Computer Aided Process Planning (CAPP) Approach for Advanced Machining Processes

2 authors:

Neelesh Kumar Jain
Indian Institute of Technology Indore

Vijay Kumar Jain
Indian Institute of Technology Kanpur

COMPUTER AIDED PROCESS PLANNING APPROACH FOR ADVANCED MACHINING PROCESSES

KEY WORDS: Process planning (PP), CAPP, AMP, Fuzzy Logic, Genetic Algorithms (GA), Optimization, Post-processor.

1.1 OVERVIEW OF CAPP

Process planning **(PP)** is an important intermediate stage between design and manufacturing of a product. It can be defined as the systematic determination of methods and means to manufacture a component economically and competitively. Being a key element of integration between design and manufacturing, process planning translates the design requirements into manufacturing specifications. It also identifies various resources of manufacturing a product. Tasks involved in the process planning include **identification** of appropriate manufacturing processes, their sequencing, machine tools, cutting tools, fixtures, product routes followed by **calculation** of machining parameters (cutting speed, feed and depth of cut), machining time, machining cost and material removal rate (MRR), tool wear rate (TWR), etc., and finally **documentation** of output in the form of route card, process planning sheet, instruction sheets or part program, which depends on the level of process planning. Task of process planning can be carried out up to **three levels**. At the first level, known as **operation planning,** all the necessary manufacturing processes are identified and sequenced to meet certain objectives like minimizing production time and cost or maximizing production rate and/or maximizing the profit earned. The output of the first level of PP is generally presented in the form of route card. The second level that is **preliminary PP**, involves selection of manufacturing resources-machine tools, cutting tools, fixtures, etc. Its output is presented as *operations sheet*. Finally, at the third level **detailed PP** involving calculations of different parameters related to the manufacturing processes are carried out and are presented in the form of *instruction sheets*.

The task of process planning in most of the labor intensive and developing countries is carried out manually. But *manual PP suffers* from the following disadvantages associated with it:

- It reflects commitment to personal experience, skills, preferences and prejudices,
- Non-uniformity and inconsistency,
- Static nature and failure to take into account the developments and advantages in manufacturing technology, processes, equipments, tools, etc.

These drawbacks led to the conclusion that the manual PP still remains as an art rather than being a technology. Also, these drawbacks compel to automate the task of process planning by exploiting the potentials of the computers. Computer Automated or Aided Process Planning (CAPP) can serve the following objectives:

- Overcomes the drawbacks of manual PP as stated above ,
- Captures the logic, experience, skills of process planners in the form of algorithms, heuristics and databases,
- Relieves the task of process planning from personal experience, skills, prejudices,
- Can generate uniform, consistent and dynamic process plans,
- Can and should provide intelligent assistance to the user rather than fully automated reasoning,
- Integrates Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM), and plays a key role in the development of Flexible Manufacturing System (FMS) and Computer Integrated Manufacturing Systems (CIMS).

Different CAPP approaches can be classified under the following categories along with their implementation strategies

- **Variant or retrieval** approach using *backward or bottom-up planning* in which workpiece is traced back from finished to raw stage,
- **Generative** approach using *forward or top-down planning* in which workpiece is traced from raw to finished stage,
- **Hybrid** approach as a combination of variant and generative CAPP,
- **Expert system** uses *Artificial Intelligent (AI) techniques* and emulates the human capacity of reasoning in a particular field of expertise and is rule-driven rather than algorithm or data-driven.

1.2 CAPP FOR AMP

Ever-growing variety and quality of difficult-to-machine materials have resulted in the development of approximately 20 different Advanced (or non-traditional) Machining Processes (AMP), which use new tools and new forms of energy. In addition to this, complexity of workpiece shape, surface integrity and precision requirements, miniaturization requirements, automation of data communication etc, have also played very vital role in the development of AMPs. These advanced/non-traditional/unconventional machining processes are classified into *four categories* according to the type of energy employed for machining i.e. chemical, electro-chemical, mechanical and thermo-electric (Table 1).

