밀링작업에서 가공 안전성을 고려한 가공조건의 결정

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Determination of Cutting Parameters Considering Machining Safety in Milling Operation

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Abstract : In metal cutting processes, cutting conditions have an influence on reducing the production cost and deciding the quality of a final product. Process planners usually make modification to recommended cutting parameters obtained from machining data handbooks in order to satisfy requirements for individual operation. The modified cutting parameters also need to be examined for the safe machining. In this paper, a new operation planning system that allows the generation and check of modified cutting parameters is proposed for the milling process. A neural network methodology is introduced to identify mathematical models for generation of the modified cutting parameters, and several simplified rules and equations are presented for the check of the cutting parameters. Finally, the results are demonstrated with an example part.

초 록 : 절삭가공에서 가공조건은 가공비용의 감소와 제품 품질의 향상에 영향을 주는 주요 요인 중의 하나이다. 일반적으로 공정설계자는 제품의 목표 품질을 만족하는 범위 내에서 비용을 줄일 수 있는 가공조건을 결정하기 위하여, 가공조건 핸드북 등에서 제공하는 표준 가공조건을 세부 공정별 요구 사항이 만족되도록 경험을 기반으로 수정한 후 작업자의 안전에 문제가 없는 지 검토한다. 본 논문에서는 공정설계자의 경험에 의해 수행되는 일련의 과정을 신경회로망 모델과 규칙에 의해 모델링한 작업설계시스템을 소개한다. 개발된 시스템은 각주형 부품의 밀링 작업에서 (1) 표준 가공조건을 세부 공정별 요구 사항이 만족되도록 신경회로망 모델에 의해 수정하고, (2) 다음으로 작업자의 안전을 만족하도록 수정된 가공 조건을 필터링하는 모듈로 구성된다. 본 논문에서는 우선 개발된 밀링 작업설계시스템의 전반적인 기능을 간략히 소개한 후, 제안된 방법론에 의한 의사결정 과정을 자세히 기술한다. 마지막으로 실제 적용 예를 통하여 개발된 시스템의 성능을 예시하도록 한다.
Key Words : machining safety, CAPP(computer-aided process planning), operation planning, cutting parameters, neural network

1. 서 론

Since 1980s many CAPP(Computer-aided Process Planning) systems[1-3] have been developed and even on S/W market even though with not much commercial success. Especially for turning operation, quite practical CAPP systems[4,5] have been developed.

However, in case milling process, systemization of operation planning is difficult for end milling, drilling, boring, etc. for prismatic parts, where cutting parameters are determined for each operation selected and sequenced in process planning. Most of systems for those operations offer means to retrieve recommended cutting parameters from machining data handbooks. Problem is that the retrieved data should be modified according to the actual operation conditions as the handbook recommends data for only a type of materials to be cut and a type of cutting tool.

Modification to the recommended data has been

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done by human operator on the basis of experience considering a variety of factors such as materials, cutting tools, etc. and the machining safety.

Related to machining safety in metal cutting, there are a representative and habitual mistake that operators perform without considering carefully the characteristic of machine or workpiece for a reduction of working hours. That is operators tend to determine excessively cutting parameters such as depth and width of cut, feed, velocity, etc. for finishing the work more quickly. It causes many potential risks. These are: a broken tool and a splitted insert can harm the operator's eyes, skin and body; hot metal and flying particles can cause skin burns and damage the eyes; and the spindle vibration of an over-loaded machine tool can make operators tense and can induce operator's secondary mistakes[6,7].

A neural network is convenient for modeling such a modification procedure and has the required capability of parallel processing of large amount of information.

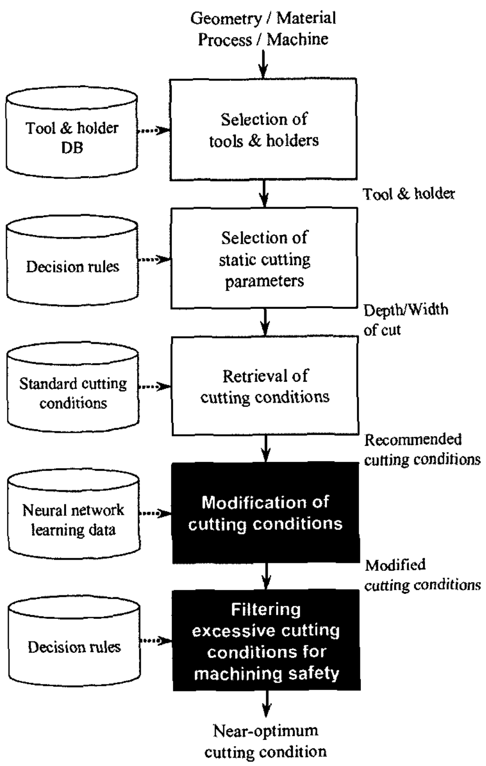

Fig. 1. Information flow in OPSS.

