEAN;
  END_ENTITY;

  (* ************************************************************ *)
  (* Cutter location trajectory                                   *)
  (* ************************************************************ *)

  ENTITY cutter_location_trajectory                           (* m0 *)
    SUBTYPE OF (trajectory);
    basiccurve:              bounded_curve;
    its_toolaxis:            OPTIONAL bounded_curve;
    surface_normal:          OPTIONAL bounded_curve;
    (*
    Information proposition:
    its_toolaxis must have the same must have the same parameter range as
    basiccurve.
    *)
  END_ENTITY;

  (* ************************************************************ *)
  (* Cutter contact trajectory                                    *)
  (* ************************************************************ *)

  ENTITY cutter_contact_trajectory                            (* m1 *)
    SUBTYPE OF (trajectory);
    basiccurve:              curve_with_surface_normal;
```