Machining Technology Optimization of Middle-convex and Varying Ellipse Piston Based on Fuzzy Logic

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Abstract. Machining precision of the middle-convex and varying ellipse piston is an important aspect influenced by machining technological, and influencing the functional performance of engine directly. The scientific and rational machining technological is the key to determine the manufacturing quality and cost-performance ratio of the middle-convex and varying ellipse piston. Machining technological evaluation of the middle-convex and varying ellipse piston is one important and complicated process influenced by many different factors directly, the fuzzy comprehensive evaluation method is proposed to evaluate the machining technological of the middle-convex and varying ellipse piston based on fuzzy logic. Finally, an example of machining technological evaluation on one certain middle-convex and varying ellipse piston for the illustration of the proposed methodology is presented. The feasibility and rationality of the methodology are verified by the experimental result.

Introduction

The middle-convex and varying ellipse piston is known as the heart of engine, its machining technological influences the functional performance of engine directly, and the scientific and rational machining technological also is the key to determine the manufacturing quality and cost-performance ratio of the middle-convex and varying ellipse piston [1-4]. However, how to evaluate the machining technological of middle-convex and varying ellipse piston synthetically is one complicated problem for the many different influencing factors.

The fuzzy comprehensive evaluation is one kind of effective multitudinous factors decision method used to evaluate the object synthetically affected by various factors [4-8], and the influence factors of the machining technological of middle-convex and varying ellipse piston always are uncertain [9-11], so the fuzzy comprehensive evaluation is the optimum method to evaluate machining technological of middle-convex and varying ellipse piston.

Decision-making of machining technological of piston based on fuzzy logic

Establishment of influence factor set

Influence factor set includes various factors influencing the machining technological design scheme directly. Manufacturing quality, machining cost and machining efficiency are the key considerations in decision-making of machining technological of middle-convex and varying ellipse piston design scheme. The influencing factor of manufacturing quality includes machining precision, surface roughness, dimensional precision and geometrical precision. The influencing factor of machining cost mainly takes into account wages, maintenance costs and depreciation expense of the manufacturing equipment, fixture costs and other expense. The influencing factor of machining efficiency mainly includes readiness time, installation and chucking time, machining time, auxiliary time and break time.

The influence factor set U of decision-making of machining technological is expressed as

$$U = \begin{pmatrix} u_1 & u_2 & u_3 \end{pmatrix} \tag{1}$$

here, subset u_1, u_2, u_3 respectively indicates manufacturing quality, machining cost and machining efficiency.

The manufacturing quality subset u_1 is expressed as

$$u_1 = \begin{pmatrix} u_{11} & u_{12} & u_{13} & u_{14} \end{pmatrix} \tag{2}$$

here, $u_{11}, u_{12}, u_{13}, u_{14}$ respectively indicates machining precision, surface roughness , dimensional precision and geometrical precision.

The machining cost subset u_2 is expressed as

$$u_2 = \begin{pmatrix} u_{21} & u_{22} & u_{23} & u_{24} & u_{25} \end{pmatrix} \tag{3}$$

here, $u_{21}, u_{22}, u_{23}, u_{24}, u_{25}$ respectively indicates wages, maintenance costs, depreciation expense, fixture costs and other expense.

The machining efficiency subset u_3 is expressed as

$$u_3 = \begin{pmatrix} u_{31} & u_{32} & u_{33} & u_{34} & u_{35} \end{pmatrix} \tag{4}$$

here, $u_{31}, u_{32}, u_{33}, u_{34}, u_{35}$ respectively indicates readiness time, installation and chucking time, machining time, auxiliary time and break time.

Establishment of evaluation set

Evaluation set is comprised of various possible evaluate results provided by the decision makers. Evaluation set of manufacturing quality subset V_1 is expressed as

$$V_1 = \begin{pmatrix} A_1 & B_1 & C_1 & D_1 & E_1 \end{pmatrix} \tag{5}$$

here, A_1, B_1, C_1, D_1, E_1 respectively indicates good, relatively good, general, relatively bad and very bad.

