International Journal of Multimedia and Ubiquitous Engineering
Vol.9, No.2 (2014), pp.65-76
http://dx.doi.org/10.14257/ijmue.2014.9.2.07

Appearance Design Evaluation on CNC Machine Tools Based on Fuzzy Synthetic Evaluation Model

Zhenhe Ye[1], Ying Li[2] and Bo Han[2]

[1]*College of Mechanical and Electrical Engineering, Agricultural University of HeBei, Baoding, HeBei, 071000, China*
[2]*College of Arts, Hebei Normal University of Science & Technology, Qinhuangdao, 066000, China*

yezhenhe@163.com

Abstract

In order to guarantee the preciseness and scientific nature of Computerized Numerical Control (CNC) machine tools appearance design, appearance design evaluation has to be made on CNC machine tools so as to change the randomness and uncertainty existed in traditional appearance design, and to establish a scientific method for CNC machine tools appearance design that meets the modern aesthetic needs. The evaluation index of hierarchical structure has been set up from four aspects as stylization, form-orientation, colorization and agreeableness that may influence the appearance design, adopting both qualitative and quantitative methods; weight for each evaluation index has been determined in accordance with Analytic Hierarchy Process ; and a two-level fuzzy synthetic evaluation model for CNC machine tools appearance design evaluation has been made and a comprehensive evaluation has been conducted through fuzzy mathematical method. By analyzing the appearance design of 2MKM95 series CNC precision vertical universal machine tools determined by Tianjin No.2 Machine Tool Corporation, this paper illustrates the preciseness and scientific nature of fuzzy synthetic evaluation model.

Keywords: *CNC machine tool; Appearance design; Fuzzy evaluation; Analytic Hierarchy Process*

1. Introduction

In 1950s, American people manufactured the first CNC machine tool of the world, and for the first time took the development of CNC machine tool into a digitalized height, after which all countries follow it and the CNC machine tool industry developed prosperously for nearly 60 years until now. Concerning of the appearance of CNC machine tool, people in the past considered CNC machine tool as a pure "tool" and a kind of heavy machining equipment which could be expressed as four words: "stupid, big, dull and thick". Along with the increasing development and integration of science technology and artistic aesthetics, CNC machine tool's appearance design began to focus more on aesthetics, art and man-machine relationship, which added more conciseness, easiness, gorgeousness, colors and humanity into the appearance design of large machines [1-3]. However, designers' intention, preference and needs in designing the appearance of CNC machine tools belong to people's subjective feeling, which is hard to grasp and evaluate precisely. Therefore, if a set of intellectualized CNC machine tool's appearance design method can be used in the beginning of designing CNC machine tool's appearance to help designers understand accurately the intention,

ISSN: 1975-0080 IJMUE

preference and needs of consumers and to successfully translate it into practical CNC machine tool's appearance, designers will be helped reduce the subjective mistakes, improve the success rate of design, lessen the design time, and shorten the development period, which can bring practical significance to the practical application of CNC machine tool's appearance design.

At present, a common method is to use the automatic generation system of intelligence algorithm, which can help designers design CNC machine tool's appearance projects quickly. For instance, the CNC machine tool's appearance design process can be realized by applying neutral networks, Grey Theory, Taboo Search and Fuzzy logic theory and by comparing CAD system and virtual reality technology. However, most of the above researches lie in the stage of basic theoretical research and prototype system trial-development, and seldom probe into the uncertain problems caused by human factors of designers. And users' expectation value for CNC machine tool's appearance is just an approximate value obtained from their feeling to CNC machine tool's appearance, rather than exact value. Users also have no idea about the specific matching method for the project generated from the above research. What's more, because of the different knowledge and experience possessed by different individuals, various cognitions for appearance may come into being. Therefore, completely depending on the existing CNC machine tool's appearance intelligent designing method cannot solve the problem of uncertainty caused by human factors of designers in designing the CNC machine tool's appearance, and it's difficult to produce design projects that meet users' real intention, preference and needs. In consideration of this, in order to guarantee the preciseness and scientific nature of CNC machine tools appearance design, appearance design evaluation has to be made on CNC machine tools so as to change the randomness and uncertainty existed in traditional appearance design, and to establish a scientific method for CNC machine tools appearance design that meets the modern aesthetic needs. The evaluation index of hierarchical structure has been set up from four aspects as stylization, modeling, colorization and agreeableness that may influence the appearance design, adopting both qualitative and quantitative methods [4-5]; weight for each evaluation index has been determined in accordance with Analytic Hierarchy Process ; and a two-level fuzzy synthetic evaluation model for CNC machine tools appearance design evaluation has been made and a comprehensive evaluation has been conducted through fuzzy mathematical method so as to objectively reflect the preciseness of CNC machine tool's appearance design, to reduce the false appearance combining form, to shorten the designing time, and to improve the design success rate, thus providing effective assistance and support for CNC machine tool's appearance designing work.

