Key Technologies for Conveying Bottle System in high Speed Filling Production line

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Abstract: The conveying bottle system meets a larger risk in high speed filling production line, and bottle falling, breaking and blocking in the high speed conveying process severely lower the production capacity and reliability of the conveying system. The effect of the bottle structure and conveying velocity on the bottle stability was analyzed. The container storage and conveying technology, conveying technology of merging into single line, and low push pressure technology of container were introduced so as to obtain high efficiency.

Keywords: filling production line; conveying bottle system; stability; conveyor

1. Introduction

Container packaging is one of the most important packaging methods widely used in medicines, chemicals, commodities and food products. Along with the rapid development of packaging industry, the production capacity of container packaging production line has been increased from 400 bottle/min twenty years ago to the current 1000 bottle/min, sometimes can even reach 1200 or 1300 bottle/min [1]. Packaging production line is developed towards high speed, high efficiency and high automatization. Thus, the bottle conveying equipment is also required for higher conveying capacity. During the high speed conveying process, some phenomena such as bottle falling, breaking, blocking, et al. not only influence the production continuity, create waste, but also may cause damage to machine, decrease the productivity. In severe case, quite a long time for repair is needed will result in stopping to provide raw materials, refrigerating the work-in-process, and even unfulfilling the contracts, then the loss can not be estimated. Thus, high speed bottle conveying may meet a high risk. The conveyor device is not the simple connection of every machine, but an integrated system [2]. For the purpose of steady and fault-free conveying during the whole process of modern high speed container packaging production line, a correct design and arrangement of conveying system is of significant importance for the performance and efficiency of the whole line [3].

2. Factors of Influence on Container Stability

During the process of high speed conveying, container falling, breaking, and blocking influence the reliability of conveying system, decrease the conveying capacity of system. The main reason for these phenomena is the unstability of container conveying process. The main factors of influence on container stability include: container itself, accuracy of manufacture, conveying speed, rationalization of process routing layout, process control parameter and reliability of control elements (especially detect sensor). Moreover, it is also related with proficiency of operators [4].

2.1. Stability Function of Container

During the conveying process, the container stability is closely related with material, weight, type, shape, quality defect, size difference, strength and stiffness of container itself. Among them, the critical inclination angle of container has direct influence on the stability of container.

As shown in Fig. 1(a), the critical inclination angle α indicates an angle turning about its edge from static position to another position with the vertical projection of center of gravity falling on its axis. When container rotates α degree from one static position, it will be in a critical state of changing pose.

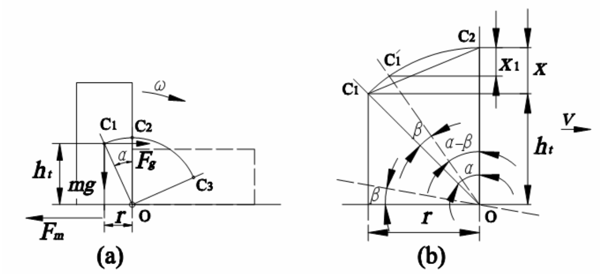

Figure 1. Calculation chart of container stability in conveying process

In fact, during the high speed conveying process, before container speed reaches its conveying speed, if container slides on the chain belt, then the generated inertial force F_g in N is equal to the maximum static frictional force F_m in N. At this time, if the moment generated by inertial force F_g is smaller than that by gravity, then even if kinetic energy increases, container can only have relative slip but not fall down. So, the condition for stable container conveying is

$$F_g \cdot h_t < mg \cdot r$$

for $$F_g = F_m = mg \cdot \mu$$

so $$r / h_t = \text{tg}\,\alpha > \mu \quad (1)$$

where, m is mass of container in kg; h_t is height of center of gravity of container in m; r is radius of container in m; μ is coefficient of friction between container and chain belt; α is critical angle of container falling in °.

Equation (1) indicates that the size of tgα determines container stability in the conveying process, so stability function of container is represented as

$$f(\alpha) = \text{tg}\,\alpha \quad (2)$$

The larger is the value of tgα, the better is the stability of container. As shown in experiments, for chain belt made of stainless steel, tgα should larger than 0.21~0.26. On the other hand, the smaller is the coefficient of friction μ, the better is the stability of container. So, for the same type of containers, lubricants can be used to decrease coefficient of friction μ so as to increase stability of container in high speed conveying process.

2.2. Limit Speed of Plate-link Chain Conveyor

Plate-link chain conveyor is one of the most important conveying machinery in high speed container packaging production line which can be operated in very high speed. The maximum conveying speed of it is limited by the stability function of container.

