Implementation of a knowledge-based manufacturing on the example of Sumar Tools OÜ

Kaarel Kruuser[a*], Jüri Riives[a], Pavel Tšukrejev[a], and Indrek Kiolein[b]

[a] Department of Mechanical and Industrial Engineering, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia
[b] Pro-Step OÜ, Tööstuse 47b-7, 10416 Tallinn, Estonia

Abstract. Higher productivity of an organization is based on modern manufacturing systems and digitizing the manufacturing processes. The problem is how to match together technological capabilities of machine tools (machining centres) with the need to manufacture a product; and how to increase the efficiency of process planning procedures. Injection molds are the products with many different features, with high quality requirements, and variable geometrical parameters. The problem is sophisticated because most of the products are unique and do not repeat. In order to be able to respond quickly changeable situations where sometimes more than 4 different programs are needed on a daily basis, manufacturing systems will have to become more autonomous. For this purpose, it is necessary to take advantages of the possibilities of modern production programs by linking them with know-how of engineers. Manufacturing operations management (MOM) and machine learning are the tools used for developing knowledge-based manufacturing solutions in the company. Framework has been developed to gather data in the company and develop the rules based on data models and information analysis. The designed solutions for feature-based machining (FBM) give high quality technological solutions and increase the efficiency of machining process by computer numerical control (CNC) programming. Product manufacturing information (PMI) model is in development together with integration of the machine learning system.

Key words: feature-based machining, knowledge-based manufacturing.

1. INTRODUCTION

Sumar Tools OÜ is a company that manufactures sophisticated plastic injection molds. The production of plastic injection molds requires high level knowledge in manufacturing technology and formulation. In order to be capable of producing plastic injection molds there is a need for accurate and high-end machine park. The company mainly uses milling; also turning centres, electrical discharge machining (EDM); also wire erosion and grinding machines to manufacture injection molds. The company's machine park also includes an innovative and high-level flexible manufacturing system. The correct use of the system ensures high productivity. The flexible manufacturing system has been integrated with one 5-axis and one 7-axis machining centre. Machining centres are capable of processing technologically complex and high precision products that require 5- and 7-axis processing technology.

It is difficult to use a flexible manufacturing system (FMS) in the company where each product is different and there is no series production. The key question is how to keep the production system cost-effective. Also, it is necessary to find the solution how to ensure maximum productivity and keep the system sustainable.

One possible solution is to find similar product lines and cluster them. To do this, we have to analyse the product portfolio and divide products into groups

---

* Corresponding author, kaarel.kruuser@gmail.com

according to the similar features. Grouping products by the features allows to develop optimal technology for the processing features. This type of manufacturing technology is called feature-based machining (FBM).

FBM is an automated programming function that eliminates manual data entry by reading in the copious design intent information that is embedded in solid models by CAD programs [1].

2. THEORETICAL BACKGROUND

Sumar Tools OÜ is using Siemens NX [2,3] design and manufacturing software (CAD CAM). This software is flexible and powerful integrated solution, which helps to deliver production faster and more efficiently. Siemens NX software enables using feature-based machining technology which allows more efficient design and manufacturing preparation.

Without machining feature the program generation is manual and the cutting path is based on the given coordinate system. Programming will take longer time and machining efficiency is significantly lower compared to the FBM. Feature-based machining can be implemented in three ways as shown in Fig. 1.

Design by the feature [5] is a technique by which the geometrical features are described and documented in a certain data-base. For instance, to define a hole, designer can specify radius, depth and parameters of location. Described features are creating the possibilities for their classification, to define the rules for their machining, and developing the similarity assessment algorithms [6].

The second approach is developed by means of pattern recognition. This method is largely used in computer-aided manufacturing (CAM) software. However, generating NC program by commercial CAM software will result in longer part program besides utilizing a large memory space in CNC machine controller [7].

