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

Part 11: Process data for milling

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

Partie 11: Données des procédés relatifs au fraisage

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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 14649-11 was prepared by Technical Committee ISO/TC 184, *Industrial automation systems and integration*, Subcommittee SC 1, *Physical device control*.

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*:

NOTE Phase numbers below refer to the planned release phases of ISO 14649 which are described in Annex D of ISO 14649-1:2002.

— *Part 1: Overview and fundamental principles* (Phase 1)

— *Part 10: General process data* (Phase 1)

— *Part 11: Process data for milling* (Phase 1)

— *Part 12: Process data for turning* (Phase 2)

— *Part 13: Process data for wire-EDM* (Phase 2)

— *Part 14: Process data for sink-EDM* (Phase 2)

— *Part 111: Tools for milling* (Phase 1)

— *Part 121: Tools for turning* (Phase 2)

Gaps in the numbering were left to allow further additions. ISO 14649-10 is the ISO 10303 Application Reference Model (ARM) for process-independent data. ISO 10303 ARMs for specific technologies are added after part 10.

ISO 14649 is harmonized 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 standardization 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 standardized by ISO 10303. This leads to the possibility of using standard data throughout the entire process chain in the manufacturing enterprise. Impediments to realizing 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 11: Process data for milling

1 Scope

This part of ISO 14649 specifies the technology-specific data elements needed as process data for milling. Together with the general process data described in ISO 14649-10, it describes the interface between a computerized numerical controller and the programming system (i.e. CAM system or shopfloor programming system) for milling. It can be used for milling operations on all types of machines, be they milling machines, machining centers, or lathes with motorized tools capable of milling. The scope of this part of ISO 14649 does not include any other technologies, like turning, grinding, or EDM. These technologies will be described in further parts of ISO 14649.

Subject of the milling_schema, which is described in this part of ISO 14649, is the definition of technology-specific data types representing the machining process for milling and drilling. This includes both milling of freeform surfaces as well as milling of prismatic workpieces (also known as 2½D-milling). Not included in this schema are geometric items, representations, manufacturing features, executable objects, and base classes which are common for all technologies. They are referenced from ISO 10303's generic resources and ISO 14649-10. 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 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 14649-10, *Industrial automation systems and integration — Physical device control — Data model for computerized numerical controllers — Part 10: General process data*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14649-10 and the following apply.

3.1
finishing
milling operation used to cut a part

NOTE The finishing operation usually follows a roughing operation. The goal of finishing is to reach the surface quality required, cf. roughing.

3.2
roughing
milling operation used to cut a part

NOTE While the aim of roughing is to remove large quantities of material in a short time, the surface quality is usually not important. The roughing operation is usually followed by a finishing operation, cf. finishing.

4 Process data for milling

4.1 Header and references

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

```
SCHEMA milling_schema;
(* Version 19 date: 2002-02-06
 * Author: ISO TC184/SC1/WG7
 *)

(* ************************************************************ *)
(* Types from machining_schema                    ISO 14649-10   *)
(* ************************************************************ *)

REFERENCE FROM machining_schema(
        bounded_curve,
        cartesian_point,
        direction,
        identifier,
        label,
        length_measure,
        nc_function,
        machine_functions,
        machining_operation,
        machining_tool,
        material,
        plane_angle_measure,
        positive_ratio_measure,
        pressure_measure,
        property_parameter,
        rot_direction,
        rot_speed_measure,
        speed_measure,
        technology,
        time_measure,
        toolpath_list,
        tool_direction);
```


4.2 Technology-specific machining operations

4.2.1 NC functions for milling

The NC functions specific to milling technologies are described in the following subclauses. These are subtypes of entity nc_function defined in ISO 14649-10.

4.2.1.1 Exchange pallet

This function is used to execute a pallet exchange.

```
ENTITY exchange_pallet
  SUBTYPE OF (nc_function);
END_ENTITY;
```

4.2.1.2 Index pallet

This function is used to place the pallet to the indicated position by the parameter index.

```
ENTITY index_pallet
  SUBTYPE OF (nc_function);
  its_index:             INTEGER;
END_ENTITY;
```

its_index: The parameter index value by which the destined position of the pallet is indicated.

