Mechanical Design of Substandard Glass-Bottled Beer Recycling Equipment

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Abstract—In beer production industry, some substandard glass-bottled beer should be recycled considering the economic benefit. The traditional way of recycling the glass-bottled beer totally depends on manpower, which limits the development of the production line. This paper proposes a new method for recycling substandard glass-bottled beer, and a relevant equipment is designed. Based on FBS model, a framework for the glass-bottled beer recycling equipment is proposed. With the implement of CATIA, the mechanical structures are modeled and a virtual assembly is conducted. To verify the feasibility of the product, a motion simulation is conducted. The equipment can coordinate recycling of beer, recycling of bottle and recycling of the cap. It frees the labor force in recycling the substandard glass-bottled beer, removing the obstacle to the development of beer-brewing industry. There exist some further work to verify the practicability of the equipment. A prototype should be made and in service in the production line to test and perfect the design.

Keywords-component;Equipment; industry; Glass-bottled beer recycling; Function-Behavior-Structure; Computer Aided Design

I. INTRODUCTION

Since 21st century, the output of beer in China has been raising every year. However, the profit ratio doesn't go up along with the productivity as expected for the fierce market competition. Under this circumstance, valid control of the links in the supply chain is the most effective way to enhance economic performance.

Inferior-quality products can not be avoided in mass production, so the way to deal with the inferior-quality comes to great significance for beer-brewing enterprises. In the majority of the beer-brewing enterprises, the inferior-quality products are recycled by manpower. There exist some obvious disadvantages in this recycle mode. First, as for the uncertainness, the inferior-quality products can not be dealt with in time. Second, manual pouring is a waste of human resource. Workers have to suspend their own duty to deal with the inferior-quality products for there is no specific workstation arranged for dealing with the inferior-quality products. Third, manual work exposed the liquid to the air for a long time, causing the carbon dioxide run away.

To propose an equipment that can be used during the production to realize the automation of the substandard glass-bottled beer recycling matches the need for the industry.

II. DESIGN METHOD

Generally, the product development design process can be divided into four steps, definition of the task, conceptual design, collateral design and detail design. Process model is a basic requirement of conceptual design. Two main methods are FB method and FBS method, among which we utilize FBS to do the design.

Function-Behavior-Structure model is first proposed by Qian and Gero[1]. Another proposition identify FBS as Function-Behavior-State[2], which insists that objects exist and be perceived in the form of state. Besides, Deng and Zhang input environmental effects and propose Function-Environmental-Behavior-Structure[3] while professor Zhou proposes FPAM based on the experience of mechanism research[4] and Song proposes H2 design frame[5].

Under FBS theory, the function of the product is mapped to the behavior, then the behavior is mapped to the structure. By analyzing the function units, we can identify the related behavior and then design relevant structures to realize the functions.

III. CONCEPTUAL DESIGN

Based on FBS theory, we did a survey to identify the expected functions. The result can be concluded as the following three.

1. The treatment efficiency is an important index, which is expected to reach at least 432 pieces per hour.

2. The equipment should ensure the purity of the recycled liquid.

3. The equipment should perfectly match the original production lines. No alter of the original production lines is permitted.

A. *Functional decomposition*

Observing actual operation of pouring, we can summarize the whole procedure as three major modules, the transportation, the separation and the collection. Each module can be divided into several function units. Transportation module consists of the input of the inferior, the output of the bottle, the output of the liquid and the output of the cap. Separation module consists of cap-remove unit and the liquid-pouring unit. Collection module consists of liquid collection unit and cap collection unit. Figure 1 shows the relationship between these units. For each feasible point , it is necessary to solve lower one level problem. For large-scale problems the amount of calculation increased significantly.

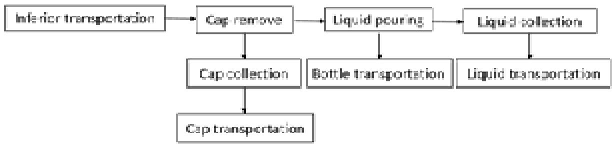

Figure 1. Function structure of mechanical system

B. *Function-Behavior Mapping*

Taking function structure as the basic, behavior structure can be modeled in principle that taking the behaviors that have no apparent logical relationship to the parallel connection to short work cycle and improve efficiency. Figure 2 shows the behavior relationships in the system.

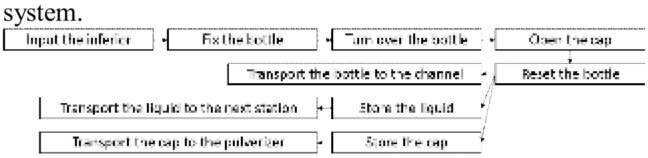

Figure 2. Behavior structure of mechanical system

C. *Behavior-Structure Mapping*

According to the analysis above, we map the behavior to specific structures to acquire the conceptual design model. The FBS mapping is shown in Figure 3 and the conceptual design is shown in Figure 4.