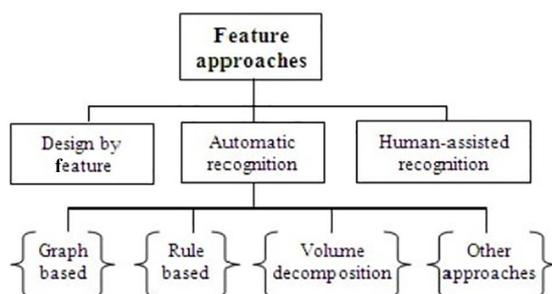The last approach is human-assisted feature recognition based on the NC program generation. This

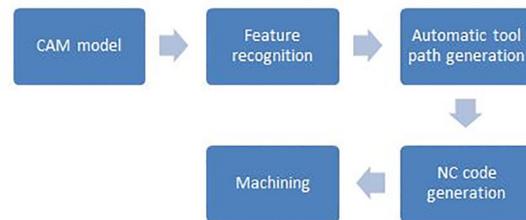**Fig. 1.** Feature approaches classification [4].

Fig. 2. Modern path from model to machining.

leads towards parametric programming implementation in feature-based machining [8].

FBM technology enables automation of preparation process of the manufacturing technology. Creation of CNC programs has risen to the new level by making manufacturing faster, more flexible and cost effective (see Fig. 2). The technology is based on the feature elements which are found from the 3D model of the product. This technology is developed to identify features and compile a technology for manufacturing elements.

Siemens NX uses information about the product and manufacturing from the 3D model (PMI), e.g. machining tolerance and surface quality information. PMI information gathered from the model is analysed and processed. The processing technology is selected based on the information.

To automate the workflow with feature-based machining, different databases will have to be developed. Databases are created by collecting information and knowhow from the company. At first, main rules are necessary to form a foundation for feature recognition. The movement of collected data is shown in Fig. 3.

3. IMPLEMENTATION OF FEATURE-BASED METHODOLOGY IN SUMAR TOOLS OÜ

The implementation of FBM technology at the company is a labor-intensive process, which however, should lead to a considerable time-saving and efficiency in preparation of the manufacturing process. Key performance indicators (KPIs) will have to be determined for separate processes and steps to analyse the implementation process [9,10]. Feature-based machining, product life-cycle management (PLM) and real-time monitoring systems of production processes should be integrated to reach the next productivity level [11,12].

In traditional manufacturing processes preparation of CNC programs for the machining centres makes almost 75% of the CAM engineer's workload. At the moment the company has two CAM engineers. One of them is committed to prepare the production technology for the
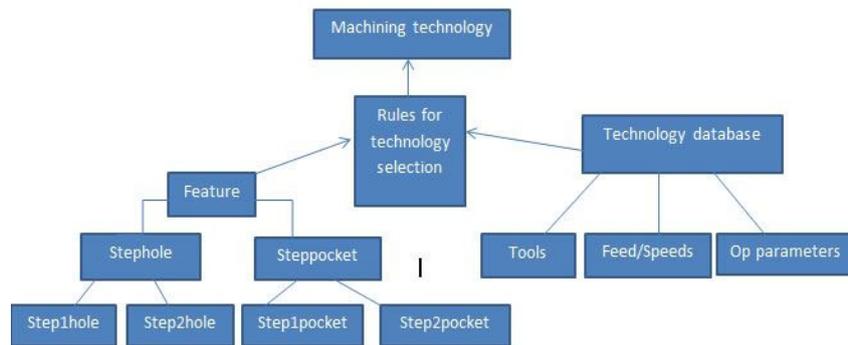
Fig. 3. Data movement in FBM system.

plate-type products. The first step in the implementation is to classify and group the features of the products. In this case, the products are divided into three groups:

(1) Group 1 – products with low precision feature elements;
(2) Group 2 – products with high precision feature elements;
(3) Group 3 – products with high precision features and 3D surfaces.

Products with low precision features include details where dimensional tolerances are not high. As a result, it is possible to process features with one operation, without stocks, ensuring that the design elements meet the precision requirements.

Products with high precision features include details where dimensional tolerances are high. This means that the elements must be processed in number of different operations to ensure that the features meet the precision requirements. In case of more precise tolerances, the product may move to different processing stations, which results in the FBM-generated program assigning workflow operations. For the sake of technological correctness, work operations are divided into groups as follows: rough machining, semi-finish machining, finish machining.

