Know-how feedback based on manufacturing features (STEP-NC Server)

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Contents

1. Introduction, objective and approach
2. Acquisition, representation and reuse of the know-how
3. Prototype development and case study
4. Perspective and conclusion
Today: Restricted exchange of information between the planning department and the shop floor

Planning department

CAD/CAM/CAPP → Design and planning data → NC programming → Post-processor → G-Code → Modification of NC programs

Geometry data + Technology data + Knowledge-base (Catalogue, rules and formulas)

- Difficult to model the cutting process
- Vendor-specific catalogues
- Diversity of the information
- Missing the practical know-how
- Difficult to maintain

Shop floor

CNC

Notes

- Missing integration of the know-how of the machine operator
- Difficult to share the direct conversation with another departments or staffs
- Ambiguous manual notes
- No automated connection between technological modifications and geometry data

• Open, common interface between CAD/CAM systems and NC controllers
• Reuse of the shop-oriented know-how of the skilled worker
Objectives and requirements

Objectives of the development

- Acquisition of the experience data from the daily NC machining process
- Reuse of the know-how of the machine operator for the new NC programming

Requirements

- Complete data model
- Easy integration in the CAD/CAM/CNC process chain
- Simplified acquisition of the know-how
- Transparency in solution finding
- User-friendliness: support of user interaction
- Possibility for evaluation
- Low effort for maintenance
Approaches

- **Data model**
  - CAD/CAM/CNC integration

- **Know-how acquisition**
  - Simplified know-how acquisition

- **Know-how representation**
  - Transparent solution finding

- **Know-how reproduction**
  - User-oriented

- **Know-how maintenance**
  - Evaluation possibility
  - Easy maintenance

- **STEP-NC data model as a bi-directional interface**
  - + Version/variant management
  - + Data model for the rule base

- **Acquisition of the know-how**
  - - Analysis of the modifications in the STEP-NC file
  - - Which machining parameters were changed and what was the effect?

- **Storage and representation of the know-how**
  - - Object-oriented handling of the STEP-NC data elements
  - - The manufacturing feature DB as a container of the experience data
  - - Shop-oriented rules: clustering the experience data to groups

- **Reuse of the know-how for further NC programming**
  - - Similarity principle: search for similar manufacturing feature cases
  - - Application of shop-oriented rules
  - - Case-based Decision Support System: proposals for the user

- **Automated adaption of shop-oriented rules**
  - - Feedback of the violated rules
  - - Attachment and branching of the rules
  - - User-defined problem area
The manufacturing feature defined in STEP-NC comprises all parameters for describing the experience data of the machine operator.

Object-oriented structure of STEP-NC enables to build an object-oriented database easily.
Principle design of a STEP-NC server

Closed loop between the planning department and the shop floor for the integration of the know-how of the machine operator

Planning department

CAD/CAM/CAPP

+ Geometry data
  + Material data
  + Tolerance data

Technology / operation data

STEP-NC Server

Case-based Decision Support System

Manufacturing feature database

CAM-planned NC programs

Variant management of NC Programs including their objects

Acquisition of the know-how of the machine operator

No

Optimised NC programs

Actualisation of the rule base

Shop-oriented rule base

Optimised NC programs

F(x)

Representation of the know-how

Acquisition of the know-how

Phenomena, effect & environment

Optimised NC programs

Know-how

Shop floor

CNC

Import optimised objects (e.g. operations)
Contents

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☐ 4. Perspective and conclusion
Analysis of the trouble shooting process of the NC program

Constraints (constant parameters)
- Workpiece geometry and material
- Quality requirements
- Performance of the machine

Machining parameters (modifiable parameters)
- Tool selection
- Operation sequence
- Cutting parameters
- Cutting strategies

Phenomena and effect
- Surface condition
- Geometrical accuracy
- Tool breakage
- Heavy burr
...

Environment (dynamic parameters)
- Temperature
- State of the machine
...