Evaluation set of machining cost subset V_2 is expressed as

$$V_2 = \begin{pmatrix} A_2 & B_2 & C_2 & D_2 & E_2 \end{pmatrix} \tag{6}$$

here, A_2, B_2, C_2, D_2, E_2 respectively indicates high, relatively high, general, low and very low.

Evaluation set of machining efficiency subset V_3 is expressed as

$$V_3 = \begin{pmatrix} A_3 & B_3 & C_3 & D_3 & E_3 \end{pmatrix} \tag{7}$$

here, A_3, B_3, C_3, D_3, E_3 respectively indicates high, relatively high, general, low and very low.

To simplify problems, the evaluation sets of manufacturing quality subset V_1, machining cost subset V_2 and machining efficiency subset V_3, are unified into one evaluation set V, and it is expressed as

$$V = \begin{pmatrix} v_1 & v_2 & v_3 & v_4 & v_5 \end{pmatrix} \tag{8}$$

here, v_1, v_2, v_3, v_4, v_5 respectively indicates excellent, good, middle, pass muster and bad.

Establishment of weight set

Weight set is comprised of weight number reflecting the importance of every influence factor. Assuming a_i is the weight number of influence factor u_i, weight set A is expressed as

$$A = \begin{pmatrix} a_1 & a_2 & \mathbf{L} & a_m \end{pmatrix} \tag{9}$$

Usually, the weight number of all influence factors need to satisfy the polarity and nonnegativity conditions. i.e.

$$\begin{cases} \sum_{i=1}^{m} a_i = 1 \\ 0 \le a_i \le 1 \end{cases} \tag{10}$$

Toward one same evaluation target, different evaluator maybe has the different attitude, and the weight numbers offered by evaluators also are different. In this paper, the weighting method is adopted to determine the weight number of every influence factor. Firstly, to make a weight distribution questionnaire (shown as table 1), and then distributing the questionnaire to some experts and related people to fill in the optimum weight number who believe, finally, taking bake the weight distribution questionnaires and calculating the weight number A of the evaluation target using weighting method.

Table 1. Weight Distribution Questionnaire

influence factor u_i	u_1	u_2	u_3	Σ
weight number a_i	a_1	a_2	a_3	1

The weight set A is calculated through the statistical investigation of the influence weight on decision-making of machining technological of the middle-convex and varying ellipse piston of the subsets u_1, u_2 and u_3. The result of statistical calculation is expressed as

$$A = \begin{pmatrix} 0.537 & 0.185 & 0.278 \end{pmatrix} \tag{11}$$

As the same way, the results of statistical calculation of the weight sets A_1, A_2 and A_3 of the subsets u_1, u_2 and u_3 also are expressed as

$$A_1 = \begin{pmatrix} 0.337 & 0.365 & 0.146 & 0.152 \end{pmatrix} \tag{12}$$

$$A_2 = \begin{pmatrix} 0.255 & 0.217 & 0.216 & 0.159 & 0.153 \end{pmatrix} \tag{13}$$

$$A_3 = \begin{pmatrix} 0.136 & 0.147 & 0.388 & 0.173 & 0.156 \end{pmatrix} \tag{14}$$

Determination of the Membership Function

Determine the degree of membership is one of the most important sectors to determine the degree of membership for decision-making on the machining technological of the middle-convex and varying ellipse piston using the methodology of fuzzy synthetic evaluation influencing the evaluate results

directly. The degree of membership of the j-th evaluating indicator of the influence factor u_i can be calculated with the membership function. The weight of the evaluating indicator a_{ij} or the span of the value a_{ij} of the degree of membership m_{ij} can be calculated using the methodology of fuzzy statistical analysis on the degree of membership of the j-th evaluating indicator of the influence factor u_i provided by every expert. The value a_{ij} of the degree of membership of the influence factor m_{ij} is shown as table 2.

