Research on Angle-area Value of Engine Valve Based on MATLAB

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Abstract. The capacities of engine intake and exhaust are directly affected by the passage ability of the space between valve and seat ring and the area of the throat section. The angle-area value is a reasonable parameter to evaluate this capability. In this paper, using MATLAB software to calculate angle-area value of Engine valve. Analyzing the influences of value phase Angle, valve diameter and valve lift on intake angle-area value to explore some rules of influence. Meanwhile, based on analysis of some problems in the design of engine valve lift height and profile, some optimal design ideas are put forward, which can provide some references for the design of engine CAM profile.

Introduction

When we design the engine, it is the airway passage capability that is one of the most concerned indicators. The air passage capacity directly affects the intake and exhaust of the engine, which determines the engine's dynamic economy and emissions. The indicators for evaluating the passing ability include various parameters such as the minimum area of the throat, the valve opening height, the time area value, the angle-area value and so on. In all those indicators, it is the angle-area value that is the most comprehensive and accurate assessment of the passage ability. The angle-area value is the integral of the actual area of the valve opening against the sustained crank angle. In other word, in order to maintain adequate passing capacity, not only the opening area of the valve must be large, but also there must be sufficient continuous crankshaft Angle. However valve opening area is affected by size factor and valve lift, and valve distribution phase affects crankshaft Angle. Therefore, how to carry out reasonable optimization will be the focus of this paper.

Theoretical Calculation of Angle-area Values

The angle-area value is the integral of the actual area of the valve opening against the sustained crank angle.

Calculated from the valve opening, at any crank angle θ, the valve opening area is defined as F(θ) at this time. Then the angle-area value from the beginning of opening the valve to the time is AF(θ) = \( \int_{0}^{\theta} F(\theta) d\theta \). In other words, the integration of the valve from opening to closing is the angle-area value of the valve.

Figure 1 is the schematic diagram of the channel structure at the initial stage of valve opening. In this figure, d1, d2 and d3 are respectively the diameter of valve head, inner diameter of valve seat, and diameter of valve cadre. γ is the back cone angle of valve, h is the valve lift at this moment, and L is the length of the round bus formed between the valve and the seat ring during the valve lift. According to the figure, it can be analyzed that the minimum area of channel is controlled by the area of the outer cone of the circular platform formed between the valve and the seat ring at this moment. Meanwhile, F(θ) can be calculated by the formula of outer conical surface of circular platform\(^{[1, 2]}\).
Figure 1. Schematic diagram of airway structure at the initial stage of valve opening.

Figure 2. Schematic diagram of airway condition with valve open at sufficient height.

\[ F(\theta) = \pi (d_2 + h \cos \gamma \sin \gamma) \times h(\theta) \cos \gamma \]  

(1)

Figure 3. Valve lift curve.

In the equation, \( h(\theta) \) is determined by the valve mechanism and CAM profile. Therefore once the law equation of valve lift is given, the specific opening area at this time can be determined.

As the valve keeps opening, the area of the outer cone of the circular platform gradually increases. If valve lift is large enough, it is possible that the outer surface area of the circular table is larger than the throat area between the valve seat ring and the valve rod as what we can see in figure 2. The passage area does not increase even if the valve continues to open. At this moment, the channel area is
a fixed value $S$, and we define the opening angle of the valve at this point to $\theta_1$. It is easy to find an inflection point where the area no longer varies with valve lift from figure 3.

$$S = \pi (d2^2 - d3^2) = F(\theta_1) = \pi (d2 + h \cos \gamma \sin \gamma) * h(\theta_1) \cos \gamma$$

(2)

$$AF(\theta) = \int_0^{\theta_1} \pi (d2 + h \cos \gamma \sin \gamma) * h(\theta) \cos \gamma \, d\theta + 2 \int_0^{\theta_2/2} S \, d\theta$$

(3)

Considering above two situations, the gas distribution phase angle is $\theta_2 = 180 + \alpha + \beta$. Then the actual angle-area value of the valve, $AF$ can be calculated by formula 3. In this condition, $\alpha$ is the inlet advance angle, $\beta$ is the inlet late closing angle. In most cases, the intake advance angle of the engine is usually 10-30°CA, and the intake late closing angle is 60-80°CA. The higher the intake lag angle, the shorter the effective compression stroke and the lower the actual compression ratio.

