CSCanada
Advances in Natural Science
Vol. 8, No. 2, 2015, pp. 20-23
DOI:10.3968/6966

ISSN 1715-7862 [PRINT]
ISSN 1715-7870 [ONLINE]
www.cscanada.net
www.cscanada.org

Construction of a Cylindrical Cam Model With Clearance for Wear Study

ZHOU Zhengzhu[a]; JIN Xiaoyi[a],*; ZHU Xingyu[a]; LIN Yuyi[b]

[a]School of Mechanical Engineering, Shanghai University of Engineering Science, Shanghai, China.
[b]Department of Mechanical and Aerospace Engineering, University of Missouri, USA.
Corresponding author.

Received 14 March 2015; accepted 8 May 2015
Published online 26 June 2015

Abstract

Using Solidworks and MATLAB as solid modeling and computation tool, a cylindrical cam model with clearance is developed in this paper. The purpose of such a model is for future study of wear, such as wear pattern and wear rate. The model is based on the reported Achard wear model. It is hoped that the model not only can predict the wear rate and depth of wear, but also serve as a tool to cylindrical cam design, for less wear and longer useful life. Wear depth prediction model established in this paper shows that the wear depth will increase, if the cam rotational speed increases.

Key word: Spatial cam model; Cylindrical cam; Clearance; Wear model

Zhou, Z. Z., Jin, X. Y., Zhu, X. Y., & Lin, Y. Y. (2015). Construction of a Cylindrical Cam Model With Clearance for Wear Study. *Advances in Natural Science*, *8*(2), 20-23. Available from: http://www.cscanada.net/index.php/ans/article/view/6966
DOI: http://dx.doi.org/10.3968/6966

INTRODUCTION

With the automation's developing, the velocity of mechanical is faster and faster, and is continuously developing in the direction of the heavy haul and precision. So more and more drive systems are in use of cam, the greatest advantage is to achieve high-speed, compact body structure, high reliability and long life. We use pneumatic means in automatic assembling, but the impact of a terminal's movement is large. Normally, we use the speed control valve to avoid this, and it has two disadvantages: longer working time and more procedures in adjusting the speed of the mechanical. On the other hand, we use cam mechanism, its moving and stopping are very stable. Even if you change the speed of cam, you can keep up with it, spatial cam mechanism is mostly used for the continuous motion into space movement. The work of spatial cam is that the rotation of the spatial cam drives the tapered roller moves in the groove, while the tapered roller drives the rod connected to it to swing. The work procedure of spatial cam is Dwell - Rise - Dwell, Dwell - Return - Dwell, shortly D-R-D (Sun & Zhou, 2009). Many scholars made a great contribution to predict the cam's friction and wear, too. Meng (1995) and Ludema (1996) noted, in the past forty years, there are more than 300 kinds of prediction model equations of friction and wear published in various files, but even the best formula also has great limitations. Their common feature is that it isolated the models to certain conditions. These models didn't play much role in predicting friction and wear, and results in the high time and cost price. In 2005, Y. Sahin designed and experimented through orthogonal design, and he applied mathematical statistics to analyze the relationship between the wear properties of alloy, also the relationship between main component of alloy content, the load, sliding distance and surface morphology (Sahin, 2005). Steele (2008) also uses mathematical statistics method to analyze the distribution of friction coefficient and amount of wear. In China, people are constantly researching on the wear of cam. The students of Wuhan University, Yu mei, Tang Shaoxiong, Ling yongjie established some wear calculation models of the flat cam. They used modern stress analysis software Ansys to analyze contact stress between cam and tappet of 2D and 3D (Zuo & Ma, 2001; Tang, 2002; Lin, 2002).

Although previous research on the cam keeps deepening, most research is about the design of the cam.

As we all know, one of the main reasons for the failure of machinery is friction and wear. Besides lubrication, work environment and other factors, another important reason to cause abnormal wear of mechanical products is intrinsic error and assemble error of mechanical parts (Tang, Zhang, & Lin, 2010). Because of the clearance, the cam motion study of this feature can't be ignored. Mukras (2010) used a program of iterative wear prediction to predict and analysis the slider-crank mechanism's wear with clearance. In the high-speed movement of the cam mechanism, the spatial cylindrical cam is used more and more widely, it has a great significance for the establishment of friction and wear prediction model, also for lifetime prediction of spatial cylindrical cam in the future. Considering the clearance, we establish the spatial cylindrical cam wear model to predict wear loss, and provide a reliable forecast for the use of cylindrical cam.

