Adaptation of The Parameters of Operations for Process Planning
- 공정계획을 위한 공정파라미터의 적응 -

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요 지

일반적으로 자동공정계획(CAPP) 시스템에서 사용되는 공정변수의 값들은 한번 적당한 값으로 선택되면 보통 변치않고 늘 사용된다. 그러나 그것들은 작업상의 여러 조건들에 따라 변하기 마련이다. 이것을 반영하지 않은 공정계획은 정확할 수 가 없다. 본 논문에서는 작업조건 및 환경에 따라 변화하는 공정변수의 값들을 실제의 정확한 값으로 유지하기 위한 방법을 개발하였다. 공정의 성공 여부가 기존의 해당 공정변수의 값들에 반영되어 새로운 값을 구하는 알고리즘이 개발되었다. 한 공정이 선행공정과 얽혀 있는 경우(coupled processes)도 고려되었다. 개발된 알고리즘은 해석적인 방법으로 증명되었다.

1. Introduction

In the previous Computer-Aided Process Planning systems, in order to represent the capability of a machine tool, a best stated dimensional capacity and dimensional and geometrical machining tolerances were used. These values were used to select appropriate machine tools for a particular form feature of a part. However the best given dimensional and geometrical machining capability represents the best machining results under an optimal machining environment only. In practice, the process planner rarely selects an operation with its extreme machining capability because some undesirable results often follow the extreme use. The CAPP system which uses such best given machining capability often generates an impractical process plan. Therefore, the pratical knowledge of processes is necessary to generate correct process plans.

The determination of the practically correct process capability is frequently not sought, but the machine capability may change over time. The following methods will be used to determine the correct process capability.

1) The training of the numerical values of the characteristics of the machining operation such as sizes, tolerances and surface roughness.

2) The adaptation is based on the report of the success or failure of the machining results of the process plans generated by the CAPP system to be developed.

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2. Machining Parameters Adaptation

Parameter adaptation is an adjusting process of a variable in order to make its value most correct. In this research, the adaptation method is used to determine the actual machining parameters of an operation such as machinable size, dimensional and geometrical tolerances, and surface roughness. The machining result of each operation of the process plan generated by the CAPP system is reported from the shop floor, and its record is kept in a datafile. By analyzing the record, the actual machinable parameters of an operation is determined. The adaptation procedure is in the next section.

2.1 Adaptation Procedure

The following notation and definition is used to discuss the adaptation procedure:

p = current obtainable machining value(tolerance) of a parameter

p^*= new p

q = designed value(tolerance) of a part

M(p) = the number of values less than or equal to p in SUCCESS_LIST
(SUCCESS_LIST will be explained later.)

N(p) = the number of values greater than or equal to p in FAILURE_LIST
(FAILURE_LIST will be explained later.)

W_M = the lower limit of M(p)

W_N = the lower limit of N(p)

W_{Lb}= the lower limit of L(p)

W_{La}= the upper limit of L(p) to try new best value of p, $W_{La} \geq W_{Lb}$

A = W_{Lb}, usually.

C_d = a multiplying constant to decrease p, $C_d < 1$

C_i = a multiplying constant to increase p, $C_i > 1$

After machining is done on a shop floor according to a process plan generated by a CAPP system, the result of each operation is reported. If a designed part specification such as tolerances and surface roughness is achieved by an operation, the corresponding machining parameter of a operation is reported as a success. If the part specification is not achieved by the operation, the corresponding parameter of the planned operation is reported as failure. The report is recorded in the CAPP system as follows:

(Procedure 1) The result of a machining operation is stored in a datafile. Each machining parameter of each operation has a SUCCESS-LIST and a FAILURE-LIST. The numerical value of a parameter of a successful machining result is stored in the SUCCESS-LIST, and that of a failed machining result is stored in the FAILURE-LIST.

When the data are accumulated in a SUCCESS-LIST and FAILURE-LIST of a parameter of an operation, the values which are in SUCCESS-LIST are counted and represented as M(p). The values which are greater than or equal to the current obtainable value of the parameter in FAILURE-LIST are counted, and the number of the values are represented as N(p) in Procedure 2. If M(p) is large, it means that the current obtainable value, p, can be adjusted to plan a part to closer tolerances. If N(p) is large, it means that the current obtainable value, p, should be adjusted since the process can not meet specifications. The adjustment is based on L(p). L(p) is defined as:

$$L(p) = M(p) / (M(p) + N(p)) \quad (1)$$

(Procedure 2) Obtain the value of M(p), N(p), and L(p).

When L(p) is greater than its upper limit, a new obtainable value is determined by decreasing p. When L(p) is smaller than its lower limit, a new obtainable value is determined by increasing p. When L(p) is between its upper limit and lower limit, the obtainable value is not adjusted. To determine a new obtainable value reliably, enough data must exist. So, the adjustment are performed when the lower limits of M(p) and N(p) are satisfied. Procedure 3 represents the above statements.

