International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 3 Issue 6 ǁ June 2015 ǁ PP.01-07

The identification of key quality characteristics based on FAHP

Chen Dejia, Mao Jian

College of Mechanical Engineering, Shanghai University of Engineering Science, 333 Long Teng Road, Shanghai 201620, China

Correspondence should be addressed to Jian Mao; jmao@sues.edu.cn

Abstract: *Aiming at the complexity of importance sorting for multiple quality characteristics of mechanical product, the fuzzy comprehensive method based on Fuzzy Analytical Hierarchy Process (FAHP) is put forward. Therefore, the problems existing in the computational process of conventional methods is solved effectively. Fuzzy theory and FAHP are introduced to establish the importance sorting model for multiple quality characteristics. Then, the weights are computed by the method of fuzzy comparison which is expressed by the triangular fuzzy number. The rationality and feasibility of this method is illustrated by a practical example.*

Keywords: *mechanical product; quality characteristics; sorting; fuzzy analytical hierarchy process;*

I. Introduction

The quality of the product need to use multiple quality characteristics to describe, and each quality characteristic must meet their specifications, the product quality is the result of these comprehensive features [1]. The complex mechanical products, such as high precision machine tool, the quality characteristics have diversity in different subsystems and different levels. The quality characteristic of the mechanical products have characteristic of multidisciplinary and multi-field intersecting in the field of characteristic; On the performance characteristics, it has the character of precision, reliability and availability; On the structural characteristics, it has multiple components and structure features. Quality characteristic of importance are also different, it generally divided into the key quality characteristic, the important quality characteristic and the general quality characteristic, the key and important quality characteristic need to be key-point control. Therefore, how to determine the importance degree of quality characteristic of mechanical product? This becomes the primary task of product development process.

In recent years, scholars at home and abroad has carried on the related research for the quality characteristic of mechanical product. Zhang genbao et al.[2] through the statistics methods of Artificial Neural Networks (ANNs), the relative importance of technical specifications of VOC and the reflecting weights of each level are obtained. A model of the key quality characteristics of complicated mechanical products based on ANNs technology is formulated. Zhang genbao et al. [3] aimed at the complexity of importance sorting for multiple quality characteristics of mechanical product, the fuzzy comprehensive method based on Fuzzy Analytical Hierarchy Process and information entropy was presented. Therefore, the subjective and ambiguous problems existing in the computational process of conventional methods was solved effectively. Yan wei et al. [4] proposed the improved information gain (IG) algorithm to process such high-dimension imbalance data. By this method, it reduces the influence of imbalance data on the performance such that the identification of critical-to-quality characteristics (CTQ) is significantly improved. Wang ning et al.[5] put forward an identification method for key quality characteristics in multi-stage manufacturing process by combining the Partial Least Squares Regression method with the state space model to improve the existing methods of identifying the key quality characteristics in multistage manufacturing process. He Yihai et al.[6] grasped the definition of the quality characteristics(QCs), the three-layer model and technical connotation of quality characteristics are presented, the evolution process model of key quality characteristics(KQCs) is created, and the key activities of KQCs evolution are discussed in the context of design for quality(DFQ). Yu Hongji [7] established a model of the multi-stage production process quality characteristic. Though this model describes the different production process quality characteristics transitive relation, and ultimately this method can identify the key quality characteristics of the multi-stage production process. Tang Weibin et al. [8] proposed a systematic top–down decomposition approach for the identification of key characteristics. The methodology of the identification and decomposition of key characteristics can be divided into two steps: first is the construction of candidate characteristics, and second is the identification of key characteristics. Ji Fuyi [9] based the simplified model of evolution chain to machining process, using QFD and neural network techniques, the extraction technology of key quality characteristics is put forward in the product machining process.

From the above research situation at home and abroad, we can be seen that it has made great achievements about the complexity of importance sorting for multiple quality characteristics of mechanical product now. Fuzzy Analytic Hierarchy Process fully considered the fuzziness of thinking, and ensured reliability and the scientificness of the sorting for the multiple quality characteristics. In this paper, the comprehensive sorting method based on FAHP is put forward, this method according to the properties of the products to build analysis model of multiple quality characteristics, and then use FAHP going to sort for multiple quality characteristics. Therefore, the reasonable and accurate sorting result is obtained.

II. The identification of key quality characteristics

FAHP is a kind of multi-objective decision method to solve the problem of multi-layered structure, it combine qualitative and quantitative decision reasonably, according to the law of thinking, psychological to hierarchical decision-making process and quantification. In view of the quality characteristics of multilayered, diversity and complexity, this article first analyzes the uncertainty of importance sorting for multiple quality characteristics, applying triangle fuzzy numbers of the FAHP, using the method of pairwise comparison to judge the weight of multiple quality characteristics index. The sorting method that based on multivariate quality characteristics of FAHP mainly includes the following steps.