Change of the modifiable parameters

**Statement of the experience**
For a given constraint A, the parameter B was changed to improve the phenomena C (to achieve the effect C) under the environment D.
Extraction of shop-oriented rules from the experience data

**Acquisition of the experience data**

<table>
<thead>
<tr>
<th>Machine Operator</th>
<th>Feature: Round_hole</th>
<th>Diameter</th>
<th>Depth</th>
<th>Surface roughness</th>
<th>Effect of the modification</th>
<th>Modifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A - 1 B-12</td>
<td>20 mm</td>
<td>40 mm</td>
<td>10 Ra</td>
<td>Burr reduction</td>
<td>Feedrate reduction at the end: 60%</td>
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</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>Deformation at the side</td>
<td>Feedrate: 25.4 -&gt; 20 mm/min</td>
<td></td>
</tr>
</tbody>
</table>

**Planned machining parameter**
- Cutting tool: drill 1
- Feedrate: 25.4 mm/min
- Spindle speed: 500 rpm

**Effect of modifications**
- Reduction of the burr
- Reduction of the workpiece deformation

**Optimised machining parameter**
- Feedrate: 20 mm/min
- Feedrate reduction at the bottom: 60%

**Extraction of shop-oriented rules by clustering the experience data**

- **Objective of the clustering**
  - To bound the parameters for “if-condition” and their values
- **First level of clustering**
  - First level of clustering is considered in the manufacturing feature defined in STEP-NC
- **Further clustering**
  - Further clustering according to the effect of the shop-floor modification
  - E.g., burr reduction, tool breakage avoidance
Case-based reasoning: clustering according to the effect of the modification

- Full set of parameters:
  - Tolerance
  - Surface condition
  - Rake angle
  - Tool exit angle
  - Yield strength of the material
  - Tensile strength of the material
  - Feature geometrical surroundings

- Cutting parameter modification:
  - 10%
  - 20%
  - 30%
  - 40%
  - 50%
  - ...

if-condition

decision

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Case-based reasoning: clustering according to the effect of the modification

**Problem (Effect)**
- Tool breakage
- Heavy burr
- Long chips

**Cause**
- Wrong drill type
- Poor coolant condition
- Incorrect speed & feed
- Incorrect drill point
- Poor point grind

**Solution**
- Correct drill type/size
- Use straight flute
- Use stub length
- Use three-flute
- Use slower helix
- Use parabolic design
- Increase coolant
- Increase mixture
- Reduce RPM
- Increase feed
- Increase RPM
- Reduce feed
- Repoint drill
- Change point style

**Certainty**
- High
- Low
- Middle

**Availability**
- Literatures for machining tests
- Monitoring
- Know-how of the machine operator
- Analysis of the NC program
Flow diagram for the reuse of the know-how

1. Planned NC program
2. Search for similar features
   - Similar features exist
     - Y: Similarity analysis
     - N: Planned NC program
3. Search for shop-oriented rules
   - Applicable rules exist
     - Y: Actualisation of the shop-oriented rule base
     - N: Similar features exist
4. Import of the operation data
   - Possible choices and final selection
5. Update of the operation data by applying the rules
6. Acceptance of the planned operation data
7. Adaption of the geometry-dependent parameter
8. Machining
9. Optimised NC program
10. Effect of modifications
11. Actualisation of the manufacturing feature database
12. Actualisation of the shop-oriented rule base
Similarity analysis based on Fuzzy set theory

Parameter for an experience case = \((X_0, Y_0)\)
Parameter for a new case = \((X_{\text{new}}, Y_{\text{new}})\)

Similarity representation based on Fuzzy set theory

Global similarity value
Automated attachment and branching of the shop-oriented rules

**Rule set A**

- **Parameter X**
- **Parameter Y**

- **Rule A-1**
- **Rule A-11**
- **Rule A2**

- **Optimised NC program**
- **Updated NC program**
- **New planned NC program**

- **Case-based rule for a case that depends on parameters X and Y**

- **Modification to achieve effect A**

**Modification to achieve effect A**

**Application of rule set A**

**Branched rule**

**New problem area**

**Rule set B**

- **Parameter U**
- **Parameter V**

- **Rule B1**

- **Optimised NC program**

- **Attachment to achieve effect B**

- **Case-based rule for a case that depends on parameters U and V**
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Prototypical implementation