Products with high precision feature elements and 3D surfaces with high tolerance requirements add complexity to the programming of FBM. It is difficult to standardize the complex operations.

As a result of the analysis of comprehensive portfolio of products, it is possible to create knowledge bases for the features of design. The feature elements can be divided into two larger groups: step hole and step pocket. We can divide these two main groups into sub-groups according to the number of steps (see in Fig. 4).

In the next technological development phase, the machining technology was developed for each group member, see Fig. 5. The numbers in the table show which operations in which order are selected for different
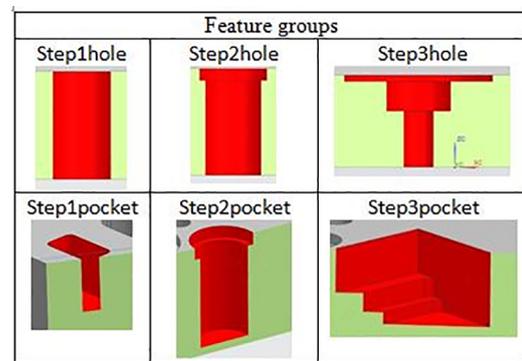

Fig. 4. Features divided into groups according to the number of steps found in the feature.

technologies. Manufacturing technology was chosen based on the working methods and capabilities of the company. For the real use of system technology, automatically generated technology must match the company's knowledge and capabilities.

To do this, the following databases must be created: tool database, database of used materials, database of cutting feed and speeds, and database of cutting operational parameters.

After the development of databases, it was necessary to create the selection rules for selection, according to which the system selects the machining operation, the tool and the corresponding cutting parameters. The PMI information is used for selecting the technology. PMI information allows decision making in the process to choose between different technologies, to make the system more flexible and more precise.

Product manufacturing information (PMI) is available from the 3D model to make the expert system work more efficiently. In case of standard technology, PMI information is available in 2D drawings. In order to avoid redundant workload of the CAM engineers and to prevent possible errors, it is necessary to involve the CAD engineer into the process in order to add PMI

Output Feature	STEP3HOLE																				
Operation set	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
↓ Input Feature ↓																					
STEP3HOLE																					
DRILL_S3H_D1	1						1	1	1	1	1	1	1	1					1	1	1
DRILL_S3H_D2	2	1					2	2	2	2	2	2	2	2					2	2	2
DRILL_S3H_D3	3	2	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	3	3	3
COUNTERMILL_S3H_D1		3	2	2	2	2									2	2	2	2			
COUNTERMILL_S3H_D2			3	3	3	3										3	3	3			
COUNTERMILL_S3H_D1_FINISH_BOT					4		4	4	4	4	4	4	4	4			4	4			
COUNTERMILL_S3H_D2_FINISH_BOT						4	5	5	5	5	5	5	5	5			5	5			
CHAMFER_S3H_CONTOUR_D1	When chamfer is needed																				
CHAMFER_S3H_CONTOUR_D2																					
CHAMFER_S3H_CONTOUR_D3																					
CHAMFER_S3H_CONTOUR_D3_REV																					
BORE_S3H_D3							6														
REAM_S3H_D3										6			6								
BORE_S3H_D2								6	7												
REAM_S3H_D2											6			7							
BORE_S3H_D1									6						4	6					
REAM_S3H_D1												6				4	6				
TAP_S3H_THREAD_D1																			4		
TAP_S3H_THREAD_D2																				4	
TAP_S3H_THREAD_D3																					4

Fig. 5. Selecting the machining technology according to the feature.

information to the 3D model. During the design process, the engineer works through the measuring circuits required for the functionality and operation of the product, and binds them with the 3D model using PMI tool that is designed for this purpose in the CAD system.

Using PMI in the design phase gives us valuable information about the features, accuracy, surface roughness, shape tolerances etc.

The use of PMI is the best solution so far for transferring engineers' wishes into expert system. In addition, PMI information can also be displayed in drawings, avoiding repetition of the same work.