2.1 Calculation of membership

Using triangular fuzzy number to express the fuzzy set $\tilde{M}$= (l, m, r), the M's membership functions as follows:

$$u(x) = \begin{cases} (x-l)/(m-l)\,, x \in [l,m); \\ (x-r)/(m-r), x \in [m,r); \\ \quad 0 \qquad\qquad ,\ \text{else} \end{cases} \tag{1}$$

$0 \le l \le m \le r$, l and r is M upper and lower bounds respectively in this formula. The membership function of triangular fuzzy number [10] is shown in figure 1.

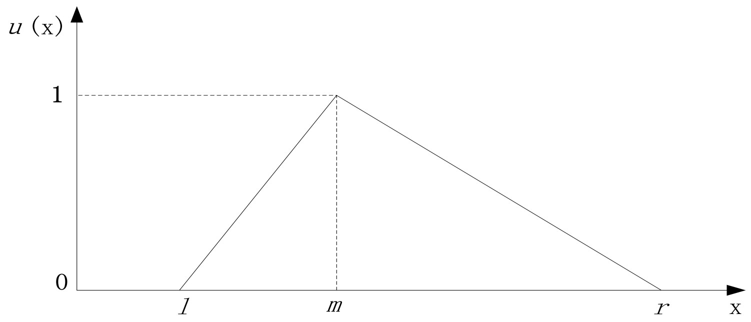

Fig.1. The triangular fuzzy number

Setting $M=(l_1, m_1, r_1)$, $N=(l_2, m_2, r_2)$ as the two triangular fuzzy Numbers, the calculation of fuzzy math as follows:

the possibility of $N \geq M$

$$L(N \geq M) = \begin{cases} \frac{l_1 - r_2}{(m_2 - r_2) - (m_1 - l_1)} & , l_1 \leq r_2 \\ 0 & , \text{ else} \end{cases} \tag{2}$$

2.2 The structure of the judgment matrix for triangular fuzzy

According to the definition of AHP's relative importance, using the method of pairwise comparison to compare the various index of the k layer, so that using triangular fuzzy number to express it. Using triangular fuzzy Numbers to go quantitative representation, so that get fuzzy judgment matrix $A=R_{ij}$. Fuzzy matrix is still positive and negative inverse matrix, the calculating formula as follows

$$R_{ij}^{-1} = R_{ij} = (\frac{1}{r_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}}) \tag{3}$$

2.3 The calculation of comprehensive value

The definition of fuzzy number

$$\sum_{j=1}^{n} M_{ij}^{k} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} r_{ij} \right), \tag{4}$$

$$M_{ij}^{k} = \frac{1}{3} \sum_{j=1}^{n} M_{ij}^{k}$$

$$i, j = 1, 2, \ldots, n \tag{5}$$

So composite triangular fuzzy degrees of the k layer as follows:

$$Y_i^k = \sum_{j=1}^{n} M_{ij}^{k} \cdot \left(\sum_{i=1}^{n} \sum_{j=1}^{n} M_{ij}^{k} \right)^{-1} \tag{6}$$

2.4 Hierarchical single sorting

$$L(Y_i^k \geq Y_j^k) = \min[L(Y_i^k \geq Y_1^k), \ldots, L(Y_i^k \geq Y_j^k), \ldots, L(Y_i^k \geq Y_n^k)] \tag{7}$$

Setting $D^k(A_i^k) = L(Y_i^k \geq Y_j^k)$, the A_i is the *i* factor for the k layer, the weight vector as follows:

$$W_k' = (D^k(A_1^k), D^k(A_2^k), \ldots, D^k(A_n^k))^T \tag{8}$$

2.5 The normalized

The k layer of all the elements make the total target about the synthesis of sorting as follows

$$W_k = (D^k(A_1^k) \Big/ \sum_{i=1}^{n} D^k(A_i^k), D^k(A_2^k) \Big/ \sum_{i=1}^{n} D^k(A_i^k), D^k(A_n^k) \Big/ \sum_{i=1}^{n} D^k(A_i^k))^T \tag{9}$$

According to the size of the weight *W* go to sort, the larger the value, to the top.

III. Numerical example

This is a transmission actuator as show in figure 2, it is consist of the belt wheel, ring flange, key, base and transmission shaft. The base is an important part in the transmission actuator, its design as shown in figure 3, we first analyze and list all the quality characteristics of the base the manufacturing process, and then build a hierarchical structure tree, as shown in figure 4.

