Analysis and Experiment of Non - circular Layered Grinding Based on Grinding Arc Length

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Abstract.. Aiming at the problem of machining quality caused by the sharp fluctuation of grinding force during the grinding process of non - circular parts, a new method for determining the transition profile based on the presetting of the grinding arc length is proposed. It is recommend to use the target profile as the reference point to reverse the normal grinding margin according to the grinding arc length by layer ,so that the grinding rate can be stable and controllable. And the calculation model of non - circular stratified method is given too. The experiments with constant grinding arc length show that the method can improve the grinding quality of non - circular grinding process effectively.

Preface

The cut-point tracking method is often used in grinding non-circular parts such as eccentric shafts, camshafts and engine combustion chambers [1-2] . Different from the grinding circle, eccentric shaft and other non-circular profile need to grind for several layers to be processed into the target profile. And the grinding point position, processing margin, grinding rate, tool wear and other processing parameters are under constantly changing which result in complex and non-uniform processing.

Some studies according to the specific characteristics of the parts were processed, respectively, in the kinematics and dynamics and other aspects [3-7]. Since this kind of research is directly related to the manufacturer's core technology and commercial interests, The design method of the key stratified grinding transition curve in the grinding process has not been reported.

Based on the non-circular grinding forming mechanism, the hierarchical transition profile planning from blank to target profile is studied on the basis of analyzing the grinding process. Aiming at the optimal design of process parameters such as cutting depth, grinding rate and so on, a generalized bias design method of transition series is proposed. Research conclusions can be extended to different forms of non-circular parts grinding.

Non-circular contour forming mechanism

In the non-circular part grinding process, assuming that the non-circular parts are fixed, the grinding process of the target contour can be understood as the variable diameter rotation of the grinding wheel around the non-circular parts, and The target contour is formed by the wheel motion envelope. The center track of the grinding wheel is the equidistant line of the target contour, see Fig1.

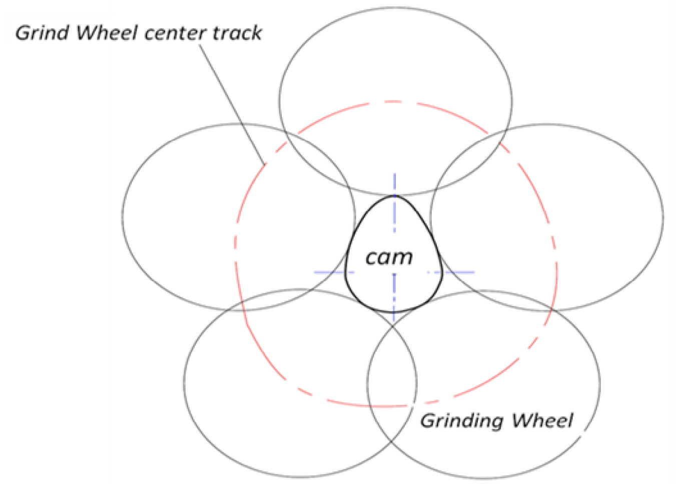

Figure 1 Non - circular contour formation process

Given the non-circular contour equation L, its vector form in the fixed coordinate system is:

$$L:\ \vec{r}(t)=x(t)\vec{e}_1+y(t)\vec{e}_2 \tag{1}$$

Set the radius of the grinding wheel is R, the track of the wheel center is the the normal equidistant line of non-circular contour, thus,grinding wheel center curve equation is given as follows:

$$\vec{r}_{\Gamma}=(x+\frac{Ry'}{\sqrt{x'^2+y'^2}})\vec{e}_1+(y-\frac{Rx'}{\sqrt{x'^2+y'^2}})\vec{e}_2 \tag{2}$$

Non-circular contour grinding is layered. Based on the point of the target contour, the transition profile is calculated according to the normal feed rateε, and then the radius R is used as the offset value,so as to obtain the center wheel track and the two-axis linkage coordinates.

