ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering

Tome XII [2014] – Fascicule 1 [February]
ISSN: 1584-2665 [print]; ISSN: 1584-2673 [online]
a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

1. Ngoc Anh TRAN, 2. Tobias TEICH, 3. Holger DÜRR,
4. Ulrich TROMMLER, 5. An Ninh DUONG

FEATURE-BASED ASSISTANCE SYSTEM FOR SELECTION OF ENERGY-EFFICIENT TECHNOLOGIES IN PARTS MANUFACTURING (FAEOT)

1-3. University of Applied Sciences of Zwickau, Faculty of Business Administration and Economics
Dr.-Friedrichs-Ring 2A, 08056 Zwickau, GERMANY
4-5. CBS Information Technologies AG, Curiestr. 3a, 09117 Chemnitz, GERMANY

Abstract: This paper describes a feature-based assistance system to determine cumulative energy expenditure for the evaluation of technological process chains. This assistance system based on the feature-oriented product models, resource models and algorithms as well as the embedding of the assistance system in an existing CAD- and ERP- environment. Necessary conditions for the realization are implementation of feature recognition methods, feature catalogue, manufacturing process catalogue and the calculation formulae for determining the energy expenditure, machining time and manufacturing costs. The implementation of the entire method as software solution FAEOT has been demonstrated with selected manufacturing examples.
Keywords: energy expenditure, feature-based assistance system, feature recognition, parts manufacturing, technology selection

1. INTRODUCTION

Energy efficiency becomes more and more an important engineering aspect as well as an economic factor for small and medium-sized enterprises in parts manufacturing [1, 2]. Especially sustainable reduction of energy expenditure requires an early consideration of technological planning including energetic process sequence optimization.

Current solutions are primarily focusing production costs and times, so energy costs are only included within overhead costs. Consequently, it is impossible to plan, optimize and select manufacturing processes while considering causal energy expenditure automatically. Increasing demands and requirements of customers from manufacturing companies especially in the area of engineering and automotive encouraged CBS Information Technologies AG to give their attention to these customer issues. The main objective of our prototypic software development is determination of energy expenditure of parts manufacturing in a cumulative and comparable manner by the development of a continuous feature-based assistance system to design energy efficient manufacturing processes.

2. STRUCTURE OF THE ASSISTANCE SYSTEM

2.1 View concept

Technological functionality provided by the assistance systems is separated into two main views: Integration and process view (Figure 1).

Initially, within the process view (part, energy and technology view), there are the development of a feature-based manufacturing process catalogue, the analysis of process variants beginning with

ISSN: 1584-2665 [print]; ISSN: 1584-2673 [online]

product requirements and available manufacturing resources, the determination of cumulated energy expenditure for all machining features within a process variant as well as technology selection. The integration view (CAD- and ERP-view) provides prepared input information via interfaces for the process view.

Consequently, it is possible to integrate the process view into existing ERP- and CAD environments of small and medium-sized enterprises in manufacturing to support continuous feature-based information processing.

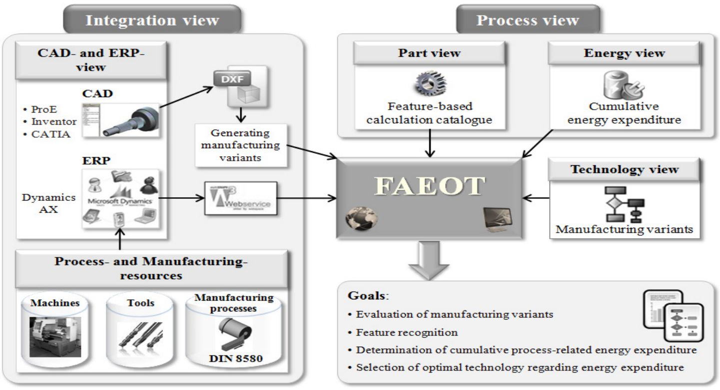

Figure 1 – View concept of the feature-based assistance system (FAEOT)

We are developing the assistance system with following capabilities:

