Structural Design of Two-Cylinder Single Overhead Camshaft

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Abstract. Due to the higher performance demand, the camshaft is the key driving part in the engine. Because it is eccentric circular section part, it is very difficult to design and manufacture this kind of axial parts. Take two-cylinder single overhead camshaft for an example, the entire process of camshaft design is analyzed. The practice has proved that the method has simple, flexible and efficient advantages, and it can greatly shorten the design of artificial computing time.

1. Introduction
Camshaft is a key part of the automobile engine and other internal combustion engines. Its quality and working efficiency has a direct influence on the quality of automotive and the development of the entire automotive industry.

In all kinds of machinery, especially the automatic machinery, automatic control device and assembly lines, cam mechanism is widely used, which can make the follower to accurately realize some expected motion law. Camshaft parts, as an important part of mechanical products such as automobiles and motorcycles, have huge demand every year. Because camshaft is the key transmission component in engine, its performance requirements are higher. Therefore, it is essential to design a reasonable contour curve of the cam shaft [1]. Computer aided design (CAD) will improve the quality and efficiency of product design to a greater extent [2][3][4][5]. Using the powerful parametric modeling technology of SolidWorks software and secondary development module provided by software, the 3D parametric design of automobile camshaft can be realized, which can speed up the design and development of new products and shorten the product development cycle[6][7][8]. The parametric design of the camshaft lays a good foundation for the subsequent camshaft cross wedge rolling [9][10]. The intake and exhaust cam arranged on the camshaft is the control mechanism that makes the valve open and closes according to the specified working sequence and valve phase [11]. The paper introduces the design of a two cylinder cam shaft, intake and exhaust cam profile design, shaft and shaft neck design, and draws the 3D parametric model of the camshaft using Solidworks 3D software. The output of practice has proved that the method has simple, flexible and efficient advantages, and it can greatly shorten the design of artificial computing time.

2. Camshaft Design
The camshaft is the main part of the valve transmission group, which has a very important influence on the performance of the valve movement and the gas distribution system [12][13].

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2.1. Introduction of Cam Design
Among all kinds of machinery used in our daily life, various cam mechanisms are widely used. For example, the gas distribution structure of the internal combustion engine involved in this design is shown in Fig. 1.

![Figure 1. Engine distribution mechanism](image)

The gas distribution structure is mainly composed of the valve group and the valve transmission group. When the cam is rotating, the shape of the cam will force the push rod to reciprocate. To enable the valve to be turned on or off, the combustible fuel is controlled to enter the cylinder or exhaust the exhaust gas in a reasonable period of time. It depends on the shape of the cam profile curve that the length of opening and closing time of the valve and the change rule of speed and acceleration.

The design of the camshaft shape structure is as follows.

2.1.1. The Design of Intake Cam Profile: The intake cam adopts a straight moving flat base push rod pan cam mechanism, its working condition is high speed light load. The motion requirements for the push rod are as follows. When the cam turns 65 degrees, push rod is rising 10mm. The push rod stops when the cam continues around 5 degrees. When the cam turns 65 degrees again, push rod is declining 10mm. The cam stops when the cam turns the other angle. The detailed design process is as follows.

2.1.2. Determination of the Basic Dimensions of the Cam Mechanism: It is preliminarily determined that the radius of the base circle of the cam is 55mm, stroke of push rod is 10mm. Its working condition is high-speed light load, therefore, the law of motion of the maximum acceleration and the maximum jump should be used, the law of motion of thrust and return motion is based on the law of five polynomial motion.

The detailed calculation process is as follows.

2.1.3. Calculation of Theoretical Profile: For the disk cam mechanism with a straight flat bottomed push rod, the theoretical profile coordinates of the cam can be obtained from the following formula[14].

\[ x = (r_0 + s) \sin \delta, \quad y = (r_0 + s) \cos \delta. \]

In the formula, displacement \( s \) should be calculated separately.

