行政院國家科學委員會專題研究計畫成果報告

計畫名稱：滾齒凸輪製造組裝預壓條件之分析與設計
Analysis and Design of Pre-load Condition for Manufacturing and Assembling on Roller Gear Cam

計畫編號：NSC-88-2212-E-009-007
執行期限：87 年 8 月 1 日至 88 年 7 月 31 日
主 持 人：曾錦煥 交通大學機械系 教授

一、中文摘要

本研究針對一種確動空間凸輪機構−滾齒凸輪，考慮機構誤差下建立其數學模型，以進行接觸預壓狀況之分析研究。在選擇以具冠狀外型之圓柱滾子做為從動件後，利用曲面雙接觸分析理論(DSCA)，在三度空間中計算探討兩冠狀圓柱滾子從動件分別與凸輪上下曲面同時接觸時，兩種機械誤差-製造與組裝誤差對預壓狀況之影響,本研究結果可作為組裝確動立體凸輪時,考慮機械誤差對預壓狀況影響之參考準則。

關鍵詞：滾齒凸輪，預壓，曲面雙接觸分析

Abstract

Positive-drive spatial cam mechanism, the roller gear cam mechanism, with mechanical errors is modeled and investigated for preload condition analysis in this paper. In the traditional model, cutters generate the roller gear cam surfaces with the same geometrical shapes as the mating roller followers. In this proposed model, cylindrical roller followers are replaced by crowned cylindrical roller followers with hyperboloidal shapes as the spatial cam surface mating part. The meshing condition between two crowned roller followers and their mating cam surfaces is modeled and analyzed by means of dual surface contact analysis (DSCA). The influences of two main mechanical errors, the manufacturing errors and assembly errors, on preload conditions are studied and discussed in three-dimensional space. This study can be a guide for adjusting the preload condition when a spatial cam mechanism is assembled with mechanical errors.

Keyword：Roller Gear Cam Mechanism, Preload, Dual Surface Contact Analysis

二、 緣由與目的

Since all industrial products have some mechanical errors, line contacts on cam surfaces often become point contacts (Rothbart H. A., 1956). When the contact point moves to the edge of the cam or the follower, it becomes edge contact, and can cause undesirable conditions such as stress concentrations and excessive wear on the contacting edges of the cam and its mating follower. Because adjustment of the relative position of the turret and the globoidal cam can introduce assembly errors, edge contact often occurs as a result of adjusting the driving or driven shafts of a cam mechanism for proper preload. In order to reduce the occurrence of edge contact, the outer rolling surfaces of cylindrical roller followers are crowned slightly, on the order of R=500 mm (MISUMI, 1993) along the axial direction in actual industrial applications. These crowned surfaces are helpful in minimizing the disadvantages caused by misalignments in cam mechanisms (Rothbart H. A., 1956).

Many types of roller followers can be selected for cam mechanisms. Generalized mathematical expressions of surface geometry for globoidal cams with cylindrical, conical, and hyperbolic meshing roller followers (Yan and Chen, 1996) have been proposed. In this paper, an other type of roller follower, a crowned cylindrical roller follower with a hyperboloidal shape is chosen as the mating part. Two roller followers on the turret of the roller gear cam contact, respectively, the upper and the lower surfaces of the globoidal cam. In the traditional model, the cam surfaces are generated by cutters with the same geometrical shapes as the mating roller followers. In this proposed model, cylindrical roller followers are replaced by hyperboloidal roller followers of the cam mechanism.

The mathematical model of the cam mechanism was first derived from the desired displacement function by using theory of gearing (Litvin, 1994) and differential geometry theory. The dual surface contact analysis (DSCA) is used to investigate the preload condition of positive-drive spatial cam mechanisms. The theory of surface contact analysis was originally proposed for gearing, and is called tooth contact analysis (TCA) (Litvin, 1994) in that field. Different from TCA and SCA, DSCA considers dual contact conditions on upper and lower cam surfaces simultaneously. The manufacturing errors on cam profiles will result when grinders with inaccurate radii are used. As with manufacturing errors, assembly errors can also cause different preload conditions in cam mechanisms with positive-drive follower motions. Such mechanical errors are defined and analyzed using DSCA in this study. The influences of mechanical errors and follower crowned radii on preload condition are analyzed and demonstrated using three numerical examples.