- ➢ Process view
- □ Continuous application-oriented feature technology
- □ Process dependent catalogue of formulas to determine cumulated energy expenditure
- □ Structured logical mapping of manufacturing schedule (operation process) focusing energy expenditure calculation
- □ Sequence model to list processing resources as well as tooling resources for each feature
- □ Feature-based algorithms to calculate cumulated energy expenditure of generated manufacturing variants
- □ Parameterized representation of process-related energy expenditure for optimal technology selection
- ➢ Integration view / Interfaces to CAD- and ERP-systems
- □ Application of Autodesk's DXF format (Drawing Interchange File) as an industry standard for comprehensive file exchange between different operating systems [3, 4, 5]
- □ Implementation of an intelligent feature recognition module based on the DXF file format, where raw part data and final part information are distinguished
- □ Comfortable, dialog-based support for unrecognized features
- □ Storage of feature-based processing and tooling resource models as well as manufacturing variants of a feature within the database of an ERP system (e.g. Dynamics AX 2012)

To support customer demands completely, we are developing the assistance system with a browser based user interface by utilization of modern information technologies, such as service oriented architecture (SOA) in combination with the web 2.0 standard.

2.2 Feature recognition

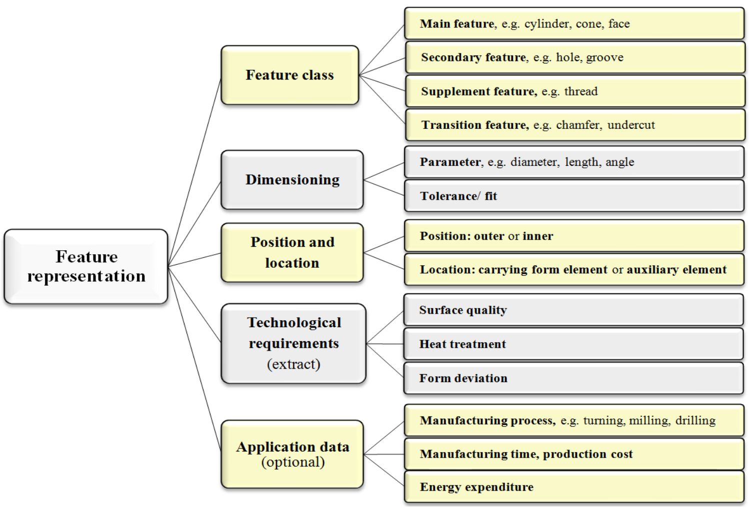

Figure 2 – Feature representation structure (extract) [7]

Features are objects for the description of workpieces containing technological properties [6]. They may also include application specific information (e.g. machining time and energy expenditure). The description of product requirements (geometrical and technological requirements) with features necessitates a modeling method. Grouping features into classes (Figure 2) supports process dependent determination of selected application data and hence is the prerequisite for evaluating technological alternatives in parts manufacturing.

Selected feature classification is distinguished in following manner:

- Main features are basis components for the description of a part's base shape
- Secondary features are defined combinations of faces, where geometric form is implicitly derived from the technical label
- Supplement features are face modifications of main and secondary features
- Transition features are edge modifications of the surrounding contour and they describe the transition especially between main features

Feature recognition algorithm

Intelligent feature recognition is the prerequisite for user-friendly application of the selected feature classification. Our developed and implemented algorithm for automated feature recognition solves the tasks illustrated in figure 3.

Figure 4 demonstrates an example of the implemented feature recognition. Every feature of the body of this bevel gear shaft has been recognized automatically.