*Pushing stage*

\[ \delta_0 = 65^\circ = 13\pi / 36. \]  
\[ s_i = 10hd^3 / \delta_0^3 - 15hd^2 / \delta_0^2 + 6hd / \delta_0 + s_i^3 \]

\[ = 2123.26d^3 / \pi^3 - 8821.20d^2 / \pi^2 + 9771.18d / \pi. \]
\[ \delta_i = \left[0.13\pi / 36\right] . \] (4)

Far resting stage

\[ \delta_{i0} = 5^\circ = \pi / 36 . \] (5)

\[ s_t = 10 , \quad \delta_i = \left[0.1 / 36\right] . \] (6)

Return stage

\[ \delta_{i0} = 65^\circ = 13\pi / 36 . \] (7)

\[ s_t = 10k\delta^2 / \delta_{i0}^2 \pi^3 - 15k\delta^3 / \delta_{i0}^3 + 6k\delta^4 / \delta_{i0}^4 \]
\[ = 2123.26 \delta^2 / \pi^3 - 8821.20 \delta^3 / \pi^4 - 9771.18 \delta^4 / \pi^5 . \] (8)

\[ \delta_i = \left[0.13 / 36\pi\right] . \] (9)

Near resting stage

\[ \delta_{i0} = 225^\circ = 5\pi / 4 . \] (10)

\[ s_t = 0 . \] (11)

\[ \delta_i = \left[0.5\pi / 4\right] . \] (12)

The coordinates of each point of the intake cam profile can be obtained from the calculation results, as shown in Tab.1.

| Circumferential angle(°) | Circumferential angle(rad) | Push strokes | Coordinates x | Coordinates y |
|--------------------------|---------------------------|-------------|---------------|---------------|
| pushing stage 0.0000     | 0.0000                    | 0.0000      | 0.0000        | 27.5000       |
| pushing stage 5.0000     | 0.0873                    | 0.0404      | 2.4003        | 27.4356       |
| pushing stage 10.0000    | 0.1745                    | 0.2853      | 4.8249        | 27.3631       |
| pushing stage 15.0000    | 0.2618                    | 0.8427      | 7.3357        | 27.3770       |
| pushing stage 20.0000    | 0.3491                    | 1.7337      | 9.9985        | 27.4707       |
| pushing stage 25.0000    | 0.4363                    | 2.9113      | 12.8524       | 27.5620       |
| far resting 70.0000      | 1.2217                    | 10.0000     | 35.2385       | 12.8257       |
| far resting 75.0000      | 1.3090                    | 9.9335      | 36.1580       | 9.6884        |
| far resting 80.0000      | 1.3963                    | 9.6963      | 36.6312       | 6.4590        |
| far resting 85.0000      | 1.4835                    | 9.1446      | 36.5052       | 3.1937        |
| far resting 90.0000      | 1.5708                    | 8.2577      | 35.7577       | -0.0001       |
| far resting 130.0000     |                         |             |               |               |
| far resting 135.0000     | 2.2689                    | 0.0404      | 21.0971       | 17.7028       |
| near resting 140.0000    | 2.3562                    | 0.0000      | 19.4453       | 19.4455       |
| near resting 145.0000    | 2.4435                    | 0.0000      | 17.6765       | 21.0663       |
| near resting 355.0000    | 6.1959                    | 0.0000      | -2.3964       | 27.3954       |
| near resting 360.0000    | 6.2832                    | 0.0000      | 0.0000        | 27.5000       |

The contour curve of the intake cam is shown in Fig. 2.
2.1.4. The Design of Exhaust Cam Profile: The exhaust cam adopts the disk cam mechanism with a straight flat push rod, its working condition is high speed light load. The motion requirements for the push rod are as follows. When the cam turns 70 degrees, push rod is rising 11mm. The push rod stops when the cam continues around 5 degrees. When the cam turns 70 degrees again, push rod is declining 11mm. The cam stops when the cam turns the other angle. The detailed design process is as before.

2.2. Design of Camshaft

2.2.1. Selection of Camshaft Arrangement. According to the layout position, the camshaft can be divided into the lower camshaft, the middle camshaft and the top camshaft, as is shown in Fig.3.

Most car engines use overhead camshaft design. That is because the cam shaft is arranged in the engine above, which can greatly shorten the distance between the camshaft and the valve. Thus the long valve tappet is omitted, the valve train mechanism is simplified, and the engine structure is more compact. Because the overhead cam shaft drives the valve through the rocker arm or the hydraulic tappet, the transmission efficiency is improved and the working noise is reduced. According to the gas distribution mechanism of quantity, overhead cam shaft can be divided into Single Overhead Camshaft (SOHC) and Dual Overhead Camshaft (DOHC).

The intake valve and exhaust valve of the single top camshaft are driven by an overhead camshaft. The intake valve and exhaust valve in the inlet position is different, therefore the accuracy of the valve opening time will be affected. Single overhead camshaft is shown in Fig.4.
DOHC is developed on the basis of a single overhead camshaft. There are two camshafts on the cylinder head. One is used to drive the intake valve, and the other is used to drive the exhaust valve. The intake valve and exhaust valve can be controlled separately; therefore, the opening time of the valve can be controlled more accurately. Dual overhead camshaft is shown in Fig.5.

