2011 International Conference on Power Electronics and Engineering Application

The Parametric Design and Motion Analysis about Line Translating Tip Follower Cam Mechanism Based on Model Datum Graph

SUN Jianping\textsuperscript{a,b}, TANG Zhaoping\textsuperscript{c, c*}

\textsuperscript{a} School of Traffic & Transportation Engineering, Central South University, Changsha Hunan, 410075, China
\textsuperscript{b} School of Railway Transportation, East China Jiao Tong University, Nanchang Jiangxi, 330013, China
\textsuperscript{c} School of Mechanical and Electrical Engineering, East China Jiao Tong University, Nanchang Jiangxi, 330013, China

Abstract

Cam mechanism can get the expected movement law by means of higher pair touch drive follower. This paper used Pro/E’s datum-graph function, to create the follower’s displacement line graph, and to control cam profile by using the displacement line graph, the line translating tip follower cam mechanism was wholly parametric designed. The system can provide 16 kinds of typical combination motion law for users. The system can generate automatically cam profile according to the parameter imported by the consumer. Furthermore, using the technology of virtual assembly and motion simulation, the visible assembly structure analysis and performance evaluation can be realized in design phase.

© 2011 Published by Elsevier Ltd. Selection and/or peer-review under responsibility of ICSS and NSFC

Keywords: Line Translating Tip Follower Cam Mechanism; Pro/E; Parametric Design; Motion simulation analysis

1. The train of thoughts to build model

By means of cam profile’s change, cam mechanism’s follower can reach the expected or any complex movement law, so as to cam mechanism is widely applied in various machinery and automatic control equipments \cite{1}. The difficult point of full parameterize design is that cam should generate automatically different profiles according to different motion laws of follower \cite{2}.

\*TANG Zhaoping. Tel.: 00-86-791-87046121; fax: 00-86-791-87046122.
\textit{E-mail address}: tzp@ecjtu.jx.cn.
Cam mechanism’s motion process is made up of four stages as rise travel, farthest dwell travel, return travel and nearest dwell travel, as shown in Fig. 1. In rise travel or return travel, there are some typical kinds of motion laws as constant velocity, constant acceleration and constant deceleration, cosine acceleration and sine acceleration, so cam mechanism products 16 kinds of motion combination. This paper took rise-travel and return-travel as design parameters, and gave 1, 2, 3 and 4 as their values to correspond respectively the four kinds of motion laws. So that only 8 corresponding motion curves were needed to create for program calling according to different parameters. Furthermore cam profile can generate automatically for 16 kinds of typical combination motion law.

This paper used Pro/E’s datum-graph function, to create the follower’s displacement line graph, and to call the displacement line graph program according to the setting of motion laws, and then to control cam section’s shape through the displacement line graph which was used at variable section sweep in modeling. Thereby it was realized that the wholly parametric design for cam profile which could automatically change with motion law’s difference. And based on this, cam-follower pair was generated. Furthermore, by using the technology of virtual assembly and motion simulation, the visible assembly interference detection and rationality analysis about product design can be realized in design phase, which will lay the foundation for the follow-up virtual manufacturing.

2. Displacement-angle relations of follower

Given cam rise travel angle is \( \delta_t \), return travel angle is \( \delta_b \), follower’s lift is h, the cam angle is \( \delta \).

The velocity of the follower in rise travel is:

- Constant velocity: \( \dot{s} = \frac{h}{\delta_t} \delta \)

- constant acceleration and constant deceleration: \( s_1 = \frac{2h}{\delta_t^2} \delta^2 \) (in the half travel of constant acceleration); \( s_2 = h - \frac{2h}{\delta_t^2} (\delta_t - \delta)^2 \) (in the half travel of constant deceleration);

- cosine acceleration: \( s = h \left[ 1 - \cos\left(\frac{\pi}{\delta_t} \delta \right) \right] \)

- sine acceleration: \( s = h \left[ \frac{\delta}{\delta_t} - \frac{1}{2\pi} \sin\left(\frac{2\pi}{\delta_t} \delta \right) \right] \)
The velocity of the follower in return travel is:

- Constant velocity: \( s = h \left( 1 - \frac{\delta}{\delta_h} \right) \)

