APPLICATION OF AHP IN TOOL DESIGN

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ABSTRACT

This paper presents the application of AHP in metal cutting tool design. Firstly, an analysis is given to assert that the key problem in tool design, the optimization of tool geometrical angle combinations, is a kind of multicriteria decision making (MCDM) problem. Secondly, taking the design of face milling cutter used in milling plate blank of Titanium Alloy as an example, an optimized combination of tool geometrical angles is obtained using AHP. It is proved that AHP has obvious advantages over traditional methods and is an economical and effective optimizing method.

AHP has already been applied successfully in planning and management, but rarely in engineering. In this paper, an attempt is made to apply AHP in metal cutting tool design of mechanical manufacturing engineering.

Any metal cutting tool has a set of geometrical angles. Different geometrical angle combinations can bring about different degrees of tool producibility and tool cutting results. Therefore, it can be said that the key problem of tool design is the optimization of tool geometrical angle combinations. With the traditional method, tools with different combinations of geometrical angles need to be designed and manufactured first, then, cutting tests are carried out for each of them. After comparing and analysing the test results, the best one is selected and used in production. The cost of using this method is very expensive for multi-edge cutting tools with complicated structures, such as face milling cutter. Using this method not only costs a great amount of manpower, material, financial resources and time, but also limits the optimizing range. So, more economical and effective methods should be sought.

1. The feasibility of using AHP

The optimization of tool geometrical angle combinations is a typical multicriteria decision making problem and it will be illustrated by the example of Titanium Alloy plate blank face milling. When designing the face milling cutter to be used, its geometrical angle combination should meet following requirements:

1) During the metal cutting process, reduce as far as possible the tool adhesiveness caused by the chemical activity of Titanium Alloy.
2) Resistance to impact in order to prevent tool break due to

the roughness, hard and brittle oxide of the surface of Titanium Alloy plate blank.

3) The chip should be in silvery white color and short helical shape and be retrieved later.

4) Easy manufacturing.

Obviously, the best tool geometrical angle combination is the one that can best meet above requirements simultaneously. So, the optimization of tool geometrical angle combinations, by its nature, is a MDCM problem. The basic problem is to choose the best from a set of competing alternatives under conflicting criteria. The AHP provides us with a comprehensive framework for solving the problem[4]. Thus it is feasible to solve the optimization problem of geometrical angle combinations in tool design with AHP.

2. The concrete application of AHP in optimizing tool geometrical angle combinations

Still taking the above example to show the concrete application of AHP. According to AHP, the optimizing steps are as follows: [3][4][5]

1) Define the problem: Optimizing the geometrical angle combination of indexable face milling cutter used in milling Titanium Alloy plate blank.

2) Construct the hierarchy structure: According to the principles of purposefulness; integrity and inter-dependence; hierarchy; comparability; and simplicity, following hierarchy is structured.

(1) Single overall objective (A): Optimizing the geometrical angle combination of face milling cutter.

(2) Sub-objectives (B): According to the characteristics of workpiece material, peculiarity of workpiece, processing requirements and producibility of tool manufacturing, the overall objective is divided into four sub-objectives.

a. Tool producibility(B1)
b. Impact resistivity(B2)
c. Cementation reducing(B3)
d. Chip in silvery white color and short helical shape(B4)

(3)Criteria (C): In order to transform above sub-objectives into certain clear, concrete and well comparable tool geometrical angles and parameters as evaluating criteria, five geometrical angles and parameters, which have main restriction on sub-objectives, are taken as element of criteria level.

a. Cutting edge inclination λs (C1): Increasing edge inclination can reduce chip cementation and force chip curving. The gradual entry of edge can increase impact resistance.[2]

b. Working clearance αf (C2): increasing αf can reduce the friction of major flank and chip cementation. But too great αf