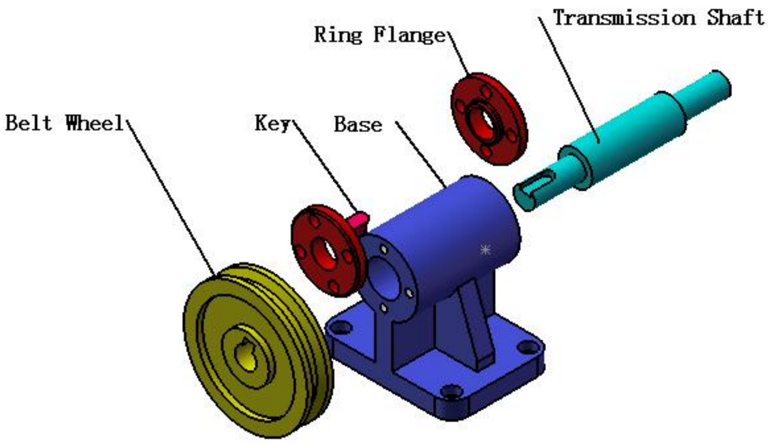

Fig.2. The explosion figure of the transmission actuator

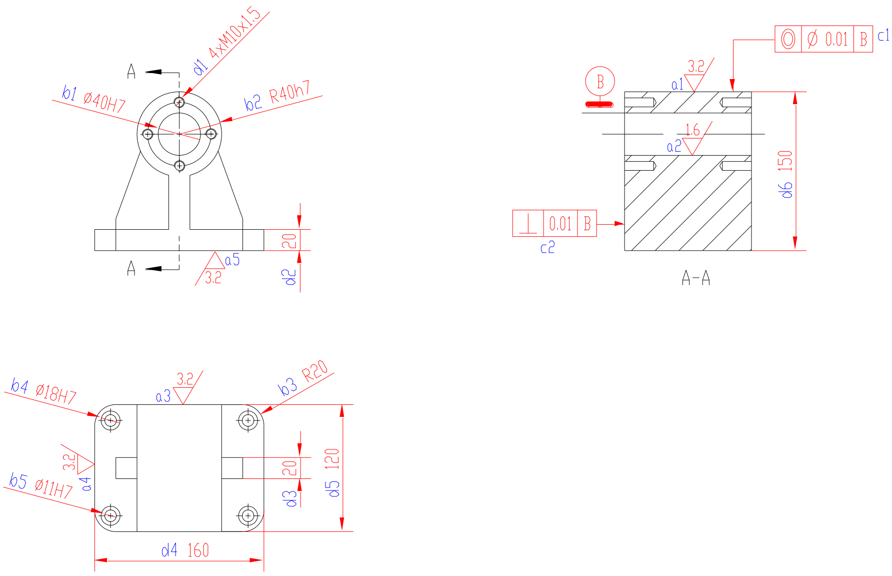

Fig.3. Design drawing of the base

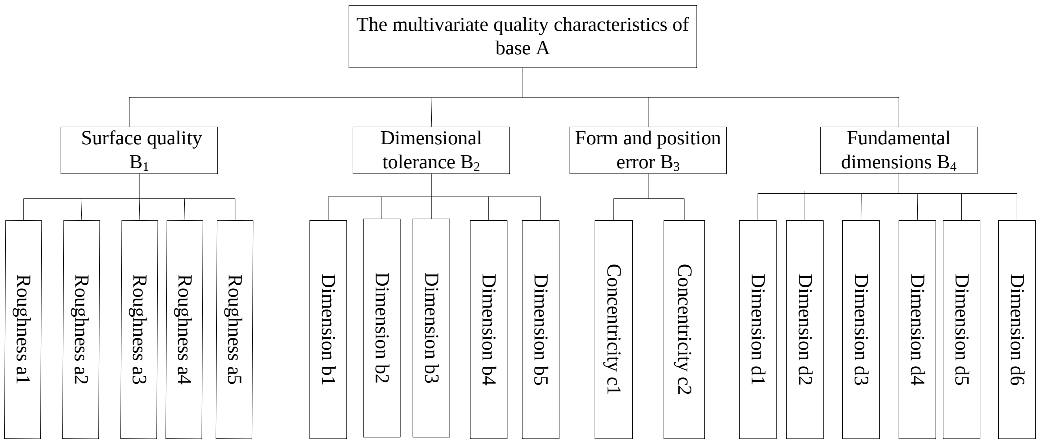

Fig.4. The quality characteristics tree of the base

Setting three experts have the equal weight coefficient, making score for the surface quality, dimensional tolerance, form and position error, and fundamental dimension (expressed in B1 ~ B4), getting the triangular fuzzy comparison matrix, as shown in table 1.

