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The creative design of special rewinding machine based on KANO/QFD and TRIZ

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Abstract
Non-standard equipment design needs the support of creative design strategy, our main task is to design a special rewinding machine. To comprehensively analyze customer requirements and creatively solve technical problem, an integrated innovation design model based on KANO, QFD and TRIZ theory is proposed. The innovation de-

sign is divided into three key procedures: requirements analysis, the conversion of technical features and creative solving. The Kano model is employed to analyze the customer requirements and QFD is employed to convert the customer requirements into technical requirements. Separation principle and contradiction matrix of TRIZ theory are employed to solve contradictions in the technical requirements. Finally the innovative design of the rewinding machine is taken as an example to verify the effectiveness of the proposed integrated innovation design model.
Key words: REWINDING MACHINE, INNOVATIVE DESIGN, KANO, QFD, TRIZ

1. Introduction

Adhesive tape as part of daily activities, can be seen everywhere in life. However, there are different requirements for different use conditions on properties of the adhesive tape. Especially under extreme conditions, such as the high temperature, high pressure, high corrosion environment, performance of the adhesive tape substrate is particularly strict. PTFE commonly known as the "king of plastic", have a good performance in various aspects, is a good choice to produce this kind of high-performance adhesive tape. Rewinding machine is a machine that unreeling the PTFE tape, and then rolling it after the single surface of the tape coated with glue through a special equipment. Different tape materials have different requirements on the rewinding machine. For the PTFE tape, existing rewinding machine do not have a good application, the problems are as follows: 1) the tension of the tape in the production process is not stable, tape is easy to deformation; 2) with the change of drum roll diameter, the speed of tape changes, which leads to poor coating quality; 3) the shafts of most rewinding machines are cantilever beams, the parallel degree will be reduced with the increase of the production time, thereby affecting the quality of the adhesive tape. Literature [1] has made some research to the design of rewinding machine, but it didn't give the detailed design scheme, such as how to ensure the parallel degree and the efficiency of roll changing. Literature [2] conducted research on the tape tension control in rewinding machine equipment, but did not take into account of how to ensuring constant speed in the same time. Therefore, it is now in great need of designing a rewinding machine which satisfies customer requirements.

2. Overview of Innovative Design Process

Literature [3] shows that 70% quality problems of the products are caused by the design time. Good design can not only reducing the cost of the product, but also improve the quality of products. However, it is the key to improve the quality and reduce the cost that choosing the right design method.

QFD (Quality Function Deployment) is an effective tools to transfer the customer requirements into the design requirements and the core of using it is establishing the House of Quality (HOQ) [4].

TRIZ means the theory of the solution of inventive problems, which is mainly composed of three parts: TRIZ basic theory, analysis tools and knowledge base [5]. Among them, as for the technical contradictions and physical contradictions in the design step, it can be solved by using the contradiction matrix and the separation principle respectively to find corresponding invention principles, and put forward innovative solutions to the specified problem.

KANO model can be used to indicate the importance of the characteristics and functions of products to the customers. And customer requirement which includes the characteristics and functions of products is split into three classes including basic requirements, functional requirements and exciting requirements [6]. Fig.(1). shows the customer satisfaction curve related to those three classes.

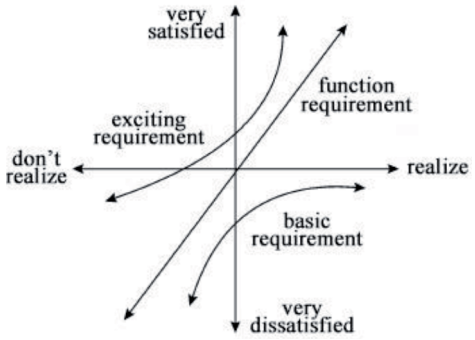

Figure 1. KANO model

The integrated design process of QFD and TRIZ have been studied by many scholars, and applied to many examples [7][8]. However, before using this method, the classification and importance degree judgment of the customer requirements are rarely studied. The classification and importance degree judgment of various customer requirements directly affects the design process and the manufacturing cost of the product, and ultimately determines the customer satisfaction with the products. Literature [9][10] conducted some theoretical research on customer requirements importance degree with KANO model modified QFD method, but the theory has not been applied to the product design process. Therefore, integrate the KANO model, the QFD and TRIZ theories, an innovation design process is established which contains the customer requirements to the technical requirements and conflict solution.