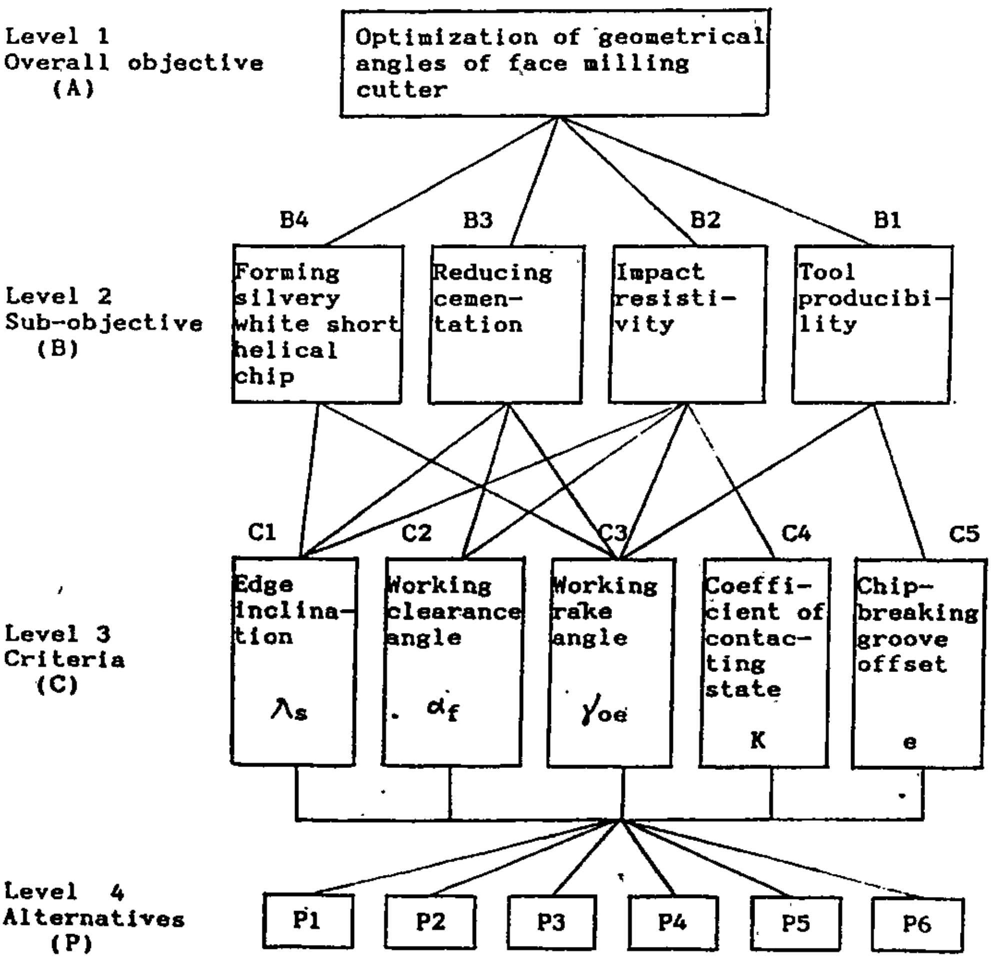
will decrease edge strength and impact resistivity.

c. Working orthogonal rake γ_{oe} (C3):[6] Increasing γ_{oe} can make tool sharper and cementation less easy to occur. γ_{oe} can still have its influence on chip curving and discharging. Too great face angle will reduce impact resistivity and increasing chip-breaking groove offset is unfavourable to tool manufacturing.

d. Coefficient of contact state K (C4): The value of K can have influence on tool impact resistivity.

e. Chip-breaking groove offset e (C5): The greater the absolute value of e, the more difficult the tool manufacturing.

(4) Alternatives(P): The angle ranges of cutting edge angle Kr, axial rake γ_p and radial rake γ_f, as recommended by [1,7], for Titanium Alloy milling can make up 100 different alterna-



tives. 25 alternatives are first chosen out by experience. In order to reduce the work amount of making pairwise comparison matrices and calculation, 6 better and most competitive alternatives with different features are chosen from the 25 alternatives for final optimization. Structured hierarchy is shown as above.

3) Construction of pairwise comparison matrices: According to the hierarchy mentioned above, 10 comparison matrices are constructed. (See Appendix)

4) Single sequencing, overall sequencing and consistency test: Processed by microcomputer, the single sequencing weights of each level are obtained (See Appendix). The composite weights of hierarchy overall sequencing of Level 3 are: C1=0.44175; C2=0.21728; C3=0.18399; C4=0.09827; C5=0.05871. The composite weights of hierarchy overall sequencing of Level 4 are: P1=0.08977; P2=0.11503; P3=0.15586; P4=0.15591; P5=0.19999; P6=0.28344. In addition, the consistency tests indicates that comparison matrices have very satisfactory consistency.

5) Analysis of the results: A set of geometrical angle combination was chosen from alternative P6 which has the greatest composite weight.

$\lambda s=14.9$; $\alpha f=8.8$; $\gamma oe=-2.7$; $K=-0.064$; $e=-45.1$

That is: $Kr=50$; $\gamma p=7$; $\gamma f=-15$

Using the indexable face milling cutter designed and manufactured with above geometrical angle combination, good results are obtained in milling plate blank of Titanium Alloy TA2. Using YG8 cemented carbide blade, when cutting speed v<87.96 m/min, depth of cut ap<8 mm, feed per tooth af<0.14 mm/z and dry cutting, the chip is in silvery white color and in short helical shape within the tool life and meets the requirement of Titanium chip retrieval. The roughness of workpiece surface is stable at Ra 3.2 um. The production efficiency is increased by 63.52% and the tool cost is reduced by more than 70%.

3. Conclusion

1) Above example is a successful application of AHP in tool design. Obvious economical benefits are achieved because the optimal tool geometrical angle combination can meet the four main requriements comprehensively.

2) Comparing with traditional method, the optimization with AHP has following advantages:

(1) Save both the high cost of designing and manufacturing many tools with different geometrical angle combinations and the cost of cutting tests.

(2) Without the so many cutting tests, all geometrical angle combinations can be taken for optimization. The enlarged optimizing range would not miss the best alternative.

