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Implicit Programming of a Flexible Manufacturing Cell

This paper describes the realisation of an integrated system for prismatic parts, to be manufactured in a flexible cell containing several machining centres. The notion of "implicit programming" appearing in the title, means that once a CAD description of the product has been made, the process planning and the NC programme generation are elaborated automatically so that the machining of the workpiece can be started without further human intervention.

A traditional description of a product with graphical entities like points, lines, arcs, ... is not suitable for automatic processing. For integrated manufacturing, the product description can be limited to the transformations the workpiece has to undergo. Such description can be easily obtained using form features. These can be standardized throughout the complete process and defined in a parameterized way.

1. Introduction

Particularly for small and medium-sized enterprises (SME), flexible manufacturing cells (FMC) are a feasible solution toward flexible production automation (FPA). Compared to flexible automated systems (FMS), the application field is much broader and the investment cost much smaller.

In order to follow smoothly the rapidly changing market requirements, an FMC has to be part of an integrated system. Indeed, although the creative steps of the product design cycle are hard to automate at the present time, the process planning and NC programme generation steps are in principle very easy to automate. All that is needed is a comprehensive product model, set up in an appropriate way [1].

Recently, part description in terms of features has become a popular approach to geometric modelling in CAD/CAM systems. One of the primary applications of features is the on-line "connection" of design to process planning. Anderson and Chang [2] proposed an automated process planner using feature based design. Gindy [3] proposed a hierarchical structure for form features. ElMaraghy and Gu [4] developed a feature based description language.

The goal of this project is to develop an integrated manufacturing system for the production of prismatic parts in a cell, possibly containing several machining centres, a transport system and a set-up station for the workpieces. The cell is not envisaged to be unattended. An operator can be charged with the tasks of clamping, tool changing, measuring reference planes, ... These tasks will be assigned by the computer system.

The flexibility of the cell should be guaranteed. By this we mean that to start the production of a new part, the preparation time should be limited.

The reference model for implicit programming is shown in figure 1.

Design is done on a CAD system. The output is a workpiece description based on form features. We consider that to be the input of the implicit programming system.

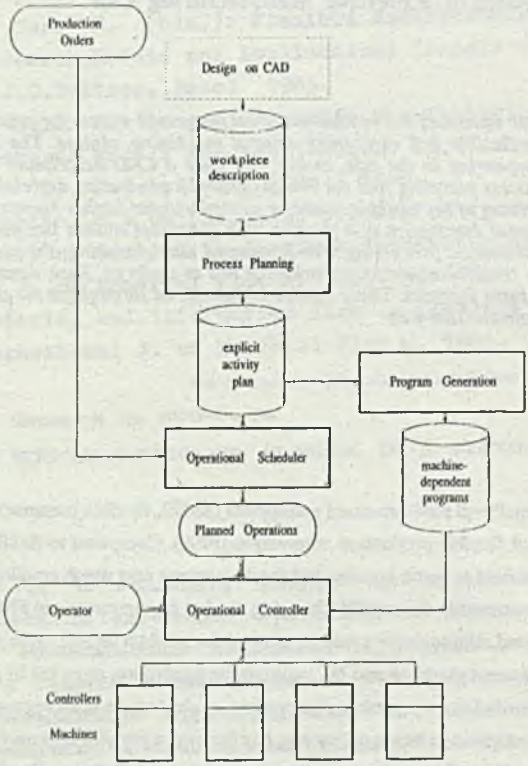

Fig. 1: Reference Model for Implicit Programming

Rys.1. Model odniesienia dla programowania niejawnego

The process planning converts the design information into process information using a generative approach based on individual features. To attain this, form features are decomposed into *manufacturing features*. These are handlings on a machine that can not be split. In order to reduce planning times, heuristics and experience-based rules are used.

The NC programme generation is obtained using a number of macros, associated to the different parameterized manufacturing features. Programmes are generated in a machine dependent form, without the need for post-processing.

In order to have different machines working together in a cell, a supervising *operational cell controller* is needed. Its main function is to perform coordination between the actions of the devices within the cell. Moreover, it has a controlling function. Errors detected by local sensors have to be managed and appropriate actions have to be taken.

2. Description of the Workpiece

As stated above, to make automatic process planning possible, the product description is limited to the transformations the blank has to undergo. These transformations are described using *form features* [5].

