A Heuristic Approach for Automated Process Sequencing in CAPP

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ABSTRACT

Process sequencing is a very complicated task. A series of operations done on a single machine can be sequenced in many different ways and still produce the part. However, some sequences are better in terms of costs than others. The problem then is to determine these more efficient sequences. This paper proposes one heuristic approach which minimizes the setup times. Constraints are used to determine which machine, fixture, and tool setup should be machined first. Then the constraints can sequence the order in the same tool setup.

1. INTRODUCTION

To generate a process plan automatically, there are three basic steps which need to be completed :

(1) extract the design data (features) in drawing files.

(2) map the data (features) to feasible corresponding operations, and then

(3) sequence these operations.

Since the first two parts have been widely discussed, we'll focus on the third part in this research. The sequencing problem is non-polynomial complete (NP-complete) which is not feasible to solve this problem using analytical approach. Hence it would be worthwhile to examine a heuristic approach for process sequencing.

Different heuristic approaches have been proposed[1,2,3,4,5,6,7,8,9,10,11,12]. However, some of them [6,10] don't have algorithms or logic steps to follow. Some of them [1,3,12,13] don't consider some important constraints such as machining difficulty and fixture grasping difficulty.

To summarize the problems mentioned above, heuristic sequencing algorithms should be clearly stated and realistic constraints such as machining, fixture etc. should be included in the system.

The following algorithm is designed for generating a better process sequence for turned parts after the features have been extracted and operation for each feature has been determined. The basic steps can be described as follows:

(1) Group the same machine setup operations.

(2) Group the same fixture setup operations.

(3) Group the same tool setup operations.

(4) Determine the natural order based on geometrical, operational, tool, geometrical tolerance, fixture and machining constraints.

2. GROUP THE SAME MACHINE SETUP

It has been reported that in batch-type metalworking shops, only about five percent of total production time is actually spent on machine tool while the remaining 95 percent of the time is spent on moving and waiting for parts in the shop. Of that five percent, only about 30 percent is spent as productive time in cutting materials. The other 70 percent is spent in positioning, loading, gagging, idle, etc [14]. Since setup times directly relate to the time spent in positioning, loading, moving, etc., to minimize the total setup times is to minimize the total manufacturing time.

After each feature is recognized, process and machine information for manufacturing this feature can be determined. Since to minimize the total machine setup times is one step to minimize the total setup times, the operations which use the same machine are grouped

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and machined together because some unnecessary positioning, loading, unloading, and moving can be avoided. The algorithm is listed as follows:

(1) Put operations into a set O*.

(2) Check whether O* is empty. If O* is empty, stop. Otherwise, choose one element from O*.

(3) Check whether the machine used for this operation already exists in M*. If it does, put this operation into m* which corresponds to the machine in M*. Otherwise, put the machine in M* and put the operation into m* which corresponds to the machine in M*.

(4) Delete the operation from O*. Go back to step 2.

3. GROUP THE SAME FIXTURE SETUP

For the round raw material shape, there are two setups for turning operations. The first setup is defined as from the face on one side to the external cylinder which has the biggest diameter in this drawing. The second setup is defined as from the face on the other side to the feature next to the external cylinder. Internal setup depends on the reference datum. For internal features, sequence starts from the internal feature which connects to the end face in the first setup. If it is possible, the internal feature should be machined in the same setup for machining quality such as tolerance. If there is one hole connecting both sides and the diameter of this hole is less than both sides, the first setup should stop here because of machining difficulty. The rest internal features would be completed in the second fixture setup. The detail algorithm for fixture grouping is as following:

(1) After machine grouping, check whether M* is empty. If M* is empty, stop. Otherwise, choose one element from M* and its corresponding element in m*.

(2) Check whether m* is empty. If m* is empty, delete the element from M* and go back to step 1. Otherwise, choose one element from m* and go to step 3.

(3) Check whether the fixture setup for this operation already exists in F*. If it does, put this operation into f* which corresponds to the fixture in F*. Otherwise, put the fixture in F* and put the operation into f* which corresponds to the fixture in F*.