2. Analysis on Influencing Factors of CNC Machine Tool's Appearance Design

The aesthetics of machine molding, the combination of technology and art, must be attached importance in modern mechanical product design. It not only improves the appearance of machines, but also brings spiritual pleasure of aesthetics to people. More important, it meets users' needs for humanization design.

2.1. Style

Style is an integral property of appearance design. People's creation style, reflected by a series of modeling elements through different constructive methods, incorporates human's opinion on objects and their perception for beauty. In the process of designing appearance, designers would usually stimulate their creativity by reasoning from the previous styles and

features. Product design process is an action covering technicality and culture. And from the cultural dimension, the product form expresses the significance and connotation of product, as well as the concept of designers. Therefore, understanding the style and grasping its expression methods will be important subjects in designing product appearance [6]. Human's cognition for style is a complex logical reasoning process that contains multiple factors, hence, characteristic elements in style design must be designed in accordance with features of this process and human's experience and knowledge accumulated in the process, thereby bridging the gap between reality and imagination, and effectively delivering the information of style. In judging a style, users observe the appearance feature firstly, feel it, compare and conclude through memory system, then generate the personal rule of judging a style, and finally make judgments for the style. Meanwhile, users would make continual corrections to the judgments, in which some features appear repeatedly and draw people's "selective attention" [7]. When users have enough stimulation to make correction to the judgment, the final stylistic cognition would be developed. Judge and conclusive process is an information processing mechanism, which involves several human factors such as memory system, cultural background, experience, faculty of understanding and so on.

2.2. Color

Color's function on human mentality and physiology is very obvious, and especially ignorable in the design [8-9]. And colors of whole machine tools, operating station, signals and workplaces have big effect on human mentality and physiology. Color, as an important factor of beauty, is the basic requirement of creating beauty and artistic fascination, and an important channel of expressing the beauty of appearance. The previous CNC machine tool used to be gray tune, grave and dark, even some were not painted, making people feel obsolete and lifeless. While the modern life requires the CNC machine tool color to be beautiful, decent, harmonious, and moderate, and to comply with product's own function, operating environment and people's aesthetic requirement. The color and tone of CNC machine tool's appearance design mainly follow three developing routines that are bright-orientation, color match harmonization, and color function diversification, of which bright-orientation refers to the overall feeling of people for product's color, color match harmonization reflects the rules that should be followed in specific color matching, and color function diversification refers to the scientific application of color in higher level. The integrated application of these three developing routines can complete well the whole color design process.

2.3. Form

Form is mainly shown through the model of product constituted by shape, surface and lines with different characteristics which form the morphological styles or morphological characteristics on the whole [10-12]. The existing CNC machine tools often have huge body, dull lines, unbalanced design, messy details, unnatural transition, as well as monotonous lines and surfaces, which results in lacking of vitality. Therefore, in designing appearance, on the basis of meeting its basic functions, the aesthetic principle of modeling exclusively for informational manufacturing equipments shall be taken into consideration, and the coordination between unity and variation, proportion and dimension, stabilization and lightness, pace and rhythm, as well as contrast and conciliation shall be handled well. By weighing deliberately the component elements of shape, surface and lines in design, morphological characteristics with visual comfort and unified features should be combined together; and on this basis, a harmonious relation reflecting the characteristic and requirement

of information age should be created through conciseness, texture, unity and associated perception. For instance, segmentation, as an important tool in modern design, can break the stiffness of design and make product seem subtle and vivid [13-14]. Especially for products with large volume like CNC machine tool, scientific segmentation can save materials and simplify process on one hand, and eliminate the feeling of bulkiness gaining the aim of pleasant appearance on the other hand.

