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Fuzzy 모델에 의한 研削 加工의 專門家 시스템의 開發

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Development of Grinding Expert System by Fuzzy Model

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抄 錄

研削 加工은 高品質 高精度를 必要로 하는 경우 매우 有效한 加工方法이지만 그 工程이 많은 Parameter에 의해 構成 되기 때문에 同一한 條件에서도 定量的인 評價가 어려우므로 作業 現場에서는 科學的 原理와 工學的 知識 보다는 熟練者의 經驗과 技能에 의존하고 있는 實情이다.

본 研究에서는 이와 같은 국면에 대처한 問題 解決을 위해 Computer가 人間思考에 近接 할 수 있도록 Fuzzy 理論과 Default 理論을 導入하고 專門家의 理論的 知識과 熟練者의 感覺的 知識을 積極 수용하여 研削用 Expert system(最適 加工 條件의 設定 System과 Trouble shooting system)을 開發하였다.

또한 研削 加工 Data의 不確實한 애매성을 效果的으로 利用 할 수 있도록 Fuzzy 可能性理論에 의해 加工 Data을 회귀 分析하여 實加工 Data base에 蓄積시켜 再活用토록 設計하였으며 開發된 본 System의 實行 結果 그 活用性이 높음을 立證하였다.

Key words : Cylindrical plunge grinding, Grinding Expert System, Actual Operation Database, Gringding Knowledge Base, Grinding Trouble Database, Optimum Grinding Cutting Condition, Fuzzy Theory, Default Theory, Fuzzy Regression Model.

1. INTRODUCTION

Grinding operation is considered as a very effective machining technology to attain the good surface quality of a components. However, the grinding operation still needs the skill and experience of an operator because of a lack of scientific and quantitative knowledge. Therefore, it has difficulty in satisfying high production rates as well as

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coping with the grinding troubles during the grinding process. The reason is that the grinding process is connected with a lot of parameters and inter-relationships of each parameter are not clearly provided for quantitative knowledge.
This is one of the main reason why grinding operations are not completely integrated in CIMS(Computer Integrated Manufacturing System).

Recently, the development is focused on Expert System[1-3] for machining which deals with domain specific knowledge to solve the above problems. To cope with uncertain knowledge, we employ fuzzy logic based on fuzzy set theory[4-6]. It is an effective way to solve the vague problem like the grinding operations.

This paper describes the basic conceptions for the grinding expert system, and presents an architecture as well as characteristics for the knowledge base. Also, this system is designed to optimize the grinding machining conditions for maximum removal rates subjective to constraints on workpiece burn, chatter vibration and surface roughness.

Moreover, the practical examples of an implementation are described.

2. BASIC CONCEPTIONS FOR THE DEVELOPED SYSTEM

Improvements for grinding operation as a metal cutting process have been achieved by solving of such complex factors[7], grinding chatter[8], grinding burn[9], and wheel wear[10]. In grinding operation as a precision machining process, the objective is to produce a workpiece with a good surface finish in the minimum time with the maximum production rates, which requires an effective design about the knowledge representation, reasoning structure, and knowledge acquisition as well as utilization method for the knowledge base and trouble-shooting. Especially, among the grinding parameters, grinding machining conditions are one of the most important factors to the surface roughness and production rates.

Therefore, we try to develop an Expert System(ES) which is a useful tool for an automation of grinding operations. In order to design for a practical grinding expert system, it is indispensable to understand the inter-relationships for the grinding parameter.

2.1 Knowledge Representation

In order to establish the efficient grinding expert system, it requires on effective knowledge representation method because the grinding operations mostly depend on experience, intuition and qualitative knowledge. Because of these reasons, the developed system adopts hybrid system involved with the frame and the production rule method.

The frame-based scheme is designed for class-instance(INSTANCE_OF relation), superclass-subclass(IS_A relation), relevance, and group(PART OF relation) and declares a function like method, trigger and value variables.

The frame-based scheme accumulated in declaration knowledge by the default theory. For instance, grinding wheel is functionally classified to grain, grain size, grade, bond and structure. The grain frame has a slot whose value is an unidirectional link to the grinding wheel frame as shown in Fig. 1.

On the other hand, procudtion rule-based scheme is inspired by attempts to model the human cognitive process, and it is represented, for example, in "IF this grinding condition holds, THEN the surface roughness is appropriate".

The following example indicates a part on the typical production rule in this system to determine the dressing condition (RULE A)

