Calculation Analysis And Simulation Design Of Mechanical-Synchronous Pendulum

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Abstract: For the purpose of solving the synchronization technology of mechanical pendulum feeding system in pitching mechanism, the principle of mechanism synthesis was applied to do the theoretical analysis of the mechanical-synchronous pendulum, then a simplified calculation model was built. Through mathematical analysis and simulation design, the equation of pitching mechanism curve was built, and the design method for mechanical-synchronous pendulum was obtained. This design has been successfully applied in a certain equipment.

1. Introduction

In the pitching mechanism(a mechanism that rotates around a fixed axis), the mechanical pendulum is always used as an intermediate transmission mechanism to realize the goods feeding. This paper discussed the mechanical principle and design calculation of automatic feeding in the mechanical pendulum. In the usual pitching mechanism, the electrical control method is always used to realize automatic feeding. This method is simple to realize mechanical automation, but it has obvious disadvantages, it may leads mechanism pendulum action lag, poor precision, difficult to adjust.

This paper introduces an automatic synchronization mechanism, as shown in figure 1, by adjusting the pivot position of the Swing-Arm Driving part in real time, the mechanical pendulum can synchronously track the pitching mechanism to realize automatic feeding. The all mechanism is forced in place, it can improve the reliability and stationary of mechanical movement. And the collision between mechanisms is eliminated, and therefore the mechanical life has been extended.

Figure 1. Mechanical-synchronous pendulum.
2. Working principle analysis
The working principle of the simplified mechanism is shown in figure 2. The mechanical-synchronous pendulum can be divided into Swing-Arm Driving part and Synchronous Adaptation part. Swing-Arm Driving part contains crank slider, connecting rods, and output shaft, etc. And Synchronous Adaptation part contains pitching mechanism, rocker arm and double slider, etc.

![Figure 2. Working principle of the simplified mechanism.](image)

2.1. Swing-arm driving part
This part uses the crank slider as the power source, it drives connecting rods to rotate around A (pivot of dynamic change). And therefore connecting rods drives output shaft to rotate a certain angle.

2.2. Synchronous Adaptation part
This part uses the pitching mechanism as the power source, O1 is the center of rotation. The rocker arm takes O2 as the rotating center. O1 and O2 are both fixed on the base. When pitching mechanism works, with O1 as the rotational center, rocker arm drives double slider to move along the fixed direction. The center of double slider is also the pivot of connecting rods in swing-arm part, which moves with the rotation of pitching mechanism.

2.3. Summary
In summary, we can control the movement of double slider by calculating the shape of pitching mechanism’s curve groove, and then provide a corresponding pivot for connecting rods. In this way, when the pitching mechanism rotates at a certain angle, the mechanical pendulum will move to the coaxial line position to realize synchronization.

3. Calculation of connecting rods’ pivot and curved groove
For the convenience of analysis, Swing-Arm Driving part and Synchronous Adaptation part are separately calculated. Finally, the two system are coupled to obtain the curve equation of the pitching mechanism’s curve groove. The calculation principle diagram is shown in the figure 3.
3.1. Calculation of swing-arm driving part

The pivot M of the double slider is fixed, and point A is taken as the driving force (the crank slider has no influence on the whole calculation, so it is omitted). The dotted line in the figure shows the end position of the mechanism, AA' is the stroke of the crank slider, corresponding to the rotation angle $\theta$ of the output shaft. $\alpha$, $\beta$ are the given angles.

\[ AA = 2r, \ AB = AB = a, \ BC = BC = b, \ TM = TM = c, \ OF = OF = d. \]

Select A as the coordinate origin and BA as the x-axis direction. Then the coordinates of the following points are

\[ A(0,0), \ B(-l,0), \ O(x_0, y_0), \ O_1(x_1, y_1), \]
\[ A(-2r \cos\alpha, 2r \sin\alpha), \ B(-l \cos\gamma - 2r \cos\alpha, -l \sin\gamma + 2r \sin\alpha) \]

Linear equation:

\[ AB: \ y = 0, \ AB: \ y = (x + 2r \cos\alpha) \tan\gamma + 2r \sin\alpha \] (1)