- Constant acceleration and constant deceleration: \( s_1 = h - \frac{2h}{(\delta_h)^2} \delta^2 \) (in the half travel of constant acceleration); \( s_2 = \frac{2h}{(\delta_h)^2} (\delta_h - \delta)^2 \) (in the half travel of constant deceleration);

- Cosine acceleration: \( s = h \left[ 1 + \cos \left( \frac{\pi}{\delta_h} \delta \right) \right] \)

- Sine acceleration: \( s = h \left[ 1 - \frac{\delta}{\delta_h} + \frac{1}{2\pi} \sin \left( \frac{2\pi}{\delta_h} \delta \right) \right] \)

3. The steps to build model

3.1. Build the relevant parameter

By using the parameters function which Pro/E provides, parameters, liked base circle radius, deviation distance, roller radius, rise-travel law, return-travel law, and so on, were set up as showed in table 1.

Table 1. The parametric table

| parameter          | rb (base circle radius) | b (cam’s width) | tui (rise travel law) | hui (return travel law) | h (lift) | dta (motion angle for rise travel) | dtast (farthest dwell angle) | dtah (motion angle for return travel) | dtap (nearest dwell angle) |
|--------------------|-------------------------|-----------------|-----------------------|--------------------------|----------|-----------------------------------|-------------------------------|-------------------------------------|--------------------------|
| value              | 40                      | 20              | 3                     | 2                        | 30       | 150                               | 30                           | 120                                 | 60                       |

3.2. Create the displacement line graph of follower

To execute the order of Insert-Model Datum-Graph, input sequentially graph name as ‘Graph1’-‘Graph4’, the displacement line graphs were designed separately which were corresponding to cam rise-travel angle of the four kinds of motion laws as constant velocity, constant acceleration and constant deceleration, cosine acceleration and sine acceleration. In the same way, ‘Graph5’ and ‘Graph10’ were designed corresponding to far stop and nearly stop travel angle, and ‘Graph6’-‘Graph9’ corresponding to return travel, as showed in Figure 2.

In order to make each displacement line graph is corresponding to its motion law, it is necessary to input separately the displacement-angle relations of Datum-Graph:

/* Graph1 (the displacement and angle of constant velocity in rise travel) 
sd3=dtat
sd4=h*/

/* Graph2 (the displacement and angle of constant acceleration and constant deceleration in rise travel) */

sd30=dtat/6
sd29=(2*h/(dtat^2))*(sd30)^2
sd26=2*dtat/6  
sd25=(2*h/(dtat^2))*(sd26)^2  
sd23=3*dtat/6  
sd22=(2*h/(dtat^2))*(sd23)^2  
sd20=4*dtat/6  
sd19= h-(2*h/(dtat^2))*( dtat-sd20)^2  
sd17=5*dtat/6  
sd16= h-(2*h/(dtat^2))*( dtat-sd17)^2  
sd10=dtat  
sd12= h  
/* Graph3(the displacement and angle of cosine acceleration in rise travel)  
sd30=dtat/6  
rd30=(sd29/3)*sin(360*sd30/dtat)  
rd26=(sd25/3)*sin(360*sd26/dtat)  
rd23=(sd23/3)*sin(360*sd23/dtat)  
rd20=(sd20/3)*sin(360*sd20/dtat)  
rd17=(sd17/3)*sin(360*sd17/dtat)  
rd16=(sd16/3)*sin(360*sd16/dtat)  
rd10=dtat  
rd11=h  
/* Graph4(the displacement and angle of sine acceleration in rise travel)  
sd30=dtat/6  
rd30=(sd29/3)*sin(360*sd30/dtat)  
rd26=(sd25/3)*sin(360*sd26/dtat)  
rd23=(sd23/3)*sin(360*sd23/dtat)  
rd20=(sd20/3)*sin(360*sd20/dtat)  
rd17=(sd17/3)*sin(360*sd17/dtat)  
rd16=(sd16/3)*sin(360*sd16/dtat)  
rd10=dtat  
rd11=h  
In the same way, the displacement-angle relations of far stop travel, return travel and nearly stop travel, can be input.  