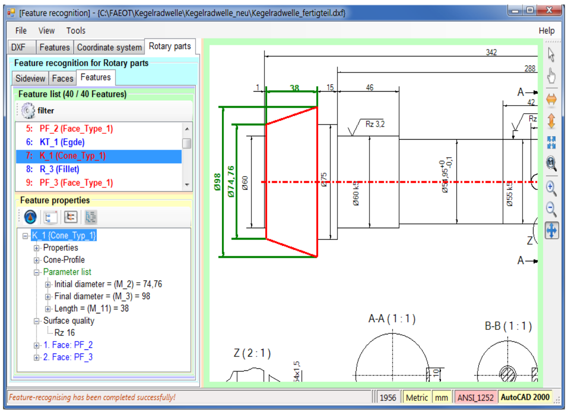

Figure 4 – Feature recognition on the example of the body of a bevel gear shaft

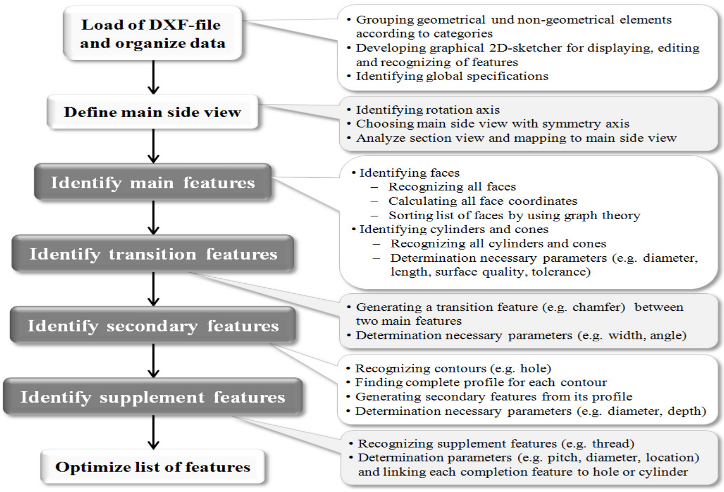

Figure 3 – Algorithm for feature recognition of rotational parts

3. CALCULATION OF EVALUATION CRITERIA

Process-related energy expenditure is the main evaluation criterion of our assistance system. To achieve a technology selection as comprehensive as possible, we calculate the machining time and production costs additionally.

3.1 Process-related energy expenditure

Calculation is based on the selected approach of cumulated feature-based energy expenditure. This method supports determination of process-related energy expenditure and hence allows a source-based evaluation of energy costs. There is a differentiation between cumulated feature-based energy expenditure per workpiece W_K and feature-based energy expenditure per operation W_{F_i} (formula 1).

□ Cumulated feature-based energy expenditure (per workpiece)

$$W_K = \sum_{i=1}^{p} W_{F_i} \tag{1}$$

where:

- W_K : Cumulated feature-based energy expenditure per workpiece (Ws)
- W_{F_i} : Feature-based energy expenditure of operation i (Ws)
- p : Number of operations per workpiece

Dependent on the consideration area we get following explanations for deriving feature-based energy expenditure for machining with geometric determined cutting edge. Calculation of feature-based energy expenditure of a operation W_{F_i} is based on Lutze et al. [8] (see formula 2).

□ Feature-based energy expenditure per operation

$$W_{F_i} = W_z * V_i \tag{2}$$

where:

- W_z : Specific energy expenditure (*Ws/mm³* resp. *J/mm³*)
- V_i : Feature-based volume to remove of the operation i (*mm³*)

In general, specific energy expenditure for cutting technologies is calculated as the required energy for the volume to remove.

Consequently, specific energy expenditure (W_z) of tool cutting edge results as follows (formula 3):

$$W_z = \frac{P_c}{Q_w} = \frac{F_c * v_c}{A * v_c} = \frac{A * k_c * \prod K}{A} = k_c * \prod K \qquad (N/mm^2) \tag{3}$$

with: $F_c = A * k_c * \prod K$

where:

- P_c : Cutting power (*W*)
- Q_w : Cutting volume (*mm³/s*)
- F_c : Cutting force (*N*)
- v_c : Cutting speed (*m/min*)
- A : Cutting cross-section (*mm²*)
- k_c : Specific cutting force (*N/mm²*)
- $\prod K$: Product of correction factors

As shown by the following conversion (formula 4) the specific energy expenditure W_z of cutting is dependent on the specific cutting force k_c (including the product of correction factors).

$$W_z = k_c * \prod K * 10^{-3} = \frac{k_{c1.1}}{h^m} * \prod K * 10^{-3} \qquad \left(\frac{Ws}{mm^3} \text{ bzw. } \frac{J}{mm^3} \right) \tag{4}$$

(1 J = 1 Ws = 1 Nm)

where:

- $k_{c1.1}$: Principal value of specific cutting force (*N/mm²*)
- h : chipping thickness of one cutting edge (*mm*)
- m : Tangent of the pitch angle of the line in the log log graph of k_c and h

Because of the dependency of the cutting force k_c on the chipping thickness h, "the specific energy expenditure is increasing with a smaller chipping thickness (the finer the chip) and vice versa" [8].