Two catalogues have been built : one for often used blanks , and one for form features closely related to common manufacturing processes (figure 2).

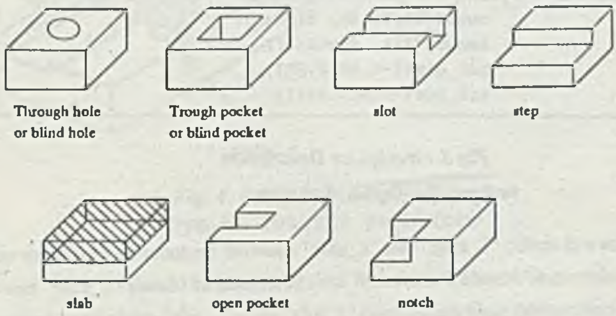

Fig. 2: Examples of form features
Rys.2. Przykłady cech form

These catalogues should be edited to match with a particular company's practice.

The catalogue of blank pieces contains for each piece a name, geometrical and technological information and the possible set-ups in which the part can be machined. The catalogue of features contains for each feature a name, geometrical and technological information and the possible decomposition of the form features into manufacturing features.

Using these catalogues the workpiece description is very compact and easily readable for a human. After identifying a blank piece and according values to the dimension parameters, the transformations are defined by choosing the needed form features, indicating the position and face in which they can be machined, and giving values to the dimensional and technological parameters (e.g. tolerance values).

An example of such a workpiece description is shown in figure 3.

Because all the different manufacturing steps have access to the same database containing the catalogues, the interface between subsequent steps is limited to the exchange of the parameter values.

In a fully integrated CAD/CAM environment the workpiece description should be the output of the CAD system. Either this CAD system (3D solid modeller) has a parametric module so that one can design the part using directly the feature catalogues (extracting volumes out of the blank piece and controlling graphically), either the CAD system has a feature recognition module so that starting with a classical drawing (with points, lines and circles) and with the assistance of a human designer a purely feature based description is extracted. The first alternative may not be accepted because such systems tend to severely limit the designer's flexibility of shape expression and they could excessively constrain the designer to think in terms of manufacturing processes at the design stage [2]. In this project the CAD system was not included. The workpiece description is considered to be the input of the system.

```
Blank Piece,
     form feature ( cast_12,
                    cast(material(GG15),
                    l1(58), ls(54), he(12)))
Transformations,
     form feature ( hole_12, hole(face(A), coord(10,34),
                    dia(14), depth(28),
                    tol_dia([-0.05,0.05]),
                    tol_loc(-0.5,0.5]))),
     form feature ( pocket_2 , pocket(face(D),
                    coord(25,12,0), side(5),
                    length(11), depth(5),
                    tol_dim([-0.05,0.05]),
                    tol_loc(-0.5,0.5])))
```

Fig 3 : Workpiece Description

Rys.3. Opis detalu

3. Process Planning

The goal of the process planning is to decide how, where and by which means a workpiece will be processed [6]. Process planning occurs before the start of the production phase. The optimal process plan is the one where the total production costs are minimized. Because of the large number of interacting aspects (e.g. the choice of the routing in the cell, the set-ups of the workpiece, the choice and sequence of operations, the selection of the tools), no simple general rules can be elaborated to obtain the *optimal solution* for the planning of the workpiece. However, it is possible to develop an algorithm that generates a *"good solution"* within acceptable execution time.

Thanks to the use of features the process planning is highly simplified. The algorithm that generates the process planning includes the following steps :

- Feature refinement
- Determination of set-ups
- Process and tool selection
- Operation sequencing

An existing program (MOPS) [7,8,9], written in PROLOG, is being adapted and extended to be used in this project.

3.1 Feature Refinement

Within this step it is possible to recognize four different sub-steps : form feature classification, feature relation identification, decomposition of form features into manufacturing features, feasible approach and feed direction determination.

In the classification step all the used features are linked to the catalogue, where all the needed information for manufacturing is available.

Nesting and intersection, operation sequence rules and relative tolerance values of features are investigated in the relation identification step. These relations are visualized by arrows in the example below (fig. 4).