三、研究方法

The symbol $\boldsymbol{\Sigma}_{cu(l)}$, used later, represents the geometrical surface of the upper/lower cam surface in the X_2-Y_2-Z_2 coordinate system, and was derived by applying the theory of conjugate analysis and differential geometry (Wang et al., 1992) as

$\boldsymbol{\Sigma}_{cu(l)}$ =

$$\begin{bmatrix} L_{u(l)} \cos S_{u(l)} \cos\phi_{u(l)} + r \sin S_{u(l)} \cos\theta_{u(l)} \cos\phi_{u(l)} - X\cos\phi_{u(l)} + r\sin\theta_{u(l)} \sin\phi_{u(l)} \\ -L_{u(l)} \cos S_{u(l)} \sin\phi_{u(l)} - r \sin S_{u(l)} \cos\theta_{u(l)} \sin\phi_{u(l)} + X\sin\phi_{u(l)} + r\sin\theta_{u(l)} \cos\phi_{u(l)} \\ L_{u(l)} \sin S_{u(l)} - r\cos\theta_{u(l)} \cos S_{u(l)} \end{bmatrix}.$$

Since each two contact surfaces between two followers and their mating cam surfaces must be in continuous tangency, that is, their position and normal vectors must coincide at any instant in the same coordinate system, the two surfaces ($\boldsymbol{\Sigma}_{cu(l)}, \boldsymbol{\Sigma}_{hu(l)}$) and their unit normal vectors ($\mathbf{n}_{cu(l)}$, $\mathbf{n}_{hu(l)}$) were transformed into the same fixed coordinate system X_f-Y_f-Z_f with manufacturing and assembly errors as ($\boldsymbol{\Sigma}_f^{cu(l)}$, $\boldsymbol{\Sigma}_f^{hu(l)}$) and ($\mathbf{n}_f^{cu(l)}$, $\mathbf{n}_f^{hu(l)}$). The surface contact condition between the upper roller and its mating cam surface is decided by following equations:

$$\boldsymbol{\Sigma}_f^{cu}(L_u, \phi_u, \zeta) = \boldsymbol{\Sigma}_f^{hu}(u_u, \rho_u, \delta_u),$$

$$\mathbf{n}_f^{cu}(L_u, \phi_u, \zeta) = \mathbf{n}_f^{hu}(u_u, \rho_u, \delta_u),$$

$$\left|\mathbf{n}_f^{cu}\right| = \left|\mathbf{n}_f^{hu}\right| = 1. \quad (13)$$

The equations to determine the surface contact condition between the lower roller and its mating cam surface are as follows:

$$\boldsymbol{\Sigma}_f^{cl}(L_l, \phi_l, \zeta) = \boldsymbol{\Sigma}_f^{hl}(u_l, \rho_l, \delta_l),$$

$$\mathbf{n}_f^{cl}(L_l, \phi_l, \zeta) = \mathbf{n}_f^{hl}(u_l, \rho_l, \delta_l),$$

$$\left|\mathbf{n}_f^{cl}\right| = \left|\mathbf{n}_f^{hl}\right| = 1. \quad (14)$$

The new calculated follower positions $\delta_u(\phi)$ and $\delta_l(\phi)$ must satisfy the constraint

$$V = \delta_u(\phi) - \delta_l(\phi). \quad (15)$$

Eqs. (13)~(15) yield eleven independent scalar equations with twelve unknowns ($L_{u(l)}$, $\phi_{u(l)}$, ζ, $u_{u(l)}$, $\rho_{u(l)}$, $\delta_{u(l)}$, X'). Variable $X'(\phi)$ denotes the new relative distance between the two rotation axes of the globoidal cam and the turret in DSCA. Eleven unknowns ($L_{u(l)}$, $\phi_{u(l)}$, $u_{u(l)}$, $\rho_{u(l)}$, $\delta_{u(l)}$, X') can only be determined by the above eleven scalar equations when the cam rotation angle ζ is given. Thus, the contact conditions between two followers and their mating cam surfaces can be sequentially calculated after the values of $X'(\phi)$ have been determined by DSCA at different cam rotation position. The preload condition index $\Delta X(\phi)$ can be derived by

$$\Delta X(\phi) = X'(\phi) - X. \quad (16)$$

The mechanical errors will cause different contact conditions when the cam rotates to different position. The cam and the turret will attempt to push away from each other when the preload exists in the assembly. Because all the components of the mechanism are assumed to be rigid, the new assembly should increase the relative distance between two rotation axes to avoid preload, and the preload index becomes positive. On the contrary, the relative distance between two rotation axes should be reallocated closer in the mathematical model if backlash appears in real assemblage. This will obtain a negative preload index.