To derive the machining time and production costs we have also select the feature-based approach.

3.2 Cumulated feature-based machining time

In order to calculate the machining time according to the time diagram REFA [9] as exact as possible, we have introduced the cumulated feature-based machining time. This time value per workpiece t_K is calculated for the manufacturing beginning with the blank until the final part as defined in formula 5:

$$t_K = \sum_{j=1}^{m} t_{M_j} \tag{5}$$

where:

- t_K : cumulated feature-based machining time per workpiece (*min*)
- t_{M_j} : cumulated feature-based machining time on the machine j (*min*)
- m : Number of machines

The cumulated feature-based machining time per machine t_{M_j} results as shown in formula 6:

$$t_{M_j} = \sum_{k=1}^{p_j} t_{f_k} \quad (6)$$

where:

- t_{f_k} : feature-based machining time per operation[1] (min) ([1] Machining features are manufactured by operations and can be consist of another base features)
- p_j : Number of operations on machine j

Calculation of the machining time per operation t_{f_k} is based on following general formula 7 [10]:

$$t_f = \frac{L * i}{v_f} = \frac{L * i}{n * f} \quad (7)$$

where:

- L : Feed distance (*mm*)
- i : Number of cuts
- v_f : Feed speed (*mm/min*)
- f : Feed per workpiece rotation by turning or tool rotation by milling, boring and countersinking (*mm*)
- n : Speed of rotation (*1/mm*)

3.3 Cumulated feature-based production costs

Within our project we have selected the approach „cumulated feature-based machine-dependent manufacturing overhead costs" (see formula 8) to calculate the production costs.

$$FGK_K = \sum_{j=1}^{m} FGK_{M_j} \quad (8)$$

where:

- FGK_K : cumulated feature-based machine-dependent manufacturing overhead costs per workpiece
- FGK_{M_j} : feature-based machine-dependent manufacturing overhead costs on machine j
- m : Number of machines

Feature-based machine-dependent manufacturing overhead costs FGK_M on machine j is calculated by the machine-hour rate multiplied with manufacturing time which is based on the cumulated feature-based machining time.

Consequently, FGK_{M_j} is calculated as follows (see formula 9):

$$FGK_{M_j} = t_{B_j} * k_{M_j} \quad (9)$$

where:

- t_{B_j} : Manufacturing time, as required on machine j
- k_{M_j} : Machine-hour rate on machine j

4. TECHNOLOGY EVALUATION

Figure 5 provides an overview of the realized main functionalities of our assistance system. These include product specification, feature recognition, machine selection, manufacturing process selection and sequencing as well as calculation of energy expenditure, machining times, manufacturing times, production costs and piece number limit. Furthermore, there is a graphical and user-friendly comparison of technologies as well as the data and result export into excel files. Catalogues of machines, materials, features and manufacturing processes are managed within a database (e.g. Dynamics AX). Calculated evaluation values can be visualized either two or three-dimensional (see figure 6).