(Procedure 3) When $M(p) \geq W_M$, $N(p) \geq W_{La}$, find p^* which satisfies

$$W_{La} \geq L(p^*) \geq W_{Lb} \quad (2)$$

by multiplying p by C_d, i.e.,

$$p^* = (p \times C_d). \quad (3)$$

When $M(p) \geq W_M$, $N(p) \geq W_M$, and $L(p) \leq W_{Lb}$, find p^* which satisfies Eq. (2) by multiplying p by C_i, i.e.,

$$p^* = (p \times C_i) \quad (4)$$

3. Coupled Processes

When a series of operations are carried out in order to create a feature of a part, the performance of an operation is often influenced by its previous operations. These are designated as coupled processes. When the result of a set of coupled machining processes is a failure, the method to deal with the failed process is explained in this section. For example, rough boring and finish boring are frequently used together to bore a hole, and the inspection is usually performed after the finish boring operation is completed. The failed operation has to be determined from the coupled operations to maintain correct process information.

Such a coupled problem should be thought about by decoupling the processes [4]. Generally, the coupled machining operations are composed of a rough operation and a finish operation, and inspection is not made between the operations.

A rough operation is frequently used as a stand-alone operation, and its machining capability information can be determined directly. In the case of a finish operation which is preceded by a roughing operation, the final quality of the feature depends on both operations. Therefore the operations are not independent and must be treated as coupled.

When the coupled operations composed of a rough operation and a finish operation are successful, both the rough operation and the finish operation are concluded to be successful. The initial tolerance information of the finish operation is determined from the past successful machining result only. Of the coupled operation has failed, then the failed result influences the tolerance information of the rough operation and the finish operation as shown in Table 1.

Table 1. Result of coupled operations

Case	Machining result	
	Rough operation	Finish operation
q<p	success	failure
q=p or L(q)≤A	indeterminable	failure
L(q)>A	failure	indeterminable

When the machining result of coupled operations composed of a rough operation and a finish operation has failed, and when the finish operation is used to obtain tolerance "q" and the reference tolerance of a process planning system is "p", each machining result. is concluded as Table 1 by comparing "p" and "q". The determination of "p" is also explained in the table. In the table, the result of the rough operation and an indeterminable result do not have any effect on the tolerance information. The tolerance information of the rough operation is determined by the stand-alone rough operation only.

4. Example of Adaptation of Parameters

A simple example is shown here to illustrate the procedure of the adaptation of the parameters of operations. The values in the SUCCESS-LIST are arranged in increasing order, and the FAILURE-LIST is arranged in decreasing order. Consider an example where the arbitrary constants are defined as follows:

$W_M=2$

$W_N=0$

$W_{Lb}=0.8$

$W_{La}=0.9$

$C_d=0.9$

Only the tolerances of diameter of rough and finish boring is considered for example.

1) The current obtainable value of the tolerance-of-diameter of rough boring is:

p=0.016

and its accumulated data in SUCCESS-LIST and FAILURE-LIST are:

SUCCESS-LIST=(0.012 0.013 0.014 0.014 0.016 0.016 0.016 0.016 0.02 0.022 …)

FAILURE-LIST=(0.016 0.01 …)

Then, M(p) and N(p) are obtained from the above lists as follows:

$M(0.016)=8 \geq W_M$

$N(0.016)=1 \geq W_M$

Their values are greater than their limit . So, L(p) is obtained as follows:

$$L(0.016) = 8 / (8+1) = 0.89 \geq W_{Lb} \quad (5)$$

It satisfies Eq. (2). Therefore, the current specification of the tolerance-of-diameter of rough boring is appropriate.

The current obtainable value of the tolerance-of-diameter of finish boring is:
p=0.004
and its accumulated data in SUCCESS-LIST and FAILURE-LIST are:
SUCCESS-LIST=(0.003 0.0034 0.0036 0.0036 0.004 0.004 0.004 0.004 0.005 0.006 …)
FAILURE-LIST=(0.004 0.0038 0.003 …)
Then, M(p) and N(p) are obtained from the above lists as follows:

$M(0.004)=8 \geq W_M$

$N(0.004)=1 \geq W_M$

Their values are greater than their limit . So, L(p) is obtained as follows:

$$L(0.004) = 8 / (8+1) = 0.89 \geq W_{Lb} \quad (6)$$

It satisfies Eq. (2). Therefore, the current specification of the tolerance-of-diameter of finish boring is appropriate.

