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How to Evaluate the Quality of Modern Mechanical Products? Modelling and Analysis

Abstract. *The new connotations of product quality, generalized quality and factors that affect product quality of mechanical product are studied. And the function of product quality elements and the equation of product quality are established. Taking into account the different weight of the factors, the concept of the rate of contribution to quality is put forward, and then the function equation is established. Finally, based on the fuzzy comprehensive evaluation method, the fuzzy evaluation model and application of the product quality are studied.*

Streszczenie. *Przedstawiono nowe sposoby określania jakości produkcji i współczynników decydujących o jakości produktów mechanicznych. Biorąc pod uwagę różą wagę współczynników zaproponowano model określający ich udział w jakości produktu finalnego. Zaproponowano też model w oparciu o logikę rozmytą. (**W jaki sposób oceniać jakość produktów mechanicznych? Modelowanie i analiza**)*

Keywords: Contribution rate, Generalized quality, Product quality, Design quality.
Słowa kluczowe: jakość produktu, modelowanie

1. Introduction

There are lot of science and technology workers which are carrying out research work for product design and varieties of different definitions on quality [1]-[2]. Early, the quality is refer to the degree which meets the requirements of the product technical features, which is called the “compliance” definition of quality; In the 1960s, quality management experts J. M. Juran, put forward the view that “quality is the degree to meet customer’s demand”, which is called the “applicability” definition of quality. The development of the concept of quality is also reflected in the standard definition that made by ISO9000 quality management system, the quality is defined as “characteristics and the total of the characteristics whose products or services to meet the requirement or potential needs” by ISO-8402-1986; ISO 8402 -1994 made little changes, and the quality is defined as “to reflect the sum of the ability characteristics of the entity to meet the explicit and implicit needs”. There is no real difference between these two definitions. They did not identify whose is “the explicit and implicit requirement”. There is a substantial change to the ISO9000-2000 quality definition, which is defined as “the degree that a set of inherent characteristics meet the requirements”. The requirements of this definition of quality refer to the “express, implied or obligatory demand” [3]-[5].

In this paper, the definition of product quality should be different due to different precondition. The product quality can be divided into narrow quality and generalized quality. As a result, the quality of certain products can be defined as “the ability and level to complete a certain job requirements in certain preconditions”.

2. Components of product generalized quality

The quality of product starts from using perspective, considers the users’ requirements, for example, the product's features are practical and effective, safe and reliable, easy to operate, pleasing in appearance, energy saving, ease of maintenance and have a long enough life. In the process of product development, design, manufacturing and sales, scientific and technological workers have already proposed the five elements of the product quality B, price C, the production cycle T, the environment E, and after-sales service S et al. Obviously, C, T, E, S are not included in the areas of product quality Q.

The product quality Q (narrowly defined) generalized quality of products (design quality) should have a different concept and meaning. The connotation of the product generalized quality is the most widely, it not only contains the users’ quality requirements, but also includes the quality requirements of enterprises and society on the product design work, it should be based on the principle of that whether all quality requirements which proposed in the whole process of the users, enterprises and society for product design, manufacturing, sales, until recycling should be reflected in the design.

Generalized quality of the products has two big type of the main content in flowing: first, the product's features (including the main functions and auxiliary functions), second, the comprehensive performance of the product (structural performance, work performance and process performance, etc.), shown in Fig 1.

3. Components and contribution rate

3.1. Formula of quality component elements

(1) Formula of the product quality component elements

From Fig. 1, it can see that the generalized quality of the product includes 5 aspects: main function, auxiliary function, structure performance, service performance and manufacturing performance, etc. Therefore, the formula of the generalized quality component elements is:

$$Q(y) = f(y_1, y_2, y_3, y_4, y_5) \tag{1}$$

where, y_1, y_2, y_3, y_4, y_5 denote main function, auxiliary function, structure performance, service performance and manufacturing performance, respectively.