Table 2. The Value a_{ij} of the Degree of Membership of m_{ij}

factor set	factor subset	v_1	v_2	$\mathbf{L}$	v_m
u_i	u_{i1}	$a_{10} - a_{11}$	$a_{11} - a_{12}$	$\mathbf{L}$	$a_{1m-1} - a_{1m}$
	u_{i2}	$a_{20} - a_{21}$	$a_{21} - a_{22}$	$\mathbf{L}$	$a_{2m-1} - a_{2m}$
	$\mathbb{N}$	$\mathbb{N}$	$\mathbb{N}$	$\mathbb{N}$	$\mathbb{N}$
	u_{in}	$a_{n0} - a_{n1}$	$a_{n1} - a_{n2}$	$\mathbf{L}$	$a_{nm-1} - a_{nm}$

Based on the table 2, the membership function is structured as follows

$$m_{i1}(x) = \begin{cases} 1 & (a_{i0} \leq x \leq a_{i1}) \\ (a_{i2} - x)/(a_{i2} - a_{i1}) & (a_{i1} \leq x \leq a_{i2}) \\ 0 & a_{i2} \leq x \leq a_{im} \end{cases} \tag{15}$$

here, $i = 1, 2, \mathbf{L}, n$.

$$m_{ij}(x) = \begin{cases} 0 & (a_{i0} \leq x \leq a_{ij-2}) \\ (x - a_{ij-2})/(a_{ij-1} - a_{ij-2}) & (a_{ij-2} \leq x \leq a_{ij-1}) \\ 1 & (a_{ij-1} \leq x \leq a_{ij}) \\ (a_{ij+1} - x)/(a_{ij+1} - a_{ij}) & (a_{ij+1} \leq x \leq a_{im}) \\ 0 & (a_{ij} \leq x \leq a_{ij+1}) \end{cases} \tag{16}$$

here, $i = 1, 2, \mathbf{L}, n$ and $j = 2, 3, \mathbf{L}, m-1$.

$$m_{im}(x) = \begin{cases} 0 & (a_{i0} \leq x \leq a_{im-2}) \\ (x - a_{im-2})/(a_{im-1} - a_{im-2}) & (a_{im-2} \leq x \leq a_{im-1}) \\ 1 & (a_{im-1} \leq x \leq a_{im}) \end{cases} \tag{17}$$

here, $i = 1, 2, \mathbf{L}, n$.

Degree of membership m_{ij} of the j-th evaluating indicator of the influence factor u_i on one certain machining technological of the middle-convex and varying ellipse piston can be calculated through the membership function, equations (15), (16) and (17).

Fuzzy Comprehensive Evaluation

Primary fuzzy comprehensive evaluation

Assuming the primary fuzzy comprehensive evaluation is evaluated on the influence factor u_i in the influence set U, the degree of membership m_{ij} of the j-th evaluating indicator of the influence factor u_i can be calculated through the membership function, and the evaluation result of the single factor u_i can be expressed by the fuzzy set R_{ij}

$$R_{ij} = \frac{m_{i1}}{v_1} + \frac{m_{i2}}{v_2} + \mathbf{L} + \frac{m_{im}}{v_n} \tag{18}$$

here, R_{ij} is the evaluation set of the single factor, it is expressed simply as

$$R_{ij} = \begin{pmatrix} r_{i1} & r_{i2} & \mathbf{L} & r_{im} \end{pmatrix} \tag{19}$$

Similarly, the evaluation set corresponding to every influence factor u_i can be obtained. And the single factor evaluation matrix R_i is expressed as

$$R_i = \begin{bmatrix} R_{i1} & R_{i2} & \mathbf{L} & R_{i4} \end{bmatrix}^T \tag{20}$$

here, R_i is the single factor fuzzy evaluation matrix.