2.4. Analysis on agreeableness

Products are used by people, so the product appearance must be comfortable and agreeable. Agreeableness in CNC machine tool products design have seven aspects to be focused: increasing transparency, reducing human involvement, market evolution, customer focus, design essentials, man-machine orientation and semantization. These seven paths are proposed from human's physiological and psychological characteristics, which can meet operator's basic needs in the progress of usage. Increasing transparency requires to increase the transparency degree of machine tool's appearance gradually on the basis of not influencing the safety and stabilization of machine tool in design process, in order to facilitate people's observation for machine internal processing process and the status inspection; reducing human involvement belongs to the intellectualized development statement of machines; market evolution is an inherent developing rule of all products driven by market, and all products have to experience the conversion process from commodity, product, service, experience to qualitative change; customer focus: most people consider the performance of machine tool as their key target of focus, so while improving the performance in appearance design, the reliability should also be considered, and the product's taste of reliability should be delivered to people via admirable and delicate appearance design; design essentials reflect different degrees of optimization in appearance design, and the optimal design should be conducted in the appearance design of CNC machine tool taking every design essentials into consideration; man-machine orientation is an evolving stage towards gradually meeting human's design statement which embodies specifically design of meeting the functions, of meeting human, and of coordination between man, machine and environment, adapting machines to different using environments and operators; semantization: through the analysis on existing machine tool products, we can find that the product appearance just envelopes the inner construction and cannot deliver the characteristics of usage and product concept, basically lying in the non-semantic stage [15-16].therefore, the characteristics of each product parts should be expressed by applying methods like model change and color design to highlight the style of product and to facilitate the usage.

3. Thinking Analysis on Fuzzy Synthetic Evaluation Form in Appearance Design

This paper aims at building a product appearance integrated fuzzy evaluation model, an integrated evaluation system based on the knowledge of fuzzy mathematics, combining the theories of analytic hierarchy process and expert evaluation method, in order to conduct systematic evaluation accurately on CNC machine tool products. Compared with previous product evaluation methods, integrated fuzzy evaluation method, based on rigorous mathematic knowledge, has good foundation of theory, so it possesses rationality and scientificity and can conduct quantitative analysis more accurately and objectively on qualitative problems such as product appearance aesthetic quality.

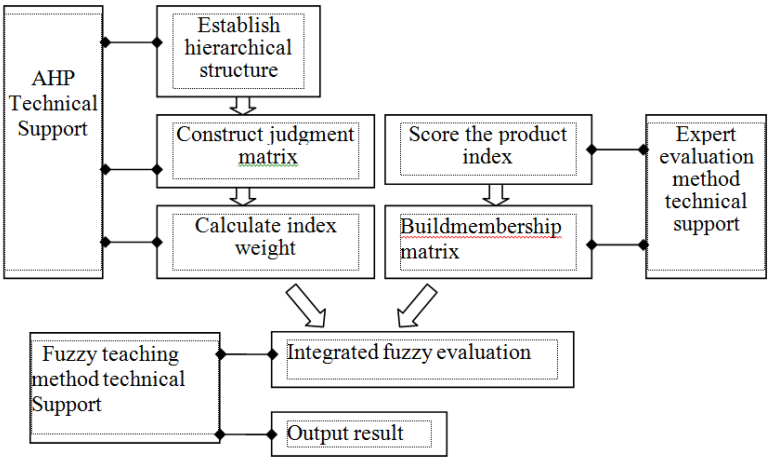

Figure 1. The process of Integrated fuzzy evaluation method to solve the problem

The process of integrated fuzzy evaluation method used to solve problems is shown in Figure 1. It decomposes and defines the problem firstly, establishes the corresponding hierarchical structure, and constructs the judgment matrix compared between two of each level by applying 9-level scale method. And then the weighted value of each evaluation index will be calculated through mathematic method, after which the membership matrix for each evaluation index under each remark will be obtained using expert investigation and scoring method. Weighing value of index and membership matrix is a significant link in subsequent evaluation models, whose accuracy may directly exert significant impact on the evaluation result. According to the above obtained weighing value and degree of membership, the evaluation index of different levels will be conducted level 1 fuzzy evaluation, level 2 fuzzy evaluation and so on. The level of fuzzy evaluation depends on the level of evaluation index, and the evaluation result can be obtained according to the rule of maximum membership degree.