This technology is developed to analyse PMI information, and for deciding what kind of manufacturing technology would be the best to use. Feature element class is determined based on the precision class and required surface quality. The precision feature is low if, the dimensional tolerance is greater than ± 0.1 mm, and the required roughness is greater than Ra 3.2 μm.

The precision feature is high if the dimensional tolerance is lower than ± 0.1 mm, and the required roughness is lower than Ra 3.2 μm.

In case the feature is classified as low precision feature, a simple manufacturing technology is used. The dimensions of the feature are achieved by creating only rough operations with stock left to zero.

In case of the high precision classified feature, more sophisticated technology is used. Generated operations are divided into rough, semi-finish and finish machining. Set of rules are developed for technology decision making. System is analysing tolerance grade based on PMI; and deciding requires extra operations, see in Fig. 6.

The tool database is created according to the tools used by the company. When creating a database, it is important that the tool is accurately described and the data correspond to the reality. This ensures that, when operation is created, a selected tool is correct and the usable operation is produced.

When describing the tool in the database, the tool's basic parameters are entered and a note indicating in which operation the tool was created (rough, finish) is added.

The choice of instruments of the database is based on technology, which results in selection of a tool suitable for the operation. Rules which have been developed for making suitable tool selection are shown in Fig. 7.

Tool selection is also influenced by the material of the workpiece; various instruments can be configured
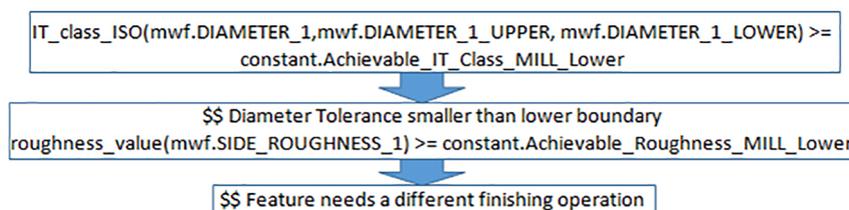
IT_class_ISO(mwf.DIAMETER_1,mwf.DIAMETER_1_UPPER, mwf.DIAMETER_1_LOWER) >= constant.Achievable_IT_Class_MILL_Lower

$$\Downarrow$$

$$ Diameter Tolerance smaller than lower boundary
roughness_value(mwf.SIDE_ROUGHNESS_1) >= constant.Achievable_Roughness_MILL_Lower

$$\Downarrow$$

$$ Feature needs a different finishing operation

Fig. 6. Decision making rules for technology selection.
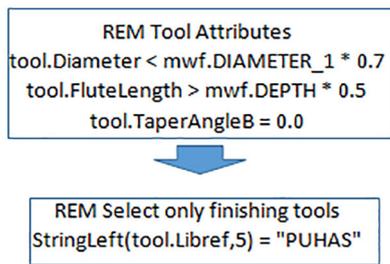
Fig. 7. Decision making rules for tool selection.

for different materials. A material database has to be prepared for the manufacturing technology. When creating a technology database, all created databases must be connected, see Fig. 8.

Adding all databases to PLM creates an expert system that can be used to prepare CNC programs for machining centres. After inserting a product into the CAM, it is necessary to identify the detail and the position of the detail in the system. Then let the system analyse and identify the features and generate work paths as shown in Fig. 9.
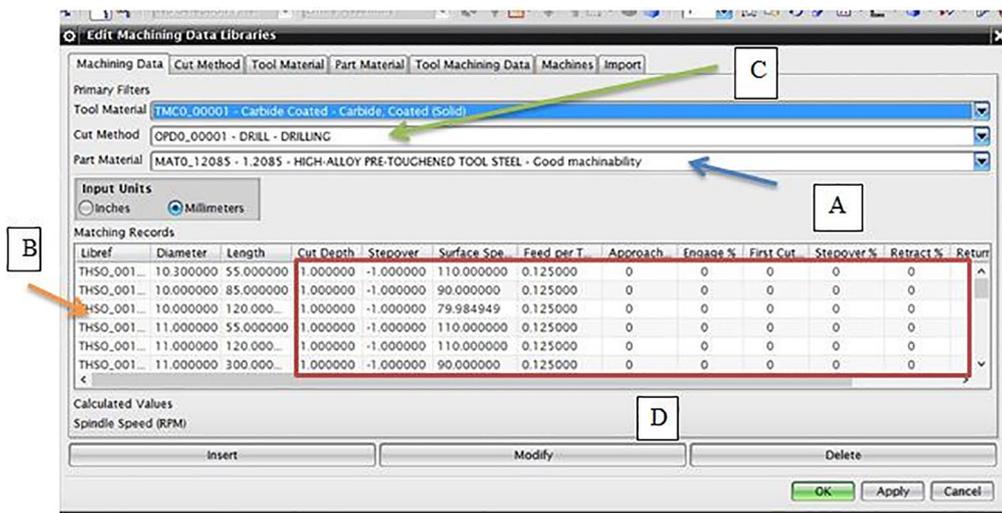