四、結果與討論

Example 1 : Influences of Different Manufacturing Errors on Preload Condition

Example 2 : Influences of Different Assembly Errors on Preload Condition

In industrial applications, the radius of the crowned roller surface R_c is set at 500 mm. In this example, the effect of crowned radius R_c on preload condition is studied. It contains the three main combined mechanical errors in Example 1, the manufacturing error Δr =-0.05 mm, the translational error Δz =0.1 mm and the rotational error $\Delta\gamma_y$=0.1^{o}. The results are shown in Fig. 4. The data for this example are the same as those in example 2, except that radius R_c is set to three different values (100 mm, 500 mm, 1000 mm).

In Fig. 4, the preload index increases when the crowned radius R_c is raised. Another result indicates that the variation in preload condition near the dwell period becoming larger as the crowned radius R_c is increased. It is concluded that preload condition is less sensitive to the same mechanical errors when a smaller R_c is chosen.

五、計畫結果自評

In this paper, two crowned cylindrical roller followers with hyperboloidal shapes were selected for mating with upper and lower surfaces generated by a cylindrical cutter in the oscillating-type of roller gear cam mechanism. The line contact between each pair of contact surfaces became point contact when crowned cylindrical roller followers were substituted for the cylindrical ones. These hyperboloidal roller followers are superior to conventional cylindrical roller followers because they provide the capacity to eliminate the edge contact caused by assembly errors when adjusting the preload in the cam mechanism. Because the shape of the crowned surface on the hyperboloidal roller follower is one segment of a circle, the cutting mechanism and manufacturing processes for crowning the cylindrical roller followers do not need to be changed. These kind of crowned roller followers have been widely used in industry. Industrial demands have been considered in this geometrical model of spatial cam mechanism.

六、參考文獻

1. Angeles, J. and Lopez-Cajun, C. S., *Optimization of Cam Mechanisms*, Kluwer Academic Publishers, P.O. Box 17, 3300 AA Dordrecht, The Netherlands, pp. 10 (1991).
2. Ardayfio, D. D. and Trower, P. S., "Kinematic Analysis of Three Dimensional Cams, " *ASME Design Engineering Division Conference and Exhibit on Mechanical Vibration and Noise*, Cincinnati, Ohio, pp. 1-11

(1985).

3. Chakraborty, J. and Dhande, S. G., *Kinematics and Geometry of Planar and Spatial Cam Mechanisms*, New York: Wiley (1977).
4. Chen, F. Y., *Mechanics and Design of Cam Mechanisms*, New York: Pergamon Press, (1982).
5. Jones, J. R., *Cams and Cam Mechanisms*, Published by Mechanical Engineering Publications Ltd. for the Institution of Mechanical Engineers, London & Birmingham, Alabama (1978).
6. Litvin, F. L., *Gear Geometry and Applied Theory*, NJ: Prentice Hall (1994).
7. MISUMI, MISUMI *Production Catalog 1993-1995*, 4-43, 2-Chome, Toyo, Koto-Ku, Tokyo, 135 Japan, MISUMI Corporation, pp. 509-514 (1993).
8. Oizumi, T. and Emura, T., "Globoidal-cam Type Gearing," *Proc. 92 Int. Power Transm. Gearing Conf. ASME Design Engineering Division*, New York, Vol. 43(2), pp. 535-541 (1992).
9. Rothbart, H. A., *Cams Design, Dynamics and Accuracy*, New York: Wiley (1956).
10. Tsai, D. M. and Huang, N. J., "Geometrical Design of Roller Gear Cam Reducers," *Power Transm. and Gearing Conf. ASME*, DE-Vol. 88, pp. 153-160 (1996).
11. Tsai, Y. C. and Chang, C. S., "An Analysis on the Contact Path of Roller Gear Cam," *Proceedings of the 12th National Conference of the CSME*, Chia-Yi, Taiwan, ROC, pp. 171-179 (1995). (in Chinese)
12. Tsai, Y. C. and Cheng, M. S., "An Study on Thrust Force on Roller Gear Cam," *Proceedings of the 12th National Conference of the CSME*, Chia-Yi, Taiwan, ROC, pp. 181-188 (1995). (in Chinese).
13. Wang, W. H., Tseng, C. H. and Tsay, C. B., "Analytical Design of a Spatial Cam Profile," *Proceedings of the 9th National Conference of the CSME*, Kaohsiung, Taiwan, ROC, pp. 297-304 (1992). (in Chinese).
14. Wang, W. H., Tseng, C. H. and Tsay, C. B., "Optimum Design of a Spatial Cam Mechanism," *Proc. of the Int. Conf. Modeling, Simulation and Optimization*, Gold Coast, Australia, Paper #: 242-068 (1996).
15. Wang, W. H., Tseng, C. H. and Tsay, C. B., "Surface Contact Analysis for a Spatial Cam Mechanism," *ASME Journal of Mechanical Design*, Vol. 119 (March 1997).
16. Yan, H. S. and Chen, H. H., “Geometry Design and Machining of Roller Gear Cams with Cylindrical Rollers,” *Mech. Mach. Theory*, Vol. 29, No. 6, pp. 803-812 (1994).
17. Yan, H. S. and Chen, H. H., “Geometrical Design of Globoidal Cams with Generalized Meshing Turret-rollers,” *ASME Journal of Mechanical Design*, Vol. 118 , pp. 243-249 (1996).