2) If a new successful value of rough boring is stored in its SUCCESS-LIST and the designed tolerance-of-diameter of a part is 0.016, the following process occurs:
The current obtainable value of the tolerance-of-diameter of rough boring is:
p=0.016
The successful value of the designed tolerance-of-diameter of a part is stored in SUCCESS-LIST as follows:
SUCCESS-LIST=(0.012 0.013 0.014 0.014 0.016 0.016 0.016 0.016 0.016 0.02 0.022 …)
FAILURE-LIST=(0.016 0.01 …)
Then, M(p) and N(p) are obtained from the above lists as follows:

$M(0,016) = 9 \geq W_M$

$N(0.016) = 1 \geq W_M$

Their values are greater than their limit. So, L(p) is obtained as follows:

$$L(0.016) = 9 / (9+1) = 0.9 \geq W_{La} \quad (7)$$

Because the value of L(p) is equal to its upper limit, a new value of the tolerance-of-diameter of rough-boring is calculated as follows:

$$p^* = 0.016 \times 0.9 = 0.0144 \quad (8)$$

3) If a new successful value of finish boring is stored in its SUCCESS-LIST and the designed tolerance-of-diameter of a part is 0.004, the following process occurs:
The current obtainable value of the tolerance-of-diameter of finish boring is:
p=0.004
The successful value of the designed tolerance-of-diameter of a part is stored in SUCCESS -LIST as follows:
SUCCESS-LIST=(0.003 0.0034 0.0036 0.0036 0.004 0.004 0.004 0.004 0.004 0.005 0.006 …)
FAILURE-LIST=(0.004 0.0038 0.003 …)

Then, M(p) and N(p) are obtained from the above lists as follows:

$M(0,004) = 9 \geq W_M$

$N(0.004) = 1 \geq W_M$

Their values are greater than their limit. So, L(p) is obtained as follows:

$$L(0.016) = 9 / (9+1) = 0.9 \geq W_{La} \tag{9}$$

Because the value of L(p) is equal to its upper limit, a new value of the tolerance-of-diameter of finish-boring is calculated as follows:

$$p^* = 0.004 \times 0.9 = 0.0036 \tag{10}$$

4) If the result of the coupled rough and finish boring is a failure, and the designed tolerance-of-diameter of a part is 0.0038, the following process occurs:

The current obtainable value of the tolerance-of-diameter of finish boring is:

$p = 0.0036$

The current data in SUCCESS-LIST and FAILURE-LIST of finish boring are:

SUCCESS-LIST=(0.003 0.0034 0.0036 0.0036 0.004 0.004 0.004 0.004 0.004 0.005 0.006 …)

FAILURE-LIST=(0.004 0.0038 0.003 …)

Then, L(p) is obtained as follows:

$$L(0.0038) = 4 / (4+2) = 0.667 \leq (W_{Lb} = 0.8) \tag{11}$$

It is less than its lower limit. Therefore, this finish boring is concluded as a failure from Table 1.

5. Convergence of The Adaptation Algorithm

The convergence of the adaptation algorithm is controlled by the constants C_d and C_i. When their values are determined by the following equation:

$$C_d \times C_i = 1 \tag{12}$$

where $C_d < 1$, and $C_i > 1$.

The new value of a parameter can oscillate because

$$p^*_{2n+2} = p^*_{2n} \times C_d \times C_i = p^*_{2n} \tag{13}$$

where 2n represents 2nth iteration.

When the values of C_d and C_i are determined by the following equation:

$$C_d \times C_i > 1 \tag{14}$$

where $C_d < 1$, and $C_i > 1$,

the new value of a parameter can diverge because the value of the following equation diverges for a large n.

$$p^*_{2n} = p \times (C_d \times C_i)^n \tag{15}$$

When the values of C_d and C_i are determined by the following equation:

$$C_d \times C_i < 1 \tag{16}$$

where $C_d<1$, and $C_i>1$,

the adaptation algorithm converges. In the cases of Eqs. (12) and (14), the adaptation algorithm diverges, and the algorithm can not find a new parameter. However, in the case of Eq. (16), the algorithm converges and it can find a new parameter. Therefore only the convergent case is practically useful and it will be discussed in the rest of this section.

A new parameter is obtained by multiplying C_d or C_i to an original parameter consecutively. Then, the new parameters of 2nth and (2n+1)th iteration are represented as:

$p^*_{2n} = pC_d^nC_i^n$ (17)

$p^*_{2n+1} = pC_d^nC_i^{n+1}$ (18)

Then, the convergence condition of the adaptation algorithm can be represented as:

$p^*_{max} - p^*_{min} > p^*_{2n+1} - p^*_{2n}$ (19)

where $(p^*_{max} - p^*_{min})$ is a feasible region.

If a new parameter falls in the region, iteration stops and a new parameter is found. Then, Eq. (19) means the difference of two consequent new parameters are less than $(p^*_{max} - p^*_{min})$ to converge. During computation, if a newly obtained parameter is less than p^*_{min}, Ci is multiplied to increase it. Therefore, a new parameter does not converge in the outside of the feasible region.