Fig. 8. Interconnection of databases. A – material, B – tools, C – operation type, D – feeds and speeds.
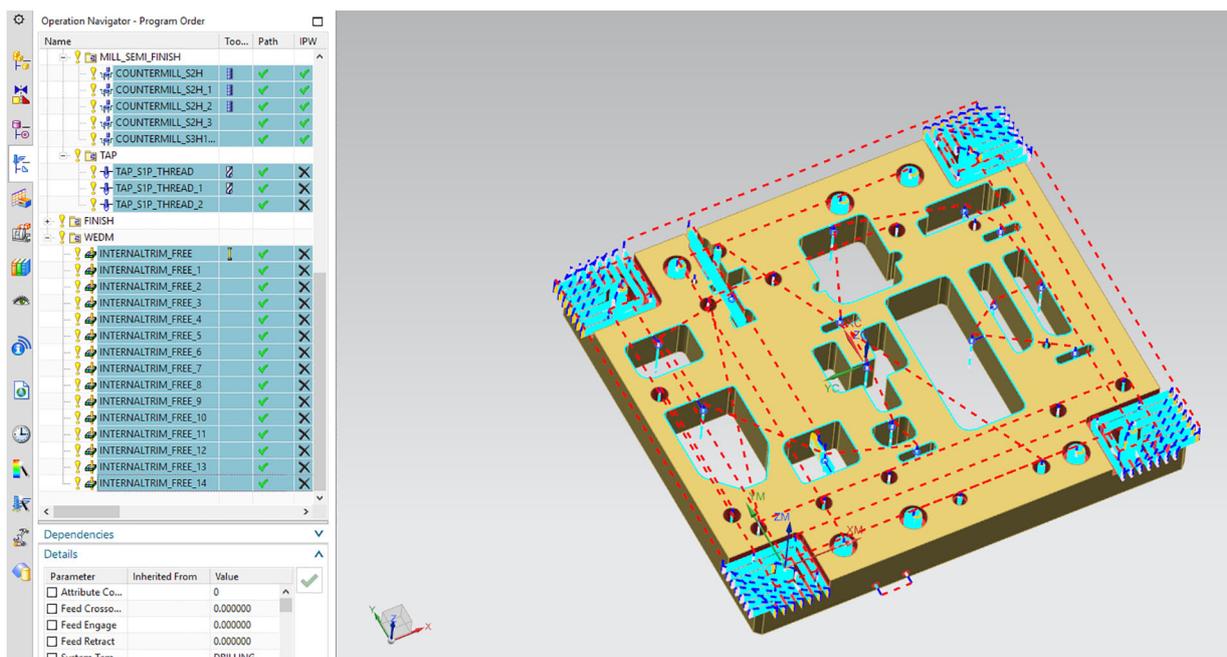

Fig. 9. Example work paths generated by the FBM.