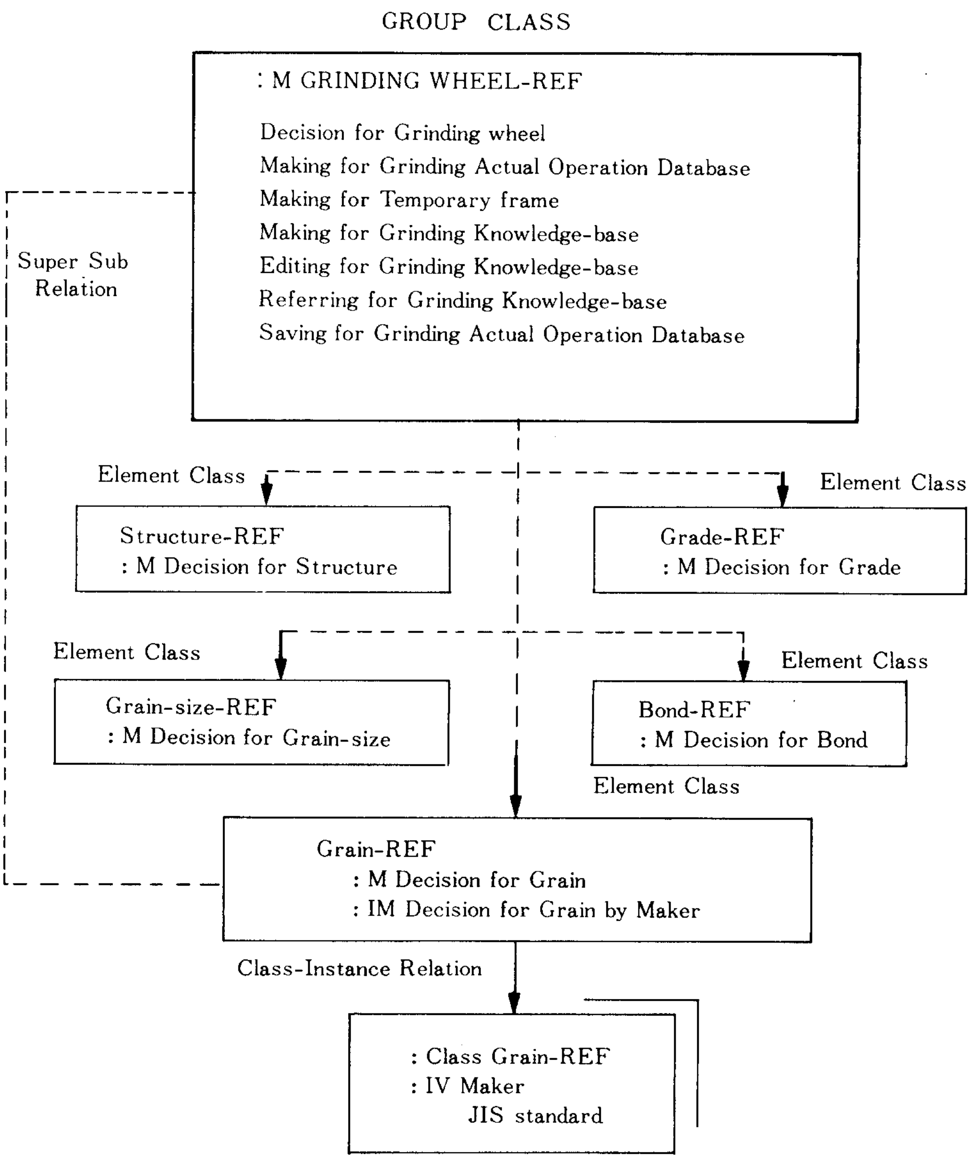


Fig. 1 Hierarchical structure for grinding wheel inframe system

by the fuzzy theory and trouble shooting for a chatter vibration (RULE B)

```
〔RULE A〕
(defruleset gr_cond_make_if)
 (defrule (dr_cond_make_if rule)
  (frame (tem_frame ? (kind of dresser ?dl) ))
  (frame* (surf-R ? (mirror ?sl) (fine ?s2) (normal ?s3) (rough ?s4) ))
→
(call (display_zentei (list ""
 (list-addstring (list "kind of dresser is" ?dl"))
 (list-addstring (list "surface is"
     (rule-addstring "(mirror" ?sl")")
     (rule-addstring "(fine" ?s2")")
     (rule-addstring "(normal" ?s3")")
     (rule-addstring "(rough" ?s4")") )) )))
(halt)
(defrule (dr_cond_make_if rule2)
 (goal (frame (sur-R ? (mirror ?) (fine ?) (normal ?) (rough ?) )) )
→
(call-ruleset surface) )

〔RULE B〕
(defruleset vibration)
(defrule vibration rule10)
 (frame (chatter_mark ?? (exit ?〈ans) ))
←
(not (frame (chatter_mark ?) ))
(→
 (bind ?ans (kdialog_quest "subsist a chater mark?") ))
```

tern matching, conflict resolution, and action. First, if the production rule is matched

The establishment of dressing condition is to start with matching the input constraints, and then accomplishes the suitable fuzzy production rule with respect to search the data file stored in each ruleset.

Production rules, in this system, have pattern matching, conflict resolution, and action. First, if the production rule is matched appropriately, the matched production rule is exected. If more than one are found, a single production rule is selected from among them and then the conflict is resolved. Finally, the action indicated by the matching rules is initiated.

Moreover, according to characteristic of data, the rule-based scheme in this system utilizes both the conventional production rule and the fuzzy production rule.

2.2 Knowledge Acquisition

Common knowledge in this system is mainly acquired from the research papers and enquete question from a skilled hand for a grinding operations.

Also, actually, grinding operations deal with a large sorts of conditions, it is difficult to store all the specialized knowledge.

Therefore, specialized knowledge as the grinding result are stored in the actual operation database. The grinding result data are accumulated in coefficients obtained from experimental equation utilizing the fuzzy regression model[6].

For instance, the models are given as follows :

$$\left.\begin{aligned} &\underset{\alpha,\,C}{\text{Minimze}}\ J(C)=\sum \vec{C}^{t}\,|X_i| \\ &\text{Subject to } Y_i \le \vec{X}_i^{t}\vec{\alpha}+(1-H)\ \vec{C}\ |\vec{X}_i| \\ &\qquad\qquad Y_i \le \vec{X}_i\ \vec{\alpha}-(1-H)\ \vec{C}\ |\vec{X}_i| \\ &\qquad\qquad C_i \ge 0,\quad i=1,\cdots\cdots,N \end{aligned}\right\}\cdots(1)$$

Above the equations, X-components are a (μm/rev), V_w (m/sec), t_d (mm), f_d (mm/rev) and G, and Y-components are R_{max} (μm) and P_r (K_w). And the H is degree of fuzzy membership function. Also, the coefficient factors which is obtained from optimization method accumulated in actual operation database as follows :

$$\ln P_r = A_0 + A_1 \ln a + A_2 \ln V_w + A_3 \ln t_d + A_4 \ln f_d \cdots\cdots (2)$$

$$\ln R_{max} = A'_0 + A'_1 \ln a + A'_2 \ln V_w + 1_n G \cdots\cdots (3)$$

Where, P_r, R_{max}, a, V_w, t_d, f_d and G are grinding power, maximum surface roughness, grinding depth of cut, workpiece velocity, dressing depth of cut, dressing lead and grain size, respectively. Grinding power is closely related to the sharpness of cutting edges in grinding wheel and the surface finish. If we are able to pre-estimate the grinding power with the lapse of time during the grinding process, it is possible to control the grinding trouble like a burning and vibration

The selection of Eq. (2) and Eq. (3) are drawn out the result of correlation for coefficients in accordance with grinding power and surface roughness based on the experimental data. Moreover, the fuzzy parameters of equations (2) and (3) mean "approximate", described by the center α and the width C. Hence, fuzzy parameters can be denoted as follows.

$$A_i\,(\alpha_i,\ C_i)\quad (i=0,\ \cdots\cdots,\ 4) \cdots\cdots (4)$$

$$A'_j = (\alpha_j,\ C'_j)\quad (j=0,\ \cdots\cdots,\ 3) \cdots\cdots (5)$$

The merit of this model is easily able to utilize the grinding result data and add to another constraint conditions.