In integrated fuzzy evaluation method, choosing each index and the determining weight are based on scientific methods. The evaluation process conforms to the general principle of product evaluation system, and has overcome the drawback that it's difficult to quantize such fuzzy situation as appearance evaluation. Under the guidance of accurate mathematic formula and numbers, the integrated fuzzy evaluation method pull the evaluation result and actuality closer and is able to evaluate product appearance intuitively.

4. Establishing Evaluation Fuzzy Model System for CNC Machine Tool's Appearance and Instance Analysis

4.1. Design of CNC machine tool's appearance design project

The final CNC machine tool appearance project can be designed through determining the style statement, and analyzing form, color and agreeableness. This paper listed three alternative schemes in total, as shown in Figures 2, 3 and 4. These three projects all chose the current fashionable closed mask structure and linear slide rail moving door, with brief and decent color, and smooth body, which reflected the feature of times and science of CNC machine tool. The following is designer's brief analysis on appearance of three projects:

Project 1 has good appearance segmentation, decorated with colored tape of nameplate which adds the jumpy and vivid nature on the whole feeling; tilting sliding door and window facilitate operating and observing; the lower part of the machine tool's front surface applies indent structure, which effectively prevents operators' kicking and touching for machine, thus reflecting the machine's concern on people. After all, this project has full and beautiful shape. Project 2 shows the features of rationality and direct, delivering CNC machine tool's connotation of precision and rigor. The door and window opened at two sides facilitates people's observation and operation, and the design of handle, which is able to remind the usage method of door parts and improves the comfort in using, is different from traditional design. This project is concise and decent, and has the sense of rationality. Project 3 adopts stepped composition,with tall and straight body. More forms improve the transparency of product and reasonable constructure make people feel safe and reliable.

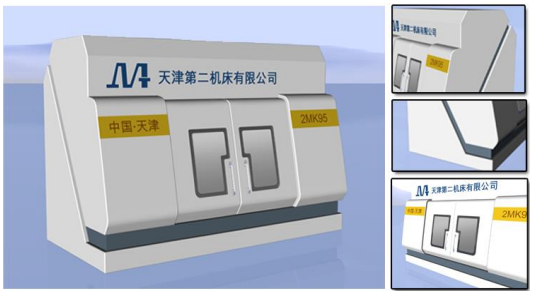

Figure 2. CNC appearance design project

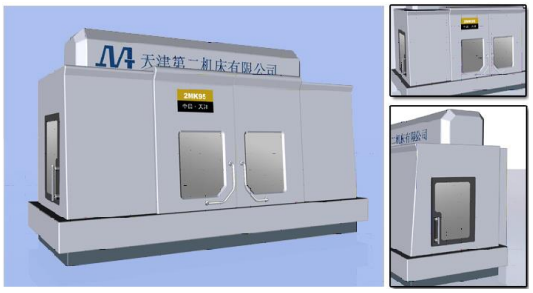

Figure 3. CNC appearance design project 2

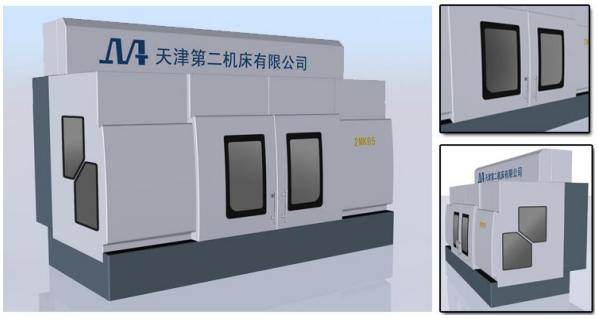

Figure 4. CNC appearance design project 3

The appearance evaluation on these three CNC machine tools adopts the established integrated fuzzy evaluation model of product appearance. Same evaluation target set and evaluation scale set should be applied in different projects' evaluation, otherwise the evaluation result will be incomparable. Due to limited space, here we take Project 2 as example which is illustrated and described in detail. As with the other projects' evaluation, only the final evaluation results are listed; and for the specific process of evaluation, please refer to that of Project 2 which is illustrated as follows.