Using the above two equations, it can be concluded that the coordinate of the point M (pivot of the connecting rods) is a function of the angle $\gamma$.

\[ M(x_M, 0), \ x_M = -2r \sin\alpha \cdot \cot\gamma - 2r \cos\alpha \] (2)

As for points M, C, B and O, they can be regarded as four-bar linkage with M and O as fixed points. According to the function-generation function of four-bar linkage and referring to relevant literature, the corresponding relationship between $\gamma$ and $\theta$ can be obtained, i.e. $\gamma = f(\theta)$. Then the coordinates of M can be transformed into a function of angle $\theta$.

\[ M(x_M(\theta), 0), \ x_M = -2r \sin\alpha \cdot \cot f(\theta) - 2r \cos\alpha \] (3)

3.2. Calculation of swing-arm driving part

In the figure, point M is the connecting rods' pivot of swing-arm driving part, and O and O1 are the fixed points of the mechanism. Therefore, when the pivot M changes with the angle $\theta$, the point T moves in a circle with O1 as the center, and the rotation angle is $\varphi(\theta)$.

The coordinates of T and F are

\[ T(x_1 + c \cos \varphi, \ y_1 + c \sin \varphi), \ F(x_1 + d \cos \varphi, \ y_1 + d \cos \varphi) \] (4)

Where $\varphi(\theta)$ satisfies $\varphi(\theta) = \tan^{-1}\left[(y_T(\theta) - y_1)/(x_T(\theta) - x_1)\right]$.

The curve groove rotates with the rotation angle of $\theta$ in the operation of the pitching mechanism, so the tracks of point F on this part is the curve groove. The shape of its curve groove is an involute.
\begin{align}
x &= \rho(\theta) \cos \theta + x_o, \quad y = \rho(\theta) \sin \theta + y_o \\
\rho^2(\theta) &= (x_f(\theta) - x_o)^2 + (y_f(\theta) - y_o)^2
\end{align}

3.3 Conclusion

It can be seen from the above calculation that the pivot (constantly changing) of connecting rods and curve groove (curve groove) are the functional relation, when the pitching mechanism rotates. Because of the large number of structural constants and the complexity of the expression, it has not been written in detail in the above analysis. In the specific production application, as to specific constants (fixed length, fixed position, fixed angle), the curve equation of curve groove can be expressed as a function of \( \theta \), and the design of mechanical synchronous pendulum can be completed accurately.

4. Simulation calculation

After the size and coordinate of the mechanism are determined, the mechanical-synchronous pendulum is analyzed by using the simulation software ADAMS according to the design requirements. The rotation center O1 of pitching mechanism is defined as the origin, and a feeding cycle is zero position-synchronous position-zero position, the time is 2S, and the pitching mechanism rotates at a constant speed of \( 1^\circ/s \) around the fixed axis. According to the motion simulation of each part, the movement law of double slider is calculated, and then the coordinate value and radius value of the pitching mechanism’s each curve segment.

Figure 4. Movement law of connecting rods’ pivot M.

| X coordinates (mm) | Y coordinates (mm) | Minor diameter of curve groove (mm) | Major diameter of curved groove (mm) |
|-------------------|-------------------|------------------------------------|-----------------------------------|
| 57.704            | 84.136            | 244                                | 320                               |
| 82.416            | 92.840            | 216                                | 294                               |
| 54.168            | 86.488            | 248                                | 324                               |
| 133.104           | 82.248            | 168                                | 244                               |
| 161.052           | 62.800            | 138.2                              | 214.2                             |
| 163.04            | 67.088            | 134.4                              | 210.4                             |

5. Conclusion

This paper analyzes the working principle of mechanical-synchronous pendulum. In the pitching mechanism, the key to realize the synchronous tracking of the mechanical pendulum is the calculation and design of the curve groove and the position change of the connecting rods’ pivot.

In this paper, the analytic relationship between the curve groove and the pitch angle is derived by means of mathematical analysis. Finally, through the calculation and simulation, the coordinates of the curve groove are simulated. The two methods can verify each other.

The design has been applied in a mechanical engineering equipment, with good performance and stable operation. Provide theoretical reference for other similar product design.
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