Fig. 2 indicates the practical result data analyzed by this model.

2.3 Reasoning Structure

Reasoning structure in this system adopts the object-oriented paradigm system. The reasoning method uses not only forward-chanining but also backward-chaining method. In the forward-chaining reasoning, the system matches the facts with the con-

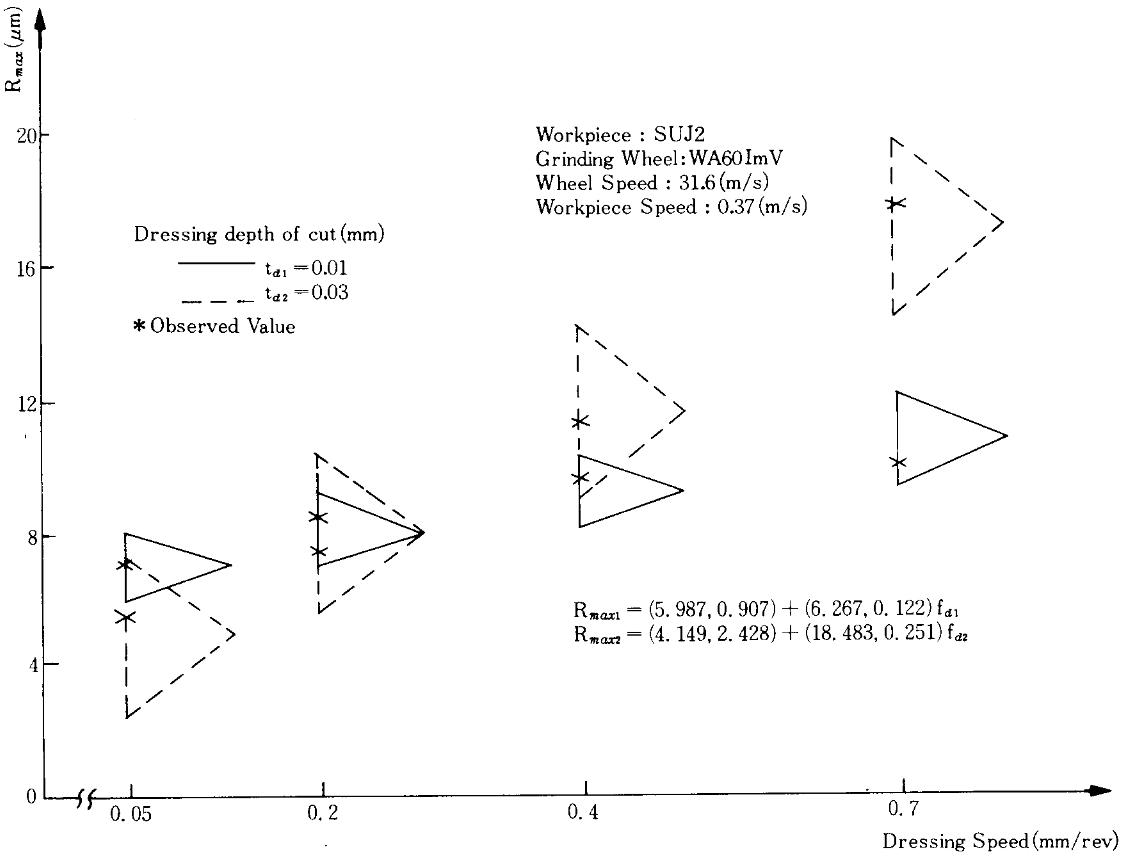


Fig. 2 Analysis result by using the Fuzzy Regression model

dition sides of the IF-THEN rules at hand. This is characteristic of deductive reasoning and its procedure is to start with a collection of facts and rules, and to try in an iterative manner, to find the available rules which condition side matches a fact (see 〔RULE A〕).

Also, backward-chaining reasoning systems tend to provide the goal-oriented focus missing in forward-chaining (see 〔RULE B〕).

Moreover, to deal with uncertain and ambiguous grinding knowledge, we employ fuzzy logic based on the fuzzy set theory. Fuzzy logic has been successfully used in several expert system[5][11].

For example, Fig. 3, indicates the reasoning process using the fuzzy production rule at the establishment of grinding depth of cut.

If the input constraints are S45C (workpiece), cylindrical plunge grinding (grinding method) and soluble type (grinding lubricant) as listed in Table 1 (A) of chapter 5, the decision of grinding depth of cut is derived from both the required surface roughness and the hardness and heat treatment of workpiece stored in the data file.