4.2. The evaluation index of CNC machine tool's appearance design

CNC machine tool indexes are mainly determined in the form of social questionnaires, combined with the suggestion of experts and enterprises. The determined evaluation index hierarchical level model can be seen in Figure 5. In questionnaires, large quantity of indexes

related to the machine tool's appearance are listed, which can be scored with three grades as -1, 0, and 0 by users according to their focus of attention. Eventually, indexes whose arithmetic mean values exceed 0 will be summarized as the evaluation indexes of CNC machine tool's appearance. And after communicating with experts and enterprises, the final evaluation indexes will be determined.

To facilitate comparison, remark set for product's appearance quality are divided into four ranges of poor, ordinary, good and excellent. The corresponding mathematical expression is: $E=\{e_1,e_2,e_3,e_4\}=\{-1,0,1,2\}$. After experts give the judgment according to the evaluation indexes' grade of excellence, the membership degree of indexes to evaluation scale will be obtained from the mathematical statistics.

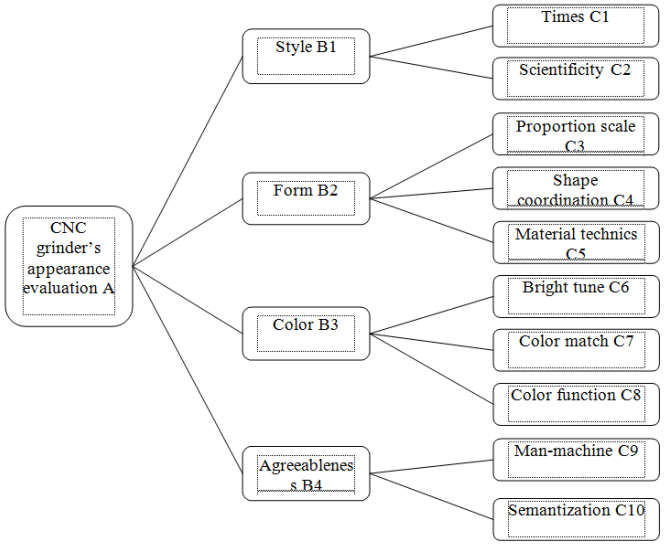

Figure 5. Hierarchy chart of evaluation index system for CNC machine tool

4.3. Determination of index weight through AHP

By establishing level-one index layer's judgment matrix compared between two based on the importance of evaluation relative to target A, and by asking for experts' opinions, the comparative judging results for each indexes are shown in Table 1.

Table 1. Comparison of CNC machine tool's level-one index Layer

	Style	Form	Color	Agreeableness
Style	1	5	7	3
Form	1/5	1	3	1/3
Color	1/7	1/3	1	1/5
Agreeableness	1/3	3	5	1

The above comparative result is expressed in matrix:

$$B=\begin{bmatrix} 1 & 5 & 7 & 3 \\ 1/5 & 1 & 3 & 1/3 \\ 1/7 & 1/3 & 1 & 1/5 \\ 1/3 & 3 & 5 & 1 \end{bmatrix}$$

The weight of each level-one index relative to Target A will be calculated with summation method:

$$B \xrightarrow{\text{Column vector normalization}} \xrightarrow{\text{Summation by row}} \xrightarrow{\text{normalization}}$$

$$\begin{bmatrix} 0.597 & 0.537 & 0.438 & 0.662 \\ 0.119 & 0.107 & 0.188 & 0.074 \\ 0.085 & 0.036 & 0.063 & 0.044 \\ 0.199 & 0.321 & 0.313 & 0.221 \end{bmatrix} \quad \begin{bmatrix} 2.234 \\ 0.488 \\ 0.228 \\ 1.054 \end{bmatrix} \quad \begin{bmatrix} 0.558 \\ 0.122 \\ 0.057 \\ 0.263 \end{bmatrix}$$