七、圖表

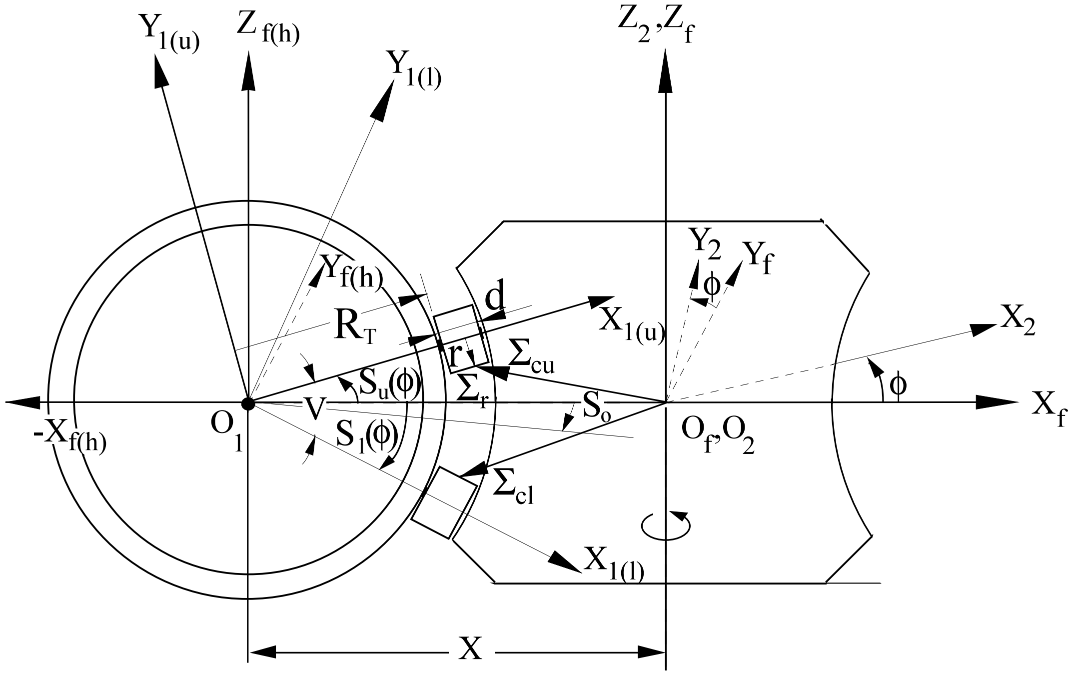

Fig.1. The coordinate systems of the cam mechanism.