It can be seen from Figure 2, the point A is on the target profile. Although the grinding margin in the grinding process and grinding wheel radius are in constantly changing, the center of the wheel is always on the normal line of the point A. If the center of the grinding wheel is understood as a slider moving in the normal direction, a machining process model in the form of a crank-like slider structure can be obtained. Set the grinding wheel wearΔ R, feed rateε, then in the triangleΔO_0AB:

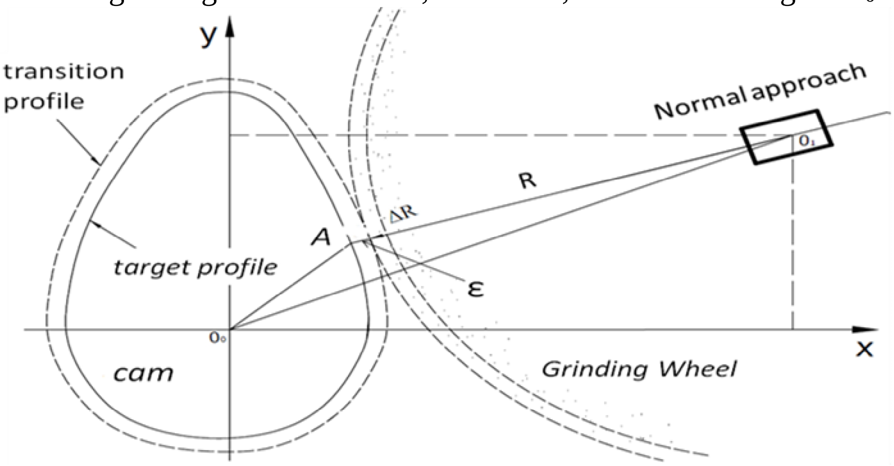

Figure 2 Normal approach calculation model

$$\overline{R}=R\text{-}\Delta R+e \tag{3}$$

By Eq. 2 and Eq. 3, the coordinates of grinding wheel center can be obtained as:

$$\begin{cases} X=x+\overline{R}\dfrac{y'}{\sqrt{x'^2+y'^2}} \\ Y=y-\overline{R}\dfrac{x'}{\sqrt{x'^2+y'^2}} \end{cases} \tag{4}$$

It is easy to find the coordinates can be converted to X-axis and C-axis linkage movement relationship when grinding non-circular contours. In fact, the grinding wheel is always tangent to the target line of the work piece, and the center of the grinding wheel is always on the normal line of contact point A.

Non - circular grinding stratification method

After determining the center of the grinding wheel for grinding non-circular parts, it is necessary to consider how the contours are layered machined from the blanks. It is need to plan the process phase transition profile, design next-grinding allowance, and ultimately get the target profile.

The transition profile should be deduced based on the target profile as the starting point, and then the outer level contour could be calculate by the required feed. The direction of the offset toward center can be determined in two ways, respectively, by the centripetal direction or the normal direction.

Centripetal approach Grinding method

Let the A point to be machined from the point A_1 on the transition layer for the amount of h, point A and A_1 are in the radial direction as shown in Fig. 3, then the equation of the transition layer:

$$\bar{r}(t)=(x-\frac{hx}{\sqrt{x^2+y^2}})\mathbf{e}_1+(y+\frac{hy}{\sqrt{x^2+y^2}})\mathbf{e}_2 \quad (5)$$

The grinding wheel and the transition profile should be tangent. And from the Eq.5,we can see that the different offset h results in a different Normal direction of the corresponding contact point in the centripetal transition layer, and the center coordinate of the wheel is also in changing. As shown in Fig. 3, O_1A and $O_2A_1$are the normal directions of A and A_1 ,therefore, the usage of this method requires the instantaneous calculation of the transition profile and normal directions, resulting in a large number of processing trajectories.