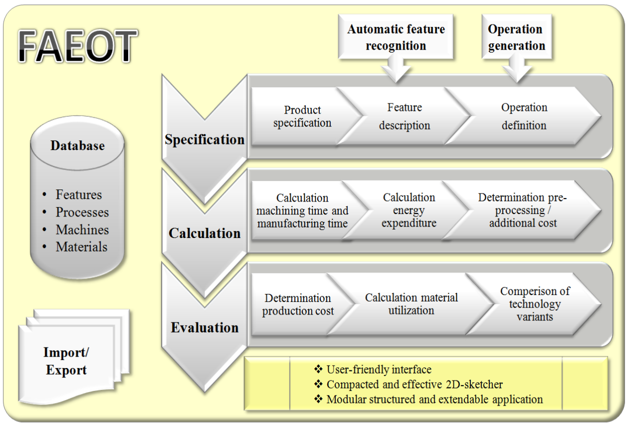

Figure 5 – Structure of the software prototype FAEOT

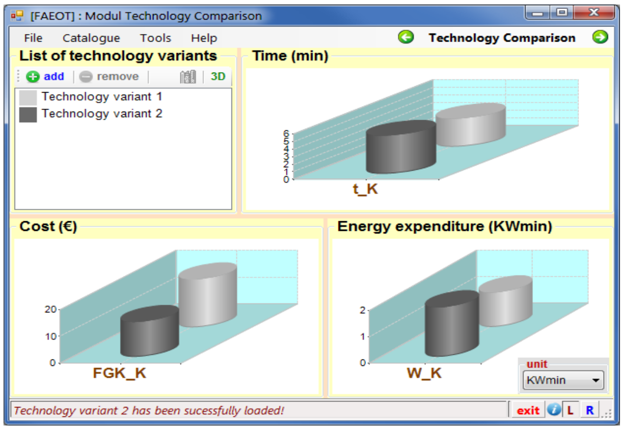

Figure 6 – Comparing technologies

5. CONCLUSION

This paper presented a feature-based assistance system that supports the cumulated and comparative determination of the energy expenditure which is required for the manufacturing of parts and therefore provides the basis for an early optimization of manufacturing technology selection and application. Feature-based product and resource models as well as algorithms and the integration of the assistance system into an existing CAD- and ERP environment are fundamental aspects of this solution. Required prerequisites are the implementation of feature recognition methods, feature description catalogues, manufacturing process catalogues including calculation and a comprehensive collection of formulas for the process-related energy expenditure, machining time and production costs. Evaluation of technological variants is cumulated for each machining feature beginning with the blank until the final part and is visualized in a user-friendly way. Technological capabilities of the assistance system are developed with consideration of practical technological strategies like complete manufacturing on machining centers, dry or wet machining as well as the combination of different technology variants. Consideration of piece number limit is also possible.

REFERENCES

[1] Newman, S. T., Nassehi, A., Imany-Asari, R.: Energy Effizient Process Planning for CNC Machining, Proceedings of eniPROD 2010, International Colloquium, Chemnitz, Fraunhofer IWU, 2010.

[2] Neugebauer, R., Wertheim, R., Harzbecker, C., Hochmuth, C., Schubert, A.: Challenges in the Metal Cutting Industry versus Shortage of Resources, International Chemnitz Manufacturing Colloquium (ICMC) - Sustainable Production for Resource Efficiency and Ecomobility, Chemnitz, 2010.

[3] Autodesk, Inc: AutoCAD 2011 - DXF Reference, Februar 2010.

[4] Rudolph, D., Stürznickel, T., Weissenberger, L.: DXF intern. Publisher Cr / Lf GmbH, Essen, 2000.

[5] Rudolph, D., Stürznickel, T., Weissenberger, L.: Der DXF-Standard, Publisher Rossipaul GmbH, München, 1993.

[6] Ehrlenspiel, K., Kiewert, A., Lindemann, U.: Kostengünstig Entwickeln und Konstruieren, 6. Printing, Publisher Springer, 2007.

[7] Dürr, H., Tran, N.A., Pilz, R.: Feature-based Decision Method for the Estimation of Technological Process Chains, Proceedings of the FAIM 2010, California State University, East Bay, Oakland Center, USA, Juli 2010, 12-14.

[8] Degner, W., Lutze, H., Smejkal, E.: Spanende Formung / Theorie - Berechnung – Richtwerte, 16. Printing, Publisher Carl Hanser, München, 2009, p. 109.

[9] REFA (ed.): Methodenlehre der Betriebsorganisation - Teil: Datenermittlung, Publisher Carl Hanser, München, 1997.

[10] Awiszus, B., Bast, J., Dürr, H., Matthes, K.-J.: Grundlagen der Fertigungstechnik, 5. Printing, Publisher Carl Hanser, München, 2012.