Main function, auxiliary function, structure performance, service performance and manufacturing performance are made up by their own elements, respectively. Therefore, the expressions of their component elements are:

$$\begin{aligned} y_1 &= f_{y1}(x_{11,}, x_{12}, \cdots, x_{1n}) \\ y_2 &= f_{y2}(x_{21,}, x_{22}, \cdots, x_{2n}) \\ y_3 &= f_{y3}(x_{31}, x_{32}, \cdots, x_{3n}) \\ y_4 &= f_{y4}(x_{41,}, x_{42}, \cdots, x_{4n}) \\ y_5 &= f_{y5}(x_{51}, x_{52}, \cdots, x_{5n}) \end{aligned} \tag{2}$$

where, x_{ij} are the component elements of y_i.

Substituting Eq. (2) to Eq. (1), we can get the expression of the generalized quality component elements, the equation should be as:

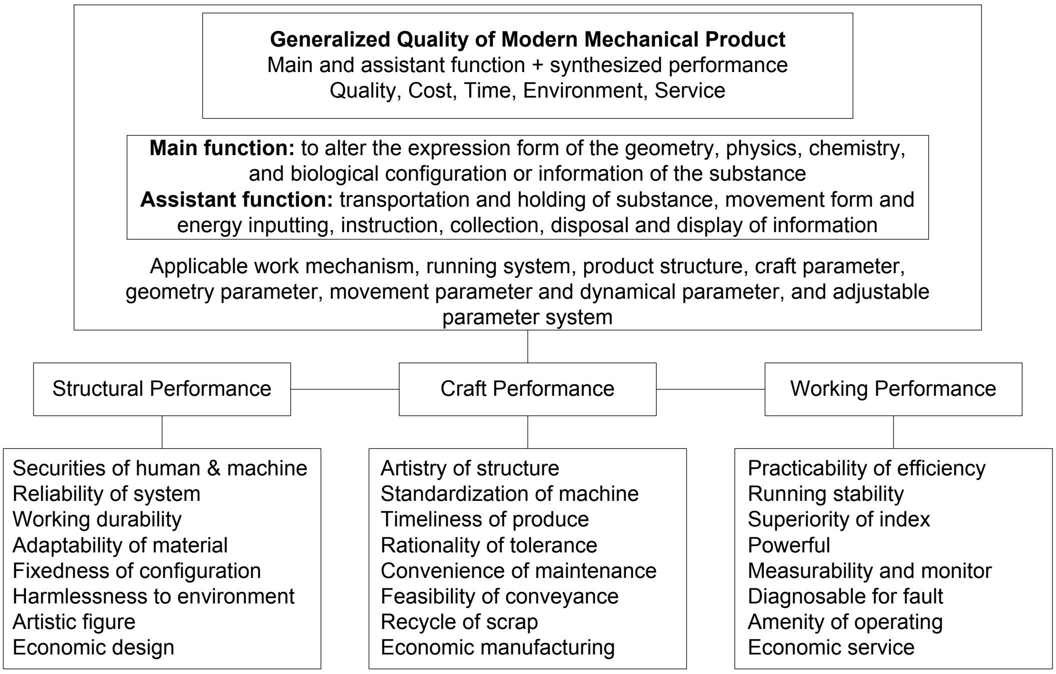

Fig. 1. Generalized quality of Modern mechanical products

(3)
$$Q(y) = f(f_{y1}(x_{11,}, x_{12}, \cdots, x_{1n}), f_{y2}(x_{21,}, x_{22}, \cdots, x_{2n}), \cdots, f_{y5}(x_{51}, x_{52}, \cdots, x_{5n}))$$

Because the connotation and component elements of quality is different with the generalized quality, their expression have some different.

(2) The kinds of elements and their function in the system

1) Essential and unessential elements

In fact, some component elements of the quality and generalized quality are unessential, while some are essential. Therefore, we should remove the unessential elements in order to simplify the calculation process.