After analysis of the above three kinds of methods, it could be found that each of them has different roles and functions in the product design process. In the acquisition of customer requirements, using the KANO model for classification, analysis, and obtaining the important degree. Based on the customer requirement and the importance degree provided by KANO model, QFD can help the design personnel to find the problems which need to be solved and the engineering technical parameters in a structured way. The related matrix of technical requirements of HoQ indicates various technical conflict or physical conflict. Then, with the help of problem solving tools in TRIZ theory, such as contradiction matrix, substance field model, and the principle of invention, substantively solve the problems which cannot be solved by QFD .The three method combined into the integrated innovation design process as shown in Fig .(2).

3. Innovative Design of Rewinding Machine Based on Integrated Innovative Design

For the existing plastic tape products, especially the PTFE tape products, its production process mainly includes three stages: 1) unwinding stage before the tape gets into the glue coating equipment; 2) glue coating stage when the tape gets into the special processing device; 3) winding stage after the glue coating. This whole process needs special designed rewinding machine to complete. Take the integrated innovative design process mentioned as the method, to carry out an innovative design of the rewinding machine, its main steps are as follows:

(1) Acquisition, analysis and classification of the customer requirements with the help of KANO model. Then obtain the importance degree of each customer requirements.

(2) Import each customer requirements to the HoQ with its importance degree, complete the HoQ and reach the technical requirements with its importance degree in the design of the rewinding machine.

(3) Analyze the technical requirements and its importance degree, and work out the conflicts that the technical requirements in negative correlation with the help of TRIZ.

(4) Evaluate solutions and technical requirements, and make out the final scheme which satisfy customer requirements.

3.1. Customer requirement analysis

Customer requirements is the driving force of new product design, and objective and accurate access to customer requirements information is the premise to make the product design scheme. For the design of the rewinding machine, the customer requirements as follows is acquired by customer presenting directly and finding relevant information: adjustable constant tension, adjustable constant speed, regularly rolling, good quality of glue coating, high production efficiency, reasonable structure, reliable working etc, denoted with CR1, CR2, CR3, CR4, CR5, CR6, CR7 successively. Investigate each customer requirements through the following two opposite problems shown in table 1 (take good quality of glue coating as an example).

According to the different feedback of customers that facing two opposite problems of the same requirements, the customer requirement could be classified. Take good quality of glue coating as an

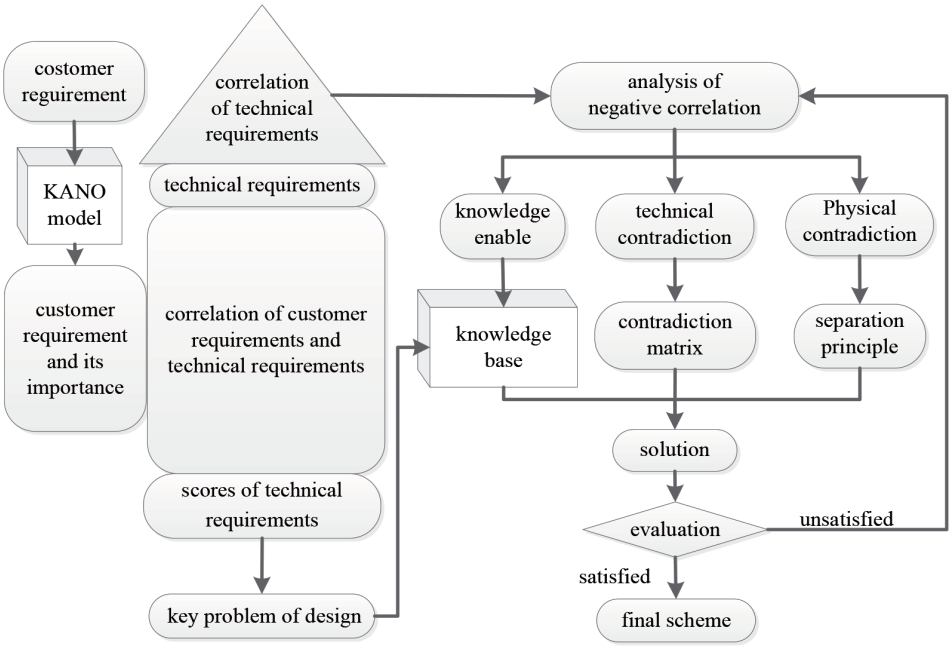

Figure 2. Integrated innovation design process based on KANO\QFD\TRIZ

Table 1. Questionnaire of customer requirements

customer requirements	quality of glue coating	
question	good	bad
Available options	quite like	quite like
	like	like
	neutrality	neutrality
	sustainable	sustainable
	dislike	dislike
customer feeling	like	dislike

example, if the customer on the positive answer is "like", on the reverse question answering "dislike", so that good quality of glue coating could be classified as a function requirements. According to the 25 different kinds of answers that are likely to appear, the corresponding classification is shown in table 2 respectively.