4. CONCLUSIONS

It can be concluded from the results of implementing FBM technology and received feedback, that applying FBM technology will considerably accelerate preparation of manufacturing process. Using FBM technology can reduce almost 20% of CAM engineers' workload. Creating a production preparation expert system can help to standardize technology design. This system can be used for producing almost all kind of plate-type products which are produced in the company. Almost 95% of holes are machinable with FBM technology. This technology involves the entire manufacturing structure of the company, and the Teamcenter solution simplifies the exchange of data between different departments. Although the technology deployment process is time-consuming, the efficiency achieved is noticeable. It also allows the system to optimize technologies due to its continuous storage system.

ACKNOWLEDGEMENTS

REFERENCES

1. Shah, J. J., Mäntylä, M., and Nau, D. S. *Advances in Feature Based Manufacturing*. Elsevier Science B. V., Amsterdam, 1994.

2. Leu, M. C., Ghazanfari, A., and Kolan, K. NX 10 for Engineering Design. Missouri University of Science and Technology, 2016. https://web.mst.edu/~mleu/nx_manuals/nx10.pdf

3. Siemens NX software https://www.plm.automation.siemens.com/global/en/products/nx/ (accessed 2018-10-21).

4. Mokhtar, A., Tavakoli-Bina, A. T., and Houshmand, M. Approaches and challenges in machining feature-based process planning. In *Proceedings of the 4th International Conference on Digital Enterprise Technology (DET2007) Bath, UK, September 19–21, 2007*, 297–305.

5. Venkataraman, S. Integration of design by features and feature recognition. MSc thesis. Arizona State University, Arizona, 2000.

6. Cardone, A., Gupta, S. K., Deshmukh, A., and Karnik, M. Machining feature-based similarity assessment algorithms for prismatic machined parts. *Comput.-Aided Des.*, 2006, **38**(9), 954–972.

7. Al'Hapis, M., Razak, A., and Zakaria, A. A Framework for a Feature Based Machining Using Macro. *Appl. Mech. Mater.*, 2012, **110–116**, 1711–1715.

8. Djassemi, M. A parametric programming technique for efficient CNC machining operation. *Comput. Ind. Eng.*, 1998, **35**(1–2), 33–36.

9. Kaganski, S., Majak, J., Karjust, K., and Toompalu, S. Implementation of Key Performance Indicators Selection Model as Part of the Enterprise Analysis Model. *Procedia CIRP*, 2017, **63**, 283−288.

10. Paavel, M., Karjust, K., and Majak, J. Development of a product lifecycle management model based on the fuzzy analytic hierarchy process. *Proc. Est. Acad. Sci.*, 2017, **66**(3), 279−286.

11. Eiskop, T., Snatkin, A., and Karjust, K. Production monitoring system with predictive functionality. *J. Eng. Sci. Technol.*, 2017, **12**(9), 2410−2425.

12. D'Antonio, G., Segonds, F., Laverne, F., Bedolla, J. S., and Chiabert, P. A framework for manufacturing execution system deployment in an advanced additive manufacturing process. *Int. J. Prod. Lifecycle Manage.*, 2017, **10**(1), 1–19.

Teadmuspõhise tootmise juurutamine Sumar Tools OÜ-s

Kaarel Kruuser, Jüri Riives, Pavel Tšukrejev ja Indrek Kiolein

Targa tootmise juurutamine aitab tootmist efektiivsemaks muuta. Targa tootmise põhimõtte raames juurutati kujuelementidel põhinev töötlusprogrammide tegemise moodul, mis on ettevõttes kasutusel oleva tootmistarkvara Siemens NX üks lisamoodulitest. Mooduli kasutamiseks tuli analüüsida kogu ettevõtte tooteportfelli. Analüüsi tulemusel jagati tooted nendel leiduvate kujuelementide põhjal kolme gruppi. Iga kujuelemendi töötlemiseks loodi vastav tehnoloogia vastavalt 3D-mudelilt saadava PMI info analüüsi tulemusele. Lisaks tehti materjalide, tööriistade ja töötlusparameetrite andmebaasid. Nende omavaheliseks koostööks tuli luua käitumise reeglid, mis võimaldavad valida õiget töötlemise tehnoloogiat. Kujuelementidel põhineva tehnoloogia kasutuselevõtu tulemusel muutus tehnoloogia ettevalmistamine kiiremaks ja efektiivsemaks.