4.2.1.3 Index table

This function is used to place the rotation table to the indicated position by the parameter index.

```
ENTITY index_table
  SUBTYPE OF (nc_function);
  its_index:             INTEGER;
END_ENTITY;
```

its_index: The parameter index value by which the destined position of the rotation table is indicated.

4.2.1.4 Load tool

This function is used to load a tool that can be selected independent from the geometrical information.


```
ENTITY load_tool
  SUBTYPE OF (nc_function);
  its_tool:              machining_tool;
END_ENTITY;
```


its_tool: The tool which has to be loaded.

4.2.1.5 Unload tool

This function is used to unload a tool.

```
ENTITY unload_tool
  SUBTYPE OF (nc_function);
  its_tool:              OPTIONAL machining_tool;
END_ENTITY;
```

its_tool: The tool which has to be exchanged. In case of an operation where more than one tool is in use at the same time this attribute has to be set.

4.2.2 Tool direction for milling

This is the base class of all tool orientations used for freeform machining. It is subtypes of entity tool_direction defined in ISO 14649-10.

```
ENTITY tool_direction_for_milling
  ABSTRACT SUPERTYPE OF (ONEOF(three_axes_tilted_tool, five_axes_var_tilt_yaw,
  five_axes_const_tilt_yaw))
  SUBTYPE OF (tool_direction);
END_ENTITY;
```

4.2.2.1 Three axes tilted tool

In this mode of operation, the tool is tilted, so the tool direction is not parallel to any of the three machine axes. However, the tool is clamped to fix the tool angle and motion is still only in the three linear axes. Unlike five_axes_var_tilt_yaw the tilt and/or yaw angles are not variable.

```
ENTITY three_axes_tilted_tool
  SUBTYPE OF (tool_direction_for_milling);
  its_tool_direction: direction;
END_ENTITY;
```

its_tool_direction: The direction of the tool in absolute machine co-ordinates.

4.2.2.2 Five axes with variable tilt and yaw angles

Simultaneous tool movements in five axes are used for machining. During motion, the tool direction is adjusted so as to follow the curve given in the toolpath instances.

```
ENTITY five_axes_var_tilt_yaw
  SUBTYPE OF (tool_direction_for_milling);
END_ENTITY;
```

4.2.2.3 Five axes with constant tilt and yaw angles

This is a special case of five_axes_var_tilt_yaw. The tool is moved so that the tilt and yaw angles are constant in each point of the toolpath, relative to the co-ordinate system given by the surface normal in the cutter contact point and the tangent in feed direction. Tilt and yaw are given as attributes of this entity. Note that these values may be overridden if an explicit tool direction curve is specified for a toolpath.


```
ENTITY five_axes_const_tilt_yaw
  SUBTYPE OF (tool_direction_for_milling);
  tilt_angle : plane_angle_measure;
  yaw_angle  : plane_angle_measure;
END_ENTITY;
```


tilt_angle: The inclination of the tool in feed direction, measured against the surface normal in the cutter contact point.

yaw_angle: The rotation of the inclined tool around the surface normal, measured against the surface tangent in feed direction in the cutter contact point.

4.2.3 Milling machining operation

This is the base class of all operations described in this part of ISO 14649. It is a subtype of entity machining_operation defined in ISO 14649-10. In case that feedrate_per_tooth of its_technology is chosen, number_of_teeth of its_tool_body of its_tool should be given.

```
ENTITY milling_machining_operation
   ABSTRACT SUPERTYPE OF (ONEOF(milling_type_operation,
  drilling_type_operation))
   SUBTYPE OF (machining_operation);
   overcut_length: OPTIONAL length_measure;
WHERE
WR1: (EXISTS(SELF.its_technology.feedrate_per_tooth) AND
     EXISTS(SELF.its_tool.its_tool_body.number_of_teeth))
     OR(NOT(EXISTS(SELF.its_technology.feedrate_per_tooth)));
END_ENTITY;
```

overcut_length: The overcut on the open side(s) of the feature. It is not allowed for manufacturing of features which are bounded by material on all sides, i. e. pockets. In case of round_hole, this attribute is allowed only for through-bottom holes. If the cutting_depth of drilling_type_operation specifies a conflicting value, overcut_ length is ignored.