The weight set for each index of level-one index layer will be: $W = \begin{bmatrix} 0.558 & 0.122 & 0.057 & 0.263 \end{bmatrix}^T$

The judgment matrix will be made consistency inspection by applying the method in Chapter 4:

$$\lambda = \frac{1}{n}\sum_{i=1}^{n}\frac{(BW)_i}{W_i} = 4.06$$

$$CI = \frac{\lambda - n}{n-1} = 0.02$$

$$CR = \frac{CI}{RI} = 0.02$$

$CR < 0.1$, therefore, this judgment matrix meets the consistency requirement and the obtained matrix W will be the weight set of each index.

The level-two index layer's weight relative to level-one index layer can be determined by applying the same method, the results of which are shown in Table 2-5.

Table 2. Target layer of style

	Times	Scientificity	Weight value W_1
Times	1	1/3	0.25
Scientificity	3	1	0.75
Inspection result for consistency	λ=2, CR=0＜0.1（meeting the demands of consistency）		

Table 3. Target layer of form

	proportion scale	Shape coordination	Material technics	Weight value W_2
proportion scale	1	1/3	3	0.260
Shape coordination	3	1	5	0.633
Material technics	1/3	1/5	1	0.106
Inspection result for consistency	λ=3.04, CR=0.03＜0.1（meeting the demands of consistency）			

Table 4. Target layer of color

	Bright tune	Color match	Color function	Weight valueW3
Bright tune	1	3	4	0.623
Color match	1/3	1	2	0.240
Color function	1/4	1/2	1	0.137
Inspection result for consistency	λ=3.02, CR=0.02＜0.1（meeting the demands of consistency）			

Table 5. Target layer of agreeableness

	Man-machine	Semantization	Weight value W4
Man-machine	1	1/5	0.167
Semantization	5	1	0.833
Inspection result for consistency	λ=2, CR=0＜0.1（meeting the demands of consistency）		

4.4. Calculating each index's degree of membership under each remark

Before calculating the degree of membership, experts' remarks on each evaluation index should be firstly surveyed. Five experts in the field are invited to involve in this evaluation, and the evaluator set P={P1,P2,P3,P4,P5} is shown in Table 6.

Table 6. Table of survey from experts

Evaluation index		Expert 1 P_1	Expert 2 P_2	Expert 3 P_3	Expert 4 P_4	Expert 5 P_5
Style B_1	Times C_1	1	1	1	2	1
	Scientificity C_2	2	1	1	2	2
Form B_2	proportion scaleC_3	1	2	0	0	1
	Shape coordination C_4	0	1	0	1	1
	Material technics C_5	2	1	-1	0	0
Color B_3	Bright tune C_6	0	-1	1	1	0
	Color match C_7	1	0	-1	-1	0
	Color function C_8	0	0	-1	0	-1
Agreeableness B_4	Man-machine C_9	2	0	1	1	0
	Semantization C_{10}	1	1	-1	1	0

Based on this table, the membership matrix for each evaluation index can be calculated, and refer to Chapter 4 for the calculating method of membership. The final results are the following:

$$R_1=\begin{bmatrix}0 & 0 & 0.8 & 0.2\\ 0 & 0 & 0.4 & 0.6\end{bmatrix} \qquad R_2=\begin{bmatrix}0 & 0.4 & 0.4 & 0.2\\ 0 & 0.4 & 0.6 & 0\\ 0.2 & 0.4 & 0.2 & 0.2\end{bmatrix}$$

$$R_3=\begin{bmatrix}0.2 & 0.4 & 0.4 & 0\\ 0.4 & 0.4 & 0.2 & 0\\ 0.4 & 0.6 & 0 & 0\end{bmatrix} \qquad R_4=\begin{bmatrix}0 & 0.4 & 0.4 & 0.2\\ 0.2 & 0.2 & 0.6 & 0\end{bmatrix}$$