(4) Delete the operation from m*. Go back to step 2.

4. GROUP THE SAME TOOL SETUP

Tool setup includes presetting the tool and loading it into the turret or station. Tool change implies that the tool is removed from the spindle and another one, which has been automatically preselected from the tool magazine, is inserted. To minimize the tool setup and tool change times is to minimize the total manufacturing time. To group the operations which have the same tool setup together is to minimize the tool setup times and tool change times.
The detail algorithm for tool grouping is as following:

(1) Copy M* to M1* and M2* before fixture grouping. Copy F* to F1* and f* to f1* after fixture grouping.

(2) Check whether M1* is empty. If M1* is empty, stop. Otherwise, choose one element from M1* and its corresponding F1*.

(3) Check whether F1* is empty. If F1* is empty, delete the element from M1* and go back to step 2. Otherwise, choose one element from F1* and its corresponding f1*.

(4) Check whether f1* is empty. If f1* is empty, delete the element from F1* and go back to step 3. Otherwise, choose one element from f1*.

(5) Check whether the tool setup for this operation already exists in T*. If it does, put this operation into t* which corresponds to the tool in T*. Otherwise, put the tool in T* and put the operation into t* which corresponds to the tool in T*.

(6) Delete the operation from f1*. Go back to step 4.

5. DETERMINE THE NATURAL ORDER

There are six kinds of constraints: geometrical, operational, tool, and geometrical tolerance, fixture and machining. These first four constraints which have been proposed [10] are for features which meet functional requirement. The last two constraints are for manufacturing consideration.

Fixture constraints can change the operation sequence. Some feature is not easy to hold for fixture (Fig. 1). The final choices would be (1) make special fixture to hold it, (2) do this operation until the last one, and (3) try to prevent this situation occurs. The second choice is better than the first choice because the fixture cost can be saved. The third choice is better than the second choice. However, the third choice is related to design. If design engineers can not change the drawing design for design reasons, the second choice is always the better choice.

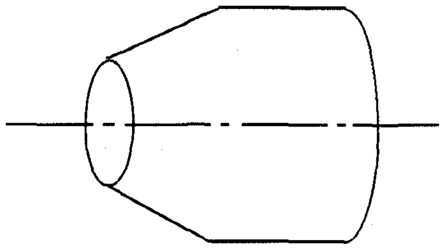

Fig. 1 Left hand taper

Some features are created foı location reference like pilot hole. Some features are used for machining easily or preventing vibration like accessary hole. These features mentioned above should be machined before other functional features are machined. Some other constraints for machining should be considered in round bar raw material shape like thread-relief for thread. This kind of feature, thread-relief, should be machined before the functional feature, thread, is machined. This kind of constraint is called "machining constraint" (Fig. 2).

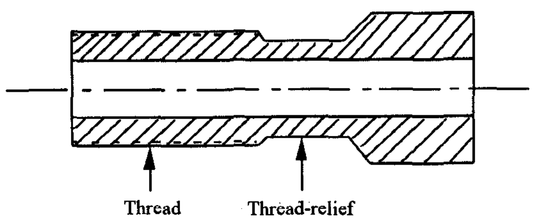

Fig. 2 Machining constraint : thread relief

Based on these six constraints, the natural order for operation sequence can be easily deduced. The logic steps are as follows:

5.1 Determine the critical side

There are two basic reference datum features, face and either internal or external diameter for each drawing. Sometimes all three are present. The reference datum is for functional and machining requirement. If we try to achieve the design quality requirement, the datum should be considered first. If these reference datum are on the same side, that side is the critical side(Fig. 3). After the datum features are machined, the other features can reference the datum features based on some geometrical tolerance constraint. In Fig. 3, all three datum are on the left-hand side. Datum A is for internal diameter. Datum B is for external diameter. Datum C is for face datum. The left hand side becomes the critical side which should be machined in the first setup.