2) Main and secondary elements

At the same time, there are main and secondary elements, and they have different contribution to the quality. Therefore, in order to improve quality and generalized quality, we must distinguish primary-secondary; hold the key links and the key elements. The auxiliary function of product includes matter translocation; transmit motion, energy transfer, command input and state test and control, etc. Therefore, their component elements also include these contents.

It can see from Fig.1 that structure performance, service performance and manufacturing performance all has 8 elements. But we should determine their primary-secondary and trade-offs, according to the different products condition.

(3) Quantity and quality of the system component elements

Quantity and quality of the system component elements can influence the system. In order to analysis the influence of each element to the whole system, we must analyze the quantity and quality of each element in the system, firstly. Quantity of elements in the system is the number of this element. For example, a factory produce a variety of products, and the number of all kinds of products is the quantity of this element. Quality of elements in the system is the quality high low of this element. For example, a factory produce a variety of products, and the value of all kinds of products is the quality of this element.

The comprehensive expression for quantity and quality of system s is:

(4)
$$P(i) = \gamma_i p_i$$

Where, p_i and γ_i are the quantity and quality for the element i.

3.2. Contribution rate of composed elements

The contribution rates various elements of the product quality to the product quality are not the same, some are big, some are small, and some even did not affect product quality. According to their contribution to the quantity and quality of the product, you can write the total amount of the contribution of the product elements

(5)
$$P(n) = \sum_{i=1}^{n} \gamma_i p_i = \gamma_1 p_1 + \gamma_2 p_2 + \cdots + \gamma_n p_n$$

where, γ_i is level of quality of element i, p_i is the number of each element.

The contribution rate of element i to quality is

(6)
$$\Delta P_i = \gamma_i p_i \Big/ P(n) = \gamma_i p_i \Big/ \sum_{i=1}^{n} \gamma_i p_i$$

According to above equation, it can analyze the contribution of the various elements on the generalized quality of the product.

4. Formulas of product quality and generalized quality

The product quality and generalized quality were generated by the accumulation of each element. So, if product quality and generalized quality consist of main function, the auxiliary function, structure performance, performance and manufacturing performance, the total absolute quality of product is:

(7)
$$Q(n) = \sum_{i=1}^{n} \gamma_i q_i = \gamma_1 q_1 + \gamma_2 q_2 + \cdots + \gamma_n q_n$$

where, q_i is i element's contribution to the generalized quality. Contribution rate of element i to the product generalized quality is described as:

(8) $$\Delta Q_i(n) = \gamma_i q_i \Big/ Q(n) = \gamma_i q_i \Big/ \sum_{i=1}^{n} \gamma_i q_i$$

If the maximum value of q_i is $q_{i\max}$, the product mass' maximum value is:

(9) $$Q_{\max}(n) = \sum_{i=1}^{n} \gamma_i q_{i\max} = \gamma_1 q_{1\max} + \gamma_2 q_{2\max} + \cdots + \gamma_n q_{n\max}$$

As the product generalized quality is lack of comparability, we get the maximum quality of product, the optimal value of product quality. At the same time, the optimal value of product quality is regarded as the product mass' maximum value. The relative quality is compare with the optimal value of product quality. In this way, we may understand the quality of a product through the relative mass.

The relative quality of product can be described as:

(10) $$\Delta Q_n(n) = Q(n) \Big/ Q_{\max}(n)$$

From this, contribution rate of element i to the product generalized quality is shown as:

(11) $$\Delta Q_{i\max}(n) = \gamma_i q_i \Big/ Q_{\max}(n) = \gamma_i q_i \Big/ \sum_{i=1}^{n} \gamma_i q_{i\max}$$

Because the contribution rate of every element to the product generalized quality is different. If its contribution rate value is large, it is the important element, if its contribution rate value is small, it is the secondary element, if its contribution rate value is zero, it is the unnecessary element. In the progress of product design, it is very important to distinguish important element and secondary element, necessary element and unnecessary element. This work provides reference to the evaluation of harmonious degree [6].