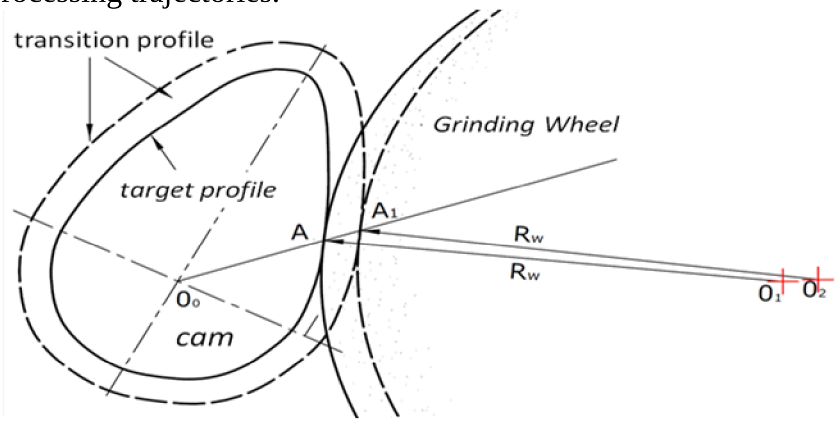

Figure 3 Centripetal approach Grinding

Normal approach Grinding method

In view of the above problems, this paper proposes a non-circular layered machining method named normal approach: that is, take the point A on the target profile both as the basis of the process and the final target, to design layered grinding transition profiles.

The normal deviations of each point are determined by the normal grinding amount, the resulting curve is the transition profile to be reached in advance when grinding the current layer. And the equidistant line based on the transition profile is the grind wheel center trajectory of outter layer. This process is done layer-by-layer until the process transition profile approach the Rough profile .as shown in Figure 4, The cutting point A2 pushed outward from the point A.

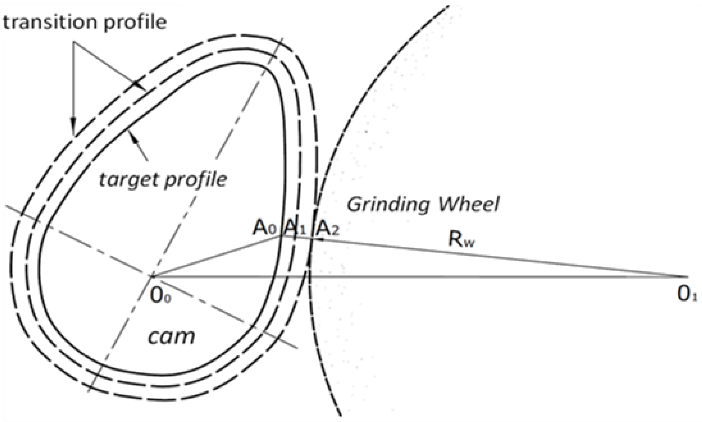

Figure 4 Normal approach Grinding

The transition profile coordinates can be calculated according to Eq.4. When the transition layers are equidistantly biased, the corresponding cutting points in the different transition layers are all in the normal direction of the target contours in whole grinding approximation process. The center of the grinding wheel moves along the normal line, the amount of movement depends only on the amount to be removed. With the characteristics of small amount of calculation, it is suitable for high-speed processing.

Non - circular grinding contact arc length

Grinding arc length of equidistant normal offset

Compared to cylindrical grinding, non-circular grinding is more similar to surface grinding. The calculation formula of the grinding rate Z is shown in Eq.6.

$$Z = SV_t = l'bV_t \tag{6}$$

S is the grinding cross-sectional area; l' is the grinding contact arc length; b is the work piece width; Vt is the cutting speed.

Considering the uniform velocity grinding under the identical transition layer, the dynamic grinding rate is directly related to the instantaneous contact arc length. As shown in Fig. 5, the middle profile is the profile obtained after the previous grinding, and the inside is the target profile. When grinding the target profile on point A, the current grinding arc length is AB_1 .It can be calculated using the following iterative method:

Let D point be the any point between the arc of A_1B_1, O_1 is the grinding point. We're going to find D start from A_1 step by step, and when D is satisfied with the Eq.7, the D point can be considered as B_1, from which can get the current grinding arc length AB_1, δ is a small amount to control the search accuracy.