Assume that a container of mass m moves horizontally at speed υ in ms^{-1}, then stops suddenly ($\upsilon = 0$), as shown in Fig. 1(b). The center of gravity of container continues to move along center O, radius is R, angular speed is ω, from point C_1 to C_2, or maybe to C_3. When the projective point of C_2 is on the left of the point O, container will be still in equilibrium state. When the projective point of C_2 is on the right of point O, container will continue to tilt until fall down on the conveying belt. In order to make sure that container may not fall down, conveying speed υ should satisfy

$$\frac{1}{2} m \upsilon^2 \le mgx$$

substituting $x = r\,\text{tg}\frac{\alpha}{2}$, gets

$$\upsilon \le \sqrt{2gr\,\text{tg}\frac{\alpha}{2}} \quad (3)$$

where, m is mass of container in kg; υ is linear speed of container in ms^{-1}; g is acceleration of gravity (9.8 ms^{-2}); x is elevated height of center of gravity of container in the turning process in m.

Likewise, for the conveying belt with slope β in °,

$$\upsilon \le \sqrt{2gr\frac{1-\cos(\alpha-\beta)}{\sin\alpha}} \quad (4)$$

The above two formulas are frequently used for calculation of conveying system. If total tilting force but not mass of container is considered, then speed value υ should increase 25%, because container itself has an 'anti-tilting force'.

According to the checking calculation for the stability parameters of conveying container, usually speed υ of conveying belt should not exceed 15~20 m/min, or it is easy to have container falling or breaking. From experience, υ = 15.2 m/min is the maximum feeding speed or output speed at exit in the production line in practice. In the high speed filling production line, for the continuous feeding of container, parallel multiseriate conveyors can be used at the entrance and exit of production line, and operation interlocking control technique should be adopted by means of programming controller [5].

3. High Speed Conveying Technology for Container Conveying System

3.1. Container Storage and Conveying Technology

In high speed container packaging production line, for the stability and continuity of production process, the best sign that conveying system could work in accordance with planned conveying capacity is that container should be sent into every single machine continuously and then sent out from them continuously.

During the conveying process of container, adjusting speed of conveying chain and setting container storer in certain locations, which means combining stoppage with speed adjustment controlled by micro-electronics to compensate the continuous fluctuation of container conveying amount, can prevent every single machine from interruption and blockage of container conveying.

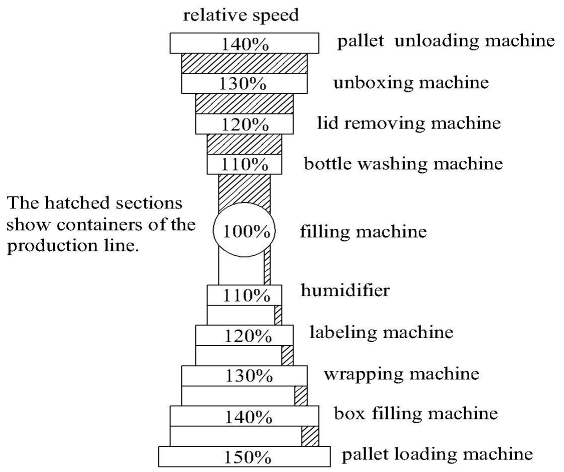

Figure 2. Chart of conveying process

The main equipment of high speed container packaging production line is filling machine which determines container conveying amounts of other equipments on line [6], as shown in Fig. 2. For the stable feeding of container, productivity of the main equipments adjacent to a filling machine must be higher than that of it. In order for filling machine to work continuously and effectively, to prevent the containers in the storer from being sent into filling machine totally, the container conveying amount

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before reaching filling machine must increase to the degree of refilling the storer with containers. On the contrary, in order to send away those already filled containers in time, avoid filling the storer with containers thus resulting in blocking up the filling machine, the speed of conveying chain at the exit of filling machine should be higher than that of filling machine itself.

How to choose the location of container storer must consider the type of container. How much is the compensation is dependent on the residence time needed. For example, a production line whose productivity is 1000 bottle/min, in order to satisfy the compensation need of temporary interruption, the storage amount of container storing section may be set as 3 minutes. If the needed storage amount is relatively large at any position in the container conveying process, then it is can be considered to set a bi-directional container collector outside the production line, and utilize a photoelectric sensor or mechanism to control its container supply in needed direction, so as to ensure normal conveying of container.

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Container storer actually is a widened multiseriate plate-link chain conveyor driven by the same shaft, the maximum width of which can reach 1.22m. When the chain belt is not filled with containers completely, containers will be dispersed, thus may increase the possibility of container falling. So, in order not to disperse containers, usually the container collector would be mounted tilting toward one direction, so as to make the container flow concentrate on the lower side, decrease fallen containers, and also make the existing fallen container roll down automatically.

