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Article

A New Design and Simulation of a Reciprocating Motion Mechanism of Dynamic Ad Devices

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Abstract: In this paper, a reciprocating motion dynamic advertisement device is designed for a new category of billboards. The core design consists of a conjugate cam and multi-link structure, based on which a kinematic model is established and ADAMS kinematic simulation is performed. The results show that the kinematic model of the designed reciprocating structure is highly accurate with an error of only 4%, and the cam mechanism has less contact force, which is of strong utilization value.

Keywords: dynamic advertisement device; reciprocating motion mechanism; conjugate cam; ADAMS simulation

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1. Introduction

With the continuous progress of science and technology and the booming development of market economy, the advertising industry is experiencing unprecedented changes. Innovative advertising device design has become the key to attract consumers' attention and enhance the advertising effect [1].

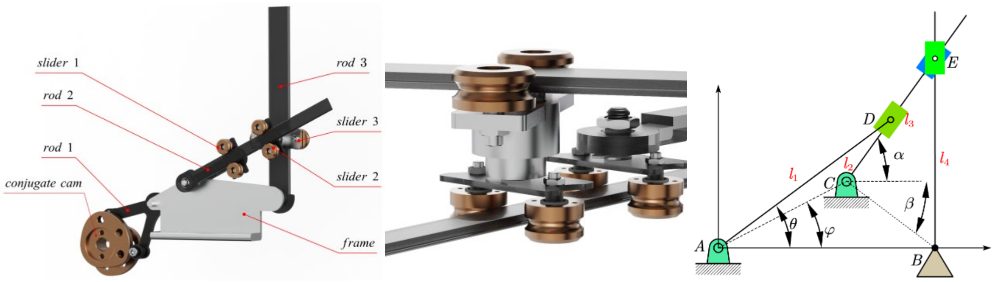
Reciprocating motion mechanism plays an important role in many fields because of its simple structure, stable motion, precise control and other characteristics. Some scholars designed an elastic buffer reciprocating mechanism to effectively reduce the self-induced jitter of inspection robots [2]. Chen et al. proposed a new electronically controlled belt-driven reciprocating liposuction device to address the shortcomings of traditional devices [3]. In the field of advertising, the application of reciprocating motion mechanisms is relatively new, but is developing rapidly, especially in dynamic ad devices and interactive advertising displays. Reciprocating motion mechanisms allow the content of an ad device to change dynamically and attract attention. With banners or panels driven by reciprocating motion mechanisms, multiple advertisements can be displayed without the need to replace physical ad devices, thus reducing costs and improving advertising efficiency. Siegal designed portable reciprocating moving ad devices that utilize the afterglow effect of the human eye to display a stable graphic or text [4]. The design adapts to the modern society's demand for timely and accurate access to information in large quantities, and achieves the purpose of rapid dissemination of information. For interactive advertising, reciprocating motion mechanisms can be used to create interactive advertising experiences, such as pop-up displays or movable ad devices, that dynamically adjust to the viewer's proximity or interactive behavior. Not only that, but reciprocating motion mechanisms can integrate sensors and intelligent control systems, allowing ad devices to reduce energy consumption during off-peak hours. Liu has designed an intelligent ad device with interactive features that actually increase the functionality and effectiveness of its application, showing users different information contents with a dynamic display effect [5].

2. Cam-Link Mechanism Analysis

Cam type reciprocating mechanism is suitable for ad devices that require precise control of motion law, speed and position, such as dynamic display ad devices [6,7]. This kind of motion control is precise, has low friction loss and high transmission efficiency, and the cam shape can be customized to achieve personalized design according to the specific needs of the ad device.

2.1. Kinematic Modeling of Multi-Link Mechanisms

The core components of the ad device reciprocating mechanism designed in this paper are shown in Figure 1(a). The mechanism consists of connecting rods 1, 2, 3, and there are also copper-roller slider 1, 2, 3. The main part of reciprocating motion of this mechanism is slider 3. When the conjugate cam is rotating, the cam contour surface is in contact with the rollers to make the connecting rods 1 rotate, and the slider 1 at the end of rod 1 slides on the rod 2. Rod 3 is fixed on the frame, and slide 3 makes reciprocating motion on rod 3. As shown in Figure 1(b), the slider 2 and 3 can rotate with each other and have bearings inside. The mechanism is simplified to the mechanism sketch shown in Figure 1(c).



(a) (b) (c)

Figure 1. Mechanical Structure: (a)Mechanism Overview, (b)Illustration of the Connection, (c)Multi-Link Mech-Anism Sketch.