IV. COLLATERAL DESIGN

A. *Tests*

Before the collateral design, we did two experiments to respectively verify the optimal pouring positon and the minimal open force.

For the toppling angle, the result shows that when the angle of inclination reaches 45 degrees, the toppling time gets the shortest. On the other hand, 20 tests are done to verify the open force. We can conclude from the results that the average open force is 21.2N while the standard deviation is 0.568N. With the knowledge of statistics, take the estimated value of the open force as 22.904N.

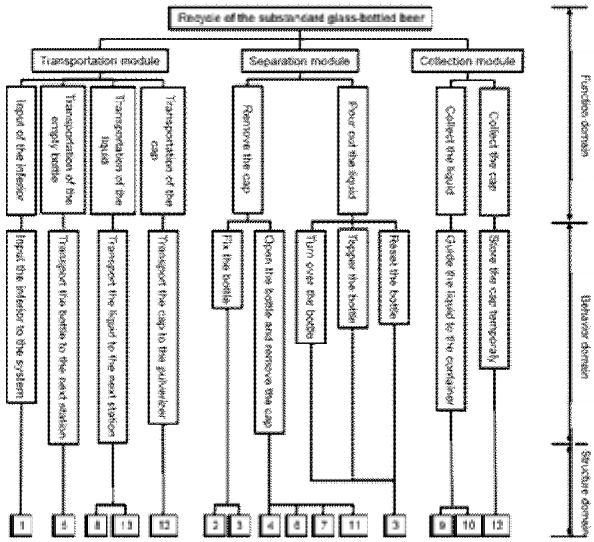

Figure 3. F-B-S mapping of mechanical structure

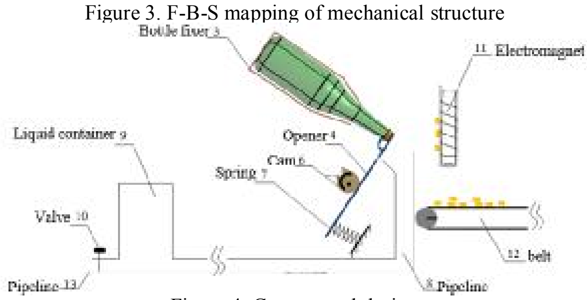

Figure 4. Conceptual design

B. *Design of overturn mechanism*

Overturn mechanism plays the role to fix the substandard glass-bottled bear by nest the outline of the bottle and turn it over. The outline of the mechanism is determined by the size of the bottle. The width is 1mm wider than the bottle to make it possible for the bottle to move. The outline of the mechanism is shown in Figure 5.

Stepper motor is chosen to conduct the movement for the angle of the mechanism should be accurately controlled. Stepper motor is selected in principle of the torque, so the maximum torque during the movement should be calculated. In CATIA, the position of the center of gravity can be posted when the model is identified with material. The gravity is 15.327N while the vertical size of the center is 112.58mm. The max torque can be calculated as 2.209Nm. Take the mechanical efficiency as 0.9. According to the stepper motor parameters, 110BF003 is selected.

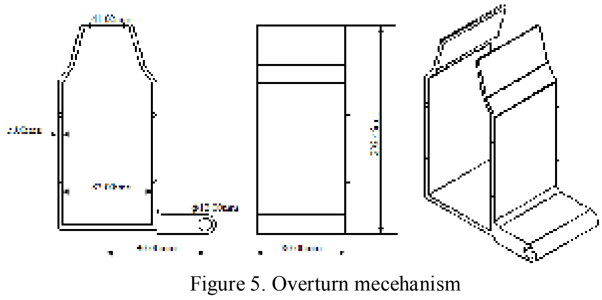

Figure 5. Overturn mecehanism

C. *Design of uncap mechanism*

The Uncap mechanism plays the role to uncap the substandard glass-bottled bear's cap. Cam mechanism is used to realize the function. Depart of the reality for the follower's track, good drive characteristic, compact size and long working life are expected. Among these goals, the size and the working life is selected as the most important factors. An optimization design based on MATLAB is conducted.

The cam system schematic is shown in Figure 6. There are several constraints to the schematic.

First, the maximum angle of the follower should be bigger than the critical value which can be calculated as 21.80degree.

Second, to confirm the strength of the cam, the radium of the base circle can not be smaller than permitted.

Third, the volume should be as small as possible.