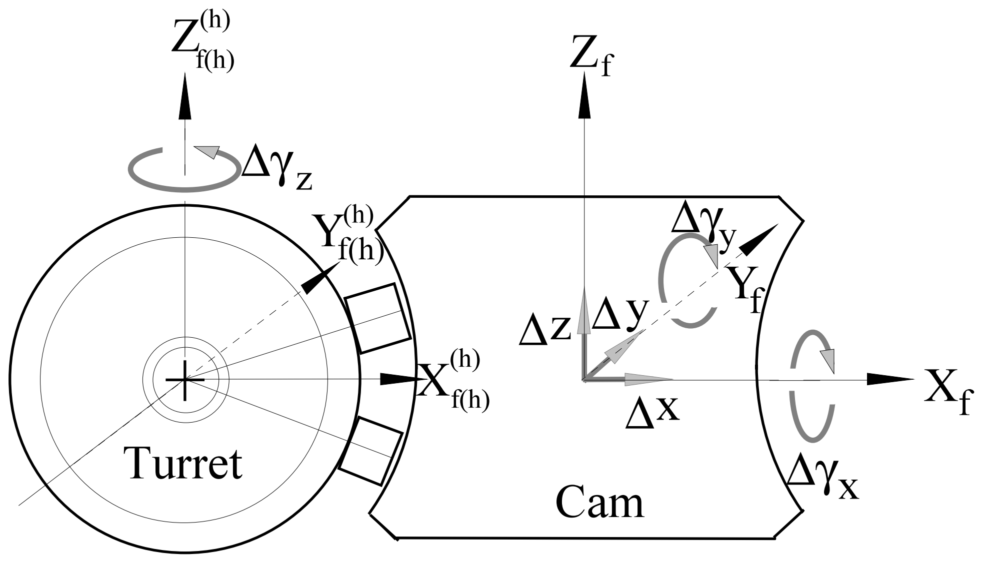

Fig.2. Definition of possible assembly errors.