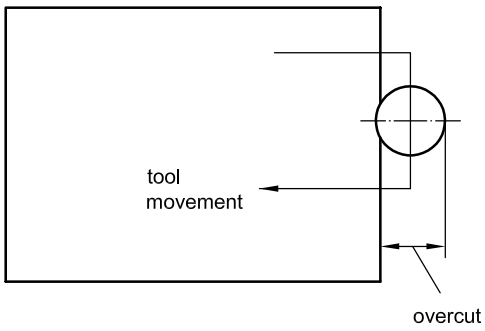


Figure 1 — Overcut

4.2.4 Milling technology

This entity defines the technological parameters of the milling operation. It is a subtype of entity technology defined in ISO 14649-10. Of the four alternatives for specifying speeds, exactly two must be given as indicated by the WHERE rules. If the attribute adaptive_controls is invoked, some or all of these values may be ignored.

```
ENTITY milling_technology
   SUBTYPE OF (technology);
   cutspeed:                          OPTIONAL speed_measure;
   spindle:                           OPTIONAL rot_speed_measure;
   feedrate_per_tooth:                OPTIONAL length_measure;
   synchronize_spindle_with_feed:     BOOLEAN;
   inhibit_feedrate_override:         BOOLEAN;
   inhibit_spindle_override:          BOOLEAN;
   its_adaptive_control:              OPTIONAL adaptive_control;
   WHERE
   WR1: (EXISTS(cutspeed) AND NOT EXISTS(spindle))
      OR (EXISTS(spindle) AND NOT EXISTS(cutspeed))
      OR (EXISTS(its_adaptive_control));
   WR2: (EXISTS(SELF.feedrate) AND NOT EXISTS(feedrate_per_tooth))
      OR (EXISTS(feedrate_per_tooth) AND NOT EXISTS(SELF.feedrate))
      OR (EXISTS(its_adaptive_control));
END_ENTITY;
```


cutspeed: Cutting speed of the tool, the speed of spindle converted into a linear speed.

spindle: Rotational speed of the tool. As defined for rot_speed_measure, positive values indicate tool rotation in mathematical positive direction of the c-axis, i.e. counter-clockwise motion if looking from the tool holder to the workpiece. Note that usual cutting tools require clockwise motion so the value of this attribute will typically be negative.

feedrate_per_tooth: Feed of the tool expressed as a distance.

synchronize_spindle_with_feed: If true, cutting speed and feed of the tool is synchronized. Therefore, the pitch of tap can be kept constant at the bottom of a hole when cutting speed is being decelerated and accelerated.

inhibit_feedrate_override: If true, the feedrate override through the operating panel or by adaptive control systems is not allowed.

inhibit_spindle_override: If true, the spindle speed override through the operating panel or by adaptive control systems is not allowed.

its_adaptive_control: Any kind of vendor specific adaptive control strategy.

4.2.4.1 Adaptive control

This entity defines the vendor-specific adaptive control strategy. At a later time, the specific nature of the adaptive control algorithm and further parameters can be specified in appropriate subtypes.

```
ENTITY adaptive_control;
END_ENTITY;
```

4.2.5 Milling machine functions

The entity describes the state of various functions of the machine, like coolant, chip removal, etc. to be applied during the time span of an operation. It is a subtype of entity machine_functions defined in ISO 14649-10.

```
ENTITY milling_machine_functions
  SUBTYPE OF (machine_functions);
  coolant                :     BOOLEAN;
  coolant_pressure       :     OPTIONAL pressure_measure;
  mist                   :     OPTIONAL BOOLEAN;
  through_spindle_coolant:     BOOLEAN;
  through_pressure:            OPTIONAL pressure_measure;
  axis_clamping          :     LIST [0:?] OF identifier;
  chip_removal           :     BOOLEAN;
  oriented_spindle_stop:       OPTIONAL direction;
  its_process_model:           OPTIONAL process_model_list;
  other_functions        :     SET [0:?] OF property_parameter;
END_ENTITY;
```