5. Quality evaluation

One application sample is used to explain the method with design quality evaluated by fuzzy synthesized evaluation method from function, structure performance, working performance and craftwork performance factors [7]-[8]. The factor sets in maind is

$\boldsymbol{U}$= {u_1, u_2, u_3, u_4} = {structure performance, working performance, craftwork performance, functions}.

Due to all the structure performance (u_1), working performance (u_2), craftwork performance (u_3) and the functions (u_4) including several sub-factors each, the primary evaluation of each one has to be done firstly respectively, then established the evaluation matrix $\boldsymbol{R}$ of whole product quality according to the first results. Thus, the two-level fuzzy synthesis evaluation of vibration screen quality will be obtained.

Establishing the decision evaluation set

$\boldsymbol{V}$= {v_1, v_2, v_3, v_4, v_5}={excellent, preferable, good, common, poor}.

In the structure performance set (u_1), 6 factors are considered. They are human-machine security (u_{11}), system reliability (u_{12}), structure compactness (u_{13}), running durability (u_{14}), environment innocuousness (u_{15}) and design economy (u_{16}). The grade importance set is

(12) $$A_1 = (0.4, 0.2, 0.05, 0.2, 0.05, 0.1)$$

The evaluation matrix R_1 of structure performance is formed according to the scores of each aspect and grade given by experts.

(13) $$R_1 = \begin{bmatrix} 0.7 & 0.2 & 0.1 & 0 & 0 \\ 0.5 & 0.3 & 0.1 & 0.1 & 0 \\ 0 & 0 & 0.2 & 0.7 & 0.1 \\ 0.8 & 0.1 & 0.1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0.1 & 0.8 & 0.1 & 0 & 0 \end{bmatrix}$$

By substituting Eq. (12) and Eq. (13) into Eq. (14)

(14) $$B_d = (b_{d,1}, b_{d,2}, \cdots b_{d,n}) = A_d \circ R_d$$
$$b_{d,j} = \sum_{i=1}^{m} a_{d,i} r_{d,ij},\ j = 1,2,\cdots,n$$

where, B_d is single factor evaluation of U_d, "$A_d \circ R_d$" is generalized fuzzy operation of A_d and R_d .The evaluation result of structure performance is obtained, and shown as Eq. (15).

(15) $$B_1 = A_1 \circ R_1 = (0.55, 0.24, 0.1, 0.105, 0.005)$$

Working performance set (u_2) mainly considered factors are work efficiency practicability (u_{21}), running stationarity (u_{22}), parameter superiority (u_{23}), equipment powerful (u_{24}), condition monitoring (u_{25}) and using economic effectiveness (u_{26}). The grade importance set is

(16) $$A_2 = (0.3, 0.2, 0.2, 0.1, 0.1, 0.1)$$

And the evaluation matrix R_2 is

(17) $$R_2 = \begin{bmatrix} 0.6 & 0.2 & 0.2 & 0 & 0 \\ 0.6 & 0.3 & 0.1 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0.3 & 0.3 & 0.1 & 0.2 & 0.1 \\ 0.2 & 0.1 & 0.5 & 0.1 & 0.1 \\ 0.1 & 0.7 & 0.1 & 0.1 & 0 \end{bmatrix}$$

In the same way, by substituting Eq. (16) and Eq. (17) into Eq. (14), the evaluation result of working performance is obtained and shown as Eq. (18).

(18) $B_2 = A_2 \circ R_2 =$ (0.46, 0.33, 0.15, 0.04, 0.02)

Craftwork performance set (u_3) includes: structural processing property (u_{31}), machine normative (u_{32}), manufacture periodicity (u_{33}), shipping feasibility (u_{34}), equipment maintainability (u_{35}) and manufacture economic (u_{36}). And the grade importance set of craftwork performance is shown as Eq. (19). And the evaluation matrix R_3 is Eq. (20).