What calls for special attention is that, in table 2, the basic requirements, function requirements and exciting requirements are of valve. The other three results as suspicious results, reverse results and don't care are undesired results and should be excluded [9]. After analyzed every customer requirements mentioned, the classification after statistics are as follows in table 3.

The initial importance degree of customer requirements matrix is obtained as IR1= (5, 4, 4, 5, 5, 4, 5) corresponding to CR1, CR2, CR3, CR4, CR5, CR6, CR7 by the group of experts scoring way. Then, according to the classification as the basic requirement, the function requirement and the exciting requirement, each customer requirement were given a correction 2, 1, 1/2 to the initial importance degree as a matter of experience. On account of that for the basic requirement, there must improve a larger proportion of the products quality to obtain a desired satisfaction. Similarly, an increase of only a small proportion of exciting requirement can create the desired satisfaction. In this way, the modified importance degree of customer requirements matrix is IR2= (6, 5, 4. 5, 6, 7, 6, 7).

3.2. Constructing and analysis of the HoQ

The technical requirements and parameters of the rewinding machine design are required in reference to a lot of information, mainly includes: speed parameters , tension parameters, formation of tape, simply supported beam ,rapid roll changing, automatic control, rigidity of the machine. Combined with the importance degree information of customer requirements, the HoQ of rewinding machine design is constructed as shown in Fig. (3).

In the correlation matrix of customer requirements and technical requirements: strong correlation denoted with 3 points; general correlation denoted with 2 points; the weak correlation denoted with 1 points; no relevant denoted with 0 points. In the correlation matrix of technical requirements: positive correlation denoted with +; negative correlation denoted with -. After analysis of the HoQ, the following conclusions can be obtained: (1) according to the scores of the technical requirements, the technical requirements could be reordered as: automatic control, rigidity of the machine, fast roll changing, speed parameters, formation of tape, tension parameters, simply supported beam.

(2)two negative correlations was found in the correlation matrix of technical requirements, one of them is the contradiction between the simply supported beam and rapid roll changing. The other one is the contradiction between speed parameters and tension parameters.

3.3. Conflict resolution

Analysis the above two technology requirements in negative correlation and solve the conflict and problems, the process are as follows.

Table 2. The classification of customer requirements

Forward problem	The reverse problem				
	quite like	like	neutrality	sustainable	dislike
quite like	suspicious result	exciting requirement	exciting requirement	exciting requirement	function requirement
like	reverse result	don't care	don't care	don't care	basic requirement
neutrality	reverse result	don't care	don't care	don't care	basic requirement
sustainable	reverse result	don't care	don't care	don't care	basic requirement
dislike	reverse result	reverse result	reverse result	reverse result	suspicious result

Table 3. Classification of customer requirements

classification	customer requirement
basic requirement	CR5, CR6, CR7
function requirement	CR1, CR2, CR4
exciting requirement	CR3

3.3.1. Establishing the model of the problem

Expressing the first problem particularly as: for the first negative correlation, in order to improve the rigidity of the machine, the roll changing system must adopt to the simply supported beam structure, but using the simply supported beam structure that the roll

