Optimization on Characteristic Angle of New Box Opening Machine

Yi Ping Li

Abstract. The process of box opening machine is analyzed, according to the maximum angle of box opening plate relative to the sucker in the course of equipment debugging. The graphic method is used to calculate the opening angle. To obtain a desired opening angle, improvement is proposed to reduce the initial relative angle that is too large to meet the production requirements between the box opening plate and the suction cup. The engineering problem is transformed into a mathematical model where analytical and graphic methods are applicable and adopted. The relative position of box opening plate is optimized conforming to the engineering design constraints, and the improvement is verified through simulation.

Keywords: Box opening machine, Box opening perspective, Optimization, Graphical method

Introduction

Advances in industrial automation in recent years leads to the increasing use of automatic packaging line. How to improve the productivity of domestic packaging machine has been attracting more and more attention in the packing industry. Box opening machine is a key device on the packaging line. The speed and quality of box opening influences the efficiency of the assembly. Prior processing and packaging researches try to improve the speed and stability through automation techniques [1,2], the technology of domestic box opening machine is still at an early development stage. Most equipment still runs at low speed [3] that can hardly meet the productivity demands of domestic pharmaceutical manufacturers that require full adjustability to package different types and sizes of medicines [4].

In current domestic market, there are three kinds of box opening method: opening box by pulling, by double suction cup and by conveyor belt and card board. The pulling method is an intermittent process which causes slower line
speed \cite{5, 6}. The double suction cup method, achieved through the motion of cam, is a continuous process with higher speed, but when the size of carton is different, the cam has to be replaced, which reduces the efficiency\cite{7}. Opening box through conveyor belt and card board is continuous, but the carton is transported by pallets, which is unstable and may result in carton scratch\cite{8}.

For the disadvantages above, a new kind is proposed and developed with higher speed and stability wherein the study on the mechanism box opening process and characteristic parameters related is fundamental and vital.

**Process analysis and improvement**

**Opening Process**

Figure 1 illustrates the mechanism of new box opening machine. The suction cup and the box opening plate move synchronously, but pivot in different ways. The paper tray is directly opened by the opening plate in three procedures. In box suction procedure, the sucker and the opening plate rotate from a release point to the position of the silo, remaining relatively static, as shown in Figure 1 (a). The cartons are sucked out from the silo by vacuum suction cup, after which it continues to pivot around the center in box opening procedure. In this process, the box opening plate moves relatively to the suction, as shown in Figure 1 (b). Then the box opening plate contacts the carton plane, and the carton surfaces are forced to rotate around the line. The opening process ends with the box opening plate reaching the position of the maximum angle, as shown in Figure 1 (c). In putting procedure, after the box is opened, the opening plate began to return and reset before reaching the point of putting box. The carton is thus placed onto the conveyor belt as the vacuum suction stops working, as shown in Figure 1 (d). The direct opening mechanism ensures box opening angle greater stability and better compatibility.

![FIGURE 1. Process of opening box.](image)

**Solution to the Box Opening Angle**

The proposed box opening machine is a new type with a turnover continuous opening mechanism. Three box opening heads are available on the rotary table on which box opening plate and the sucker are mounted. The box opening head is shown in Figure 2.
The box opening plate and the sucker have different motion states. Through the test, the relative maximum angle between box opening plate and the suction cup is $161^\circ$ in the opening process. Box opening angle can be calculated by graphic method. As the suction remains stationary, the box opening plate rotates relatively to the suction cup. When the box opening plate contacts the box surface, the box will be opened gradually under the pressure of the box plate. In this process, when box opening plate rotates $161^\circ$, according to tangent relationship, the location of the corresponding planar carton will be drawn, and thus the box opening angle can be measured by measurement tool.

**FIGURE 2.** Structure of opening box head.

**FIGURE 3.** Opening box angle.

Finally, the graphical method is used to calculate the box opening angle, as shown in Figure 3, illustrating that the carton suction plane is the "carton plane 1" and the opening box plane is the "carton plane 2". When box opening plate pivots to the position of the maximum angle, carton gets the shape as shown in dash dot painted, demonstrating the actual carton opening size. The box opening angle measured is $160.83^\circ$ as, larger than the expected $125^\circ$, and does not meet the required box opening angle.