3) The application of AHP in optimizing tool geometrical angle combinations has universal significance. Though cutting tools are of great many types and with different service conditions, like face milling cutter, geometrical angle optimization of different types of tool is of the comprehensive comparison problem of multi-objectives, multi-criteria and multi-alternatives. AHP decomposes the complex comparison problem into hierarchical and single pairwise comparisons, thus greatly facilitating the alternative comparison. It can be seen if AHP was applied to the design of every type of tool there would be huge economical benefits.

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Appendix: Comparison Matrices

1. Comparison matrix (elements of sub-objectives B with respect to the overall objective A)

A	B1	B2	B3	B4	W
B1	1	1/3	1/5	1/5	0.07045
B2	3	1	1/2	1/2	0.19259
B3	5	2	1	1	0.63830
B4	5	2	1	1	0.36830

$\lambda max=4.004$, CI=0.0014, RI(4)=0.9 CR=0.0015

2. Comparison matrices (elements of criteria C with respect to sub-objectives B1,B2,B3 and B4)

1) B1--C

B1	C3	C5	W
C3	1	1/5	0.16667
C5	5	1	0.83333

$\lambda max=2$
CI=0
RI(2)=0
CR=0

2) B2--C

B2	C1	C2	C3	C4	W
C1	1	1/2	1/5	1/7	0.06408
C2	2	1	1/3	1/4	0.11855
C3	5	3	1	1/2	0.30805
C4	7	4	2	1	0.50933

$\lambda max=4.021$
CI=0.0071
RI(4)=0.9
CR=0.0079

3) B3--C

B3	C1	C2	C3	W
C1	1	1/2	3	0.33253
C2	2	1	3	0.52783
C3	1/3	1/3	1	0.13964

$\lambda max=3.054$, CI=0.0268
RI(3)=0.58, CR=0.0462

4) B4--C

B4	C1	C3	W
C1	1	5	0.83333
C3	1/5	1	0.16666

$\lambda max=2$, CI=0
RI(2)=0, CR=0

3. The composite weights of hierarchy overall sequencing of Level 3:

C1=0.44175 C2=0.21728 C3=0.18399

C4=0.09827 C5=0.05871

CI=0.0112 RI=0.3873 CR=0.0290

4. Comparison matrices (elements of alternatives P with respect to criteria C1,C2,C3,C4 and C5)

1) C1--P

C1	P1	P2	P3	P4	P5	P6	W
P1	1	1/2	1/3	1/3	1/5	1/6	0.04728
P2	2	1	1/2	1/2	1/3	1/3	0.08455
P3	3	2	1	1	1/2	1/3	0.13503
P4	3	2	1	1	1/2	1/3	0.13503
P5	5	3	2	2	1	1/2	0.23849
P6	6	3	3	3	2	1	0.23849

$\lambda max=6.074$
CI=0.0147
RI(6)=1.24
CR=0.0119

2) C2--P

C2	P1	P2	P3	P4	P5	P6	W
P1	1	1/2	1/3	1	1/2	1	0.09868
P2	2	1	1/2	2	1	2	0.18830
P3	3	2	1	3	2	3	0.32763
P4	1	1/2	1/3	1	1/2	1	0.09868
P5	2	1	1/2	2	1	2	0.18830
P6	1	1/2	1/2	1	1/2	1	0.09868

$\lambda max=6.014$
CI=0.0028
RI(6)=1.24
CR=0.0022

3) C3--P

C3	P1	P2	P3	P4	P5	P6	W
P1	1	1	2	1/3	1/2	1/4	0.08912
P2	1	1	2	1/3	1/2	1/4	0.08912
P3	1/2	1/2	1	1/4	1/3	1/5	0.05461
P4	3	3	4	1	2	1/2	0.24803
P5	2	2	3	1/2	1	1/2	0.16241
P6	4	4	5	2	2	1	0.35672

$\lambda max=6.065$
CI=0.013
RI(6)=1.24
CR=0.0105

4) C4--P

C4	P1	P2	P3	P4	P5	P6	W
P1	1	1	1	1/2	1/2	1/3	0.09868
P2	1	1	1	1/2	1/2	1/3	0.09868
P3	1	1	1	1/2	1/2	1/3	0.09868
P4	2	2	2	1	1	1/2	0.18330
P5	2	2	2	1	1	1/2	0.18330
P6	3	3	3	2	2	1	0.32736

$\lambda max=6.014$
CI=0.0028
RI(6)=1.24
CR=0.0022

5) C5--P

C5	P1	P2	P3	P4	P5	P6	W
P1	1	2	4	2	4	4	0.36364
P2	1/2	1	2	1	2	2	0.18182
P3	1/4	1/2	1	1/2	1	1	0.09091
P4	1/2	1	2	1	2	2	0.18182
P5	1/4	1/2	1	1/2	1	1	0.09091
P6	1/4	1/2	1	1/2	1	1	0.09091

$\lambda max=6$
CI=0
RI(6)=1.24
CR=0

5. The composite weights of hierarchy overall sequencing of Level 4:

P1=0.08977	P2=0.11503	P3=0.15586
P4=0.15591	P5=0.19999	P6=0.28344
CI=0.0098	RI=1.24	CR=0.0079