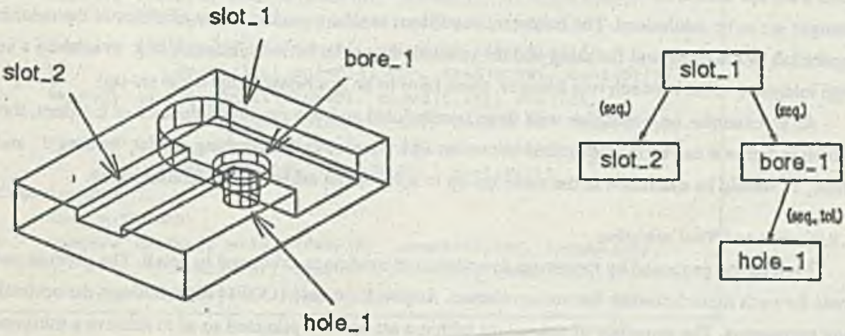

Fig. 4: Relations between form features
Rys.4. Związki cech form

In this case there are two relations between "hole_1" and "bore_1" ; there is a relative tolerance between the two and "bore_1" should be machined first. Moreover it should be machined after "slot_1". It is also convenient to machine "slot_2" after "slot_1" considering their intersection and the fact that "slot_1" is deeper.

To be able to optimize the operation sequencing later on, the form features used in the design stage should be decomposed into elementary manufacturing features. These are handlings on a machine that can not be split.

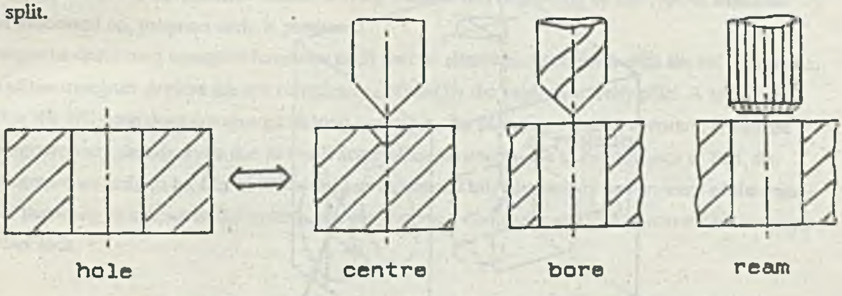

Fig. 5: Decomposition of form features into manufacturing features
Rys.5. Dekompozycja cech form na cechy wytwarzania

For example, *hole* can be decomposed into *centre-drill-ream* (fig. 5). This decomposition will not only depend on the form feature but also on the tolerance values. The relations that exist between manufacturing features (sequence of operation, tolerance values) derived from the same form feature are identified and added to the relations that already existed at the form feature level. Thus, one gets a complete tree of relations between all manufacturing features.

Depending on the position of a feature within a workpiece, or the position within another feature, the normal approach and feed directions could contain obstacles. These cases should be recognized by automatic geometrical reasoning and a solution to remedy the problem has to be found. For example by the use of another process or another machine.

3.2 Determination of Set-ups

First, all manufacturing features are classified depending on the machine they can be performed on. Then, within each machine, the manufacturing features are grouped in feature clusters. Each cluster represents a set-up. This is an optimization problem where the number of set-ups and the number of tool changes are to be minimized. The boundary conditions are the geometrical possibilities of the machine, the separation of roughing and finishing and the relations that exist between features (e.g. to achieve a very high tolerance value between two features, these have to be machined in the same set-up).

As an example, on a machine with three translational and one rotational degrees of freedom, the part shown in figure 6 can be manufactured in two set-ups. Moreover the finishing cut for "pocket_1" and "hole_1" should be machined in the same set-up to achieve the asked high tolerance value.

3.3 Process and Tool selection

Each set-up proposed by the set-up determination module is examined in detail. The process and the tools for each manufacturing feature are chosen. A special module (COP) [10] calculates the optimal cutting parameters. The sequence of operations within a set-up are optimised so as to achieve a minimum processing time for each set-up.

3.4 Operation Sequencing

Different set-ups in the same type of machine can be grouped into set-up clusters. Again this minimizes the total processing time by decreasing transport times. This can be done as long the sequence relations allow it (e.g. if set-up B on machine 2 has to be done before set-up C on machine 1 then set-up A on machine 1, that must come before set-up B, cannot be grouped with set-up C on the same machine).

