SIMULATION TOOLS FOR SUPPORTING ROBUST PROCESS PLANNING IN THE FIELD OF NC TURNING

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Abstract

The flexible production engineering for manufacturing industry requires robust production planning that uses technological alternatives in order to meet the demands of the rapid change of states or goals of production. Computer aided NC programming allows processing and post-processing NC program alternatives. A new generation of NC simulators required to support the decision making of production engineering. This paper outlines a conception of NC simulator, which tries to fill this gap.

Keywords*: Virtual Manufacturing, Robust NC technology, OOSE, Simulation, CAPP.*

1 The role of simulation in CAPP

Market demands for increasing the flexibility and efficiency of part manufacturing urge the firms to improve the robustness of their process plans. Computer Aided Process Planning (CAPP) is one of the main components of the engineering applications of Computer Integrated Manufacturing (CIM). However, up to now the number of implemented applications of CAPP are still less than other engineering applications (for example CAD, PPS or MES components). The reason for this phenomenon can be found in the serious difficulties which arise in planning reliable models for cutting processes. In the last decade the 3D geometric modelling methods of parts or assembly of machines have achieved important development in the parametric and feature based CAD systems. Programming of NC machine tools also requires precise geometric modelling for tool path generation and computing of tool correction. Integrated product design and NC programming systems (traditionally named CAD/CAM systems) provide good methodology to use concurrent engineering techniques in CIM environment for designing part models for NC machining.

Another important field with rapid development in a CIM environment is the computerised engineering activity of Production Planning and Scheduling (PPS). The PPS software components are integrated into the Management Information System (MIS) or into the Enterprise Resources Planning System (ERP) to provide an effective supporting the decisions making of production management.

At the shop floor level, the Manufacturing Execution System (MES) components offer new possibilities for efficient information flow between the Shop Floor Control (SFC) and the work places or machines, through the Local Area Network (LAN).

Operations in manufacturing technology processes can be interpreted as dynamic objects by which parts or assemblies are transformed from the raw material or components to a finished part or product in due time. From the manufacturing engineering point of view there are a lot of important state variables characterising this process. Some of them are: volume produced per unit time, operation time, material transportation time, waiting time, operation cost, tool cost, storage cost, quality attributes of finished parts, load rate of manufacturing equipment, technological intensity of operations, lateness or tardiness of production jobs, failure rate, and so on. These state variables can be calculated (planned) on the base of adequate mathematical models or can be estimated by experience based heuristic methods. There are several computer simulation software tools that support the production management in this field.

At present there are two types of widespread simulation tools used in supporting process planning in the field of cutting. They are as follows:

- Simulation of cutting tool movement along tool path for NC operations using the CLD (Cutter Location Data) file planned by a CAD/CAM or an NC programming system.
- Production process simulation of the manufacturing system, by discrete event driven methodology with many parallel process components, based on the scheduling of manufacturing tasks.

Unfortunately, there is a great lack of experience in using process simulations with precise models for part and cutting tool geometry, which is changing in time and in estimating the most important state variables (cutting force, cutting power, tool wear, cutting intensity, operation time, and so on.). If the simulation software enables defining the cutting operations geometrically and physically and it has methods to estimate the cutting parameters and the summarised result of manufacturing variables, it may be called *Process Simulator* for *Virtual Manufacturing* (VM). Fig. 1. shows the main relations between simulation tools and the CIM components.

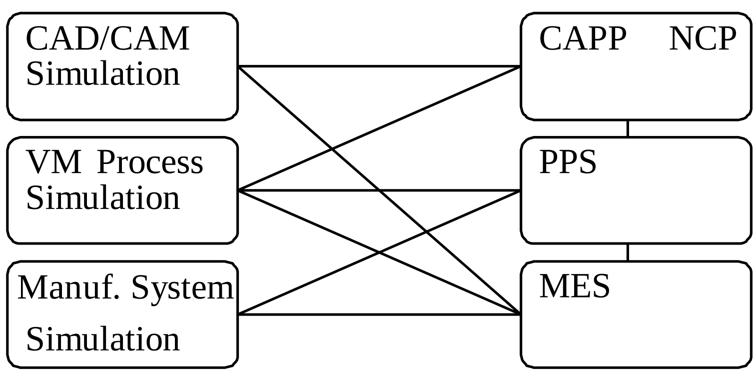

Figure 1. Relations between the simulation tools, and CIM components in case of cutting technology processes.