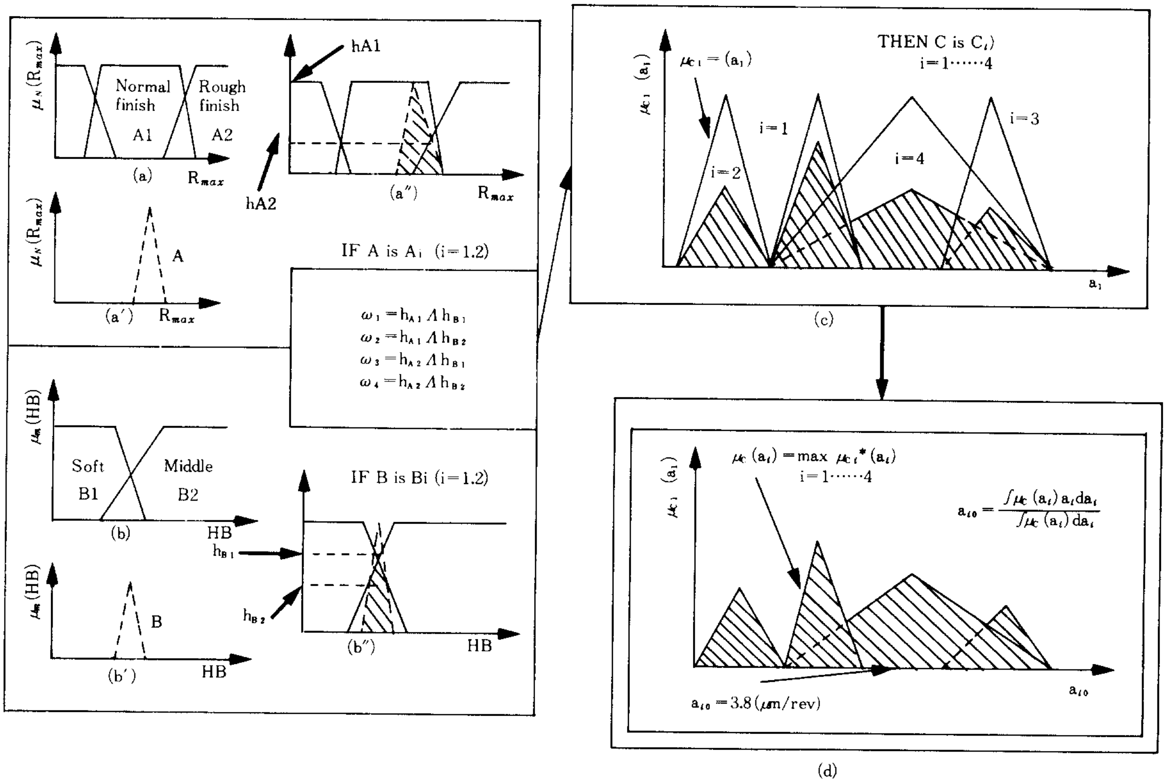


Fig. 3 Reasoning process in Fuzzy production system

That is, the eatablishment of grinding depth of cut is established as follows : A_i, B_i and C_i (i=1, 2) are maximum surface roughness, Brinel hardness and grdining depth of cut, and they are fuzzy sets on the product space parameters defined by membership function. The membership functions are represented by $A_i(R_{max})$, $B_i(HB)$ and $C_i(a)$.

Also, if the present ambiguous states are represented by fuzzy sets A and B, the membership functions are defined by $\mu_A(R_{max})$ and $\mu_B(HB)$, respectively. Now, degree of the fitting for the fuzzy production model about the (A and A_i) and (B and B_i) are calculated by

$$\left.\begin{aligned} H_{A1} &= \{\mu_{A1}(R_{max}) \wedge \mu_A(R_{max})\} = 1.0 \\ H_{A2} &= \{\mu_{A2}(R_{max}) \wedge \mu_A(R_{max})\} = 0.34 \\ H_{B1} &= \{\mu_{B1}(HB) \wedge \mu_B(HB)\} = 0.82 \\ H_{B2} &= \{\mu_{B2}(HB) \wedge \mu_B(HB)\} = 0.372 \end{aligned}\right\} \cdots\cdots\cdots\cdots (6)$$

Degree of the fitting for the antecedent can be derived by

$$\left.\begin{aligned} W_1 &= H_{A1} \wedge H_{B1} = (1.0) \wedge (0.82) = H_{B1} = 0.82 \\ W_2 &= H_{A1} \wedge H_{B2} = (1.0) \wedge (0.37) = H_{B2} = 0.37 \\ W_3 &= H_{A2} \wedge H_{B1} = (0.34) \wedge (0.82) = H_{A2} = 0.34 \\ W_4 &= H_{A2} \wedge H_{B2} = (0.34) \wedge (0.37) = H_{A2} = 0.34 \end{aligned}\right\} (7)$$

Also, if the priority the fuzzy production rule rely on the degree of weight represented by

α_i (i=1, ……, 4) = 1.0,

$\mu_{ci}^*(a) = \alpha_i\ \omega_i\ \mu_i\ (a)$ ………………… (8) 〔See Fig. 3 (c)〕

Therefore, we can calculate the output value denoted by fuzzy membership function

$\mu_c(a_i) = \max\ \mu_{ci}^*(a_i)$ ……………… (9) 〔See Fig. 3 (d)〕

The output value in Fig. 3(d) become the fuzzy set of membership function, we can obtain the grinding depth of cut by the following equation.

$$a_0 = \frac{\int \mu_c \cdot (a_i) \cdot a_i \cdot da_i}{\int \mu_c \cdot (a_i) \cdot da_i} \quad \cdots\cdots\cdots (10)$$

〔See Fig. 3(d)〕

Furthermore, in this system, referring work of an important knowledge during reasoning process is accomplished by the concrete default theory.

3. ARCHITECTURE OF THE DEVELOPED EXPERT SYSTEM

As shown in Fig. 4, the developed system is composed of interface, inference engine, knowledge base management system, grinding knowledge base, actual operation database, grinding trouble knowledge base, and temporary frames.

We used the KBMS (Knowledge Base Managment System) as a software tool, common Lisp and Fortran77 as computer

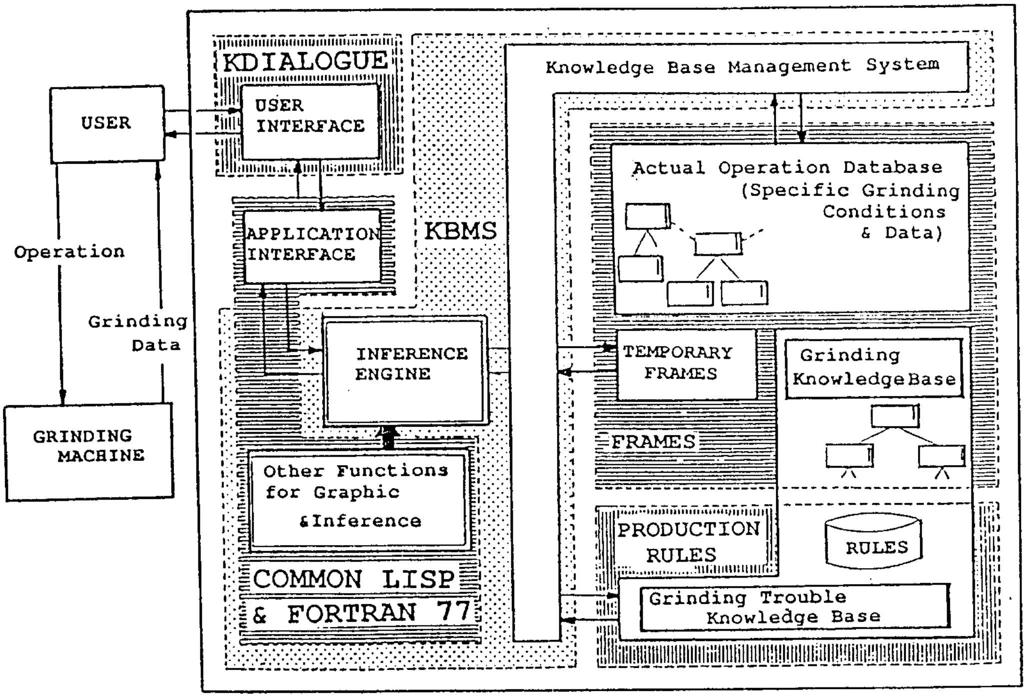


Fig. 4 Architecture for the developed grinding Expert system

languages, and Kdialog for the purpose of satisfying the user interface.