In this work, the modification process of recommended cutting parameters by machinists has been replaced by neural network and filtering modules, and has been adopted in the operation planning system, called OPSS(Operation Planning System considering machining Safety). The information flow of OPSS is shown in Fig. 1. Functions in the shaded blocks in Fig. 1 correspond to the process through which a machinist makes a recommended value more optimal one considering machining safety.

2. Modification of cutting parameters

For the selected cutting tool, depth and width of cut, optimal cutting speed and feed must be determined in order to get a high quality surface economically.

In this study, there are two steps in modifying recommended cutting parameters retrieved from database. The first is the modification process of cutting parameters by neural network where the influence of the factors which are not taken into account in reference database are considered. The second is filtering process where the modified cutting parameters are checked to see whether it can guarantee the safety of machinist.

2.1. Retrieval of recommended cutting parameters

In order to search for recommended condition for a certain tool, five metal cutting databases based on machining data handbooks and data from tool manufacturers have been constructed in a database system as shown in Fig. 1.

After geometry of machining feature, type of process, machine tool identification, and material code are provided by previous functions such as CAD and CAPP, the OPSS lets the system operator interactively select cutting tool and tool holder from available ones suggested by the system. Then the depth and width of cut are calculated automatically based on rules by the system. Using the mapping relation, appropriate cutting speed and feed are retrieved from the recommended cutting condition database.

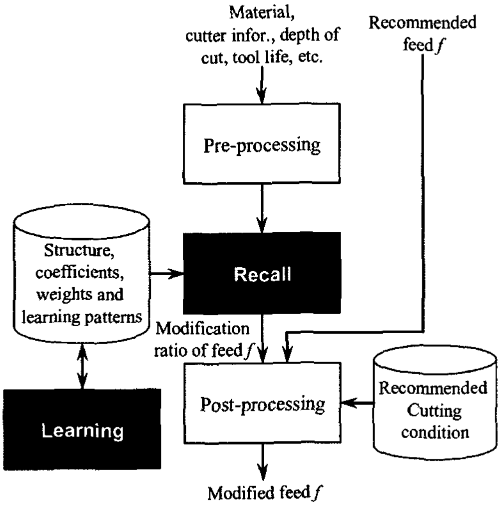

Fig. 2. Modification process of cutting parameters by the neural network.

2.2. Neural network model for modification

By using the advantage of neural network for expressing the non-linear relation among many factors simultaneously through parallel processing of data, influence of factors like surface condition and chip disposability of a feature are considered. The modification process consists of four modules and neural network database as shown in Fig. 2.

Structure of a neural network and learning algorithm

The 4-layer neural network as shown in Fig. 3 was used for the modification, and the back-propagation learning algorithm is employed in the neural

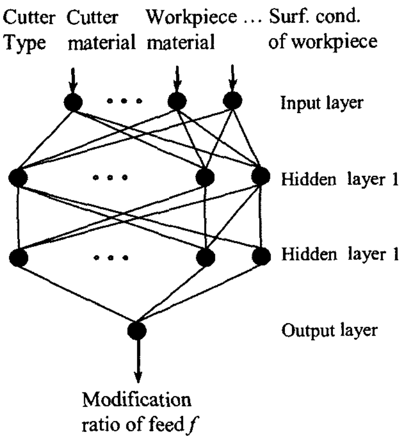

Fig. 3. Neural network for modification.

network training[8]. The neural network consists of an input layer with 15 neurons, 2 hidden layers with 15 neurons each, and an output layer with one neuron. This structure was chosen from several different compositions tested during learning process, as it showed the fastest learning rate.