1. THE SPATIAL CAM MODEL

1.1 Set Parameters of Spatial Cylindrical Cam

In this paper, we use the common spatial cylindrical cam, pushing the angle of the cam mechanism is ϕ=144°, far angle of repose is ϕ_s=0°, return angle is ϕ'=144°, near the angle of repose is ϕ'_s=72°, follower lift is h=150mm, radius of base circle is R_b=110mm, radius of roller is R_r=20mm, allowable pressure angle is $[\alpha]$=25°, the follower motion rule adopts cycloidal motion law, the angle of the cam mechanism in the beginning and end of the segment is separately 1/8 of the pushing, that is $\phi_1=\phi_2=\phi/8$. Exported the date of parameter theory contour through MATLAB software program is shown in Table 1. The three-dimensional model of cylindrical cam by solidworks software is shown in Figure 1.

Table 1
Corresponding Value of Theory of Contour Lines

Perimeter	*X*-axis value	*Y*-axis value	*Z*-axis value
0	0	0	0
1	1.1	0.0001	0
2	2.2	0.0009	0
3	3.3	0.0030	0
4	4.4	0.0070	0
5	5.5	0.0136	0
6	6.6	0.0235	0
7	7.7	0.0373	0
8	8.8	0.0556	0
9	9.9	0.0789	0
10	1.0	0.1080	0
⋮	⋮	⋮	⋮
623.8	686.2	0.0044	0
625.3	687.8	0.0015	0
626.8	6895	0.0003	0
628.3	691.2	0	0

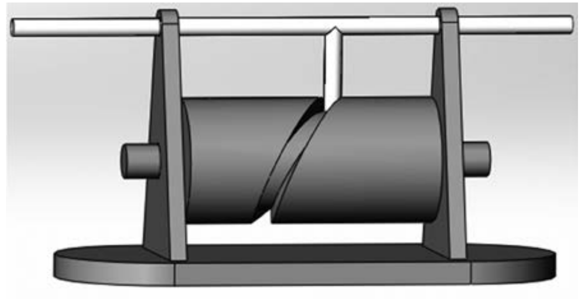

Figure 1
Model of Spatial Cylindrical Cam

1.2 Defined the Clearance Between the Roller and Cam

Usually, in the model, there's no distance between the center line of mates and the cam groove of the spatial cylindrical cam, as shown in Figure 2, the spatial cylindrical cam with clearance connect to the roller. The roller radius is R_1, the cam groove radius is R_2, and therefore the clearance distance in ideal conditions is $C = R_2 - R_1$. Normally, the dynamic movement of kinematic pair with clearance has three motions: a) Roller keeps in contact with one side of the cam groove all the time. b) Roller moves freely in cam groove without any contact with any side of the cam groove, but the bottom of the groove. c) Roller moves and collides with both sides of the cam grooves and has a collision force. Because of the presence of mating tolerances, manufacturing errors, wear and other factors, there must be a clearance between the driven roller and cam, it will have a greater impact in operation, especially in the phase of forward and back, the roller will generate a lateral impact in the cam groove, causing noise and wear, we need to consider the spatial cylindrical cam clearance issues during the movement. As shown in Figure 3, the O_1 and O_2 respect the centerline of the cam profile and a roller center separately. In Figure 3, r_i and r_j are the position vector of roller and the cam at a certain position relative to the world coordinate, e_{ij} is the offset vector of the roller relative to the centerline of the cam profile, e_x and e_y are components of X and Y directions. The normal vector in the impact is as follows:

$$n = \frac{e_{ij}}{\sqrt{e_x^2+e_y^2}}. \tag{1}$$

Collision depth is defined as δ, r is the vertical offset between roller and centerline of the spatial cylindrical cam profile, then the formula is as follows:

$$\delta = \sqrt{e_x^2 + e_y^2} - r. \tag{2}$$

$$r = R_2 - R_1. \tag{3}$$

Obviously the above formula indicates clearly the state of the roller's motion in the cam groove. When $\delta>0$, the roller contacts with the cam groove border, there is elastically deformed. When $\delta = 0$, the roller and cam does not coincide with the center line, and are just in touch. When $\delta < 0$, roller moves in the groove, and does not contacts with the cam groove border.

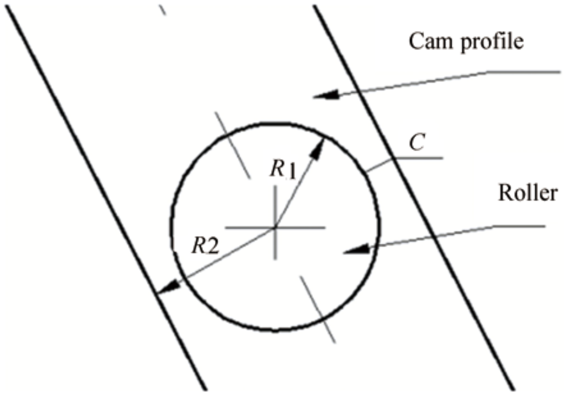

Figure 2
Cam Coupled With Roller With a Clearance

When we study cam wear problems, especially the study of wear rates, we usually only consider wear rate between the follower and the end face of the cam, it is an important factor that impact a lot on cam utilization. However, friction and wear between the cylindrical cam and follower can't be ignored. The mechanical's operation instability increased because of the screaming collision produces and vibration, and this instability with the wear between the parts is also exacerbating, it finally leads to the failure of component.