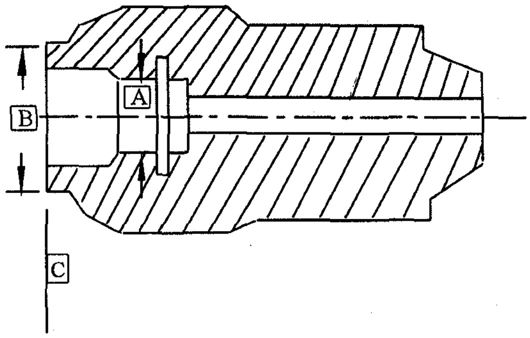

Fig. 3 Datum for the same side

If the two or three datum are on different sides, internal datum diameter is difficult to maintain and it determines the critical side. If internal datum diameter does not exist, external datum diameter can determine the critical side. Because face datum can be maintained easily in machining, it becomes less important (Fig. 4).

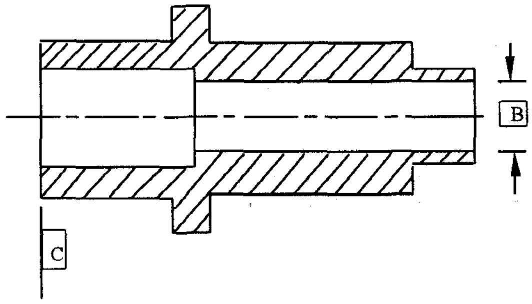

Fig. 4 Datum for different sides

If the internal length is too long to drill, a gun drill is used. If the internal datum diameter is equal to the tool size, the critical side can be determined by fixture problems. The drawing quality can be maintained no matter where the face datum is (Fig. 5). The internal hole is gun-drilled. Because the right hand side is not easy to hold for fixture, the left hand side is determined as the first side to machine. Though datum

A is on the right hand side, the datum B has been created and datum A becomes less important.

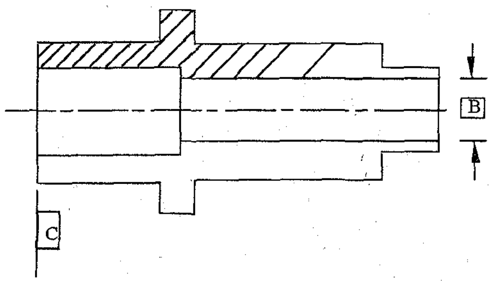

Fig. 5 Internal datum for gun drill

If the internal length is too long to drill, a gun drill is used. If the internal datum diameter is equal to the tool size, the critical side can be determined by fixture problems. The drawing quality can be maintained no matter where the face datum is (Fig. 6). The internal hole is gun-drilled. Because the right hand side is not easy to hold for fixture, the left hand side is determined as the first side to machine. Though datum A is on the right hand side, the datum B has been created and datum A becomes less important.

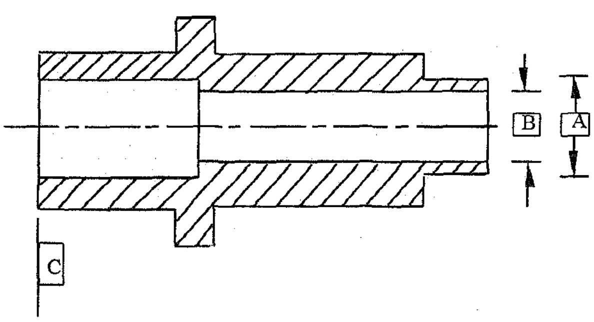

Fig. 6 Internal datum for gun drill

In some parts, the reference datum is not as important. For example, a machining part which is not for assembly. This factor would not need to be considered. Then the fixture problem should be considered for the second factor. The fixture problem can create more costs for designing a new fixture. The side more difficult to hold by the fixture is usually arranged on the second setup. Then the new fixture design costs can be saved. However, the fixture problem can degrade the functional requirement. We need to make sure the fixture problem is considered after the quality is guaranteed. If there is no fixture problem on either side, this factor is ignored and machining difficulty factor is considered. Also, if both sides have fixture problem, machining difficulty becomes the main factor to determine the critical side. The side which has higher machining difficulty value is chosen as the first setup because this side takes more time to finish or easier to be destroyed. If this side is destroyed, the part is discarded. The other side is the second setup. The difficulty of each operation is defined in Table 1. Table 1 was created by two human experts who have more than 10 years of experience.