**Improvement**
In order to achieve the desired value of box opening angle, the mechanism should be improved. When the relative maximum angle of box opening plate is reduced, box opening angle can also be reduced. In this case, the suction angle is determined by the transition mechanism of box opening machine. As the transition mechanism changes with the opening plate angle, improvement could be complex due to its high cost and low efficiency. The graphic method provides a good option for the issue. It is found that the initial relative position of box opening plate and the sucker have an impact on box opening angle. If
the desired angle can be achieved by changing the initial position of box opening plate and the sucker, it will save time and reduce cost.

Relative position Improvement of box opening plate
Relative Position Calculation of Opening Box Plate
The white cardboard carton is commonly used in pharmaceutical packaging. For common carton, for example, the short side is 45mm, and long side is 55 mm, so as to improve the initial relative position of box opening plate. The rotation center of the box plate is established as the origin of the coordinate system, as shown in Figure 4. AB=55mm, BC=45mm, according to the size of the mechanism. The corresponding points can be obtained, as shown in Figure 5. The contact center point of the suction cup and the carton is E (0, -12), and the paper box line coordinates is B (-11, -12), as shown in Figure 4. The maximum angle of box plate relative to sucker is 161°, and the desired box opening angle is 125°. The position of the desired angle can be found firstly, as shown in Figure 4. The intersection coordinates of AB and Y axis is F (0, 27), and the top of box opening plate is an arc with small radius that is eventually tangent to the carton surface. Set the top circular arc of the box opening plate and the carton edge A’ B point of tangency as (x₀, y₀) to the desired value, and initial coordinate of the point is (x, y). In box opening process, the tangent point rotates 161° around the origin position, while the desired angle is 125°. At this time, the point of tangency is in a straight line, according to the geometrical relationships among the corresponding equations to solve.

Suppose xₐ and yₐ is the coordinates of rotation center, θ is the contrarotate angle. When the initial coordinate system turns to angle θ, the conversion formula is as follows:

\[
\begin{align*}
    x_0 &= (x - x_a) \cos(\theta) - (y - y_a) \sin(\theta) + x_a \\
    y_0 &= (x - x_a) \sin(\theta) - (y - y_a) \cos(\theta) + y_a
\end{align*}
\]  

(1)

FIGURE 4. Coordinate system selection.  
FIGURE 5. Position of opening box plate.
In this coordinate system, the center of rotation is \((0, 0)\), setting \(\theta = 161\), the formula (1) is simplified.

\[
\begin{align*}
  x_0 &= -0.946x - 0.326y \\
  y_0 &= 0.326x - 0.946y
\end{align*}
\]  

(2)

The linear equation of \(A'B'\) is

\[ y = kx + b \]  

(3)

Points B and F are on a straight line. According to the coordinate value of B and F, the value of \(k\) and \(b\) is available, \(b = -27\), \(k = -15/11\). According to the formula (3), the linear equation is obtained

\[ y = -15x/11 - 27 \]  

(4)

From the formula (2), \((x_0, y_0)\) is set into (4), the following equation can be obtained.

\[ 0.964x + 1.39y - 27 = 0 \]  

(5)

Equation (5) shows that the optimized tangent points are on a straight line. Replace the linear equation by \(l_1\) and the line \(l_1\) is drawn in the coordinate system, as shown in Figure 5.

Although the points on line \(l_1\) meet the requirements of theoretical analysis, the structure has limits in real conditions.

Firstly, the box opening plate cannot be disengaged from the tray surface \(AB\) in the opening process. Therefore, the minimum rotation radius between the point of tangency and rotation center (origin) can not cross a line point B, and the maximum radius should not exceed the point A. Circle \(C_1\) is drawn with the minimum radius, as shown in Figure 5. In the desired state of box opening process, point A should turn to position A'. By measurement, \(OA = 67\) mm, \(OA' = 60\) mm.