**Valve Lift Rule Analysis**

Once the engine design is completed, the CAM profile is fixed and the valve lift curve equation can be obtained. Under the trend of modern optimal design, the camshaft generally takes a high power polynomial. In this paper, the design is a power polynomial, and the fullness coefficient is about 0.68. As we know, the larger the fullness coefficient is, the greater the valve acceleration will be, and the more serious the impact wear noise will be\[3\]|4]. Therefore, some engines’ valve lift curves are directly designed as sinusoids, whose fullness coefficient get to about 0.64 either. The biggest advantage of positive selection curve is that it is continuous no matter how many reciprocal orders, resulting in small impact wear. If the positive curve is the valve lift curve, then the valve lift can be calculated by equation 3, and the lift curve is shown in figure 4.

$$h(\theta) = H \sin(\theta)$$

(4)

Where, $H$ is the maximum valve lift.

**Valve Diameter and Related Dimension Analysis**

When we arrange valve in cylinder head, it involves many problems such as valve seat ring installation, spark plug arrangement, inflow and exhaust resistance, cooling system water jacket arrangement and inlet and exhaust passage arrangement. Taking the valve arrangement of the popular 4 valve engine as an example, we analyze the valve arrangement on the cylinder head, which is shown in figure 4.

Figure 4. Four valve engine cylinder head layout diagram.
In a four-valve engine, the same valve spacing N1 is at least 0.12D, the minimum distance N2 between the intake and exhaust valves is 0.12D, and the minimum distance N3 between the two exhaust valves is 0.13D, where D is the cylinder diameter of the engine. To avoid affecting the exhaust, after the inlet valve opens, the minimum distance of the head and cylinder wall, n1 is 0.02D, minimum distance from the exhaust valve to the cylinder head wall, n2 is 0.03D, the minimum distance between the inlet valve head and the injector or spark plug, n3 is 5-6mm, the minimum distance between the exhaust valve and injector head or spark plug, n4 interchange for 6 to 8 mm, and the diameter ratio of intake and exhaust valve is generally about 1.2. Therefore, for a four-valve engine, the maximum diameter of the planar intake valve shall not be greater than 0.36D, and the diameter of the exhaust valve shall not be greater than 0.31D \cite{5}. Generally speaking, the intake valve of two-valve engine is about 0.5D, and the exhaust valve is 0.42D. Hemispherical and awning combustion Chambers increase slightly, but the increase is limited considering compression ratio.

Another factor affecting the ability to pass, or the angle-area value, is valve seat diameter d2. Considering the analysis in figure 1, it is necessary to design the back cone for the valve in order to seal. Now the back cone angle of the engine is generally 45, and the minimum width of sealing cone is 0.8-1mm. To ensure repair and installation requirements, the d2 diameter of the valve seat is generally 5-6mm smaller than the d1 diameter of the valve head, and valve cadre diameter is generally around 6-8mm.

**MATLAB Simulation and Analysis**

According to above analysis, the preparation of MATLAB program is in the appendix. MATLAB was used to calculate the influence of valve, valve phase, value diameter and angle-area value of cylinder diameter.

The relationship between the gas distribution phase and angle-area value is shown in figure 5, when the valve maximum lift is 10mm, the cylinder diameter is 95mm, and the ratio of valve diameter to cylinder diameter is 0.32. It is obvious in the drawing that there is basically a linear relationship between the angle-area value and the valve train phase. When the valve train phase angle increases, the angle-area value increases almost linearly. The increase of distribution phase angle means the increase of integral interval. So an increase in the integral is an increase in the angle.

Therefore, in the current engine design, in order to increase the passing capacity, the valve distribution phase angle is constantly increasing, and intake lag angle is close to 80° CA. Especially high-speed engine, valve phase Angle is larger. However, the larger intake late closing angle seriously affects the actual compression ratio of the engine and reduces the thermal efficiency of the engine, which is also a reason for the deterioration of the high-speed engine economy. Therefore, if there are other methods to ensure the ventilation capacity, too large valve distribution phase angle is not recommended.

![Figure 5. Effect of valve phase Angle on diagonal face value.](image)
Figure 6 shows the influence curve of valve radius and cylinder diameter relative to angle-area value when the valve maximum lift is 10mm and the valve diameter is 95mm. According to the figure, as the ratio of valve radius to cylinder diameter increases, so does the angle-area value. However, the increase of valve radius ratio in small valve radius ratio is greater than that in large valve radius ratio. That means that the first half of the increase is fast, and the second half of the increase is slow. The reason is that the difference between throat diameter and valve head diameter is a basically 5-6mm fixed value. When the valve diameter is small, the influence is large, but decreases after reaching a certain degree.

For a 4-valve engine, the valve radius ratio is about 0.18, at which point the angle-area value is close to 7000mm$^2\text{°CA}$, and the sum of the angle-area value of the two intake valves is close to 140000 mm$^2\text{°CA}$. For two-valve engine, the ratio of inlet valve radius to cylinder diameter is about 0.25, and the angle-area value is about 120,000 mm$^2\text{°CA}$. Therefore, using 4 valve technology can increase angle-area value by 17% compared with 2 valve engine under the same conditions.