Table 1. The definition of machining difficulty

Internal/External	Feature	Difficulty
Internal	groove	5
Internal	taper	5
Internal	thread	5
Internal	hole	4
Internal	concave	7
Internal	convex	7
External	taper	4
External	thread	3
External	cylinder	1
External	convex	8
External	concave	6
External	groove	2

The machining difficulty value is relative. The range is from one to ten. The higher the machining difficulty value, the more difficult the machining operation. The setup which has the highest machining difficulty value is chosen as the first setup. The other is the second setup.

5.2 Determine internal or external features machined first

Based on the machining difficulty value (defined by two experts who have ten year working experience), it is determined to machine internal or external features first. If a tie occurs, the feature which is defined as datum is chosen.

For example, in Fig. 7, there are ten features, two faces, five cylinders, one groove and two holes. From external shape, they have the same machining difficulty. From internal shape, both have one hole. If either side includes the groove feature, that side becomes critical side. For the concentricity constraint, internal shape should be machined at the same setup. From the right-hand side, the left-hand side hole is difficult to machine. So the left-hand side becomes the better candidate for critical side. There is one groove in the internal feature which has machining difficulty "five". Internal features should be machined before external features.

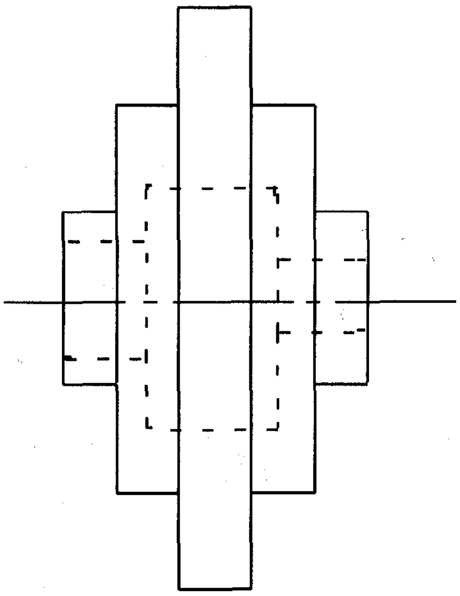

Fig. 7.An example for a round part

5.3 Determine machining order

The detail algorithm is as follows:

(1) After tool grouping, put constraints into C*.

(2) Check whether C* is empty. If it is, stop. Otherwise, choose one element from C* and two corresponding features.

(3) Check whether these two features need different machines. If they do and the machine precedence relationship for these two features is different from that in this constraint, exchange the machine order in M2* and go to step 6. Otherwise, go to step 4.

(4) Check whether these two features need different fixtures. If they do and the fixture precedence relationship for these two features is different from that in this constraint, exchange the fixture order in F* and go to step 6. Otherwise, go to step 5.

(5) Check whether these two features use different tools. If they do and the tool precedence relationship for these two features is different from that in this constraint, exchange the tool order in T* and go to step 6. Otherwise, if the feature precedence relationship for these two features is different from that in this constraint, exchange the operation order in t* and go to step 6.

(6) Delete this constraint from C* and go back to step 2.

6. CONCLUSIONS

This system has been implemented and named Intelligent Automated Process Sequencing System (IAPSS) which is one sub-system of Integrated Intelligent Process Planning System (IIPPS) developed by MIS Department in National Pingtung Polytechnic Institute in Taiwan. This system provides process planners with a decision support system. In addition, the operation sequence is more realistic than most existing systems because reference datum, machining difficulty, and fixture constraints are considered. The output validation is made and the results show highly comparable with a good process planner who worked in factories for ten years.

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