$$R - \overline{O_1D} \le d \tag{7}$$

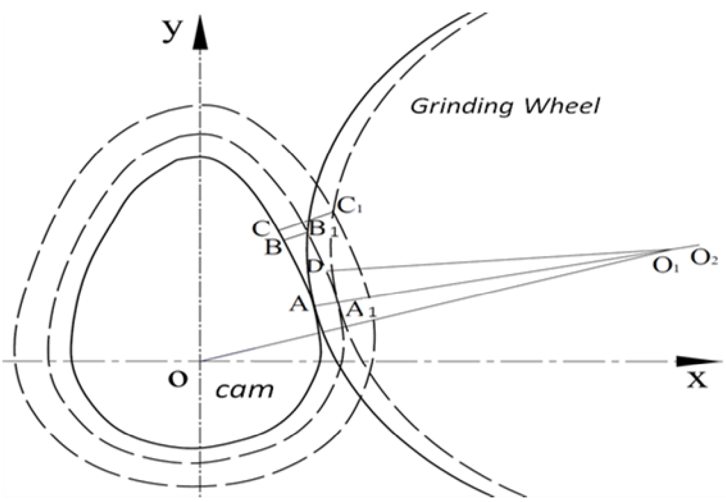

Figure 5 Equidistant normal offset

Take a certain type cam as an example, the cut depth is 50 microns, the grinding wheel radius is 250mm. According to Eq.7, the trend of grinding arc length is given in Figure 6

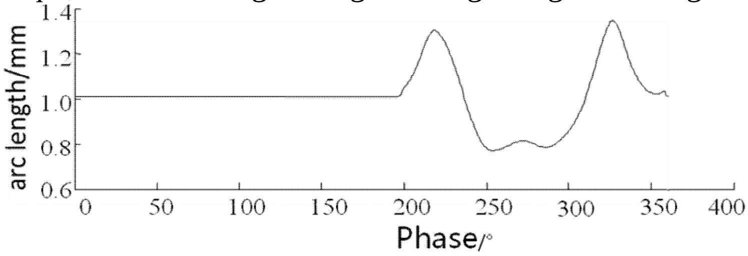

Figure 6 grinding arc length by equidistant normal offset

Constant grinding arc length normal offset

When the normal offset is constant all around, the length of the grinding arc waves violently, which result in fluctuating removal rate and abrupt grinding force in the non-circular grinding. From the perspective of kinematics and dynamics, this profile layered way is extremely unfavorable.

Therefore, it is necessary to consider a reasonable adjustment of the grinding allowance for planing the transition profile, so as to optimize the contact arc length. For example, the calculation process for constant arc length is shown in Fig. 7. To grind point A, we should determine the point B_1 in advance with preseting the length of the grinding arc length. Then the point B can be found through the variable step iteration method , where the normal line and the wheel intersect at the point B_1. The normal offset amount of point B is determined to obtain the desired contact arc length for grinding point A. When the point A moves along the profile, the normal offset amount satisfying the contact arc length of the layer is obtained by the method described above, and the contour of the transition layer is generated. The outer contours are determined by the constant grinding arc length finally until the size of the blanks.

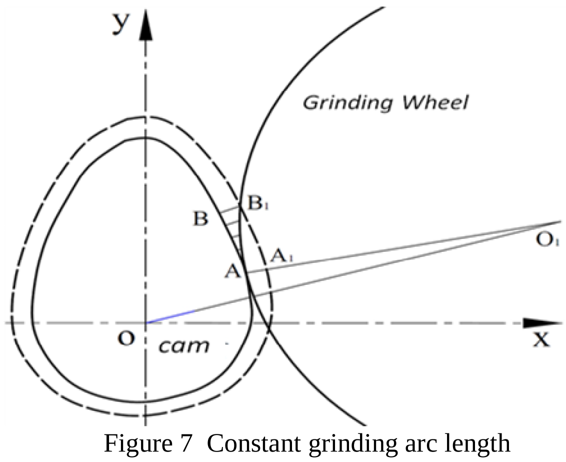

Figure 7 Constant grinding arc length

By the means of planning grinding arc length,the grinding rate achieve controllability through adjusting the normal feed, so as to avoid the fluctuation of grinding, reduce the grinding force oscillation. Constant arc length method makes it possible to improve the accuracy of the processing profile.