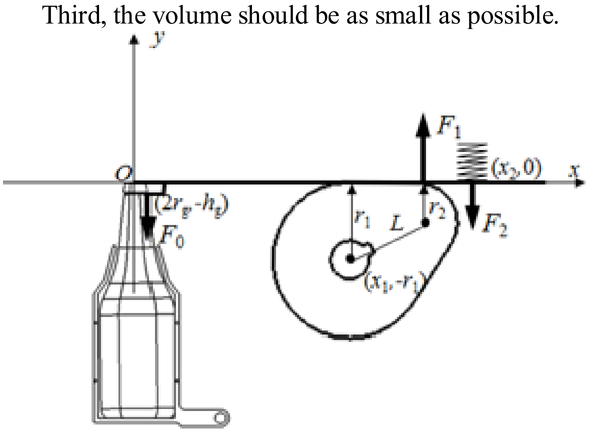

Figure 6. Cam system schematic

Based on the constraints, mathematical model for optimization design of the cam mechanism is built.

$$\begin{cases} X=[r_1,r_2,L,B,x_1,x_2,F_2]^T \\ \min\ f(X)=\min[w_1 f_1(X)+w_2 f_2(X)+w_3 f_3(X)] \\ s.t. g_i(X)\geq 0 (i=1,2,...,15) \end{cases} \quad (1)$$

$$f_1(X)=V_t(X)=[(\pi-\theta)r_1^2+(r_1+r_2)L\sin\theta+\theta r_2^2]\cdot B \quad (2)$$

$$f_2(X)=\sigma_{H\max}(X)=\sqrt{\frac{F_{1\max}}{\pi B\Delta r_2}} \quad (3)$$

$$f_3(X)=\varphi_0-\varphi_{\max}(X)=21.80°-\sin^{-1}\frac{r_1+L+r_2}{\sqrt{x_1^2+r_1^2}}+\sin^{-1}\frac{r_1}{\sqrt{x_1^2+r_1^2}} \quad (4)$$

The model is optimized by genetic algorithm. The Searching results are shown in Figure 7 while the optimized results are shown in Table 1.

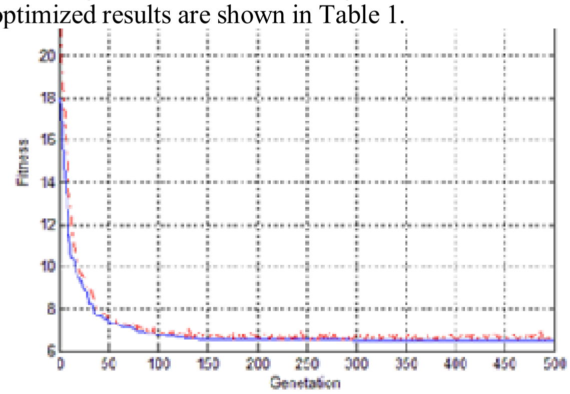

Figure 7. Searching results

TABLE I. OPTIMIZED RESULTS

r1	r2	L	B	x1	x2	F2	Vt	$\sigma_{H\max}$	$\varphi_{\max}$	θ
47.3 mm	22.4 mm	47.9 mm	21.4 mm	182 mm	248 mm	12 N	1.73×10^5 mm^3	40.0 MPa	24°	59°

D. Other Subassemblies

Other subassemblies includes the belt system, the frame, the solenoid module, guide slot car and the beer reservoir. The assembly drawing is shown in Figure 8. The system is confirmed effective through CATIA simulation.

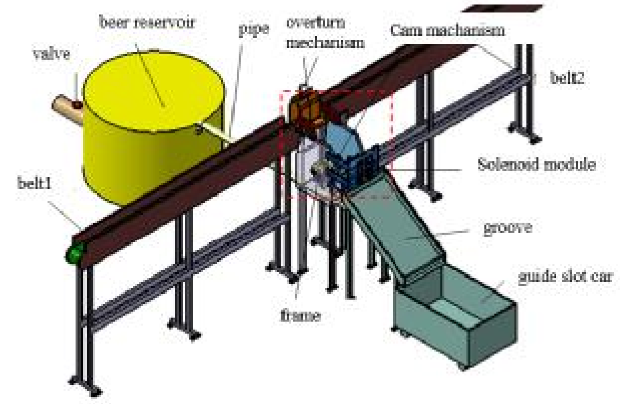

Figure 8. Assembly of the equipment

V. CONCLUSION

This paper proposed a mechanical design of substandard glass-bottled beer recycling equipment according to the need of the beer-brewing industry. We do the modular design which mainly includes the overturn mechanism, the cam mechanism and other subassemblies based on FBS.

With the support of the experimental data and some mechanical principle, we finish the shape design and the basal dimension is determined. For the purpose of optimization design, a model is built and solved through MATLAB.

The equipment can coordinate recycling of beer, recycling of bottle and recycling of the cap. It frees the labor force in recycling the substandard glass-bottled beer, removing the obstacle to the development of beer-brewing industry.

There exist some further work to verify the practicability of the equipment. A prototype should be made and in service in the production line to test and perfect the design.

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