coolant:	If true, the coolant is activated.
coolant_pressure:	Optional specification of the pressure of the coolant system. Only valid if coolant is true.
mist:	If true, activate mist coolant. Default is false. Only valid if coolant is true.
through_spindle_coolant:	If true, activate coolant through the spindle. Default is false.
through_pressure:	Pressure of coolant through the spindle. Only valid if through_spindle_coolant is true.
axis_clamping:	Describes which axes are to be clamped, e.g. x, y, a. Note that this information is machine dependent and should be avoided.
chip_removal:	If true, activate chip removal.
oriented_spindle_stop:	If specified, the spindle will stop in the given direction relative to the machine zero position of c-axis in case a spindle stop occurs during or at the end of the workingstep.
its_process_model:	Optional information for process control.
other_functions:	Optional list of other functions of generic type.

4.2.5.1 Process model list

For each workingstep, one or more process models may be started. These are modules for process control like chatter avoidance, thermal compensation, etc.

```
ENTITY process_model_list;
  its_list: LIST [1:?] OF process_model;
END_ENTITY;
```

its_list:	List of process models for the current workingstep

4.2.5.1.1 Process model

Special machine-specific functions to make the machining process more secure and accurate. (e.g. chatter avoidance, thermal compensation, ...)

```
ENTITY process_model;
  ini_data_file:  label;
  its_type:       label;
END_ENTITY;
```

ini_data_file: A filename including path of the file containing the initialization data of the process model.

its_type: The type of process model (e.g. chatter avoidance, thermal compensation, etc.)

4.2.6 Milling type operation

This is the base class of all operations for milling. It includes all necessary attributes to describe technology and strategy. It is a subtype of entity milling_machining_operation.

In general, there are two types of machining operations: roughing and finishing. The roughing is to remove all material from the original raw piece surface down to the bottom or side of the feature minus the finishing allowance in multiple passes. The finishing will then remove the finish allowance to yield the final surface of the feature. In case of pre-cast features, e.g. pre-cast holes and pockets, roughing operation need to be one pass. This special condition is considered in the 2½D milling strategy with the attribute allow_multiple_passes.


```
ENTITY milling_type_operation
  ABSTRACT SUPERTYPE OF (ONEOF(freeform_operation, two5D_milling_operation))
  SUBTYPE OF (milling_machining_operation);
  approach:          OPTIONAL approach_retract_strategy;
  retract:           OPTIONAL approach_retract_strategy;
END_ENTITY;
```


approach: Optional information about approach (plunge) strategy to reach the first cut. If multiple layers are cut, as specified by allow_multiple_passes, this strategy will also be used to move from one layer to the start point of the next layer.

By default, the NC controller decides about the approach strategy. It may decide not to use any approach movement at all if the start point of cutting coincides with the end point of cutting for the preceding operation. If its_toolpath is given, this attribute will be ignored.

retract: Optional information about retract strategy after finishing the last cut. By default, the NC controller decides about the retract strategy. It may decide not to use any retract movement at all if the end point of cutting coincides with the start point of cutting for the next operation. If its_toolpath is given, this attribute will be ignored.

4.2.6.1 Approach retract strategy

Base class for the approach (plunge) and retract strategy. All approach and retract strategies are defined relative to the start or end point of the cutting operation, whether this is explicitly given in the operation of determined by the NC controller. The resulting start point of the approach or end point of the retract movement are defined to be the start and end point of the current operation. The feed rate on the approach or retract path is the feed rate specified for the related start or end point, respectively, of cutting.

```
ENTITY approach_retract_strategy
  ABSTRACT SUPERTYPE OF (ONEOF (plunge_strategy, air_strategy, along_path));
  tool_orientation: OPTIONAL direction;
END_ENTITY;
```

tool_orientation: Only for machines with five-axis positioning capabilities. This specified the tool orientation at the beginning or end, respectively, of the approach or retract movement.

4.2.6.2 Plunge strategy

This is the base class for all approach movements which include cutting of material. This is typically the case for pocketing operations where the approach to the depth of the first cutting layer or between cutting layers requires the removal of material in order to create the approach path.