3. 1 Grinding Knowledge Base

The grinding knowledgebase in this system stored in common knowledge obtained from research papers and a skilled hand. Knowledge repersentaion for the grinding knowledgebase is described in various degrees of declarative and procedural knowledge contents. The grinding knowledge base is constructed by parameters for grinding condition, experimental equations, and procedural knowledge for setting the grinding conditions and trouble shooting. The grinding knowledge is accumulated to be classified into grinding method, grinding machine, kind of workpiece, shape of workpiece, kind of grinding wheel, shape of grinding wheel, grinding lubricant, kind of dresser, grinding conditions, dressing conditions and grinding result. Fig 5 indicates a part of the grinding knowledge base.

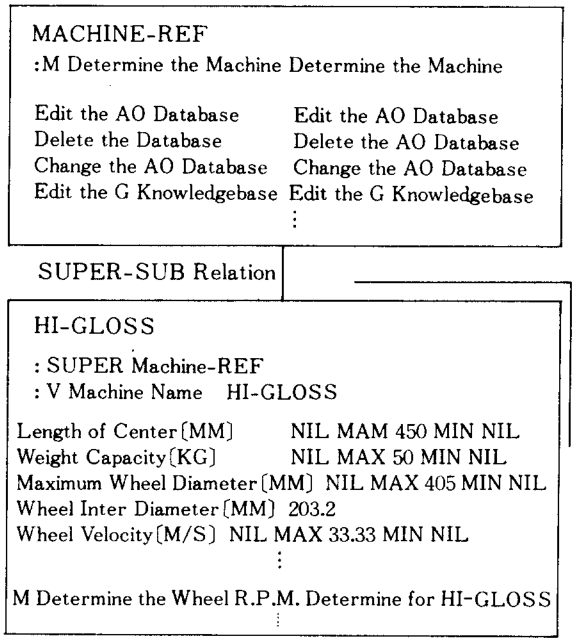


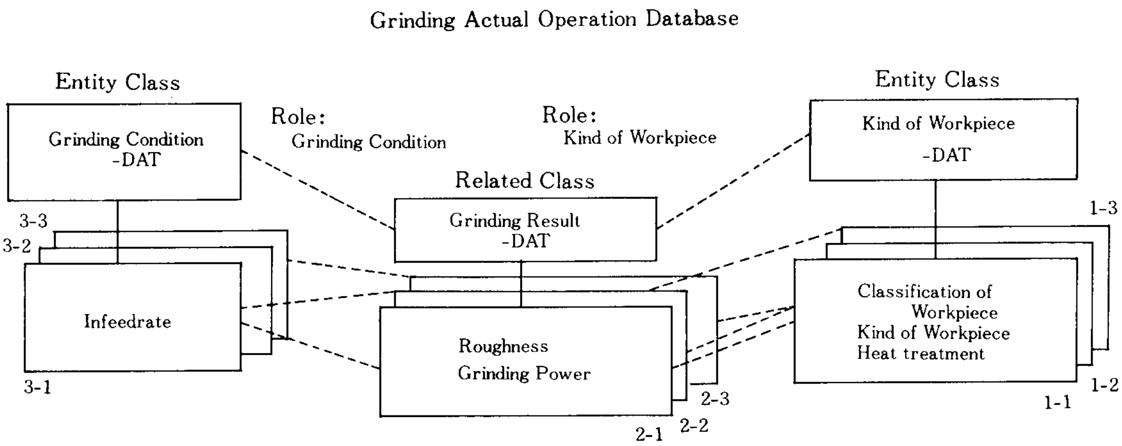
Fig. 5 Structure for the grinding knowledge base (grinding machine)

3. 2 Grinding Actual Operation Database

Due to the wide range of the various factors that influence the machining process, the grinding results are actually different from expectation of surface roughness and trouble in compared with pre-established machining condition. The recent papers[12-14] deal with the reliable mathematical model which is rendered indispensably necessary for the construction of database system. However, the grinding result have statistical and dispersive characteristics. Therfore, it is difficult to accumulate all the specialized knowlwdge. The specialized knowledge for the grinding operation is acquired from the actual operation database. Coefficients in the experimental equation, the suggested equations (Eq. 2 and Eq. 3) in section 2. 2, are obtained through the fuzzy regression model[6] and stored in the actual operation database.

Also, the database structure is designed for utilizing the grinding result according to the grinding conditions by classifying into functional group class. Fig. 6 indicates the grinding result data class interacts the grinding condition class and a part of structure.

To utilize the actual operation database, it requires a function that differentiate the grinding result in accordance with each conditions. The data of grinding process are stored in the instance under the each class. When we require the some grinding condition,



TARGET : Searching the Instance Frame of the Grinding Condition-DAT

Constraints : Classification of Workpiece = Carbon Steel   Instance 1-1
Kind of Workpiece = S45C
Heat Treatment = Annealing

Constraint : Roughness = (1.5 0.0 0.2 1.3 1.7 1.0)   Instance 2-1 2-2
RESULTS : Instance 3-1 3-4

Fig. 6 Interacts the actual operation data base during the establishment of cutting conditions

this system is easily performed by checking the result data accumulated in database. Therfore, the actual operation database is coped with uncertain grinding condition and qualitative knowledge. It can increase an efficency on the utilization of database.