(19) $$A_3 = (0.3, 0.1, 0.2, 0.05, 0.05, 0.3)$$

(20) $$R_3 = \begin{bmatrix} 0.8 & 0 & 0.2 & 0 & 0 \\ 0 & 0.1 & 0.6 & 0.2 & 0.1 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0 \\ 0.6 & 0.2 & 0.2 & 0 & 0 \end{bmatrix}$$

In the same way, the evaluation result of craftwork performance is obtained with Eq. (14), and shown as Eq. (21).

(21) $$B_3 = A_3 \circ R_3 = (0.47, 0.27, 0.205, 0.045, 0.01)$$

The function evaluation set (u_4) also includes 6 factors: work structuring (u_{41}), machine structure (u_{42}), geometric parameters (u_{43}), motion parameters (u_{44}), dynamic parameters (u_{45}), adjustability of parameters system (u_{46}).And the grade importance set of it is shown as Eq. (22), evaluation matrix R_4 is shown as Eq. (23).

(22) $$A_4 = (0.17,0.17,0.14,0.14,0.17,0.21)$$

(23) $$R_4 = \begin{bmatrix} 0.7 & 0.15 & 0.05 & 0.1 & 0 \\ 0.2 & 0.1 & 0.4 & 0.2 & 0.1 \\ 0 & 0.9 & 0.1 & 0 & 0 \\ 0.9 & 0.1 & 0 & 0 & 0 \\ 0 & 0.1 & 0.4 & 0.5 & 0 \\ 0.5 & 0.3 & 0.2 & 0 & 0 \end{bmatrix}$$

The result of function is obtained and shown as Eq. (24).

(24) $$B_4 = \left(0.384, 0.2625, 0.2005, 0.136, 0.017\right)$$

From B_1, B_2, B_3 and B_4, we can find the difference among the structure performance, working performance, craftwork performance and the function. And the designer can modify the design based on the result if the design quality does not satisfy the demands of consumer and supplier.

Therefore, the evaluation matrix R_R of two-level fuzzy synthesis evaluation of vibration screen quality obtained.

And the grade importance set of structure performance, working performance, craftwork performance and function is shown as Eq. (26).

(25) $$R_R = \begin{bmatrix} 0.55 & 0.24 & 0.1 & 0.105 & 0.005 \\ 0.46 & 0.33 & 0.15 & 0.04 & 0.02 \\ 0.47 & 0.27 & 0.205 & 0.045 & 0.01 \\ 0.384 & 0.2625 & 0.2005 & 0.136 & 0.017 \end{bmatrix}$$

(26) $$A_A = \left(0.3, 0.3, 0.2, 0.2\right)$$

Then, by substituting Eq. (25) and Eq. (26) into Eq. (14), the evaluation result of the vibration screen is obtained as Eq. (27) shown.

(27) $$B_B = A_A \circ R_R = \left(0.474, 0.277, 0.156, 0.080, 0.013\right)$$

From B_B, it can see that the percentage of excellent is almost 47, the preferable is 28, and the good is 16, so the design quality of the vibration screen obtained and is excellent.

6. Conclusions

It can obtained flowing conclusions from this work:

(1) Product design can give the "congenital advantages and disadvantages" quality characteristics to the product quality. Therefore, it is necessary to first establish the quality elements to the product design.

(2) Because of the different impacts on product quality that the composed element make, establishing the contribution rate function equation of the elements makes the design process more targeted, improves the product performance-price ratio and helps to optimize the product quality characteristics.

(3) The quality composed elements and the establishment of the contribution rate equation conducive to the establishment of product quality evaluation model, to the quantitative evaluation of product quality and to other studies.

(4) One application sample has been used to explain the design quality evaluation method based on fuzzy synthesized evaluation from four factors, the function, structure performance, working performance and craftwork performance.

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