Training

Information provided by ASME, SME, and other

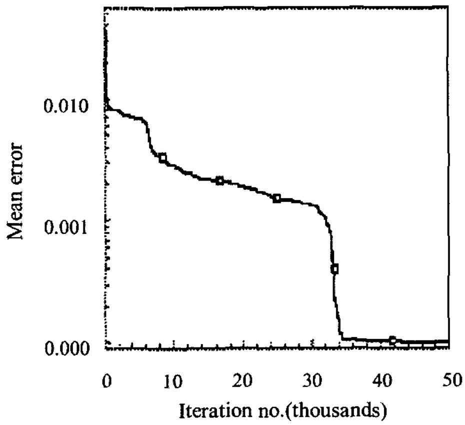

Fig. 4. Convergence of the output mean error.

Table 1. Classification of input parameters

Input parameters	Class no.						
	1	2	3	4	5	6	7
	8	9	10	11	12	13	14
Tool type	Drill	Tap	End mill	Face mill	Bore	-	-
	-	-	-	-	-	-	-
:	:						
Tool material	HSS	Carbide	-	-	-	-	-
	-	-	-	-	-	-	-
Raw material	Carbon steel	Alloy steel	Cast irons	Aluminium alloy	Coppers	-	-
	-	-	-	-	-	-	-
R_{LA}	0.7	0.8	0.9	1	1.5	2	3
	4	5	6	7	8	9	10
Surface condition of raw material	Surface with scale of heat treatment	Shot blasted cast	Cast without shot blasting	-	-	-	-
	-	-	-	-	-	-	-

Where,

$$R_{LA} = \frac{\text{Lead angle of selected tool} + 15}{\text{Lead angle of reference tool} + 15}$$

references[9,10] was utilized for the preparation of learning data. Fig. 4 shows the procedure of training of neural network. Seven factors, fifteen parameters and their values are listed in Table 1.

The training of neural network took about 2 minutes for 124 learning patterns on a personal computer. When η was 0.9, α was 0.1, and number of iterations was 50,000, the mean of error was 0.000099. Table 2 shows learning conditions and results of the neural network.

2.3. Determination of modification ratio

The generation of the modification ratio by the trained neural network is carried out as follows:

Step 1. When input data are given, the neural network is constructed, and then the class numbers are given for each input data.

Step 2. If the value of an input parameter is a real number, and does not belong to any class, the class number of the parameter is interpolated using the nearest two class numbers.

Step 3. The neural network is propagated in order to obtain the modification ratio of feed f using the selected class numbers for input parameters.

Step 4. Input feed f is modified by the modification ratio generated by the neural network.

Table 2. Learning conditions and results

NN coefficients & learning parameters		Values
Neural network model		Multi-layered feed forward network
Learning algorithm		Back-propagation learning algorithm
Number of nodes of each layer	Input	15
	Hidden	15
	Output	1
Number of hidden layer		2
Number of learning patterns		124
Learning rate, η		0.9
Momentum term, α		0.1
Error bound		0.000099
Number of iteration		50,000
Time spent for NN training (sec)		115

2.4. Evaluation of modified cutting parameters

In general, because the performance of neural network model is affected by its learning patterns[8], the 124 learning patterns used in this work examined and corrected by scientists. And the mean of difference between desired output and actual output of neural network was 0.000099 in Fig. 4. Therefore, the results of modification are reliable.

3. Filtering of Modified Cutting Parameters for Machining Safety

The modified cutting parameters are checked to see whether they satisfy the capacity of machine tool and guarantee machinist's safety using simplified rules and equations for each machining operation. For example, in case of face milling equations checking whether the cutting power derived from cutting parameters is high than the maximum cutting power of the selected machine are as follows.

$$N_r = 1000\, S_{ret} / (\pi D) \quad (1)$$

$$P_{kw} = K_s\, Dc\, Wc\, F_{ret}\, Z_n\, N_r / (612000\eta) \quad (2)$$

$$F_{kw} = 612000\eta P_{nominal} / (K_s\, Dc\, Wc\, Z_n\, N_r) \quad (3)$$

If $P_{kw} > P_{nominal}$

then

$$F_{mod} = F_{ret} - (F_{ret} - F_{kw}) / 2 \text{ and} \quad (4)$$

$$S_{mod} = S_{ret}\, F_{kw} / F_{ret} \quad (5)$$

End if

where, N_r ; No. of calculated spindle rotation(rpm)
K_s ; Special cutting force (kg/mm^2)
η ; Machining Efficiency (0.7~0.8)
$P_{nominal}$; Available cutting power (Kw)
Z_n ; No. of tooth (tooth/rev)
Dc, Wc ; Depth and width of cut, respectively (mm)
F_{ret}, F_{mod} ; Retrieved and modified feed, respectively (mm/tooth or mm/rev)