By determining grinding arc length of the points on the the transition profile, the reverse curve is designed in the outward direction. As the normal offset of each point varies, the transition profile obtained by the varying offset method is the inconsistentl offset line of the target profile. The transition profile coordinates can be calculated according to Eq.8:

$$\begin{cases} X_i = x + \dfrac{e_i y'}{\sqrt{x'^2 + y'^2}} \\ Y_i = y - \dfrac{e_i x'}{\sqrt{x'^2 + y'^2}} \end{cases} \quad (8)$$

It is obvious that the center of the grinding wheel and the X_C linkage coordinate can be calculated on the basis of the equidistant bias.

Non-circular layered grinding example

grinding with Equidistant normal offset method

To a certain type of cam processing, for example, set the wheel radius Rw = 250mm, take the layer processing margin of 5 um ,10 um,20 um respectively. The simulation results are shown in Fig. 8.

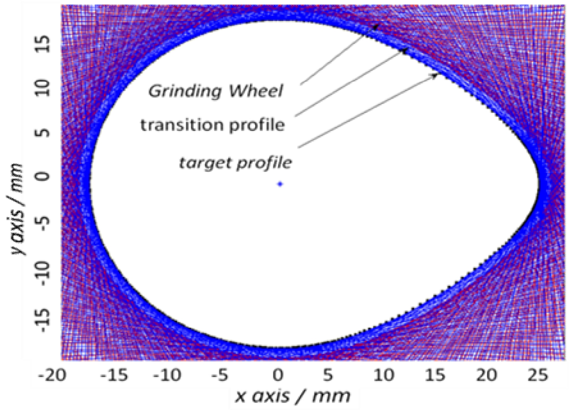

Figure 8 Equidistant transition profile simulation

The contour error of the cam profile is shown in Fig.9 measured by the L-2000 camshaft measuring instrument .

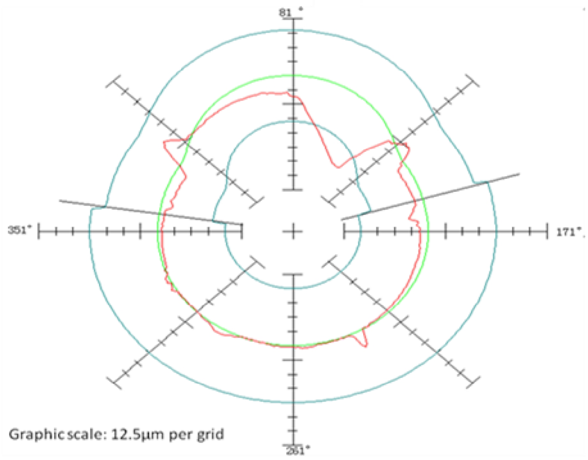

Figure 9 The contour curve of the cam profile with Equidistant normal offset

grinding with constant arc length method

It can be seen that the amplitude of the error varies greatly due to the change of the curvature of the non-circular profile, and the grinding rate and the grinding force are fluctuant in the process of the whole circle. So in the case of other parameters unchanged, layered contour is proceed according to the constant grinding arc length offset design method, the result is shown in Figure 10. On this basis, we get ununiform normal offset profile, as shown in Fig.11.