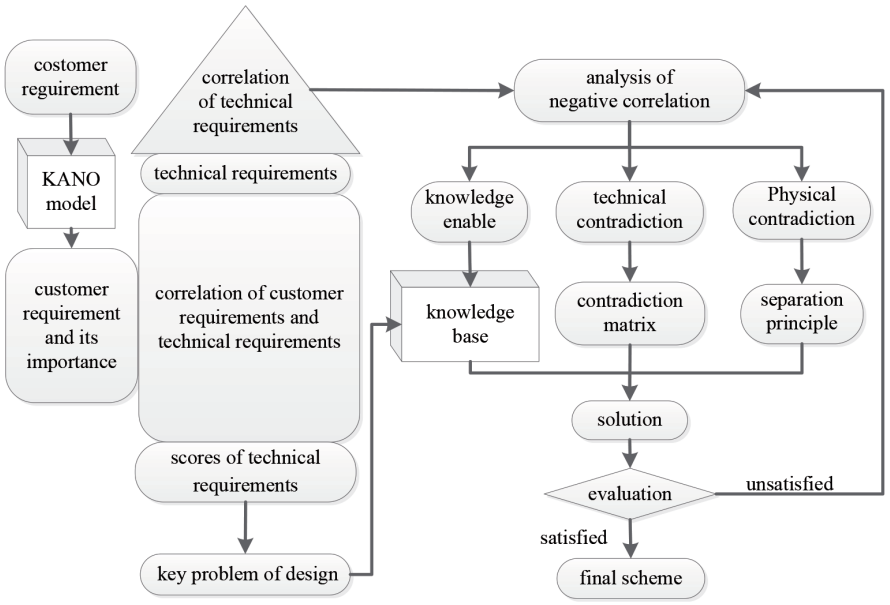

Figure 3. Establishment of HoQ of rewinding machine design

changing time is greatly increased compared with the cantilever beam structure. It reduces the roll changing efficiency, thus contrary to rapid roll changing requirements. Ideally, the roll changing system should be simply supported beam structure in the work time; when the roll changing, system should not be simply supported beam structure, so as to meet the two technical requirements. Therefore, the core of the contradiction is to achieve the conversion of the simply supported beam system and not simply supported beam structure rapidly.

3.3.2. Solving the problem

In the analysis tools of TRIZ, technical contradiction is expressed by 39 standard engineering parameters. And then check the contradiction matrix to find the corresponding invention principles. The final choice of invention principles applicable to solve the practical problems is confirmed after further analysis [11]. Physical conflicts is solved through 4 separation principle as spatial separation, time separation, condition separation, separation of the components and the overall, and they have corresponding relationships with the 40 invention principles as shown in table 4.

Table 4. The corresponding table of separation principle and invention principle

separation principle	invention principle
spatial separation	1, 2, 3, 4, 7, 13, 17, 24 ,26 ,30
time separation	9, 10, 11, 15, 16, 18, 19, 20, 21, 29, 34, 37
condition separation	1, 5, 6, 7, 8, 13, 14, 22, 23, 25, 27, 33
separation of components and overall	12, 28, 31, 32, 35, 36, 38, 29, 40

The first contradiction is confirmed belonging to physical contradictions after analysis. Aiming at this problem, time separating principle has some guiding significance. The invention principles corresponding to time separation principle are as follows: NO.9 prereaction method; NO.10 preaction method; NO.11 preset prevention method; NO.15 dynamic method; NO.16 part beyond method; NO.18 mechanical vibration method; NO.19discretion method; NO.20 continuly effective operation method ; NO.21 rapid method; NO.29 pressure method; NO.34 autogeny method; NO.37 thermal expansion method [12] . Based on the indepth study of the invention principle, the conclusion that NO.15 invention principle would be the largest help to solve the first contradiction could be drawn. The detailed understanding of NO.15 invention principle are as follows : (1) changing the nature of the object or the external environment; (2) transforming the non moving objects into dynamic objects, increase the moveability; (3) transforming the object to be able to be divided into different parts that can change the relative position.

3.3.3. Identifing the solution

Set the a fast dismounting bearing seat based on the analysis of the NO.15 invention principle and general design of the rewinding machine, the detail are as follows in Fig. (4).

In the roll changing process, the fast dismounting bearing seat of pneumatic core shaft is shown in Figure 4: through a quick disassembling structure, move disc 1, so that the the square head of pneumatic core shaft is exposed from the bearing 2 that rotating coaxial with the motor ; the cross section of the bearing 2 is a “U” shaped section, the pneumatic core

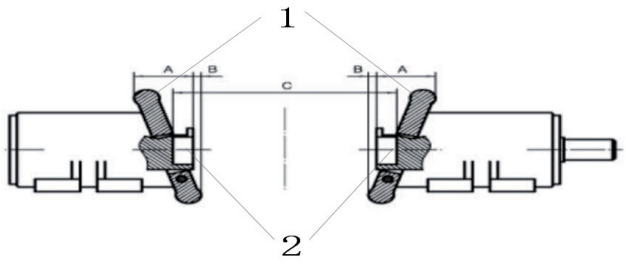

Figure 4. Fast dismounting bearing seat

shaft can be easily taken out from the upper opening for roll changing when the disk is removed ; After roll changing is finished, place the square head of the pneumatic core shaft on the bearing of "U" shaped section , then move the disk gently to the middle on both sides , the inner part of the disk just lock the upper of the pneumatic core shaft , which centering the pneumatic core shaft on the concentric line together with the bearing of "U" shaped section and then rotating with the motor.