The primary evaluation set B_i can be obtained through the fuzzy comprehensive evaluation on the influence factor u_i.

$$B_i = A_i \mathbf{o} R_i = \begin{pmatrix} b_{i1} & b_{i2} & \mathbf{L} & b_{im} \end{pmatrix} \tag{21}$$

Secondary fuzzy comprehensive evaluation

With the primary evaluation set B_1, B_2, $\mathbf{L}$, and B_k, the single factor evaluation matrix R of the influence factor set U can be expressed as

$$R = \begin{bmatrix} B_1 \\ B_2 \\ \mathbf{M} \\ B_K \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \mathbf{L} & b_{1m} \\ b_{21} & b_{22} & \mathbf{L} & b_{2m} \\ \mathbf{M} & \mathbf{M} & \mathbf{M} & \mathbf{M} \\ b_{k1} & b_{k2} & \mathbf{L} & b_{km} \end{bmatrix} \tag{22}$$

The fuzzy comprehensive evaluation set B can be obtained through the fuzzy comprehensive evaluation on the influence factor set U, and it can be expressed as

$$B = A \mathbf{o} R = \begin{pmatrix} b_1 & b_2 & \mathbf{L} & b_m \end{pmatrix} \tag{23}$$

The fuzzy comprehensive evaluation on one certain machining technological of the middle-convex and varying ellipse piston can be carried out with the method of maximum degree of membership, the weighted average method or the fuzzy distribution method through the normalization of the fuzzy comprehensive evaluation set B.

Example of Machining Technology Evaluation of Middle-convex and Varying Ellipse Piston

An example of machining technology evaluation of middle-convex and varying ellipse piston is illustrated. The diameter of workpiece is $f70$, machining precision is IT7, roughness concentration is Ra1.6, ovality is 0.6, upper deviation is $e_s = 0.02$, lower deviation is $e_i = 0$, material is aluminium casting alloy. It needs to select the optimum machining technological from the four alternatives. The degrees of membership of manufacturing quality, machining cost and machining efficiency of every machining technological design scheme are calculated (shown as table 3) with primary fuzzy comprehensive evaluation based on the membership function.

Table 3. Degree of Membership of Influence Factors

alternative design scheme	manufacturing quality	machining cost	machining efficiency
1	0.422	0.277	0.309
2	0.509	0.483	0.519
3	0.553	0.516	0.563
4	0.466	0.548	0.415

The evaluation matrix R of the single factor of the four alternatives is expressed as equation (24) based on the degrees of membership of manufacturing quality, machining cost and machining efficiency of every machining technological design scheme.

$$R = \begin{bmatrix} 0.422 & 0.509 & 0.553 & 0.466 \\ 0.277 & 0.483 & 0.516 & 0.548 \\ 0.309 & 0.519 & 0.563 & 0.415 \end{bmatrix} \tag{24}$$

The four alternatives and the decision-making value of every machining technological of the middle-convex and varying ellipse piston clculated with the method of maximum degree of membership are shown as table 4. Finally, the third machining technological is chosen as the optimum design scheme from the result of the fuzzy comprehensive evaluation of the four machining technological design schemes.

Table 4. Value of Fuzzy Comprehensive Evaluation

number	machining technological design scheme	evaluation value
1	ⓐ rough turning ⓑ diecapitated ⓒ chamfering ⓓ radial facing	0.422
2	ⓐ rough turning ⓑ half finish turning ⓒ radial facing ⓓ grinding	0.509
3	ⓐ rough turning ⓑ half finish turning ⓒ radial facing ⓓ finish turning	0.537
4	ⓐ rough turning ⓑ half finish turning ⓒ finish turning ⓓ chamfering	0.466

Conclusion

Evaluation of machining technological of the middle-convex and varying ellipse piston is a typical combinatorial optimization problem in manufacturing technologies. Fuzzy comprehensive evaluation is one effective evaluation methodology for multitudinous factors. In this paper, the evaluation methodology of the machining technological of the middle-convex and varying ellipse piston based on fuzzy comprehensive evaluation is proposed, and the optimum machining technological of the middle-convex and varying ellipse piston is chosen from the alternatives of one given work-piece using the methodology. It can avoid the rigidity of the decision model and correct some error of judgment in the traditional methodology of decision-making on machining technological of the middle-convex and varying ellipse piston, and it also can optimize the machining technological and improve the intelligece

of decision-making on the machining technological design scheme of the middle-convex and varying ellipse piston.

Acknowledgements

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