CAD/CAM/CAPP

- CATIA V5, Dassault Systèmes
- TOPAC, WZL

STEP-NC Server

- Manufacturing feature DB
- Shop-oriented rule base
- User-interface

STEP-NC programs

NC controller

- Sinumerik 840D, Siemens

Interactive input of the effect of modification

STEP-NC programs
### Simulation of the experience data for holes

#### Planned technology data

<table>
<thead>
<tr>
<th>Feature ID</th>
<th>ID</th>
<th>Diameter (mm)</th>
<th>Depth (mm)</th>
<th>Depth/Diameter</th>
<th>Operation type (STEP-NC)</th>
<th>Feedrate (mm/rev)</th>
<th>Spindle speed (RPM)</th>
<th>s_s</th>
<th>f_s</th>
<th>L_s</th>
<th>s_e</th>
<th>f_e</th>
<th>L_e</th>
<th>L_o</th>
<th>t_d</th>
<th>f_r</th>
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#### Optimised technology data

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<tr>
<th>Feature ID</th>
<th>Effect of modification</th>
<th>Operation type (STEP-NC)</th>
<th>Feedrate (mm/rev)</th>
<th>Spindle speed (RPM)</th>
<th>s_s</th>
<th>f_s</th>
<th>L_s</th>
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<th>f_e</th>
<th>L_e</th>
<th>L_o</th>
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</tbody>
</table>

**Effect of the modification**

- 9 experience data for the round hole
- 7 shop-oriented rules related to deep drilling, workpiece deformation and burr reduction

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Parameters for the drilling according to the STEP-NC data model

- **Geometry data of the hole**
  - \( L_h \): Depth of hole
  - \( D_h \): Diameter of hole

- **Depth of drilling**
  - \( L_a \): Retract plane
  - \( L_b \): Overcut length
  - \( d_c \): Cutting depth

- **Tool data**
  - \( T_a \): Tool tip half angle
  - \( D_t \): Diameter of tool
  - \( L_c \): Cutting edge length

- **Feedrate and cutting speed**
  - \( f_0 \): Feed
  - \( s_0 \): Spindle
  - \( L_s \): Depth of start
  - \( L_e \): Depth of end
  - \( f_s \): Reduced feed at start
  - \( s_s \): Reduced cutting speed at start
  - \( f_e \): Reduced feed at end
  - \( s_e \): Reduced cutting speed at end
  - \( t_d \): Dwell time at the bottom

- **Multi-step drilling**
  - \( d_r \): Retract distance
  - \( d_0 \): First depth
  - \( d_s \): Depth of step
  - \( t_s \): Dwell time step
  - \( d_b \): Offset before step

---

Reduced feedrate
Feedrate
Retract speed

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# Simulation of the experience data for pockets

## Planned technology data

<table>
<thead>
<tr>
<th>Feature ID</th>
<th>Dimension (length*width*depth in mm)</th>
<th>Approx. Volume (cm³)</th>
<th>Operation type (STEP-NC)</th>
<th>Type</th>
<th>Diameter (mm)</th>
<th>No. of tooth</th>
<th>Feed per tooth (mm/tooth)</th>
<th>Spindle speed (RPM)</th>
<th>removal rate (mm³/min)</th>
<th>dₐ</th>
<th>dₜ</th>
<th>aₘ</th>
<th>a₀</th>
<th>Sₜ</th>
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<td>Endmill - HSS</td>
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## Optimised technology data

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<th>Impact of modification</th>
<th>Operation type</th>
<th>Type</th>
<th>Diameter (mm)</th>
<th>No. of tooth</th>
<th>Feed per tooth (mm/tooth)</th>
<th>Spindle speed (RPM)</th>
<th>removal rate (mm³/min)</th>
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<td>Pocket.2</td>
<td>Surface finish improvement</td>
<td>Bottom_and_side_finish_milling</td>
<td>Endmill - HSS</td>
<td>10.00</td>
<td>4</td>
<td>0.012</td>
<td>1350.00</td>
<td>259.20</td>
<td>2.00</td>
<td>-</td>
<td>-</td>
<td>contour parallel</td>
<td>-</td>
<td>5.00</td>
<td>climb</td>
<td></td>
</tr>
</tbody>
</table>

## Parameters according to the STEP-NC data model
- da: Axial cutting depth (mm)
- dr: Radial cutting depth (mm)
- as: Finish allowance side (mm)
- ab: Finish allowance bottom (mm)
- St: Type of machining strategy
- LOL: Overlap length (mm)
- LOC: Overcut length (mm)
- C_m: Cutting mode (conventional or climb)