3. 3 Grinding Trouble Knowledge Base

The grinding trouble knowledge base are stored in coping with the grinding trouble-shooting. The knowledge of trouble-shooting is adopted in symptom/cause rule-set method. The grinding trouble knowledgebase is divided into general and special knowledge for effectively coping with the various situations. When a trouble occurs during the process, strategic flow passes iteratively through five conceptional steps as shown in Fig. 7.

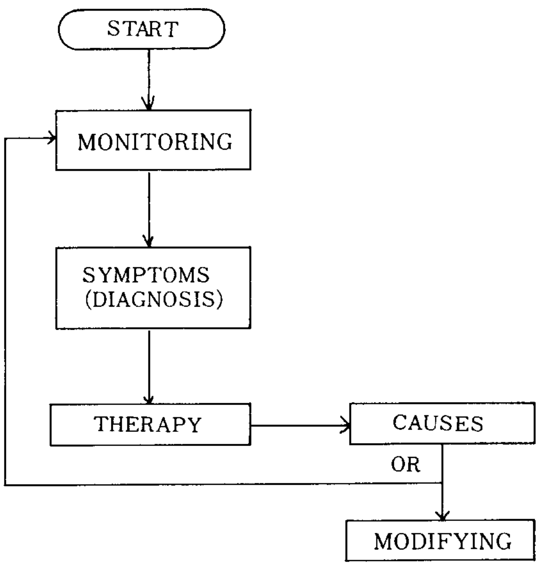


Fig. 7 Conceptional flow for the Trouble-shooting

1. Monitoring checks on information, and provides information which is derived from the trouble knowledge base. There are two types of monitoring information. The one is based on the general knowledge, and the other is based on the specialized knowledge.

In this system, the specialized knowledge is the actual signal based on the grinding power obtained from experimental data, and the general knowledge is the intuitional or experimental knowledge based on the common sense.

2. Symptom (Diagnosis) is the output of the monitoring. The developed system about the symptom deals with ground surface, grinding wheel and signal of grinding power.

3. Cause attempts to determine what parameter makes a symptom.

4. Modifying is the process of decision whether try therapy on the parameter.

5. Therapy is determining what to do, when the parameter is suspected of being faulty.

The occurrence of chatter and burning in the grinding process are one of the most important criteria for the grinding trouble. Therfore, kind of grinding trouble, in this system, adopts the chatter vibration, grinding burn and surface roughness. These troubles are the most frequent occurrence during the grinding process and have an effect on the surface finish. The knowledge of diagnosis and symptom are divided into object class by hierarchical decision tree method at firstly as shown in Fig. 8. Then, this is converted into IF-THEN rule.

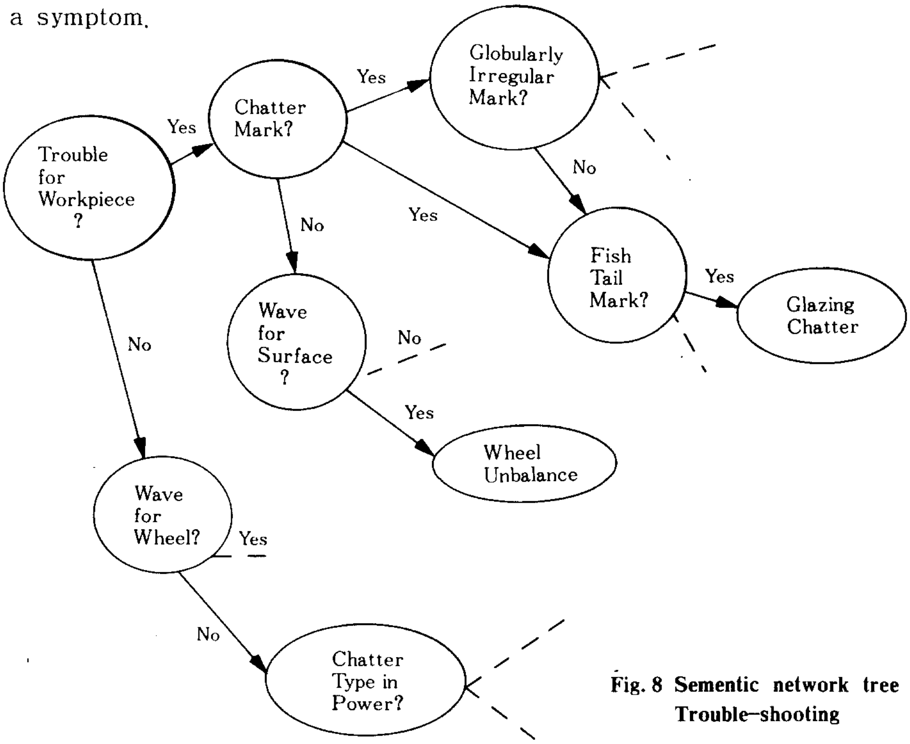


Fig. 8 Sementic network tree for Trouble-shooting

4.1 OPTIMUM FLOW FOR THE GRINDING EXPERT SYSTEM

Optimization of machining process generally requires identification of several operating parameters which will satisfy the objective subject to constraints. Optimal operating conditions arise due to a trade-off with fast removal rate of reduced machining time its associated cost without the grinding troubles. The production rates which can be attained by grinding are limited by various constraints. The constraints, in this system, include surface finish, grinding burn, chatter vibration and machine power capacity.

In the several papers[15-16], various method are reviewed for optimization of existing grinding operations. In this system, to satisfy the stated objective, a grinding cycle for cylindrical grinding cycle consists of a rough, find and spark-out stage as shown in Fig. 9.