2 Robust process planning

In the course of any engineering process planning there is a general demand for optimising the planned process in accordance with the goal of the production management. Optimised process plan is a selected plan of some alternatives which meets all the constraints and guarantees the extreme (minimum or maximum) of an objective function preferred by the user. For example, time, cost, volume produced or their weighed portfolio could be one of these goals. Depending on the concrete type of process plan, the searching space containing all the alternatives may be continuous, discrete or hybrid. In general, optimising tasks can not be solved by means of a closed algorithm. Of course, there are some special classic tasks where the optimal parameters are easy to find by computing algorithms (for example the rough removal of the outer layer at rough turning operations). In some other cases a seeking procedure (based on, for example, heuristic, branch & bound or genetic algorithm) can find the extreme. Commonly, the result will be a quasi-optimum.

There are some important issues in terms of engineering applications in finding the optimal variant of a process plan. These are as follows:

- The optimal variant is a function of model parameters. If these parameters are changing, the extreme of the objective function is not guaranteed.
- The optimal variant is a function of constraints. If these are changing the result is not optimum, even worse, it can not be realisable at all.
- The optimal variant as a result, refers to the given and actual objective function. If the goal changes, (the reason of this could be business or engineering one), the optimum is not usable.

The optimal control theory suggests the use of robust control that assures less sensitivity for the changing of process parameters or constraints, and for the change of the goal function, in more general sense.

In analogy to robust control we define the robust technology process plan. It represents that kind of planned technology process, which is not sensitive to technology parameters or constraints, and forms a group of alternatives (population) from which the production management can easily select the appropriate one in accordance with the actual demand.

The main goal of robust technology process planning is to produce flexible and adaptive plans that are easy to apply when the business or engineering environment changes. This can be reached in the following ways:

- Making alternative plans in the early period of product and process planning with concurrent engineering methods in the pre-manufacturing phase. These serve for preparations to manage the changing environment during the life cycle of the products.
- Making robust plans that exist in a single form but can easy be transformed accordingly to the different requirements of the actual production management goal. (This is an extended application of the processor – post processor principle proposed in APT (*A*utomatically *P*rogrammed *T*ools system at first (1955-58)).
- Making plan classes with integrated that provide possibility to generate plan objects in the period of execution. (This is the principle of object oriented modelling methods.) The use of Group Technology (GT) and the intensity-based technology

planning approach suggested by Hungarian experts (*Tóth & Erdélyi*, 1997) can be regarded as this kind of methods.

The robust technology process planning presents a multi-level hierarchical structure. On the top of this hierarchy there are different, variants-based conceptions. On the bottom level we suggest to insert the parameterised NC part program populations.

3 Simulation tools for supporting alternative NC programs

The primary purpose of generating NC part programs is to define sequence of commands for the NC machine tools. The commands cause tool motions that accomplish the finished geometry form of the part to be originated from the rough material. The CAD/CAM software components provide efficient tools for generating robust process plans in the form of parameterised NC programs. Such kinds of parameters are as follows:

?? tool parameters,
?? tool path strategy,
?? depth of cut in subprograms (in macros),
?? technological intensity suggested by *Tóth*, 1988, (e.g.: in case of cutting: cutting rate or the rate of stock removal),
?? feed rate or cutting speed.

In generating a parameterised part program population, the programs must be analysed from different points of view. Some of these analyses may be accomplished with the optional service functions of the computer aided NC programming software. The correct geometry of the part model and the theoretical accuracy of the finished surfaces are two important components to be considered. In general, the built-in simulation tools of CAD/CAM systems use the CLD file for this analysis. This is the legacy of the APT conception and it makes possible to use this file as a source for many post-processed NC part programs. If the CLD file contains the tool path velocity data, the CAD/CAM simulation is able to calculate a first estimate of cutting time (main time component) as well.

Running the NC part program (executing the operations) is possible in a post–processed form, which is the input language of the NC machine tool controller. The post-processor generates this form according to the syntactic rules of controller vendors. An important new task of NC simulation is the syntactic verification of the NC part program in order to avoid tool collision or other machining faults.