By substituting p^*_{2n+1} and p^*_{2n} of Eq. (19) by Eqs. (17) and (18) the following equation is derived:

$p^*_{max} - p^*_{in} > pC_d^nC_i^n - pC_d^nC_i^{n+1}$ (20)

Then the above equation becomes:

$(C_dC_i)^n < (p^*_{max} - P^*_{min})/[p(C_i-1)]$ (21)

From Eq. (21),

$n > \log\{(p^*_{max}-p^*_{min})/[p(C_i-1)]\} / \log(C_dC_i)$ (22)

In the above equation, if m is the iteration number, n is the greatest integer less than (m/2 + 1), when m is odd. When m is even, n is m/2. Eq. (22) states that there exists a positive integer n which satisfies Eq. (19). Therefore, the convergence condition algorithm developed is proved.

From Eq. (22), the effect of each variable can be known. The numbers of iterations according to the changed of variables are plotted in Fig. 1. The term (C_i-1) is fixed as 0.1 in the figure. Fig. 1 (a) shows that the iteration number is enormously large, when C_dC_i is close to 1. C_d is a decreasing factor and C_i is an increasing factor, and C_dC_i determines the convergence of the algorithm as Eqs. (12), (14), and (16). Fig. 1 (b) shows that the iteration number is enormously for smaller feasible region. From Fig. 1, it is recommended that C_dC_i is less than 0.85.

6. Conclusions

A method of parameter adaptation was developed to keep the various parameters of machining operations practically correct under the varying machining environment. The method relies on the feedback data of a certain machining operation. Its success or failure result is reported to the system and the corresponding parameters are updated. An algorithm was developed to do that. It also considers the coupled operations. Its convergence was proven analytically. The adaption result was good, especially, it would be well applied for highly-automated manufacturing systems.

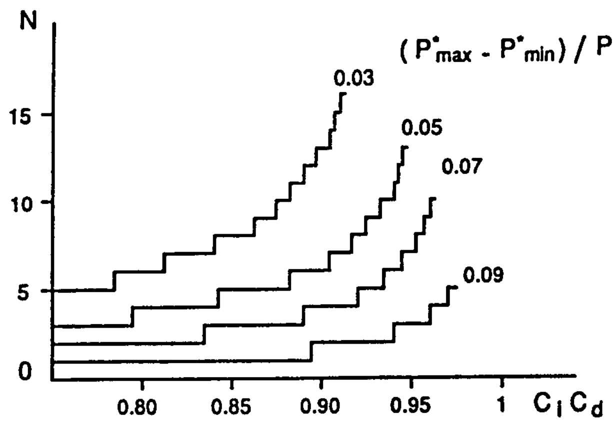
References

[1] Chang, T.C., and Wysk, R.A., *An Introduction to Automated Process Planning Systems*, Prentice-Hall, Inc., Englewood Cliffs, N.J., USA, 1985

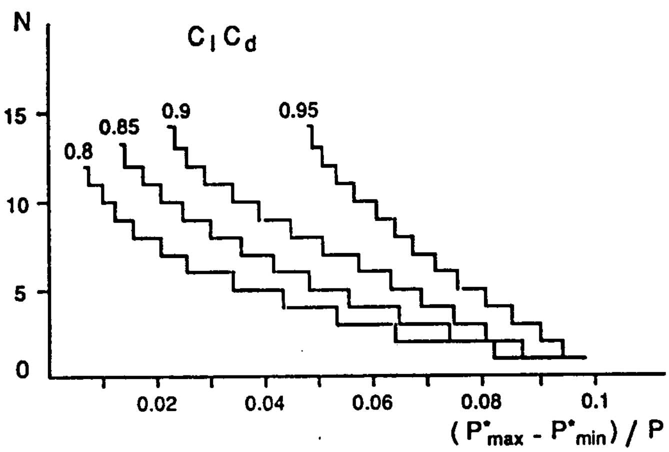
[2] Chang, T.C., *Expert Process Planning for Manufacturing,* Addison-Wesley Publishing Co., Reading, Massachusetts, USA, 1990

[3] METCUT, Research Associates, Inc., *Machining Data Handbook,* Machinability Data

Center, Cincinnati, Ohio, USA, 1980
[4] Sue, N.P., Bell, A.C., and Gossard, D.C., *"On an Axiomatic Approach to Manufacturing and Manufacturing Systems,"* Journal of Engineering for Industry, Vol. 100, No. 2, May 1978



(b) Iteration numbers according to C_d C_l



(b) Iteration numbers according to $(p^*_{max} - p^*_{min})/p$

Figure 1. Number of iterations of the adaptation algorithm