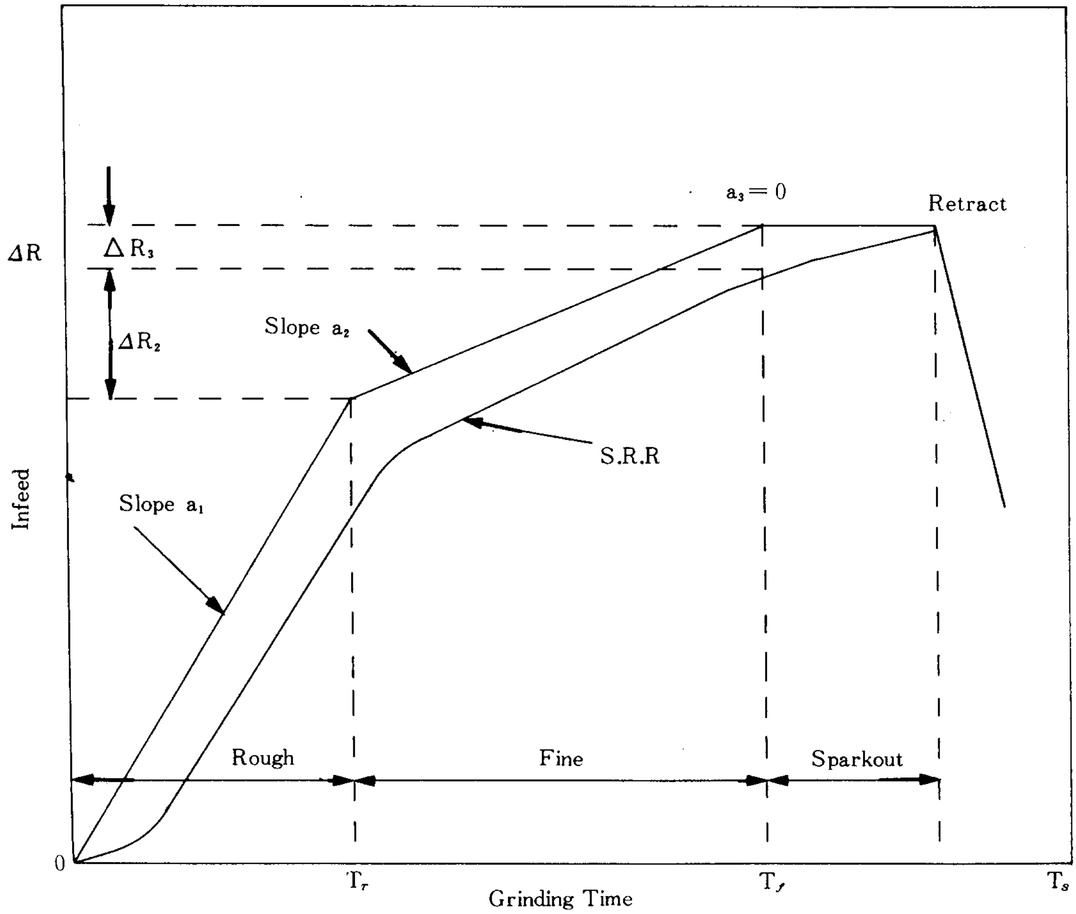


Fig. 9 Structure in grinding cycle adopted in this system

The objective in each cycle is to maximize the removal rate or minimize cycle time without violating product constraints. The optimization strategy adopts the quantitative optimization system utilizing the fuzzy theory as stated above in charter 3. 2. Fig. 10 indicates flow steps for the establishment of optimum machining conditions. The flow steps are as follows :

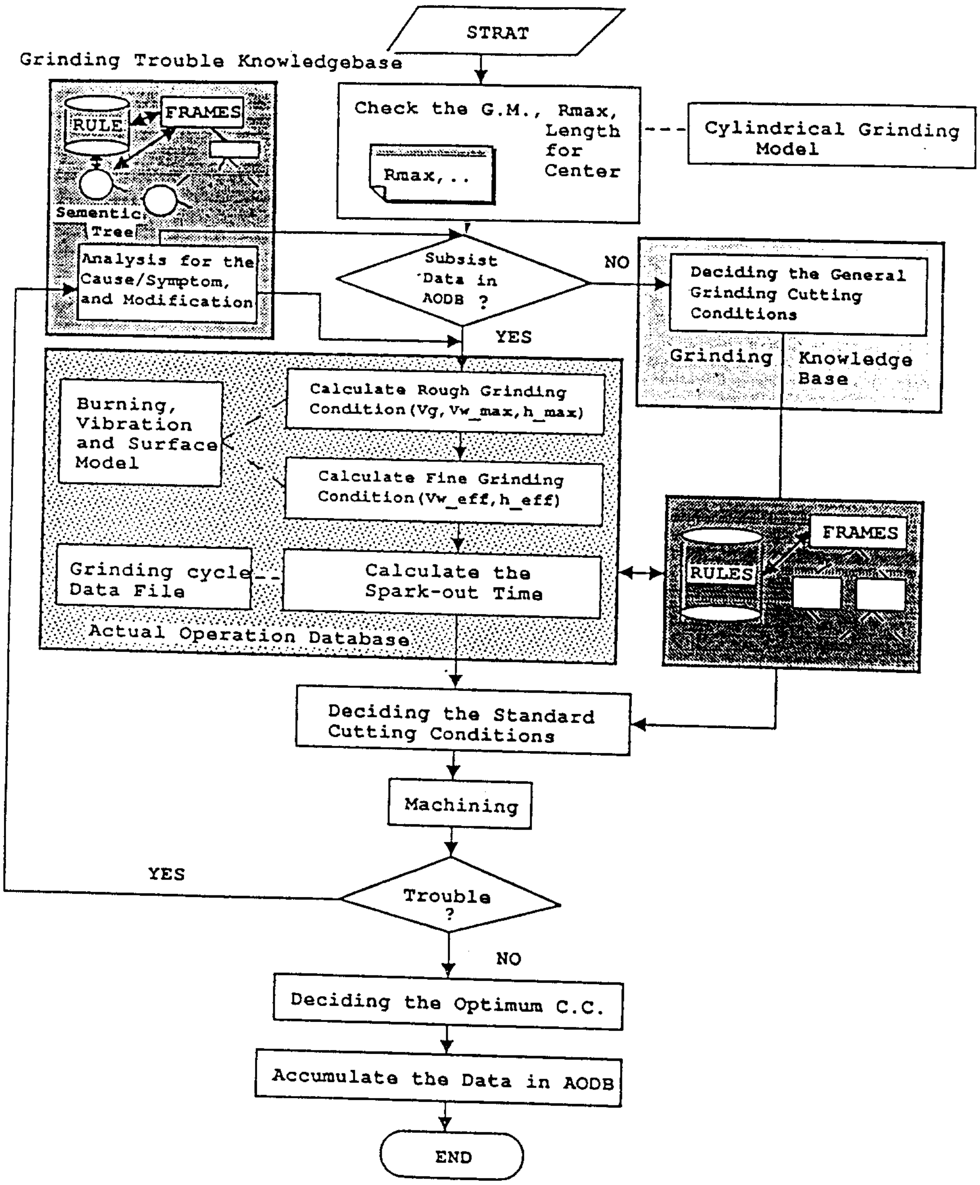


Fig. 10 Optimum flow for the establishment of cutting conditions

(1) Check the grinding method, kind of workpiece, required surface roughness, and machine power capacity, and so on.