The scheme uses the time separation principle, creatively improved the structure of the bearing seat which can transform into two forms rapidly. The solution solved the physical contradiction well in the design, meeting the requirements of both using of simply supported beam structure and rapid roll changing.

The detailed description of the second correlation is mentioned below. By the formula indicating, with the change of the rolling diameter, the output of the torque must be varying with the time in order to maintain the constant tape tension. And the formula indicates that with the change of the rolling diameter, the output of the rotating speed must be varying with the time in order to maintain the constant line speed of the tape. The resulting conflicts. Using the same process analyzing the contradiction, the following conclusions can be drawn. The contradiction belongs to physical contradictions as well. Apply to the space separating principle to analyze the contradiction and find that, NO.1 separation method and NO.3 local quality improving method could solve the conflict. That is adopting the speed control system in winding end and the tape tension control system in the unwinding end respectively to achieve the control of speed and tension simultaneously, and then satisfies the requirement of the customers.

3.4. Getting the overroll scheme

According to the technical system evolution theory, the rewinding machine will evolve towards highly automated, high efficient direction. Combining the existing mature technology of rewinding machine and the specified conflict solution based on TRIZ, the overall scheme of the rewinding machine is proposed as shown in Fig. (5).

The rewinding machine mainly consisted of unwinding system, flattening roller, tape coating processing equipment, winding system and error correcting system according to the running routes of tape. Among them, the unwinding system is an independent closed-loop control system to control the adjustable constant tension; the winding system is an independent closedloop control system to control the adjustable constant speed; the error correction system is an independent closed-loop control system. The above each part fixed on standard industrial aluminum frame with enough strength. The virtual prototype Figure of the rewinding machine is shown in Fig.(6). through 3D modeling based on the final scheme.

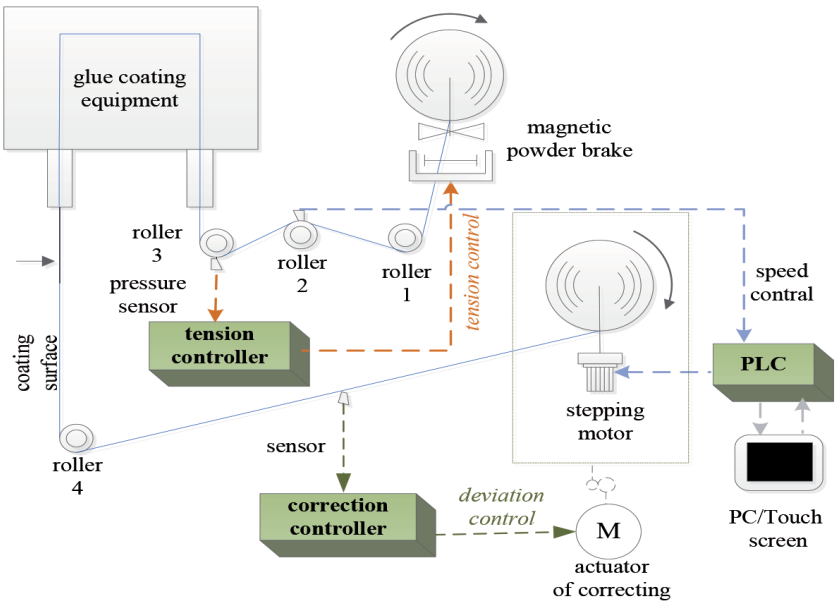

Figure 5. The design scheme of rewinding machine

Figure 6. The virtual prototype Figure of the rewinding machine

Conclusions

The KANO model, QFD and TRIZ theory are integrated in an innovative design model. The three methods play their respective advantages, complete and promote each other in product design, to assist product innovation design process. Based on sufficiently analyzing of the customer requirements, in view of the existing problems in design of rewinding machine, use QFD as the main framework for translating customer requirements into technical requirements and pointing out the direction of innovative design, and then solve the problems faced in the design with the help of TRIZ. A design of quick disassembling bearing seat solves the contradiction between simply supported beam and rapid roll changing, ensures the rigidity of the machine and the parallelism of the pneumatic core shaft while improving the roll changing efficiency. The contradiction between control constant tension and constant speed simultaneously is solved by arranging speed control system and tension control system respectively in the winding end and unwinding end. Synthesized with other key design issues the innovative design scheme of integrated rewinding machine is finally proposed, and the virtual prototype figure is obtained through the computer 3D modeling. This paper not only solved the encountered problems when design the rewinding machine, improved the performance and efficiency of the rewinding machine, but also demonstrated the feasibility of integrated innovation design process based on KANO model, the QFD and TRIZ .

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