Storage technology is not only used to balance all the procedures in the production line, but also provide essential time for online maintenance or fault removal. Thus avoid the production interruption of the whole line caused by local temporary interruption in the production process. It is the most effective method to ensure the reliability of whole production line. So, the intermediate strorer plays an important role in the system.

3.2. Conveying Technology of Merging into Single Line

What is called conveying technology of merging into single line is a method to merge multiple-line container conveying into single line conveying by means of guiding side plate with its width decreasing little by little.

In order to satisfy the need of high speed filling, higher conveying speed than 15.2m/min should be taken in other places of the conveying system, such as at the entrance or exit of filling machine, in front of or behind labeling machine and checking machine and so on. In these places, because single channel is required and container speed need to reach 50~60m/min, so it is almost impossible to take single-stage conveying speed. In order to raise the conveying speed, step speedup conveying chain and guiding plate structure which can increase conveying speed gradually could be adopted. The container conveying speed could be increased step by step from container collector to the end of the current conveying chain where single line conveying is formed, and it can reach about 61m/min.

Consider a container with its radius being 30mm and height of center of gravity being 80mm, its speed change should take two steps, more concretely, firstly from 60 m/min to 41 m/min, then from 41 m/min to 22 m/min. If in the situation of superspeed, it is recommended that the part above 40 m/min should reduce speed by $\sqrt{2}$, and that below 40 m/min should reduce speed by $\sqrt{3}$. This technology is only applicable to cylindrical container.

3.3. Low Push Pressure Technology of Container

During the process of high speed conveying, in some places such as side guiding plate and storing section where it is easy for containers to push each other, the pressure of push is a number of times lager than the product of container weight and frictional coefficient between container and chain plate, it is easy to cause container breaking and falling.

Low push pressure technology of container takes method of storage, through setting sensors like phototube, limit switch, etc. and interlocking devices, keep a certain interval between containers, so as to avoid collision and push among containers. In order to prevent crash to the front containers, usually a kind of large conveyor with lower conveying speed and bigger width is adopted to separate containers on the conveyor, its width can reach 2~3 times of 19cm, thus a higher level of productivity can be kept, at this time the speed of conveyor can reach 15.2 m/min.

In the conveying system, the push length of high speed section must be appropriate, because appropriate push length can limit push pressure between containers and also pressure from container on chain plate.

When taking this conveying method, noise can decrease obviously, containers which are not very strong could also be conveyed smoothly. Moreover, containers that are not cylindrical may achieve high speed conveying too.

4. Conclusion

During the process of high speed conveying, container falling, breaking, and blocking greatly influence the reliability of conveying system, and decrease conveying capacity of the system. In order to ensure the stability of container in the conveying process, the stability function of container should satisfy $f(\alpha) = tg\alpha > \mu$. Decreasing frictional coefficient μ can increase conveying speed. The maximum conveying speed of plate-link chain conveyor is limited by the stability function of container, its conveying speed υ should not exceed 15~20m/min, or it is easy to produce container falling or breaking. The main equipment of high speed container packaging production line is filling machine which determines container conveying amounts of other equipments on line. For the stable feeding of container, productivity of the main equipments adjacent to a filling machine must be higher than that of it. The storage conveying technology is the most effective method to ensure the reliability of whole production line. In order to raise the conveying speed, conveying technology of merging into single line which includes step speedup conveying and gradual speed increase of container conveying could be adopted. In addition, the generated pressure because of push among containers is also a problem that cannot be ignored.

High speed conveying technology of container is a combined application of the latest achievements in mechanics, electromechanics, electrotechnics, electronics, etc. Thus conveyors could convey containers at a very high speed.

References

[1] He Xiaowu, Chen Nengyu. On the design of conveying bottle system. China packaging industry, 1998, 54(12), p 15-16.

[2] Braglia, Marcello. Designing a belt conveyor controller in a bottling plant using fuzzy logic and genetic algorithms. Packaging Technology and Science, 2001,14(6), p 231-248.

[3] Hall, William C. Bottle producers drive conveying chain innovation. Glass International, 2005, 28(4), p 25-26.

[4] D. K. Smith, Package Conveyors: Design and Estimating, Griffin, London, UK,1972.

[5] J. F. Hanlon, Handbook of Packaging Enginneering. McGraw-Hill Book Co., New York, 1975.

[6] M. Bakker, The wiley encyclopedia of packaging technology. John Wiley and Sons, New York, US, 1986.

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