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Import of the optimised operation data for a new workpiece

New workpiece

List of manufacturing features and their operations

<table>
<thead>
<tr>
<th>No</th>
<th>Feature type</th>
<th>Feature ID</th>
<th>Depth (mm)</th>
<th>Diameter (mm)</th>
<th>Operation type</th>
<th>Operation imported?</th>
<th>Rule applied?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>round_hole</td>
<td>Hole.1-1</td>
<td>70</td>
<td>15</td>
<td>drilling</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>round_hole</td>
<td>Hole.1-2</td>
<td>60</td>
<td>15</td>
<td>drilling</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>round_hole</td>
<td>Hole.1-3</td>
<td>50</td>
<td>15</td>
<td>drilling</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>round_hole</td>
<td>Hole.1-4</td>
<td>40</td>
<td>15</td>
<td>drilling</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>closed_pocket</td>
<td>Pocket.1-1</td>
<td>20</td>
<td>-</td>
<td>bottom_and_side_rough_milling</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>bottom_and_side_finish_milling</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>closed_pocket</td>
<td>Pocket.1-2</td>
<td>15</td>
<td>-</td>
<td>bottom_and_side_rough_milling</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>bottom_and_side_finish_milling</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

- Import of 3 operation
- Application of rules for 5 operation

In the same manner, the sequence of operation, cutting strategy and cutting parameters can be imported from the STEP-NC server in batch in principle.
Contents

☐ 1. Introduction, objective and approach
☐ 2. Acquisition, representation and reuse of the know-how
☐ 3. Prototype development and case study
■ 4. Perspective and conclusion
State of development and items to do for a pilot product

<table>
<thead>
<tr>
<th>Step/Item</th>
<th>Progress</th>
<th>Items to do</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STEP-NC Data Handling</strong> (Read/Write, DBMS)</td>
<td>80 %</td>
<td>• Handling of special curve types</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Graphical representation of feature</td>
</tr>
<tr>
<td><strong>Revision history</strong></td>
<td>70 %</td>
<td>• Handling of more manufacturing features</td>
</tr>
<tr>
<td>(Version and variant management)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Know-how manipulation algorithm</strong></td>
<td>60 %</td>
<td>• Manipulation of geometrical surroundings</td>
</tr>
<tr>
<td>(Acquisition, representation, reuse)</td>
<td></td>
<td>• Addition of problem areas covered</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Trend analysis</td>
</tr>
<tr>
<td><strong>Interface with the planning department</strong></td>
<td>60 %</td>
<td>• Tolerance &amp; surface condition input</td>
</tr>
<tr>
<td>(Data consistency)</td>
<td></td>
<td>• Integration with the tool database</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Integration with the material database</td>
</tr>
<tr>
<td><strong>Interface with shop floor</strong></td>
<td>70 %</td>
<td>• Feedback of modifications in the toolpath level</td>
</tr>
<tr>
<td>(Data consistency)</td>
<td></td>
<td>• Feedback of the inspection result</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Machine-dependent data feedback</td>
</tr>
</tbody>
</table>

March 2003
Perspective

Profit
- Accumulation and reuse of the know-how
- Saving in the NC programming time
- Saving in the test machining effort

Effort
- System development and maintenance
- Training
- Hardware and software cost

Application time

Know-how
for a special / critical machining cases

Workpiece/feature spectrum of a manufacturer

Features covered by an experience data

Accumulation of the know-how in a specific machining area

Profit / Effort
Conclusion: Benefits of the application of the STEP-NC Server

- Use of the optimised manufacturing features and operations (as defined in STEP-NC) as building blocks for the NC programming
- Easy integration in the CAD/CAM/CNC process chain:
  - Bi-directional exchange of STEP-NC file
- Simplified acquisition of the know-how of the machine operator
- Hybrid representation of the know-how:
  - Manufacturing feature database and shop-oriented rule base
- Transparent reuse of the know-how by applying similarity principle
- User-oriented solution for the decision support
- Easy maintenance:
  - Automated accumulation of shop-oriented rules from daily NC processes
- Reduction of efforts for the test machining at the shop floor
- Reduction of efforts for the NC programming at the planning department
- Share of the machining know-how within a shop floor, company or customer