The cam mechanism is omitted from the mechanism sketch because the normal action of the whole linkage mechanism is the key to the normal reciprocating motion of the whole cam linkage mechanism. Therefore, the kinematics of the connecting rod is first modeled and analyzed. The closed positional vector equation for this mechanism is equation system 1:

$$\begin{cases} \boldsymbol{l}_1 = \boldsymbol{l}_{AC} + \boldsymbol{l}_2 \\ \boldsymbol{l}_3 = \boldsymbol{l}_{CB} + \boldsymbol{l}_4 \end{cases}, \quad \begin{cases} l_1 \mathrm{e}^{\mathrm{i}\theta} = l_{AC}\mathrm{e}^{\mathrm{i}\varphi} + l_2 \mathrm{e}^{\mathrm{i}\alpha} \\ l_3 \mathrm{e}^{\mathrm{i}\alpha} = l_{CB}\mathrm{e}^{-\mathrm{i}\beta} + \mathrm{i}\, l_4 \end{cases} \tag{1}$$

It is expressed as a complex vector and expanded according to Euler's formula, with the real part and imaginary part both being equation system 2:

$$\begin{cases} l_3\cos\alpha - l_{CB}\cos\beta = 0 \\ l_3\sin\alpha + l_{CB}\sin\beta - l_4 = 0 \\ l_1\cos\theta - l_{AC}\cos\varphi - l_2\cos\alpha = 0 \\ l_1\sin\theta - l_{AC}\sin\varphi - l_2\sin\alpha = 0 \end{cases} \tag{2}$$

The kinematic key parameters are solved for equation system 3:

$$\begin{cases} \alpha = \tan^{-1}\left(\dfrac{l_4 - l_{CB}\sin\beta}{l_{CB}\cos\beta}\right), \quad l_3 = \dfrac{l_{CB}\cos\beta}{\cos\alpha} \\ \theta = \sin^{-1}\left(\dfrac{-l_{AC}\tan\alpha\cos\varphi + l_{AC}\sin\varphi}{\sqrt{l_1^2 + l_1^2\tan^2\alpha}}\right) + \Phi, \quad \Phi = \cos^{-1}\left(\dfrac{l_1}{\sqrt{l_1^2 + l_1^2\tan^2\alpha}}\right) \end{cases} \tag{3}$$

Perform the derivation of the equation with respect to time for velocity analysis, and ditto for the result, as equations. Similarly, the results of the acceleration analysis can be obtained as equation system 4,5:

$$\begin{cases} \dot{\alpha} = \dfrac{\dot{l}_4}{l_3\tan\alpha\sin\alpha + l_3\cos\alpha}, \quad \dot{l}_3 = l_3\dot{\alpha}\tan\alpha \\ \dot{\theta} = \dfrac{l_2\dot{\alpha}}{l_1\cos(\theta - \alpha)}, \quad \dot{l}_2 = \dfrac{\dot{\theta}l_1\cos\theta - l_2\dot{\alpha}\cos\alpha}{\sin\alpha} \end{cases} \tag{4}$$

$$\begin{cases} \ddot{\theta} = \dfrac{\dot{\theta}^2 l_1\sin(\theta - \alpha) + 2\dot{\alpha}\dot{l}_2 - l_2\ddot{\alpha}}{l_1\cos(\theta - \alpha)}, \quad \ddot{l}_3 = l_3\dot{\alpha}^2 + \ddot{l}_4\sin\alpha \\ \ddot{\alpha} = \dfrac{\ddot{l}_4\cos\alpha - 2\dot{\alpha}\dot{l}_3}{l_3}, \quad \ddot{l}_2 = l_2\dot{\alpha}^2 - \ddot{\theta}l_1\sin(\theta - \alpha) - \dot{\theta}^2 l_1\cos(\theta - \alpha) \end{cases} \tag{5}$$

Where l_1 is 232mm, l_{CB} is 125mm, φ is 25°, β is 10.5°. Equation system 1-5 the kinematic model of the reciprocating device can be solved by MATLAB.

2.2. Conjugate Cam Mechanism Design

The driving part of the reciprocating motion mechanism in this ad device is a conjugate cam, which is more accurate and does not require additional springs. The length of the swing arm of the main cam was determined empirically to be 143 mm with a center distance of 150 mm in the x direction and 110 mm in the y direction, and the length of the swing arm of the secondary cam was determined to be 134 mm. the phases of cam motion were determined to be lift-far dwell-return-near dwell. The law of motion is selected as modified sinusoidal law, as Figure 2(b) shows. In CamTrax, according to the selected center distance, swing arm length and the motion pattern in Figure 2(b), the roller radius of 40mm is selected according to the manual to build the solid of the blank and establish the conjugate relationship between the primary and secondary cams. The solid of the cam is shown in Figure 2(a). The main and secondary cam contours are shown as black solid lines in Figure 2(c), and the dotted lines around them are the theoretical contour lines of the main and secondary cams, respectively.