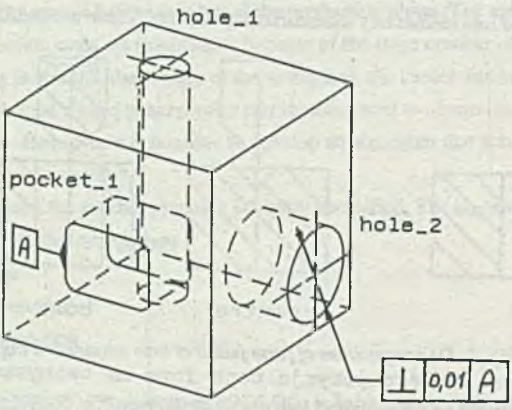

Fig. 6: Determination of set-ups

Rys.6. Określenie ustawień

3.5 Output of the Process Planning

The output of the process planning, which contains all the details about the activities that should take place in the cell to manufacture the workpiece, is called the "Explicit Activity Plan". An example is shown in figure 7.

Here the output is also readable by a human so that process plans not generated by the expert system can always be entered into the system.

```
Clamping(B2)
     device(MAHO)
     feature (centre, centre(face(A), coord(10,34), depth(8),
                spindle(900), feed(0.15), tool(C1)))
     feature (centre, centre(face(B), coord(5,15), depth(6),
                spindle(900), feed(0.15), tool(C1)))
     feature (drill, drill(face(A), coord(10,34), dia(14),
                depth(28), spindle(900), feed(0.09), tool(D1)))
     feature (drill, drill(face(B), coord(5,15), dia(10),
                depth(14), spindle(1300), feed(0.09), tool(D2)))
     feature (ream, ream(face(B), coord(5,15), dia(10), depth(14),
                spindle(800), feed(0.01), tool(R1)))
Clamping(A3)
     device(PEGARD)
     feature (pocket, mill_3(face(B), coord(30,15), length(10),
                width(15), depth(14), cutting_speed(42), feed(2),
                spindle(1300), tool(M2)))
```

Fig. 7: Explicit Activity Plan

Rys.7. Plan działania jawnego

4. Program Generation

The program generation module converts the explicit activity plan into machine commands. By the use of macros associated to the different manufacturing features and depending on the type of machine they will be processed on, program code is generated.

The programs describing transport functions need special attention. In contrast with the NC programs, the actions of the transport devices are not completely defined by the explicit activity plan. A second difference is that the NC code does not change as long as the process planning remains constant, while the transport programs may change even due to small scheduling variations. As a consequence of this, the transport programs are only to be assembled at the last moment. Only elementary movements of the transport devices, that exist as macros in the system, are programmed during the program generation by assigning parameters to it.

5. Operational Scheduler and Operational Controller

Contrary to the process planning activity that only uses time-invariant information about the facilities and the products, production control has to deal with the *execution* of the plans generated in the planning phase. Production control consists of operation scheduling and shop floor control. The aim of operation scheduling (off-line scheduling) is to *assign* tasks, identified in the plans, to factory resources. The real time control of the cell is the task of shop floor control (on-line scheduling). It is responsible for the execution, coordination and monitoring of tasks, from the moment they are scheduled to the moment they are completed.

The operational scheduler that will be used for this cell is an expert-based system written in Prolog [11], originally meant for scheduling of flexible assembly systems. It will be adapted for FMC-environments.

The operational controller that is being developed, is a rather simple shop floor cell control system, temporarily without provision for state feedback to the scheduler for contingency planning.

6. Conclusions

The construction of a *general* implicit programming system is a task that is beyond present capabilities. By restricting oneself however to feature based design, this aim may be concretely achieved. Moreover, the experience acquired in this project can be very useful for future generalization.

In this project only process planning, program generation and operation control [12] have been dealt with so far. Operation scheduling will be considered at a later stage.

A catalogue of features and a Prolog-based language for the workpiece description were constructed. Within the process planning the determination of set-ups and the process and tool selection were developed based on existing packages. Presently, work is been done on feature refinement and program generation.

Bibliography

[1] B. Wauterickx, H. Van Brussel, Implicit Programming of a Flexible Manufacturing Cell, ISO/TC184/SC3/WG2, doc. nr. N-20, KU Leuven 89P46, 1989.