For the rough grinding state, grinding power may be used maximum capacity which do not occur the grinding burn.

(2) To apply the user's requirment, the objective constraints try to match the antecedent from the actual operation database (AODB). If the matching is succeeded, go to next step(3). Or do not succeed, the grinding condition, so called general standard machining condition, is determined from grinding knowledge base (GKB), and go to step (4).

(3) All the antecedent part may be matched, calculate the adaptable grinding machining conditions to each cycle phase. In this system, grinding cycle are classified to three steps in order to satisfy the stated objective.

Rough grinding phase is calculated in maximum grinding depth of cut (a_r) and workpiece velocity (V_w) that do not occur the chatter vibration and burning. Also, the main objective of the fine grinding is to obtain the correct geometrical form and required surface roughness. The grinding depth of cut during this phase should be relatively low.

The surface roughness is considered to be functionally dependent upon the grinding depth of cut and workpiece velocity in case of cylindrical plunge grinding.

(4) If the standard machining conditions are determined from actual operation database or grinding knowledgebase, the grinding process is started.

(5) Occur the trouble during the machining process, utilizing the grinding trouble database, the modified machining conditions are calculated against the three phase, respectively.

(6) Do not occur the trouble during the process, this machining condition are determined to initial optimal machining conditions, and that result data analyzed coefficient factors are accumulated in actual operation database by using the fuzzy linear possibility model described in section 3. 2.

In this system, the optimization object is to maximize removal rate which satisfying workpiece burn and chatter vibration. The division of the grinding operation into the rough and fine phase requires a decomposition of the optimization task.

Additionally, Establishment of grining wheel component and dressing conditions are are determined to previous step.

Furthermore, the performance of the grinding process is the material removal rate which for cylindrical grinding can be written :

$$Z = B \cdot V_w \cdot a \quad \cdots\cdots (11)$$

Where, B is wheel width(mm) and Z is amount of material removal per unit time (mm^3/sec). The objective of the optimization is to maximize Z subject to the constraints of workpiece burn, chatter vibration and surface roughness requirement. In the cylindrical plunge grinding, the wheel velocity, workpiece diamenter and grinding width is fixed. The performance parameter can be taken as the a and V_w

The optimization problem can be written :

$$\begin{aligned} &\text{Maximize : } a,\ V_w \\ &\text{Subject to } P_r \leq P_r(b) \\ &\qquad\qquad R_{max} \leq R_{max(max)} \end{aligned} \quad \text{------------ (12)}$$

Where, $P_r(b)$ is grinding power at the occurrence of grinding burn, and $R_{max(max)}$ is maximum for surface roughness limit.

performed by the rule and frame database. The activation of method under the knowledge base is accomplished in conjunction with temporary frames.

For instance, Table 1 indicates the practical implementation results about the fine grinding cycle. Under the various conditions in Table 1(B), the results deduced from reasoning process are summarized in Table 1(C). Each

Table 1 Implementation results for several grinding constraints

A. Common Condition s at the Setting-up			
Type of grinding : Cylindrical and plunge cut Workpiece : S45C Grinding lubricant : Water (soluble type)			
B. Changed Conditions from the Setting-up			
	(1)	(2)	(3)
Heat treatment	Normalizing	Normalizing	Quenching and Annealing
Required surface finish	Fine 1(± 0.1)	Normal 5(± 1)	Normal 5(± 1)
C. Results of Grinding Conditions Obtained from Reasoning Process			
	(1)	(2)	(3)
Grain	A	A	A
Grain size	60	46	46
Grade	K	L	L
Bond	V	V	V
Structure	M2	M2	M2
Grinding wheel velocity(m/s)	31.8	31.8	31.8
Workpiece velocity(m/s)	0.144	0.144	0.144
Infeedrate(μm/rev)	2.4	3.8	3.3
Dressing depth of cut(μm/rev)	20.0	22.5	22.5
Dressing speed(mm/rev)	0.200	0.325	0.325

5. IMPLEMENTION RESULT FOR THE MACHINING CONDITION

The implementation of this system is

grinding condition is coped with the input data constraints. When the required surface roughness change from fine to normal finish as listed in Table 1(B), the grinding conditions for grainsize, grade, grinding depth of cut, dressing depth of cut, and dressing lead are changed from Table 1[C-(1)] to Table 1[C-(2)]. This means that the change of surface roughness is effectively reflected to the establishment of the grinding condition. However, the grinding wheel velocity (V_g) and the workpiece velocity (V_w) are unchanged beacause they are limited by mechainical constraints.

This simulation results are well agreed with the result of papers[17-20] and have effected on the establishment of the grinding conditions.

5. CONCLUSIONS

This paper has presented an architecture and basic strategy for grinding expert system. We have suggested an effective mechanism for knowledge base based on fuzzy set theory. This system can handle vague and uncertain knowledge, and presents a scheme for integrating data with various kinds of grinding knowledge in knowledge base. The knowledge base establishes the tree parts so as to functionally cope with various knowledge. The developed system performed in using the KBMS and engineering work station (Apollo DN4000).

1. The hybrid model based on frames and production rules is utilized to represent domain specific knowledge such as experiences and intuitions. Also, a default theory for the frame and fuzzy logic for the rule based on fuzzy set theory are adopted to utilize the vague grinding knowledge.

2. The developed system is composed of interface, inference engine, grinding knowledge base, actual grinding operation database, grinding troule knowledge base, knowledge base management system, and several temporary frames.

3. The procedures which are necessary to determine the grinding conditions are separated into modules which are accumulated to the grinding knowledge base. The grinding data are used to calculate coefficient factors of exeperimental equations and stored in the actual operation database.

4. This system is based upon a practical optimization strategy designed to maximize removal rates subject to several constraints on chatter vibration, workpiece burn and surface roughness, although other parameter limitations are considered.

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