4.5. The fuzzy evaluation result of CNC machine tool's appearance

Compared the membership matrix of each level's indexes with the index weight value calculated above, the level-one fuzzy evaluation for CNC machine tool's appearance can be conducted by applying the formula $S_i = W_i R_i$. The following is level-one fuzzy evaluation process of each different index:

$$S_{\text{Style}} = W_1 R_1 = \begin{bmatrix} 0.25 & 0.75 \end{bmatrix} \times \begin{bmatrix} 0 & 0 & 0.8 & 0.2 \\ 0 & 0 & 0.4 & 0.6 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0.5 & 0.5 \end{bmatrix}$$

$$S_{\text{Form}} = W_2 R_2 = \begin{bmatrix} 0.26 & 0.633 & 0.106 \end{bmatrix} \times \begin{bmatrix} 0 & 0.4 & 0.4 & 0.2 \\ 0 & 0.4 & 0.6 & 0 \\ 0.2 & 0.4 & 0.2 & 0.2 \end{bmatrix} = \begin{bmatrix} 0.0212 & 0.3996 & 0.505 & 0.0732 \end{bmatrix}$$

$$S_{\text{Color}} = W_3 R_3 = \begin{bmatrix} 0.623 & 0.24 & 0.137 \end{bmatrix} \times \begin{bmatrix} 0.2 & 0.4 & 0.4 & 0 \\ 0.4 & 0.4 & 0.2 & 0 \\ 0.4 & 0.6 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 0.3476 & 0.4208 & 0.2306 & 0 \end{bmatrix}$$

$$S_{\text{Agreeableness}} = W_4 R_4 = \begin{bmatrix} 0.167 & 0.833 \end{bmatrix} \times \begin{bmatrix} 0 & 0.4 & 0.4 & 0.2 \\ 0.2 & 0.2 & 0.6 & 0 \end{bmatrix} = \begin{bmatrix} 0.1666 & 0.2334 & 0.5666 & 0.0334 \end{bmatrix}$$

The level-one fuzzy evaluation results show the merits of level-one evaluation index. According to the principle of maximized membership, the following can be seen: the style membership of Project 2 for "good" and "excellent" are 50% respectively, so its appearance has good style; similarly, we can see that its form is "good", color "ordinary", and agreeableness "good". With level-one fuzzy evaluation, the level-two appearance fuzzy evaluation can be conducted finally and it will be calculated with formula

$Q = W_i S_i$.

$$Q = W_i S_i = \begin{bmatrix} 0.558 & 0.122 & 0.057 & 0.263 \end{bmatrix} \times \begin{bmatrix} 0 & 0 & 0.5 & 0.5 \\ 0.0212 & 0.3996 & 0.505 & 0.0732 \\ 0.3476 & 0.4208 & 0.2306 & 0 \\ 0.1666 & 0.2334 & 0.5666 & 0.0334 \end{bmatrix}$$

$$= \begin{bmatrix} 0.0662 & 0.1341 & 0.5028 & 0.2967 \end{bmatrix}$$

The final evaluation result of Project 2 is "good", and the degree of membership for this remark is 50.28%. Other projects' evaluation processes are the same with Project 2 and formulas used in evaluation of Project 2 are all introduced in detail in Chapter 4.

The final evaluation result of Project 1 is:

$$Q_1 = \begin{bmatrix} 0.0429 & 0.3437 & 0.525 & 0.0882 \end{bmatrix}$$

The final evaluation result of Project 3 is:

$$Q_3 = \begin{bmatrix} 0.0323 & 0.475 & 0.4612 & 0.0313 \end{bmatrix}$$

The final evaluation results for three projects are all "good". The difference lies in that Project 1 has higher degree of membership for remark "good", being 52.5%, so Project 1 is the optimal solution. If the evaluation results for each project are different, the optimal project will be chosen in the sequence of "excellent, good, ordinary and poor".

5. Conclusion

In accordance with the existing status quo of CNC machine tool's appearance design, analyzing from four aspects as stylization, form-orientation, colorization and agreeableness that may influence the appearance design of CNC machine tool, the two-level fuzzy comprehensive evaluation model is established. By evaluating the three projects' appearance design of 2MKM95 CNC machine tool series of Tianjin No.2 Machine Tool Corporation, it proves that the evaluation result is the best appearance design project and such evaluation result based on fuzzy synthetic evaluation model coincides with the practical situation of production and sales. Therefore, according to the case study results, the established two-level fuzzy synthetic evaluation model for CNC machine too's appearance design has good operability and effect, which can also provide important reference of feasibility for the appearance design evaluation standards of other large machinery and equipments.