Table 1 The comparison matrix of Triangular fuzzy number

A	B_1	B_2	B_3	B_4
B_1	$\begin{bmatrix}1 & 1 & 1\\1 & 1 & 1\\1 & 1 & 1\end{bmatrix}$	$\begin{bmatrix}2/3 & 3 & 3/2\\2/5 & 2 & 2/3\\2/3 & 5 & 1\end{bmatrix}$	$\begin{bmatrix}2/3 & 4 & 3/2\\1/3 & 2 & 5/2\\2/3 & 3 & 3/2\end{bmatrix}$	$\begin{bmatrix}2/7 & 5 & 2/5\\2/3 & 3 & 1/2\\2/5 & 5 & 2/3\end{bmatrix}$
B_2	$\begin{bmatrix}2/3 & 1/3 & 3/2\\3/2 & 1/2 & 5/2\\2/5 & 1/5 & 3/2\end{bmatrix}$	$\begin{bmatrix}1 & 1 & 1\\1 & 1 & 1\\1 & 1 & 1\end{bmatrix}$	$\begin{bmatrix}5/2 & 3 & 7/2\\3/2 & 2 & 5/2\\5/2 & 3 & 7/2\end{bmatrix}$	$\begin{bmatrix}1 & 1/2 & 3/2\\2 & 2/5 & 3/2\\2 & 2/3 & 5/2\end{bmatrix}$
B_3	$\begin{bmatrix}2/3 & 1/4 & 3/2\\2/5 & 1/2 & 2\\2/3 & 1/3 & 3/2\end{bmatrix}$	$\begin{bmatrix}2/7 & 1/3 & 2/5\\2/5 & 1/2 & 2/3\\2/7 & 1/3 & 2/5\end{bmatrix}$	$\begin{bmatrix}1 & 1 & 1\\1 & 1 & 1\\1 & 1 & 1\end{bmatrix}$	$\begin{bmatrix}2/5 & 2 & 1/2\\1/2 & 1 & 2/3\\2/5 & 2 & 1/3\end{bmatrix}$
B_4	$\begin{bmatrix}5/2 & 1/5 & 7/2\\2 & 1/3 & 5/2\\3/2 & 1/5 & 5/2\end{bmatrix}$	$\begin{bmatrix}2/3 & 1 & 2\\2/3 & 1/2 & 5/2\\2/5 & 1/2 & 3/2\end{bmatrix}$	$\begin{bmatrix}2 & 1/2 & 5/2\\3/2 & 1 & 2\\3 & 1/2 & 5/2\end{bmatrix}$	$\begin{bmatrix}1 & 1 & 1\\1 & 1 & 1\\1 & 1 & 1\end{bmatrix}$

By the formula (4) and formula (5) calculate the triangular fuzzy number, the result as shown in table 2.

Table 2 Comprehensive triangular fuzzy number

A	B_1	B_2	B_3	B_4
B_1	(1.000, 1.000, 1.000)	(0.578,3.333,1.556)	(0.611,3.000,1.833)	(0.451,4.333,0.522)
B_2	(0.856,0.344,1.833)	(1.000, 1.000,1.000)	(2.167,2.667,3.167)	(0.522,1.667,1.833)
B_3	(0.578,0.361,1.667)	(0.324,0.389,0.489)	(1.000, 1.000, 1.000)	(0.433,1.667,0.500)
B_4	(2.000,0.244,2.500)	(0.578,0.667,2.000)	(2.167,0.667,2.333)	(1.000, 1.000, 1.000)

By the formula (6) calculate the comprehensive triangular fuzzy degree as follows:

$$Y_1 = (2.640,11.667,4.911) \times (1/24.233, 1/23.339, 1/15.264) = (0.109,0.499,0.321)$$

$$Y_2 = (4.454,5.678,7.833) \times (1/24.233, 1/23.339, 1/15.264) = (0.188,0.243,0.513)$$

$$Y_3 = (2.335,3.417,3.656) \times (1/24.233, 1/23.339, 1/15.264) = (0.096,0.146,0.240)$$

$$Y_4 = (5.744,2.578,7.833) \times (1/24.233, 1/23.339, 1/15.264) = (0.237,0.110,0.513)$$

By the formula (2) and formula (7) calculate the weight of each indicator as follows:

$L(Y_1 \geq Y_2) = 1, L(Y_1 \geq Y_3) = 1, L(Y_1 \geq Y_4) = 1;$

$L(Y_2 \geq Y_1) = 0.611, L(Y_2 \geq Y_3) = 1, L(Y_2 \geq Y_4) = 1;$

$L(Y_3 \geq Y_1) = 0.270, L(Y_3 \geq Y_2) = 0.349, L(Y_3 \geq Y_4) = 1;$

$L(Y_4 \geq Y_1) = 0.509, L(Y_4 \geq Y_2) = 0.710, L(Y_4 \geq Y_3) = 0.920$。

$D'(B_1) = L(Y_1 \geq Y_2, Y_3, Y_4) = min(1,1,1) = 1;$

$D'(B_2) = L(Y_2 \geq Y_1, Y_3, Y_4) = min(0.612,1,1) = 0.611;$

$D'(B_3) = L(Y_3 \geq Y_1, Y_2, Y_4) = min(0.270,0.349,1) = 0.270;$

$D'(B_4) = L(Y_4 \geq Y_1, Y_2, Y_3) = min(0.509,0.710,0.920) = 0.509$。

By the formula (8) calculate the weight vector as follows:

$W' = (1.000,0.611,0.270,0.509)$。

By the formula (9) get the sort of weight as follows:

$W_{\mathrm{A}} = (0.418,0.256,0.113,0.213)$。

Using the same method to calculate the layer 2 index, getting the corresponding weights of sorting as follows:

$$W_{\mathrm{B1}} = (0.374,0.131,0.126,0.104,0.265), W_{\mathrm{B2}} = (0.295,0.184,0.132,0.218,0.171),$$

$$W_{\mathrm{B3}} = (0.723,0.177), W_{\mathrm{B4}} = (0.190,0.150,0.146,0.252,0.135,0.127)$$

According to the indicators of layer 1 and layer 2, getting the final results:

W=(0.156,0.055,0.053,0.043,0.111,0.076,0.046,0.034,0.056,0.044,0.082,0.031,0.040,0.032,0.031,0.054,0.029,0.027)。

The quality characteristics have a total of 18 in this instance, according to the 2/8 principle, we can choose 4 as the key quality characteristics, namely roughness a1, roughness a5, dimension b1 and concentricity c1.

IV. Conclusion

The sorting for multiple quality characteristics of mechanical product is a complex problem. In this paper, aiming at the complexity of the sorting for multivariate quality characteristics, The comprehensive method based on triangular fuzzy number of FAHP is used, the ambiguous problems existing in the computational process of conventional methods is solved effectively, then the accuracy and rationality for sorting is improved. Form this example, we can be seen that the method is more reasonable and practical, and provides a new train of thought for the sorting of multiple quality characteristics.

V. Acknowledgements

We would like to acknowledge the support of the National Natural Science Foundation of the People's Republic of China (No. 51175322).

Reference

[1] Tian Xiao. The quality inspection of mechanical product [M]. Beijing: China metrology press, 2006

[2] Zhang Genbao, Ji Yifu, Ren Xianlin, Ge Hongyu, Zhang Shuhui. Key quality characteristics extraction model of complicated mechanical and electrical products [J]. Journal of Chong qing University, 2010, 2(33):8-14

[3] Zhang Genbao, Pang Jihong, Ren Xianlin, Chen Guohua. Importance sorting method for multiple quality characteristics of

mechanical product [J]. Computer Integrate Manufacturing Systems, 2011, 1(17):151-158

[4] Yan Wei, He Zhen, Tian Wenmeng. Research on identification of critical-to-quality characteristics for complex products [J]. Industrial Engineering Journal, 2012, 3(15):75-79

[5] Wang Ning, Xu Jichao, Yang Jianfeng. Identifying method of key quality characteristics in multistage manufacturing process [J]. Computer Integrate Manufacturing Systems, 2013, 4(19):888-895

[6] He Yihai, Tang Xiaoqing. Design for quality based on product key quality characteristics [J]. ACTA AERONAUTICA ET ASTRONAUTICA SINICA, 2007, 6(28), 1468-1480

[7] Yu Hongji. Identify key quality characteristics of the multi-stage production process [D]. Zhengzhou University, 2013

[8] Tang Weibin, Li Yuan, Yu Jianfeng, Zhang Jie, Yu Lin. A systematic top–down approach for the identification and decomposition of product key characteristics [J]. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 2014, 10(288):1305-1313

[9] Ji Fuyi. Study on extraction and prevention-control of key quality characteristics in the product machining process. College of Mechanical Engineering of Chongqing University, 2011

[10] Zhao Xi. Research on control technology of key quality characteristic in the manufacturing process of complex electromechnical products [D]. College of Mechanical Engineering of Chongqing University, 2009