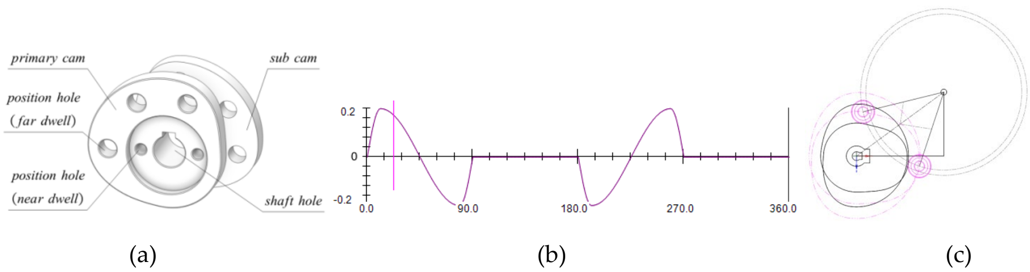
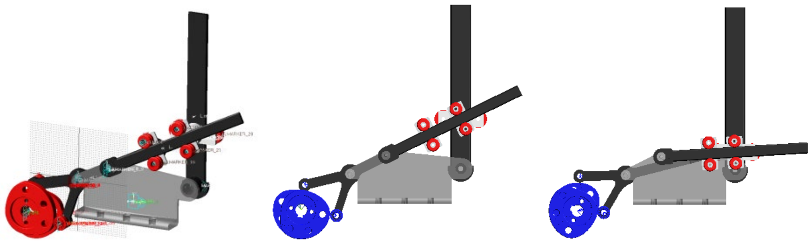


Figure 2. Cam Design: (a)Conjugate Cam, (b)Modified Sine Velocity, (c)Sketch in Camtrax.

3. Mechanism Dynamics Simulation

The assembled multi-link mechanism is assembled with conjugate cam mechanism in Solid Works and exported in Parasolid format. In ADAMS, set up the rotation of cam and ground for the cam, apply the fixed vice of earth to the frame and apply the cylindrical vice between slider 1,2,3 and the corresponding connecting rods as well as between the rollers and the base plate of the slider respectively. The applied motion is angle=10deg/s.

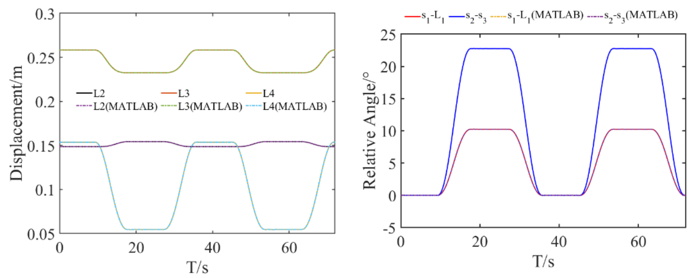
At last, a 72s-simulation is performed, all as shown in Figure 3(a). According to the foregoing, the reciprocating motion of the slider 3 is the power source of the present reciprocating ad device. As shown in Figure 3(b) and Figure 3(c), in the simulation under the action of the conjugate cam, slider3 will follow the reciprocating motion on rod 3. Position A is the peak position of the external ad device in the vertical direction and position B is the minimum position of the external ad device.



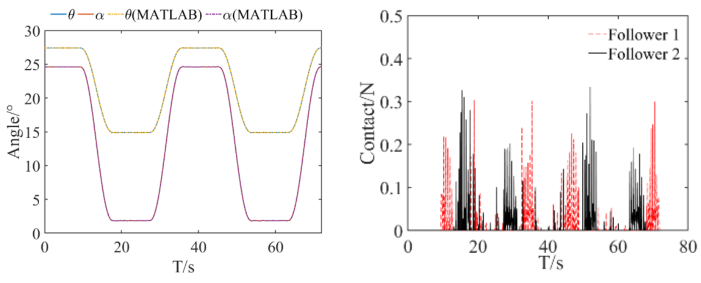
(a)Mechanism in ADAMS (b)Position A (c)Position B

Figure 3. Simulation in Adams: (a)Settings, (b)Position A: Peak Position, (c)Position B: Minimum.

Based on the previously established kinematic model, the cam motion law was implemented in MATLAB to calculate the motion parameters over a 72-second period, as shown in Figure 4, in a word, the correctness of the MATLAB kinematic model established with equation systems is proved by ADAMS simulation, the maximum error is only 4%. For the displacement of the slider, as shown in Figure 4(a), it varies periodically with little fluctuation; for the rotation of the slider for the corresponding connecting rod, as shown in Figure 4(b), it is proved that under the action of the conjugate cam, the slider can move smoothly for the connecting rod; and for Figure 4(c), similarly, the pattern varies periodically with a small error. It is worth noting that the amplitude of the contact force between the conjugate cam and the two sliders f1 (corresponding to the master cam), f2 (corresponding to the slave cam) is not large, and the contact force of the master and the slave cams shows a phase change of about half a cycle, as Figure 4(d) shows.



(a)displacements (b)relative angles



(c)angles (d)contacts

Figure 4. Simulation in Adams: (a)Displacements, (b)Relative Angles, (c)Angles, (d)Contacts.

4. Conclusion

In this paper, the detailed structural design of reciprocating motion dynamic ad device is firstly designed and rendered, based on which position, velocity and acceleration analyses are carried out, and finally ADAMS simulation is utilized to verify the achievability and reasonableness of the design of the ad device in this paper, which has a small contact force and is able to change periodically according to the design.

Author Contributions: S.Y. conceived the idea of the study. K.X. performed the simulation. Y.R. analyzed the data and wrote the paper.

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