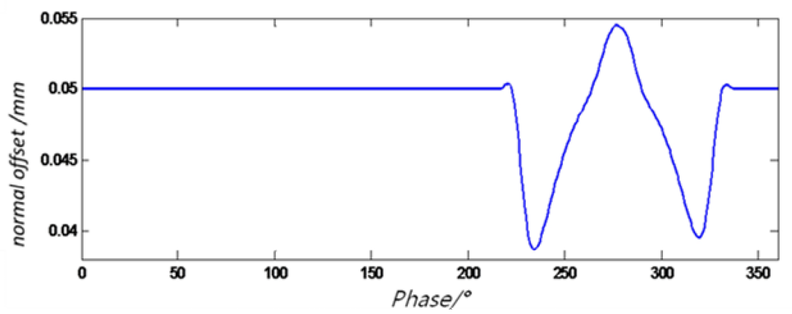

Figure 10 The normal offset with Constant grinding arc length

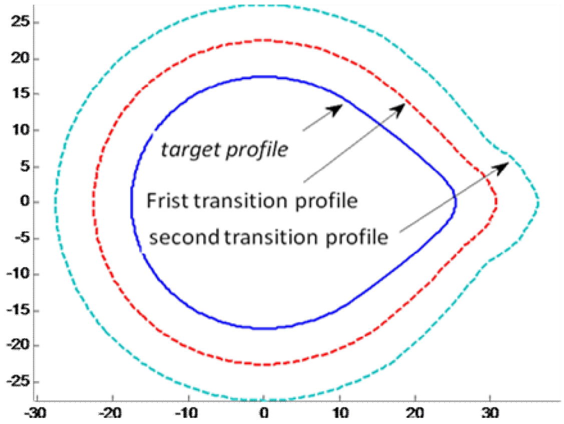

Figure 11. The transitiont profile with constant grinding arc length (magnified 100 times)

The contour error of the cam profile grinded by constant arc length method is shown in Figure 12. It can be seen that the fluctuation of the grinding force is slowed down due to the smooth design of the grinding force,which also makes the fluctuation of the contour error tend to be significantly reduced.

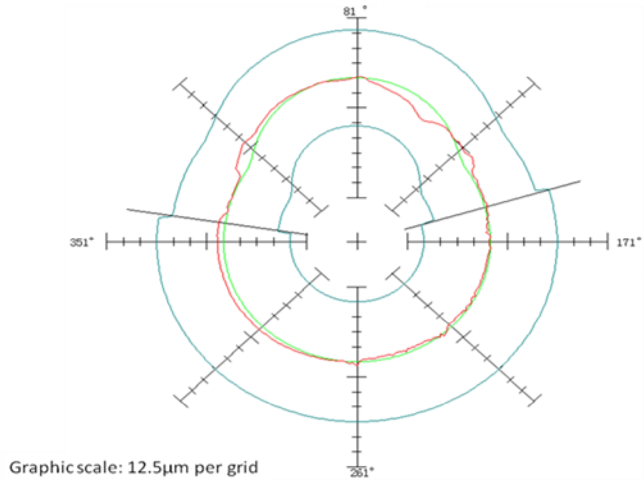

Figure 12 The contour error of the cam profile with Constant grinding arc length

Conclusion

(1) Due to the change of the curvature radius of non-circular , the fluctuation of the contact arc length in the transient grinding process will fluctuate severely with constant rotation velocity during the non-circular grinding process.

(2) The arc length planning method is useful in non-circular grinding process, which can improve the grinding environment, reduce the fluctuation of grinding force and improve the grinding precision and surface quality.

(3) based on the research Conclusion , two parameters of grinding speed and grinding arc length shoould be synchronously optimized in next work , to avoid the contour interference and the speed impact of the two linkage shaft.

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References

[1] ZHANG Lixiu, WU Yuhou. Study about Key Grinding Technique of Non-circle Section[J]. Machine Tool & Hydraulics, 2006,10: 4-6.

[2] Guangsheng Chen, Xuesong Mei, Tianyu Zheng. Research on the key technologies of CNC noncircular camshaft grinding[C]// Mechatronics and Automation. IEEE Trans, 2009 :4528 – 4533.

[3] Manchao Zhang, Zhenqiang Yao, Jun Hu. Offset algorithm for non-circular contour with point cloud data [C]// Computer Application and System Modeling (ICCASM).2010(9): V9-150 - V9-153.

[4] Toenshoff Hans, Kurt Scherger, M Stephan,Hinkenhuis Helmut. Adaptive process control in noncircular grinding[J].American Society of Mechanical Engineers, Dynamic Systems and Control Division,1999,67:923-929.

[5] Jing Li, Yongyi He, Nanyan Shen, Minglun. Research on the Servo Lag Error and Compensation in Cam Non-circular Grinding Process [C]// Measuring Technology and Mechatronics Automation, 2009. ICMTMA '09. International Conference on , 2009(3): 843 - 846.

[6] Hu Zhanqi et al. Research on Intelligent System of CAD/CAM/CNC for Planer Cams Grinding [C]// Proceddings of the Intelligent Conference on Surface Finishing Technology and Surface Engineering. 2006: 429-432.

[7] Qiushi Han, Baojie Xu,Zhi Tu. The Study of Cam Grinding Velocity Rule[J]. Machinery Manufacturing Engineer，2000,04:14-16.