3.3. Sketch cam theoretical curve  

By use of variable section sweep tool, each part of cam can be gotten which correspond to four motion stages, shown as Figure 3. Each trajectory for the sweep was fragmented arc on Front plane, which took half of base circle radius as its radius and cam angle as its central angle. Sweep’s section is a rectangle gone through the control point of sweep’s trajectory, which took cam’s width as its width and its length was associated with displacement line graph by Trajpar’s parameter in relations, so as to control cam profile.
By setting rise-travel parameter ‘tui’ and return-travel parameter ‘hui’, the systems can auto-chose corresponding displacement line graphs according to different motion laws, so as to get proper size’s cam section, furthermore realized 16 kinds of combined motion. So, during sweep, cam profile will change with follower’s displacement line graph. Sweep was divided into four parts (360° in total); the precise cam model could be built, as shown in Figure 3(b).

The relation’s details of rectangle section were shown in follow:
```java
if(tui==1)
    sd7=rb/2+evalgraph("Graph1",trajpar* dtat)
endif
```
......

In the same way, input the other section relations. Then follower, fixture, and so on, were parametrically modelled in sequence. It is necessary to think carefully their assembly relations about design place, shape and size, and to establish beforehand datum point and axis.

![Fig. 3. (a) Assemble; (b) connection](image1)

4. Virtual assembly of cam mechanism

New-built a assembly as follow: firstly, to insert the fixture using the default method, secondly, to insert the follow by pin connected method which the fixture’s role axis aligned follower’s and pre-created datum point aligned each other, as shown in Fig.4 (a).

5. Cam mechanism’s motion simulation

After connections’ definitions were completed, designer can add corresponding drive to them by the mechanical module. Designers choose “Application Program”-“Mechanism”, enter the mechanism module, as shown in Fig.4 (b).

To click “Drag” button, open dialog box, move follower’s height position and make its matching surface near cam’s matching surface, drag and rotate cam’s starting location which touched with follower, cam and follower’s location was adjusted.

Cam-follower connection was created in this way, to click “Cam-Follower Connection Definition” button, open dialog box, tick the checked box “auto select” in “cam 1” and “cam 2” option cards, choose respectively cam and follower’s tip surface as cam surface. Cam 2 needed to choose the two end of tip line as front or back reference, which was specially drawn for defining the cam pair. The line was on the front plane, through tip’s centre and perpendicular to follower’s axis.

Then, to Create spring, damper, define servo motor and analysis parameters they were ready for motion analysis.
6. Motion simulation results analysis

There are some kinds of parameter may be measured in mechanism module, such as “Position”, “Velocity”, “Acceleration”, “Connect Reaction”, “Net Load” etc.

To click the button of “Generate measure result of analyses”, new-built measures from Measure1 to Measure3, and choose the “Graph measurement separately”, click the button of “Graph selected measures for results sets” in dialog box, measure values can be exported by the graph and the data. It is perceptual intuition and accurate, as Fig. 5 showed.

![Fig. 5. The diagram of the follower’s displacement, velocity and acceleration](image)

From all above the output graph of motion simulation, there were following three points can be seen.

1. In the left of Fig. 5, the follower’s displacement and velocity showed along cosine acceleration law in rise travel, and constant acceleration and constant deceleration law in return travel. They were consistent with their theory running.

2. In the right of Fig. 5, the follower’s displacement and velocity showed along constant velocity law in rise travel, and sine acceleration law in return travel. They were consistent with their theory running.

3. In Fig. 5, the follower’s acceleration are approximately consistent with their theory running, though somewhere, as the points of 260° in the left of Fig. 5 and 280° in the right of Fig. 5, had some deviations which due to the spline curve was used in drawing displacement line graph. Nevertheless the method had still increased design accuracy comparing to traditional handicraft graphic method.

7. Conclusions

To sum up, by using powerful design software pro/e, complicated disc cam mechanism was full parametrically designed and their motion was simulated and analyzed. Not only had it built high accuracy model but also realized 16 kinds of typical combination motion law. It improved design flexibility tremendously.

References

[1] CAO Ju-jiang,LI Long-gang,LV Kai-gui,LI Zhong-yan. 3D solid modeling and simulation machining of globoidal indexing cam based on UGNX6.0. Machinery Design & Manufacture, 2011,1:169-171.

[2] Zhang Youhu,Xia Qihua. Conical Cam Mechanism Parametric Design and Movement Simulation based on Pro/E, Journal of Mechanical Transmission, 2011,35(1):31-33