All plunge movements are guaranteed to occur within the boundaries of the underlying feature. All plunge movements will start at the retract plane valid for the current operation. They will end in the start point of the cutting operation, with the tangent of its approach path coinciding with the tangent of the ensuing cutting motion.

```
ENTITY plunge_strategy
  ABSTRACT SUPERTYPE OF (ONEOF (plunge_toolaxis, plunge_ramp, plunge_helix,
    plunge_zigzag))
  SUBTYPE OF (approach_retract_strategy);
END_ENTITY;
```

4.2.6.2.1 Plunge tool axis

Plunge in the direction of the tool axis.

NOTE If the milling tool itself is unable to cut its way into the layer, a plunge drilling operation with a separate tool is required. As each operation can have only one tool, this will require the definition of a preceding drilling_type_operation. In this case, no plunge strategy should be given for the milling_type_operation, and the cut_start_point of both the milling_type_operation and the drilling_type_operation must coincide.


```
ENTITY plunge_toolaxis
  SUBTYPE OF (plunge_strategy);
END_ENTITY;
```

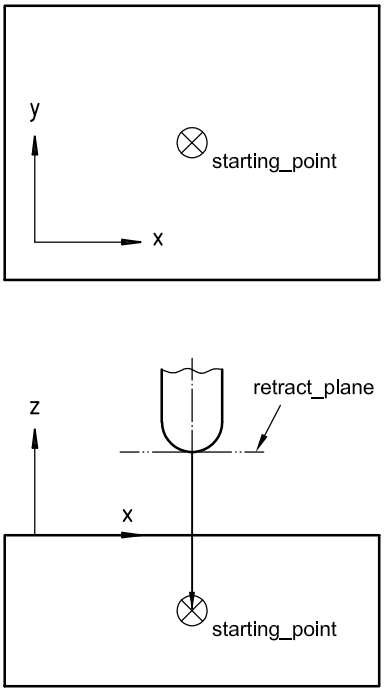
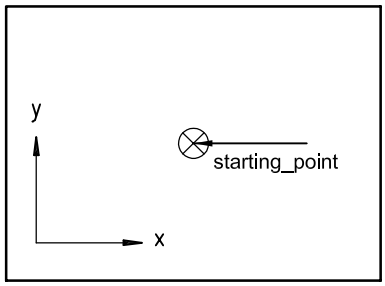



Figure 2 — Plunge tool axis

4.2.6.2.2 Plunge ramp

Plunge on a linear path which forms an angle with the feature surface.



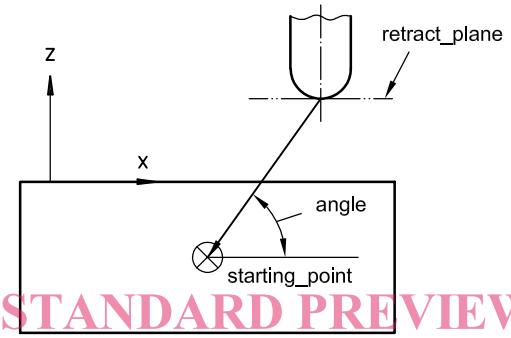


Figure 3 — Plunge ramp


```
ENTITY plunge_ramp
  SUBTYPE OF (plunge_strategy);
  angle: plane_angle_measure;
END_ENTITY;
```

angle: The angle of the ramp movement versus the surface in the end point of the approach.

NOTE Start and end point can be calculated from the restrictions in 4.2.6.2.

4.2.6.2.3 Plunge helix

Plunge movement forming a helix. The path is defined by specifying the radius and grade of the helix. A circular movement can be specified by setting grade to zero.

```
ENTITY plunge_helix
  SUBTYPE OF (plunge_strategy);
  radius  :  length_measure;
  angle   :  plane_angle_measure;
END_ENTITY;
```

radius: Radius of the helical movement.

angle: The angle of the helical movement versus the surface in the end point of the approach.

NOTE Start and end point can be calculated from the restrictions in 4.2.6.2.