Table 1: Existing Classification of Advanced Machining Processes

Type of Energy	Mechanism of Material Removal	Transfer Media	Energy Source	Processes
Mechanical	Erosion	High Velocity Particles	Pneumatic or Hydraulic Pressure	AJM, WJM, AWJM, USM, AFM
Chemical	Ablative Relation	Reactive Environment	Corrosive agent	CHM
Electro-chemical	Ion Displacement	Electrolyte	High Current	ECD, ECG , ECH, ECM
Thermo-electric	Fusion	Hot Gases	Ionized Material	EBM, IBM
		Electrons	High Voltage	EDM, WEDM
	Vaporization	Radiation	Amplified Light	LBM
		Ion Stream	Ionized Material	PAM

There may be other criteria for the classification of AMPs like material removal rate (MRR), shape applications of processes and physical parameters. These AMPs cannot replace conventional machining processes but find suitability only under certain conditions. Following factors reflect the need to automate the process planning for the AMPs:

- Non-versatility of the AMPs, because no single AMP is suitable under wide variety of the problems generally encountered in engineering applications,
- Large number of alternatives being offered by AMPs even for a tough job unlike conventional machining process,
- Uncertainties regarding the capabilities of the processes and flexibility in the requirements,
- With the increasing rate of technological changes more specialized and less experienced engineers are being involved in the design process therefore there is a growing need for the systems to aid the decision making (ie decision support system-DSS) regarding process selection and manufacturability,
- Increasing level of flexible automation in the area of AMPs,
- Existing shortage of skilled and experienced planners for the AMPs,
- Use of empirical relations for the design and development of the process and tools ,

- Consideration of different aspects of engineering in the optimized process parameter selection,
- Relatively higher cost of initial investment and also higher operating and maintenance cost of AMPs.

The above-mentioned factors (particularly first four) highlight the necessity of efficient and economic **process selection** among different AMPs, design of cutting tools (if required), selection of machine tools, selection of optimized process parameters and selection of auxiliary requirements for a particular process like electrolyte in ECM or dielectric in EDM, etc.

Thus, the task of PP for AMPs broadly involves process selection, optimized process parameters selection for the chosen process, determination of auxiliary requirements, process sequencing, product routing, calculation of machining time and cost and, finally documentation.

Some CAPP systems, mainly for ECM, EDM and USM, have been developed in the past. Also, there are some systems for the preliminary process selection and process parameter optimization for ECM and EDM considering linear objective function(s) subjected to some linear constraints only. But a comprehensive and generalized CAPP system, incorporating these different tasks in a single system, is yet to be developed.

(2) SOLUTION STRATEGY

To carry out the different tasks involved in the PP for AMPs, a generalized CAPP system should possess the features described below. It should:

- Identify the feature(s) and/or surface to be produced by the AMP,
- Select the suitable AMP and if more than one AMP are found suitable rank them,
- Design the cutting tools, and select the machine tools and other auxilliary requirements,
- Select optimized process parameters,
- Calculate the MRR, tool wear rate (TWR), machining time and cost,
- Generate NC/CNC-Code, if required.

2.1 PROCESS SELECTION PROCEDURE

To make efficient use of advanced machining processes, careful selection of the suitable process for a given problem is essential. The process selection procedure depends to a large extent on the knowledge and experience regarding the AMPs, nature of a particular application and availability of the required data. Usually the data are available either in hand-books or in simple proprietary guides of the manufacturing firms. Experienced experts often make correct decision regarding process almost instantly, but this experience and expertise cannot be transferred from person to person and infact it has to be acquired individually through a time consuming process. It is in this context that an interactive computer program can aid an engineer in making decision regarding process selection and manufacturability.

The **factors** which, must be considered during the selection procedure for AMPs, are as follows:

- **Part material characteristics** such as electrically conducting or non-conducting, low or high thermal conductivity, brittle or ductile, chemically reactive or non-reactive, optically reflective or non-reflective, etc.,
- **Operational requirements** of a part with the relative weightage or importance. These operational requirements include desired MRR, minimum tolerance, minimum surface finish, minimum surface damage (chemical, mechanical, thermal), minimum tolerable taper, minimum corner radii desired, minimum hole diameter to be produced, minimum width of cut, minimum overcut which can be tolerated and maximum depth to diameter ratio,
- **Shape requirements** such as whether blind or through cavity, workpiece is thin/thick section, profile of the contour, etc.,
- **Economic Considerations** such as initial investment cost, tooling cost, maintenance and operating cost of the process,
- **Physical parameters** of the process.

The **selection procedure** can be carried out at different levels. At the *first level*, some AMPs can be eliminated based on the work part material characteristics. Operational requirements and shape requirements can further eliminate some more AMPs during the *second level* of the selection procedure. *Finally*, economic considerations can be used to rank the different viable (or selected) AMPs for a particular application.

Most of the process capabilities of advanced machining processes are expressed in the ranges and linguistic terms that too with a certain degree of the **uncertainty** about their lower and upper bounds. Further, in most of the engineering applications there is a flexibility about the different operational requirements, therefore fuzzy logic seems to be the most effective and suitable tool for making the process selection.