[2] D.C. Anderson, T.C. Chang, Automated Process Planning Using Object-Oriented Feature Based Design, International Symposium on Advanced Geometric Modelling For Engineering Applications, Berlin, November 1989, 233-245.

[3] N.N.Z. Gindy, A hierarchical structure for form features, Int. J. Prod. Res., 1989, Vol. 27, No. 12, 2089-2103.

[4] H.A. ElMaraghy, P. Gu, Feature Based Expert Parts Assignment in Cellular Manufacturing, McMaster University, Hamilton, Ontario, Canada, Journal of Manufacturing Systems, Vol. 8, No. 2, 139-152.

[5] K.E. Hummel, S.L. Brooks, XPS-E revisited : a new architecture and implementation approach for an Automated Process Planning system, DR-88-PP-02, CAM-i, Arlington, TX, 1988.

[6] J. Carlier, J. Peters, MOPS, A Machining Centre Operation Planning System, Annals of CIRP, Vol. 34/1/1985.

[7] B. Zwaenepoel, Y.D. Willems, An Expert System for Process Planning of NC Machines (in dutch), KU Leuven, Faculteit der Toegepaste Wetenschappen, Departement Computerwetenschappen, Celestijnenlaan 200 A, B-3030 Leuven, Belgium, 1988.

[8] S. Tilly, J. Pinte, J. Peters, Expert Systems for Automated Process and Operation Planning, CIRP International Workshop on Computer Aided Process Planning, Hannover, West Germany, Sept. 1989.

[9] J. Peters, J. Pinte, S. Tilly, CIM and the Globalization of the Manufacturing Process in SME, A.S.M.E KU Leuven 89P25, 1989.

[10] J. Peters, J. Pinte, Computer Aided Programming of Machining Parameters, Symposium of Cutting and Wear-related Phenomena, Lausanne Switzerland, September 3-4 1979.

[11] H. Van Brussel, F. Cottrez, P. Valckenaers, SESFAC : A Scheduling Expert System for Flexible Assembly Cells, to be presented at the IEEE International Conference on Robotics and Automation, KU Leuven 89P45, 1990.

[12] H. Claus, About Flexibility and Mechanical Tooling, WTCM-Machinebouw, Celestijnenlaan 300 C, B-3030 Leuven, Belgium, February 1990.

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Wpłynęło do Redakcji do 1990-04-30

PROGRAMOWANIE UWIKŁANE W ELASTYCZNIE AUTOMATYZOWANEJ PRODUKCJI

S t r e s z c z e n i e

W pracy opisano realizację zintegrowanego systemu wytwarzania elementów graniastych w elastycznie automatyzowanej jednostce produkcyjnej zawierającej kilka centrów obróbki. Pojęcie "programowania uwikłanego" zawarte w tytule oznacza, że po utworzeniu opisu produktu w systemie CAD. planowanie procesu i generacja programu NC dokonywane są automatycznie tak, że obróbka detalu może odbywać się bez interwencji człowieka.

Tradycyjny opis wyrobu, zawierający pojęcia graficzne jak punkty, linie,łuki itp. nie nadaje się do automatycznego przetwarzania. Dla potrzeb zintegrowanego wytwarzania opis wyrobu można ograniczyć do opisu transformacji detalu. Opis taki można łatwo uzyskać wykorzystując cechy form. Cechy te można standaryzować w całym procesie i definiować w sposób parametryczny.

НЕЯВНОЕ ПРОГРАМИРОВАНИЕ В ГИБКО АВТОМАТИЗИРОВАННОЙ ПРОДУКЦИИ

Р е з ю м е

В статье описывается осуществление интегральной системы производства призматических элементов в ячейке ГАП состоящей из нескольких обработывающих центров. Находящейся в заглавии поняте "неявное програмирование" обозначает, что после описания продукта в САПР. планирование процесса и генерация программы цифрого управления происходят автоматически. Это значит, что обработку детали можно начать без посредничества человека. Традиционное описание изделия использующие графические понятья такие как пынкты, линии, дуги и др. не подходят для автоматического преобразования. В процессе интегрального производства описание продукта можно свести к описанию трансформации детали. Такое описание можно легко получить используя признаки формы. Эти признаки можно стандартизировать в целом процессе и определять параметрическим способом.