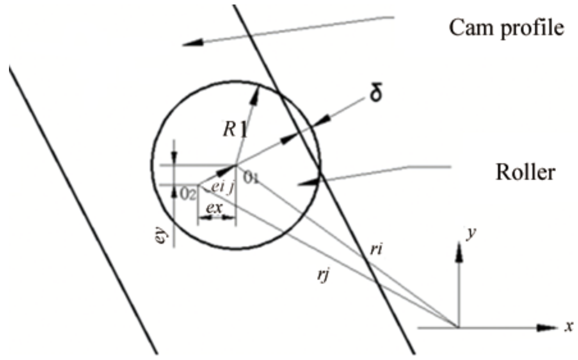

Figure 3
Contacting Model of Cam System With a Clearance

2. TANGENTIAL FRICTION MODELS

Roller radius is usually small compared with the cam profile's radius of curvature. The roller scroll in the cam groove. Considering the friction conditions of spatial cylindrical cam groove boundary, we use a tangential friction model to show the contact characteristic. In this paper, we use the well-known Coulomb friction model, which is expressed as follows:

$$F_\tau = -\mu(v_\tau)F_n\frac{v_\tau}{|v_\tau|}. \tag{4}$$

Among them: is relative tangential velocity, is the normal contact force. is dynamic coefficient of friction, it is concerned with the tangential sliding speed, it can be determined by the following formula.

$$\mu(v_\tau) = \begin{cases} -\mu_d \operatorname{sign}(v_\tau) & |v_\tau| > v_d \\ -\left\{\mu_d + (\mu_s - \mu_d)\left(\frac{|v_\tau| - v_s}{v_d - v_s}\right)^2\left[3 - 2\left(\frac{|v_\tau| - v_s}{v_d - v_s}\right)\right]\right\}\operatorname{sign}(v_\tau) & v_s \le v_\tau \le v_d \\ \mu_s - 2\mu_s\left(\frac{v_\tau + v_s}{2v_s}\right)^2\left(3 - \frac{v_\tau + v_s}{v_s}\right) & v_\tau < v_s \end{cases}. \tag{5}$$

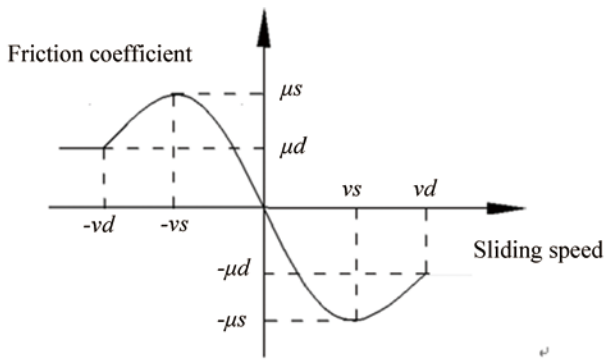

Figure 4
Modification Coulomb Friction Model

3. ESTABLISH THE WEAR MODEL

There are many versions of mechanism and model about adhesive wear, for example, Holm, Archard, Bowden, Tabor, Bucly have many in-depth studies. In this paper, we mainly use Archard adhesive wear model accepted by many scholars all around the world. Achard used the yield stress and sliding distance to express the metal wear volume. The solid surface is uneven, therefore, even with tiny load, the surface has at least three points in touch. When load increases, the contact area increases in two ways, the contact area of the original contact point increases and the new contact point increases.

Expression of the Archard wear model is as follows.

$$W_v = \frac{KLS}{H}. \tag{6}$$

W_v is metal wear volume, K is the adhesive wear coefficient, L for the normal load, S is the sliding distance, H is the hardness of a softer material. Achard model clarifies simply the relationship of the load, the material hardness, the sliding distance and the amount of wear.