Fuzzy logic can be best understood from the fact that binary logic, which has only two distinct possibilities, is a special case of the fuzzy logic. Key elements in the human thinking process are the linguistic terms and not the numbers. Human beings are always comfortable with making imprecise verbal statements rather than being quantitative in expressing their preferences, predictions, prejudices and judgments in relatively uncertain environments. These imprecise and incomplete statements can be best evaluated using fuzzy logic theory. Fuzzy logic theory has gained wide acceptance in decision making methods due to its capabilities in handling impreciseness and incompleteness which commonly exists in system specifications, states and alternative ratings. Thus, fuzzy logic theory is the most effective and suitable candidate to select an AMP while considering operational requirements and shape requirements, which are quantitative and qualitative in nature, respectively. Consideration of these two requirements is the most important and exhaustive in the selection procedure for AMPs.

2.2 SELECTION OF MACHINE TOOL AND DESIGN OF CUTTING TOOL

Suitable *machine tool* for a particular application can be selected by referring to the database containing information about the different machines available for the various AMPs. Different economic aspects should also be considered while finalizing the selection of a machine tool.

If a *cutting tool* is also to be designed for the selected AMP for a particular application, the factors like shape of the workpiece to be produced, tool kinematics, required material removal rate, etc. must be given due consideration.

2.3 PROCESS PARAMETERS OPTIMIZATION

The objective functions of most of the AMPs are non-linear in nature and are subjected to the non-linear constraints. The situation is more complicated by the fact that economic and efficient utilization of the most of the AMPs require a number of the objectives to be fulfilled simultaneously. Some of these requirements are of conflicting nature and some trade-off is to be made. Though there are a number of conventional optimization methods available, but they are unsuitable for **multi-objective optimization of non-linearly constrained non-linear objective functions** problems as encountered in AMPs. **Genetic Algorithms** (GAs) are the most effective and efficient unconventional optimization tools available to suit such type of optimization problems, because GAs offer the following advantages:

- They work with a population of points instead of a single point, therefore a number of optimum solutions can be obtained simultaneously,
- They use coded strings instead of variables, thus discretizing search space and a **discontinuous or discrete objective functions** can be handled,
- They do not require objective function to be **unimodal, continuous and/or linear,**
- GA operators are *probabilistic* in nature while traditional optimization methods use deterministic algorithms,
- Traditional methods **cannot** be *parallelized* as they use serial algorithm,
- Constraints of any nature can be handled by GA,
- For multi-objective optimization GA gives a set of pareto-optimal solutions.

GA mimics the principles of the genetics and natural selection. Depending on the requirements they can be **binary coded** (for discrete search space) or **real coded** (for continuous search space), or mixed. GAs carry out the task of optimization process using **reproduction, crossover** and **mutation operators.**

The **reproduction operator** works on the philosophy of "survival of the fittest" in which current population is exploited without generation of a new string. The most commonly used reproduction operators are Roulette wheel selection, stochastic remainder and tournament selection. The **crossover operator** uses the philosophy that "two good parents can make a better child" and responsible for the exploitation of good strings of the present for the better strings of the future. It is the operator, in which new strings are created, which can be constructive or destructive. Commonly used crossover operators are single point crossover, two point crossover and uniform crossover. The philosophy of **mutation operator** is "flipping of a coin with the probability p" and it is responsible for maintaining diversity in the current population. Commonly used mutation operators are bitwise and biased.

The important **GA parameters** which, are to be selected before using GA for a particular application along with their determining factors are as follows:

- String length which depends on the accuracy needed in the solution,
- Population size which is determined by convergence time and computational complexity,
- Number of generations,
- Type of reproduction, crossover and mutation operators,
- Crossover probability,
- Mutation probability.

CALCULATION AND DOCUMENTATION

It is desired in most of the engineering applications of process planning to calculate the machining time and cost so that economic aspects of a particular process can be evaluated. Theoretically available material removal model and economic model of the selected process can be used to calculate the total machining time incorporating various practical allowances. Various costs involved in the process can be used to calculate the corresponding total machining cost.

The last but not least task involved in the PP is the **documentation** of the output of the different tasks of PP in the desired standard format. Wherever NC/CNC control is available, this output is desired to be generated in the form of NC/CNC part programs, so that the final output of the CAPP can be directly downloaded to the CNC machines, most of which may be remotely located. Since NC/CNC codes are specific to the machine tool-control unit combination type, it is advisable that the coordinates of the movement of the cutting tool are generated in the form of cutter location data (CLD) file, which is independent of the machine too-control unit combination. Sometimes, commercially available **post-processor** software can be used to convert these CLD files into the NC/CNC part program according to the controller type being used. Otherwise, a post-processor software logic can also be incorporated in the generalized CAPP system.