References

[1] C. -C. Yang, P. -J. Lin, C. -C. Sun, "Product Form Design Using Virtual Hand and Deformable Models", International Journal of Digital Content Technology and its Applications, Advanced Institute of Convergence Information Technology, vol. 6, no. 11, **(2012)**, pp. 8 ~ 17.
[2] Q. -h. Zhou and H. Zeng, "The grey fuzzy syn-thetic assessment on design scheme of mechanical product", Machinery Design & Manufacture, vol. 38, no. 3, **(2001)**, pp. 6-8.
[3] G. Jianya, "An Unified Data Structure Based on Linear Quadtress", Acta Geodaetica ET Cartographica Sinica, vol. 21, no. 4, (**1992**), pp. 259-266.
[4] Z. Ye and X. Li, "Model Evaluation Based on Emotional Furniture Industrial Design Elements", International Journal of Advancements in Computing Technology, vol. 22, no. 4, **(2012)**, pp. 73-78.
[5] L. W. Mei and S. L. Huai, "Fuzzy data envelopment analysis (DEA): Model and ranking method", J of Computer and Applied Mathematics, vol. 223, no. 2, **(2009)**, pp. 872-878.
[6] Z. Zheng and J. Zhang, "Model for Evaluating the Industrial Design with Interval Grey Linguistic Variables", International Journal of Digital Content Technology and its Applications, Advanced Institute of Convergence Information Technology, vol. 6, no. 15, **(2012)**, pp. 136 ~ 142.
[7] C. Jie and Y. Hong, "Studying scheme of green products manufacturing process", Chinese Journal of Mechanical Engineering, vol. 38, no. 7, **(2002)**, pp. 126-130.
[8] Y. Zhang and X. J. Wang, "Study on evaluation method for investment project based on DEA and fuzzy theory", Technology Economics, vol. 29, no. 2, **(2010)**, pp. 64-67.
[9] Z. Ye and Q. Bai, "Agricultural Implementation Security Research Based on Ergonomics", Journal of Convergence Information Technology, vol. 20, no. 7, **(2012)**, pp. 65-71.
[10] S. W. Duan and P. S. Shen, "Application of fuzzy comprehensive evaluation and data envelopment analysis in selection of engineering scheme", J of Hydraulic Engineering, vol. 5, no. 5, **(2004)**, pp. 116-121.
[11] W. Qing and Q. Ershi, "Measuring and calculating of talents job fit based on AHP-fuzzy comprehensive evaluation", Chinese Journal of Ergonomics, vol. 13, no. 2, **(2007)**, pp. 19-22.
[12] W. Qiong-bo, Z. Shi-sheng, G. Li-wen, *et al.*, "Transmission design evaluation model based on fuzzy genetic neural network", Mechanical Trans-mission, vol. 22, no. 4, **(1998)**, pp. 19-21.
[13] C. Ai-min, C. Liang-song, L. Dong-liang, *et al.*, "Fuzzy synthesisevaluation and judgment analysis of GIS data quality", Geo-Information Science, vol. 7, no. 2, **(2005)**, pp. 50~53.
[14] L. Jijian, Z. Yang and S. Chundi, "Fuzzy comprehensive evaluation on safe operation of water conveyance structures", Water Resources and Hydropower Engineering, vol. 38, no. 3, **(2007)**, pp. 62-64, 68.
[15] G. Fa-liang, "Study on fuzzy evaluation for mechanical design scheme", Journal of Shanghai University of Technology, vol. 14, no. 1, **(1993)**, pp. 51-57.
[16] S. Yu-ying, C. Fu-zhi, Z. Bo-peng, *et al.*, "One of case-based reasoning product conceptual design systems", Journal of Qinghua University, vol. 38, no. 8, **(1998)**, pp. 5-8.

[17] D. Xue and Z. Dong, "Coding and clustering of design and manufacturing features for concurrent design", Computers in Industry, vol. 34, no. 1, **(1997)**, pp. 139-153.

