A Technologically Oriented Approach for the Economic Tool Selection and Tool Balancing of Milled Components

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A technologically oriented tool selection and tool balancing system for milled components is presented. The system is capable of selecting the most economical tool set and, where necessary, adjusting the cutting conditions for all the features of a batch of components. Several key parts of the system such as the method for estimating the remaining tool life of a cutter used for selected different cuts, the cost equation used and the method of searching for the most economical tool set are discussed. The system has been used to analyse the tools required for the machining of a typical milled component. This analysis considered the influence of batch size, the number of repeat batches, the number of sister tools, inventory cost and of varying the cutting velocity within a given feature.

Keywords: Milling; Optimisation; Tool balancing; Tool selection

1. Introduction

The interest of the discrete part manufacturing industry in the automation of process and operations planning activities is rapidly growing because of continually increasing market demands for smaller batch sizes and shorter delivery times. In small-batch manufacturing, process and operations planning is becoming the core of both the technical and logistic control systems. There is a growing need for computer-based tools which can support the technical and logistic planning of manufacturing processes and operations.

As a link between computer aided design (CAD) and computer aided manufacturing (CAM), computer-aided process planning (CAPP) is a critical element in computer-aided manufacturing systems. To date, various CAPP systems have been developed and many of these have been reported on in various surveys [1-6]. However, owing to the complex and interdependent nature of the functions in process planning, a successful CAPP system has yet to be fully implemented in industry. Some of the functions in a CAPP system, especially those involved with cutting processes, are particularly difficult to implement.

One of the important functions in a CAPP system is tool selection, by which more detailed information about the use of tools is provided. Tool selection also plays an important role in other systems such as tool management (TMS). Many different approaches have been used to construct tool selection procedures, including expert systems [7,8], generative approaches [9-11] and concurrent engineering [12]. With the expert-system approach, the information about tools, machine tools, etc., is usually stored in a database, and various rules are used to select the appropriate tools. Such an approach still requires a procedure for dealing with the tool life spent in cutting processes in order to obtain precise information about the tool usage [13]. Concurrent engineering is a high-level strategy in system integration. Using such an approach to construct a tool selection system requires many fundamental modules within which the cost estimation, machine parameters, tool usage, etc., are obtained from appropriate equations [12]. In tool selection systems, various methods have been suggested to solve the requirement of selecting tools, cutting paths, cutting conditions, tool material, workpiece material and cost evaluation.

Some of these systems include only the local cutting conditions optimisation in tool selection, while others have not given a complete picture of how the problem of selecting a tool set for a batch of components from all the possible tools for individual features was solved.

In fact, as an economic action, only being able to select tools for a given component is not enough to satisfy the economic requirements in today's manufacturing industry. In general, the ideal tool set selected should be the most economic of all the possible tool sets in an actual environment. Achieving this, however, is difficult because of the nature of the multi-objectives and multi-constraints of such a tool selection process.

In this paper, a technologically oriented approach to tool selection and tool balancing is presented. The system is part of a more comprehensive CAPP system, TECHMILL, developing at UMIST. The principle of the tool selection and tool balancing system is introduced. It includes the functions of possible tool selection for features, tool-path generation,
cutting conditions optimisation and tool balancing, together with a tool-management system for providing the required tool data to the tool selection and tool balancing system. Some key methods used in the system, such as the evaluation of remaining tool life (RTL) of a cutter in different cuts, the total cost evaluation when evaluating a possible tool set for machining a given batch of components, the concepts and methods of tool balancing for batches of components, etc., are also presented. A typical milled component is used to demonstrate the effectiveness of the system.

2. Possible Tools Selection

As a part of the whole TECHMILL system, the system of tool selection and tool balancing obtains the information about the features of a component from a previous module, i.e. the feature recognition module. A feature is normally described with a solid model and the basic required information linked with each feature is:

1. The dimensions of a feature and tolerance requirement.
2. The machine tool and operation types for a feature.
3. The machining sequence of the features and other information such as material properties.

In order to provide the tool information, a tool database was built in an INGres database. A link between the tool selection and tool balancing system and the tool database was set to select all the possible tools for a given feature. The following stages were used to construct the link.

First, the various operations which can be performed on a machining centre were classified. These are:

1. Face milling.
2. Square shoulder milling.
3. Side milling.
4. Slot milling: square shoulder type slot milling, side and face type slot milling, pocket type slot milling, contour type slot milling.
5. Slot drilling.
6. Copy milling.

Corresponding to each of the operations, the cutting surfaces, precise surfaces and cutter axis direction when using these operations were established as discussed in [14].

Secondly, the link between the various cutter types and operation types was established. This was because the operation type is only a name given to a particular machining method, of more fundamental importance are the precise cutting geometry and the surfaces which are generated.

In the selection procedure, all the particular types of cutter linked with an operation type, which can satisfy other constraints such as the limitation on cutter diameter and tolerance requirements are identified as the possible tools for the operation type corresponding to a feature. In this way, all the possible tools for machining a feature are selected from the tool database.

The information about a tool is stored in the system. The types of tool information required in the different stages of the system will vary depending on the use of the tool. A complete description of the tool information was given in [14]. The information comprises:

1. The geometry related information, i.e. dimensions of a tool.
2. The material properties of tools.
3. Cost data, i.e. tool cost and reshaping cost.

3. Tool-Path Generation

Since CNC (computer numerical control) machine tools became widely used, much progress in generating tool paths has been made following academic and industrial research. Tool path generation is mainly restricted by the geometrical limitations of a component, such as the radius of the fillets on the component, the width and the depth of the component, etc. For a 2½-D component, the height of the component affects the number of tool paths along the axial direction of a cutter, according to the cutter length. Therefore, the tool-path generation for a 2½-D component in milling is actually equal to the one in 2D space (as a plane).

Considering geometry limitations is not enough when creating tool paths since cutting takes place when a tool path is being created. On the one hand, the constraints of a cutting process, such as the influence of cutting force and tool deflection, will affect the tool path generated. On the other hand, the pattern of tool paths generated will also affect some methods used in other parts in the system, for example, the method of evaluating the machining time of a cutter. From this point of view, it seems to be unreasonable to create tool paths without considering the various factors in the cutting process. Nevertheless, it is difficult to deal with the tool-path generation and the cutting conditions optimisation together. To overcome this problem in this research the following technical factors were considered when generating tool paths.

3.1. Cutting Modes

A cutting mode is a presentation of the relationship between a cutter and a cutting geometry. To overcome the disadvantage of the traditional classification of cutting modes in which only three of them, i.e. up-milling, down-milling and slotting, were considered, more modes, such as symmetrical milling, pro-down-milling, pro-up-milling and combined milling were added to the classification of cutting modes by Lau [15]. Apparently, the influence on cutting conditions caused by the mode type will vary. From a technological point of view, some of these modes are preferable to others. For example, in order to allow the cutter to move smoothly into the next tool path, the same mode is preferred for both paths. As shown in Fig. 1, in which a face feature is machined, the spiral form of tool path is preferred rather than the zigzag one because the former can keep the same cutting direction (down-milling) in all of the tool paths but the latter cannot.