The real set-up time and cycle times of operations belonging to the NC program are the two significant data of shop floor management used as input data for the MES software component. These time data have a significant influence on the shop floor scheduling and consequently, on the lateness and tardiness of production jobs.

The operation time and the cost components are essential parameters in controlling the manufacturing processes in flexible and robust way at the shop floor management level. In the case of cutting processes it is very important to follow-up the tool wear, because decreasing of operation time may cause the decrease of tool life. The tool cost is a function of the tool life. Determining the correct tool life is a very difficult task because the tool wear is a complicated and integrated (summarised) function of many cutting parameters. Moreover, tool life is a stochastic variable function of cutting intensity.

The research that has recently been in progress in the Department of Information Engineering at the University of Miskolc is targeted to the development of a new NC part program simulation tool. The main goal is to accomplish a correct analysis for giving a good estimate of production management state variables. The results of simulation serve useful support for flexible decision making at shop floor management level.

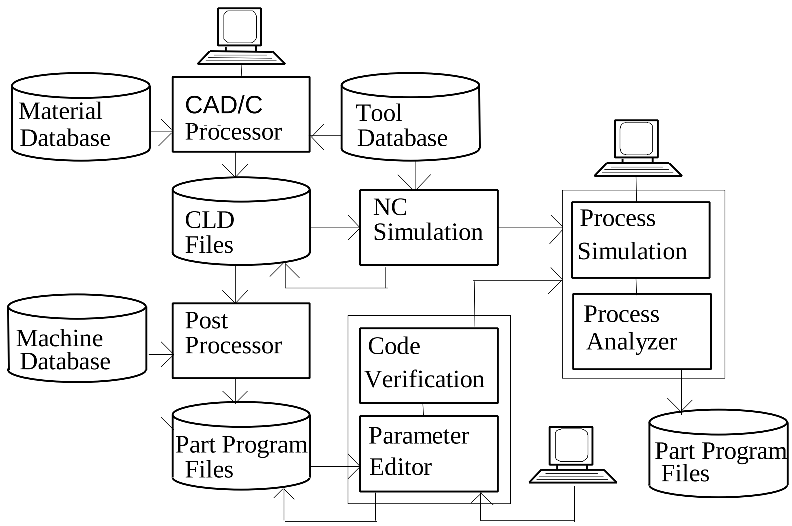

Figure 2. Extended simulation system for supporting NC part programming

Fig. 2. demonstrates the general components of this planning system concept including the process simulator, too. The simulator supports the technology process planner, to make an interactive loop in generating different NC part programs. These part programs will build-up a robust database suitable for flexible execution in any later period of the manufacturing process.

The first version of our process simulator for turning has been written in C++ developing environment, utilising object oriented methods. The second phase is under development and it will include neural network methods for modelling cutting processes.

4 Software engineering tools for NC simulation

The Object Oriented paradigm (OO) provides many features that help in effective software development and maintenance.

During the Object Oriented Analysis and Design a set of classes has been worked-out for representing the geometric and technology entities of NC simulation. The use of OO technology makes it possible creating interfaces with these classes to other existing classes. It also supports software modules being under development or going to be developed in the future. The instances of these classes are the simulation objects involving all the information what an NC program can contain. Some aggregate management indexes of NC cutting operation (e.g. machining time, cost) can be evaluated as the time-integrated sum of certain attributes. Simulators in common use also provide graphic animation to check the NC program for semantic errors. Due to enclosing properties of objects each object is responsible for its representation during the animation. This also means that the attributes and member functions of an NC entity are suitable not only for modelling a real existing object but for supporting the software representation as well.

The process analyser of the NC simulator uses the management indexes. Most of them appear as non-linear functions of the cutting parameters. It is expedient to use AI methods for modelling those relationships. An Artificial Neural Network (ANN) module can be used to predict the cutting forces and tool life. Time related attributes could be directly predicted from the feed-rate and the tool path data of NC program. After computing these parameters, many other state variables can easy be estimated. This introduces a new generation of NC simulation.

5 Conclusions

Recently, the rapid development of computing capacity provides new possibilities for extending the benefits of Computer Aided Process Planning (CAPP) technology. One of these possibilities is the use of process simulation over geometric simulation of NC part programs. Process simulator can support the production management in decision making, when goals of business change frequently. This is a step for realising Virtual Manufacturing in the field of NC turning. This paper and the background activity contribute to these aspects.

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