The maximum rotation radius should be taken as small as 60mm. The circular \(C_4\) is drawn with the maximum radius, as shown in Figure 5. It shows that the smallest circle \(C_1\) and straight line \(l_1\) intersection is located on the right side of the Y axis, which does not meet the requirement that the box opening plate should be on the left side to the coordinate axis. In order to meet the requirement, turning radius of the tangency point should be larger than the radius of the circle \(C_2\) (\(C_2\) pass through line \(l_1\) and Y axes intersection). Due to the problem of interference, the box opening plate cannot interfere with the suction box rod. Therefore, circle \(C_3\) is drawn, which passes through the intersection point G between \(l_1\) and the side of box suction rod. The points on the straight line from the circle \(C_3\) to \(C_4\) may meet the engineering requirements.
Optimization of the Characteristics Position

Since there are numerous points on the line segment applicable to the situation, how to find the most advantage points both conforming to the constraints and satisfying the design requirements is the key challenge. The following principles are:

(1) The distance between the side surface of the suction rod and the box opening plate is not less than 5mm.

(2) The arc radius of box opening plate head is 3mm.

The most advantageous position can be calculated by the graphic method in AutoCAD, and then the relative position of the plate can be determined. In case of non-opening stage, box opening plate and sucker is relatively stationary. The position of the two members is on their initial position. The box opening plate tangency point calculated should be on the line $l_1$, but the point may not necessarily tangent with the straight line $l_1$, which means it is difficult to find the optimum point on the straight line $l_1$. The tangency point can be found easily on the line A'B. The initial position of the corresponding point can be found by rotating 161° clockwise around the coordinate origin. At this time, the key problem is how to associate the optimal tangency point with two limited conditions. In order to avoid interference, distance between box opening plate and suction rod lateral must not be less than 5mm. The side surface of the suction rod is shown by $l_2$, as shown in Figure 6.

In order to find optimum point, the tangent point must be found. Once the constraint conditions are transferred into the solution of the tangent point position, the optimal point is thus to be obtained. After rotating 161° from the origin, $l_2$ reaches the position $l_2'$. After 5mm translated, $l_2'$ reaches the new position $l_2''$. Circle $C_5$ with radius 3 mm is drawn, which is tangent with $l_2''$ and A'B, as shown in Figure 6. The optimal point is the tangent point. The distance from the tangent point to $l_2''$ is 5mm, equivalent to 161°, which means that the minimum distance between side surface of the suction rod and the box opening plate is exactly 5mm, and meets the actual requirements. As the plate and the opening box rod is on an assembly, to ensure the system stability after the optimization, box opening plate shall be made into an independent component. The plate is directly replaced in order to change the initial angle between the plate and sucker. Figure 6 illustrates the overall structure of the box opening plate. When the plate reverses 161°, the initial position of the box opening plate is obtained, as shown in Figure 7 (b).
The initial relative positions between the plate and the sucker are shown in Figure 7 (a). The improved relative positions are shown in Figure 7(b). By comparison, the length of the improved box opening plate becomes smaller and the angle of box opening rod changes.

**Simulation**

The improved relative position of the box plate and the suction is used to calculate the angle of opening box through graphic method. The results are compared with the desired angle.

As shown in Figure 8, the rotating angle of box opening plate is still 161°. According to the tangent relationship, the angle between carton and opening box is 125°, reduced by 35.83° compared to the initial 160.83°. The desired angle of opening box is achieved, indicating the feasibility of the improvement method.

The method above is versatile to the improvement of dimensional design and initial position of the box opening plate when the carton changes in production in the future.

**Conclusion**

The box opening process is analyzed. According to the maximum angle between box plate and sucker, the graphic method is used to calculate the box opening angle. By improving the initial relative position between the box opening plate and the sucker, the desired box opening angle is obtained. The improvement method can effectively reduce the optimization time and the cost.
of the transition mechanism. The combination of analytic geometrical and graphic method is used. The graphics software is used to obtain the optimum position.

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