The simulation will use two cylinder single top camshaft design.

2.2.2. Selection of Camshaft Arrangement.
   a) Arrangement of Cam
       • parallel twin cylinder
         There are two kinds of crankshaft arrangement in parallel twin cylinder engine, that is, 180 degree crankshaft and 360 degree crankshaft. For two types of crankshaft, engine working intervals are 180 degrees and 360 degrees respectively.
         180 degree crankshaft: Its work order can be expressed as: 1→2→0→0. In this way, the second cylinder can work after the first cylinder does 180 degrees. The two cylinder top dead center of the 180 degree crankshaft engine is 180 degrees apart. That is, they are relative distribution on the flywheel or stator rotor. Therefore, the phase angle difference between the two cams is 90.
         360 degree crankshaft: Its work order can be expressed as: 1→2. This shows that the second cylinders do work after the first cylinder does 360 degrees. Therefore, the phase angle difference between the two cams is 90.
       • Opposed twin cylinder
Opposed twin cylinder engine is more than 180 degree phase crankshaft, the working order phase of
two cylinder can be expressed as:1→2.
- V type twin cylinder

Recently, the 360 degree of phase crankshaft is widely used in the V cylinder engine. The 360
degree crankshaft is explained in this paper. 360 degree crankshaft is adopted, and the angle between
two cylinder axes is 60 degrees. Two cylinder power order phase can be expressed as: 1→2. When the
first cylinder works 360 degrees plus 60 degrees, the second cylinders do the work.

b) Ignition sequence

The cylinder arrangement and engine firing sequence are as follows. To arrange the firing sequence
of multi cylinder engine, it is necessary to make the two cylinders of continuous work as far away as
possible, in order to reduce the load of main bearing and avoid the possibility of air inlet overlap. The
work interval should be uniform. That is to say, when the engine completes the crank angle of a
working cycle, each cylinder should be fired to do work once, and the interval time of each cylinder
firing is represented by the crank angle, which is called the firing interval angle. The four stroke engine
completes a working cycle and the crankshaft rotates two cycles with a turning angle of 720 degrees.
When the crank angle is 720 degrees, each cylinder of the engine should be ignited to do the work once,
and the ignition interval angle is even, therefore, the ignition interval of the four stroke engine is 720/I,
(i is number of cylinders). That is to say, every turn angle of the crankshaft is 720/I, there should be a
cylinder to do work to ensure the smooth operation of the engine.

Therefore, the firing interval of two cylinder camshaft is 720°/2=360°. That is to say, every turn
angle of the crankshaft is 360, there should be a cylinder to do work. Therefore, the working order of
each cylinder of the camshaft can be determined, as shown in Tab. 2.

| Crank angle   | First cylinder | Second cylinder |
|--------------|---------------|----------------|
| 0-180°       | Do work       | Air intake     |
| 180-360°     | Exhaust       | Compress       |
| 360-540°     | Air intake    | Do work        |
| 540-720°     | Compress      | Exhaust        |

2.3. Design of Shaft and Neck

The diameter of the cam base circle is 55mm, so the shaft diameter is 45mm. The maximum diameter
of the cam profile is 77 mm, the outer diameter of the journal should be the largest outer diameter of the
camshaft so as to facilitate the installation, so the diameter of the shaft neck is 79mm. Thus, axial
dimensions of the camshaft can be designed, as shown in Tab. 3.

| Shaft section position | Axis 1 section | Shaft neck 1 | Axis 2 section | Exhaust cam 1 |
|------------------------|---------------|-------------|----------------|--------------|
| Axial dimension        | 48            | 25          | 26             | 33           |
| Axial dimension        | 26            | 33          | 26             | 35           |
| Axial dimension        | 26            | 33          | 26             | 33           |
According to the above calculation data, the overall structure of the camshaft can be determined. The 3D modeling of the camshaft is shown in Fig. 6.

![3D modeling of two cylinder camshaft](image)

**Figure 6.** 3D modeling of two cylinder camshaft

### 3. Conclusions

3D solid modeling and parametric design has become an important method of modern design. In this paper, the solid modeling and parametric method of camshaft are studied by Solidworks, and the 3D entity design of the part is realized. This method will improve the quality and efficiency of product design to a greater extent. The parametric design of the camshaft lays a good foundation for the subsequent camshaft cross wedge rolling.

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