S_{ret}, S_{mod} ; Retrieved and modified speed, respectively (m/min)

4. Case Study

OPSS has been developed on a personal computer. A commercial database management system and a CAD system were employed in the system. Material of the test workpiece for case study is heat treated carbon steel. Vertical machining center is supposed to be used. A finished component has holes, a pocket, a step, surfaces to be faced, and slot features as shown in Fig. 5.

For face milling operation on surface feature, cutter and its' insert has been selected. Tool diameter is 125 mm, number of edge is 8, and lead angle is 45degree. With this tool, depth and width of cut are given 3.0mm and 83.3mm respectively, recommended cutting parameters, speed 145m/sec and feed 0.27mm/tooth has been retrieved.

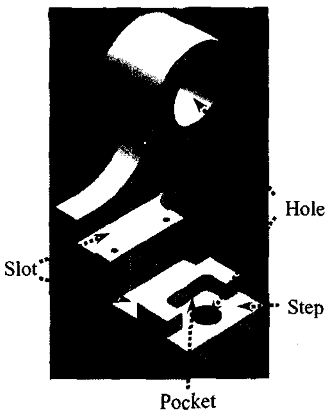

Fig. 5. An example part.

Table 3. Input values for determining the modification ratio and the results

Factors	Input parameters	Value of input parameter	Class no.	Modif. ratio of cutting parameters
Tool life	Tool material	Carbide	2	
	R_{TL}	2	6	
Depth of cut	Raw material	Carbon steel	1	
	R_{DC}	0.75	1, 2	1.09
Insert shape	R_{LA}	4	8	
Surface condition of raw material		Surf. with scale of heat treatment	1	

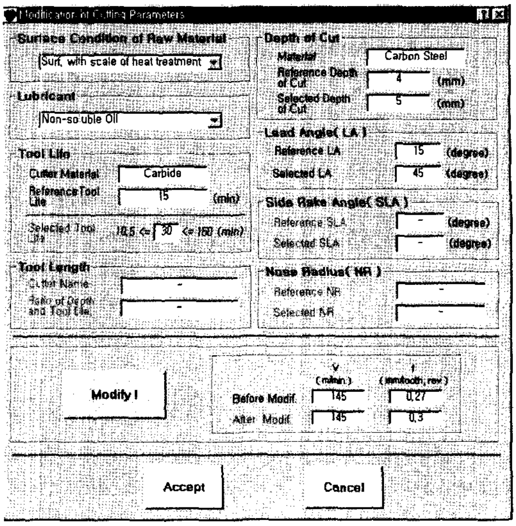

Fig. 6. Results of the modification of cutting parameters.

Table 3 shows procedure which calculates a modification ratio of feed in case of face milling. Cutting speed and feed have been modified from 145 m/sec and 0.27mm/tooth to 145m/sec and 0.3mm/tooth using the values shown in Table 3. Fig. 6 shows the result of modification.

Modified cutting parameters are filtered by equations checking maximum cutting force, possibility of spindle vibration, maximum spindle speed, machining stability for satisfying the machinist's safety. Current result of 145m/sec and 0.3mm/tooth satisfies the limit of the selected machine tool.

5. Conclusion

In order to produce practical and safe cutting parameters for the machining of prismatic components, the modification and examination processes on recommended data which used to be done by machinists has been modeled and added to OPSS.

In the modification process, recommended cutting parameters are modified into more effective one. The modification process which is largely non-linear and difficult to be expressed in conventional algorithm has been modeled by using neural network. The error between training data and the output of the constructed neural network converges within one thousandth (1/1000) which is accurate enough considering the range of the modification rate. Also, in the examination process, the modified cutting parameters are filtered off to satisfy the capacity of machine tool for safe machining.

The extensions of this study will include the following:

1) The method of modeling and the structure of neural network have been proposed, but more training of the neural network is necessary.

2) The metal cutting experiment will be carried out to validate and enhance the practicality of the system.

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