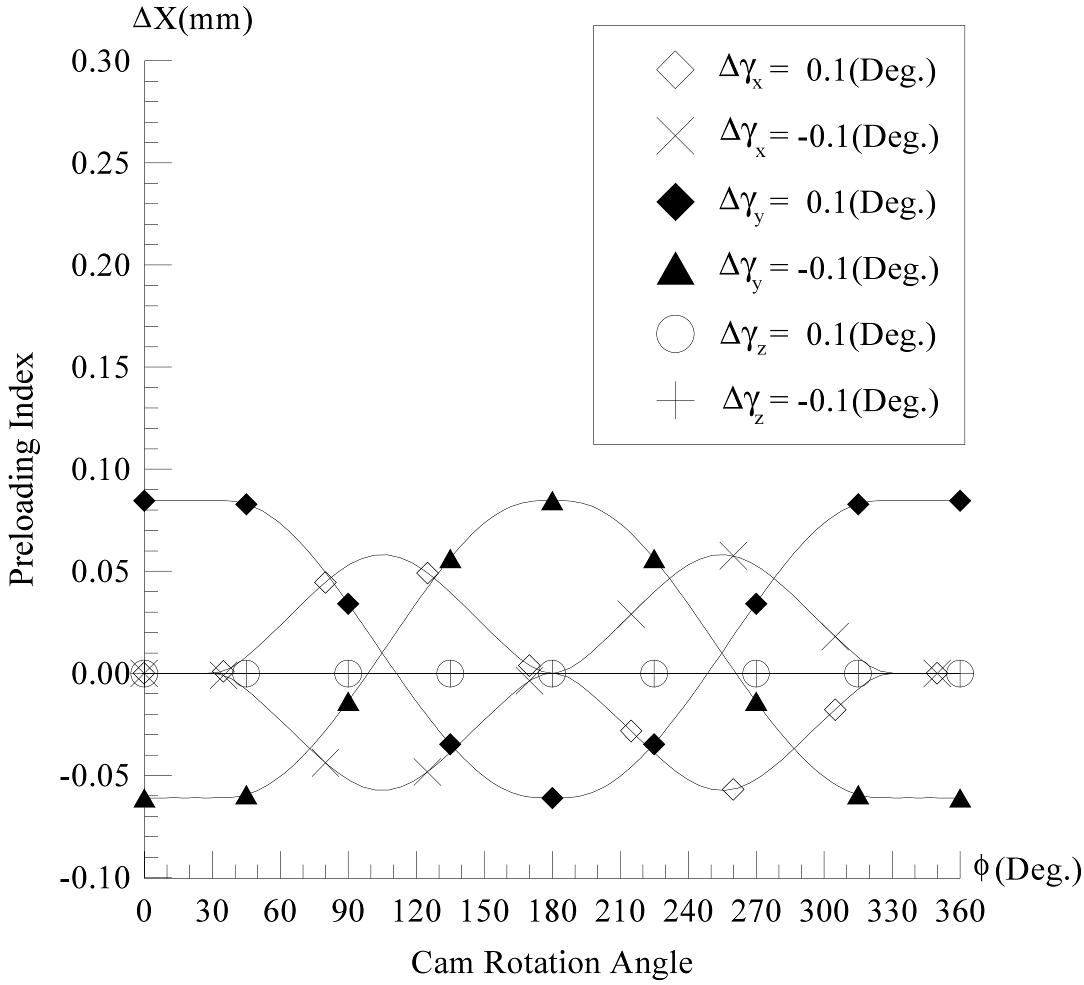

Fig.3. Influences of rotational errors on preload condition.

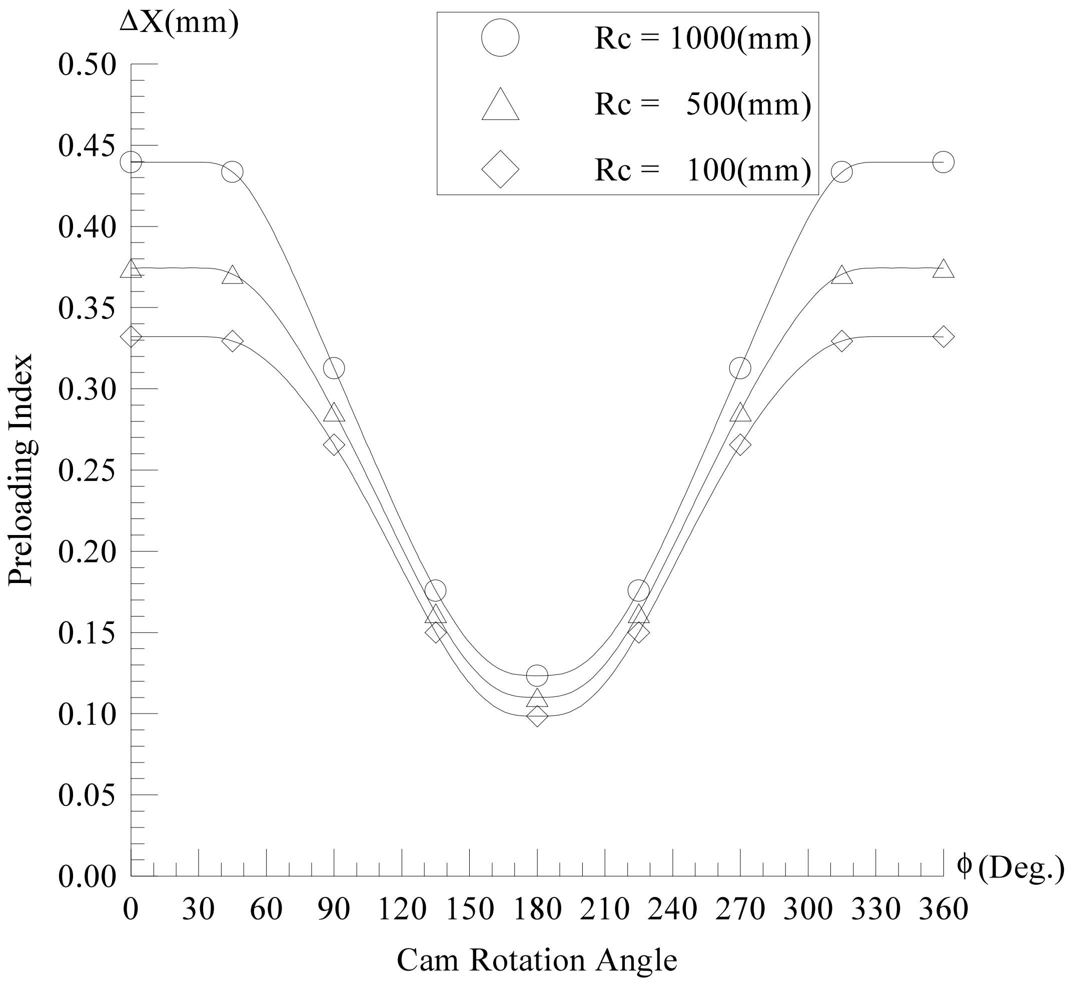

Fig.4. Influences of crowned radius R_c on preload condition.