But in the study process of spatial of cylindrical cam, the cam wear depth study is of greater significance than the cam wear volume. Considering the existence of the cylindrical cam's clearance, cam wear depth is δ. Therefore the establishment of wear equation is as follows:

$$d\delta = k\sigma ds. \quad (7)$$

σ is contact stress of cam roller, s is sliding distance, k is the wear factor, it set constants. Because of the spatial of cylindrical cam in the operation process, and the direction change of link's movement, the original formula for friction and wear need to be handled. When sliding distance is set, the contact of roller and cam groove wall is constantly changing. Therefore, the wear depth formula is as follows:

$$d\delta = \frac{1}{2}k\sigma ds. \quad (8)$$

Inductive formula:

$$\frac{d\delta}{dt} = \frac{1}{2}k\sigma\frac{ds}{dt} = \frac{1}{2}k\sigma v. \quad (9)$$

Among them, v is the relative speed of the cam roller. Assuming the roller in this paper is fixed, then v is the velocity of the spatial of cylindrical cam, and the cam speed can be obtained by angular velocity.

$$v = R_r\,\omega. \quad (10)$$

R_r is the base circle radius of cam, is the cam angle speed, so

$$\frac{d\delta}{dt} = \frac{1}{2}k\sigma R_r\,\omega. \quad (11)$$

Assuming the cylindrical cam has been used for a while, the surface of the groove's wear can be obtained by the integral equation of time.

$$\delta_p = \int_0^t \frac{1}{2}kP_p(t)R_r\,\omega(t)dt. \quad (12)$$

δ_p is wear depth of p points,δ_p is contact pressure of p points. Obviously, according to the definition of the clearance, we know that only when the cam and roller contact, that is $P_p > 0$, and $\delta_p > 0$, wear exits. Because the time integral of the formula is tedious, and during movement, the most intuitive judgment is the rotational angle of the cam, so the formula can be modified.

$$\delta_p = \int_0^\varphi \frac{1}{2}kP_p(\varphi)R_r\,\omega(\varphi)d\varphi. \quad (13)$$

As shown in the above formula, during exercise, is normal pressure between cylindrical cam and roller. Assume that cylindrical cam is pure rolling during the movement between rollers and cam, the angular velocity is the angular velocity of the cam. Here, we take the literature by Wen and Huang (2012), the wear coefficient of steel and copper is k=1×10-^{12} mm^3·N^{-1}·m^{-1}. According to the above formula, the cylindrical cam's wear depth (×10^{-8}) within a period can be obtained by MATLAB, shown in Table 2.

Table 2
Prediction of Wear Depth of Cylindrical Cam at Different Speed

n	40	50	60	70	80	90	100
δ	4.60	5.75	6.90	8.05	9.20	10.35	11.50

Among them, n is the movement speed of the cylindrical cam, the unit is r/min. δ is cam wear depth, unit is ×10^{-8} mm.

CONCLUSION

Through the above analysis, according to the actual movement of the cylindrical cam, we establish the three-dimensional model of cylindrical cam. Considering the clearance between the roller and the cam groove, and combine with the nature of the cam motion, and on the basis of the Achard wear model, we establish suitable friction and wear model for cylindrical cam and obtained the formula 13 of cylindrical cam to estimate wear depth. We calculate and verify, the wear depth of the cylindrical cam increases with the rotational speed of cylinder cam. We can see that in the calculation process, in order to reduce friction and wear, we should control the speed of cylindrical cam. And to obtain a more accurate prediction value of the friction and wear, we should establish a more reasonable calculation model. For more complex cam, this paper provides a reliable and simple research method to estimate the cam friction and wear value, to analyze the factors affecting the wear process, and to reduce the wear value.

REFERENCES

Lin, Y. J. (2002). *Tribological design and wear simulation of the cam mechanism in engine*. Wuhan, China: Wuhan University of Technology.

Ludema, K. C. (1996). Mechanism-based modeling of friction and wear. *Wear,* (200), 1-7.

Meng, H. C., & Ludema, K. C. (19095). Wear models and predictive equations: their form and content. *Wear,* (183), 443-457.

Mukras, S., Kim, N. H., & Mauntler, N. A., et al. (2010). Analysis of planar multibody systems with revolute joint wear. *Wear, 268*(5-6), 643-652.

Sahin, Y. (2005). The prediction of wear resistance model for the metal matrix composites. *Wear,* (258), 1717-1722.

Steele, C. (2008). Use of lognormal distribution for cofficients of friction and wear. *Relability Engineering & Syetem Safety,* (93), 1574-1576.

Sun, S. F., & Zhou, Y. Q. (2009). Design of spatial cam based on non-uniform rational *B*-splines. *Journal of Mechanical Engineering, 45*(8), 125-129.

Tang, S. X. (2002). *Internal combustion engine cam tappet wear calculation and computer simulation*. Wuhan, China: Wuhan University of Technology.

Tang, Q., Zhang, Y. C., & Lin, L. (2010). Overview and consideration on cam wear. *Journal of Mechanical Transmission, 34*(8), 95-97.

Wen, S. Z, & Huang, P. (2012). *Principles of tribology.* Beijing, China: Tsinghua University Press.

Zuo, Y. M., & Ma, L. (2001). Study of engine cam tappet wear numerical calculation method. *Journal of Wut, 23*(3), 40-43.