When the valve radius ratio is 0.16 and the valve phase Angle is 240°CA, the influence curves of the maximum angle-area value of valve lift with cylinder diameter of 50, 75 and 95mm are shown in figure 7, 8 and 9 respectively. On the other hand, figure 10 shows that the valve radius ratio is 0.25 and the valve distribution phase angle is 240°CA. The cylinder diameter is the influence curve of the angle-area value of the valve maximum lift when the valve is 95mm.

We can get from figure 7-10 that there is an obvious inflection point in all angle-area value curves, but the inflection point appears at different positions due to different conditions. When the maximum valve lift is less than the inflection point, the angle-area value is completely controlled by the actual opening height of the valve. Therefore, with the increase of the maximum valve lift height, the angle-area value linearly increases. However, when the maximum valve lift exceeds a certain value, the maximum valve lift at the inflection point, the actual lift curve of the inlet valve in the first half of the angle-area value is controlled, while the second half is controlled by the throat section. Therefore, even if the valve lift is increased, the minimum area at the throat is not sensitive to the increase in the time-area value. So in designing camshaft profile, it is advisable to take the maximum valve height slightly higher than the inflection point. For example, as shown in figure 7, the valve radius ratio is 0.16, the valve phase angle is 240°CA, and the cylinder diameter is 50mm. The maximum valve lift is 4mm. As shown in figure 8, the valve radius ratio is 0.16, the valve phase angle is 240°CA, and the cylinder diameter is 75mm. When the cylinder diameter is 75mm, the valve maximum lift is enough. And when the valve radius ratio shown in figure 9 is 0.16, the valve phase angle is 240°CA, and the cylinder diameter is 95mm, the maximum valve lift can be set at 9mm.
Figure 7. Relation between angle-area value and valve lift when cylinder diameter is 50mm.

Figure 8. Relation between angle-area value and valve lift when cylinder diameter is 75mm.

Figure 9. Relation between angle-area value and valve lift when cylinder diameter is 95mm and valve radius ratio is 0.16.

Figure 10. Relation between angle-area value and valve lift when cylinder diameter is 95mm and valve radius ratio is 0.25.
Comparing figure 9 and figure 10, it can be found that with the same cylinder diameter and different valve radius ratio, the position of maximum valve lift at the inflection point is different. On the one hand, when the valve radius ratio is 0.16 in figure 9, the maximum valve lift at the inflection point is about 7mm; on the other hand, when the valve radius ratio is 0.25 in figure 10, the maximum valve lift at the inflection point is more than 12mm. Figure 9 is equivalent to 4 valve engine, and figure 10 is equivalent to 2 valve engine. With the larger valve diameter, the greater the maximum valve lift height at the inflection point will be.

Figure 6 shows a case with a maximum valve lift of 10mm and a larger radius ratio of 0.18 for a 4-valve engine. At this time, the angle-area value of a single valve is close to 7000mm$^2$CA, and the sum of the angle-area value of two inlet valves is close to 140000 mm$^2$CA. In figure 10, the ratio of inlet valve radius to cylinder diameter is about 0.25, which is equivalent to 2 valve engines. According to the observation image, if the valve's maximum lift is a little bit after the inflection point, when 13mm is taken, the nominal value of hour angle is about 140000 mm$^2$CA. The comparison shows that the angle-area value of the valve is equivalent to that of the four-valve technology and the two-valve technology, which means there is no obvious advantage of the four-valve.

Naturally, in actual operation, the ventilation capacity of engine 4 valve is better than that of engine 2 valve, and the power performance can be improved by about 10% \cite{2}, which has been reported in other literatures. The difference between the calculation and the actual engine is that the maximum valve lift of the 2-valve engine is basically controlled below 10mm in order to reduce acceleration and wear, thus sacrificing the angle-area value. The same valve maximum lift has been analyzed in figure 6.

**Conclusion**

This paper uses MATLAB software to calculate the angle-area value of the intake angle of the engine, and analyzes the influence of valve phase angle, valve diameter and valve maximum lift on the angle-area value of the intake angle. It is concluded that the angle-area value of intake angle increases with the increase of valve phase angle, valve diameter and valve maximum lift. The increase of valve lift and diagonal angle-area value provides a reference for CAM profile design. With the increase of valve lift, there is an inflection point of the increasing trend of angle-area value, which provides reference for CAM profile design. By comparing the largest angle-area value of 2 valve engine with that of 4 valve engine, it is concluded that the reason why the 4 valve engine has a higher actual passing capacity than the 2 valve engine is that the 2 valve engine cannot choose the maximum valve lift corresponding to the best angle-area value.

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