Design of A Dual-rotor Engine Driving by the Elliptic Gear

Yi Fan
Transportation College, Nanning University, Nanning, Guangxi, 530200, China
E-mail: 64608769@qq.com

Abstract. Aiming at the shortcomings of the crank-connecting rod mechanism engine, such as low transmission efficiency and high side pressure between the piston and the cylinder, the paper proposes a kind of dual-rotor engine driving by the elliptic gear. The left and right rotors are driven by the gas pressure in the cylinder, and then the elliptic gears on the output shaft are driven by the circular gears and the elliptic gears on the intermediate shaft. When the gears rotate, the output shaft connected outputs power again and again. The rotor rotates one circle, the four "cylinders" separated by the rotor work one time respectively, and the output shaft rotates two circles. The results of the calculation and the simulation test show that the serialization design can be carried out by setting different parameters of the long half-axis and the eccentricity. When the value of the long half-axis (100mm in this design) is fixed and the eccentricity is 0.4, 0.6 or 0.8, the rotation angle and the speed of the left and right rotors change obviously. The greater the eccentricity, the greater the difference of the rotation angle and the speed of the left and right rotors. The higher the compression ratio of engine, the higher the transmission efficiency.

1. Introduction
The automobile industry has been developing for more than 100 years. Its power source is mainly the internal combustion engine. The core structure of the power transmission in the internal combustion engine is the crank-connecting rod mechanism[1]. Numerous enterprises and research institutes have made continuous modification in improving the combustion efficiency[2] and reducing the fuel consumption[3], noise[4], wear and tear. However, the crank-connecting rod mechanism has its inherent defects[5], such as "dead point" in the piston operation process. When the maximum pressure appears in cylinder, and the force arm transmitted to the crankshaft is the smallest; when the force arm transmitted to the crankshaft from the piston is maximum, the pressure in the cylinder is in a lower state. Thus, the maximum efficiency is only about 40%. Under good lubrication conditions, the larger side pressure between the piston and the cylinder makes them one of the most wearable parts in the internal combustion engine[6]. Therefore, in the research process of the engine industry, various new power transmission devices have appeared, such as the horizontal opposed engine[7], the triangular piston engine[8], etc. However, due to the reasons of wear, lubrication and sealing, they cannot be popularized in the automobile industry. In this paper, a dual-rotor engine driving by the elliptic gear is proposed, which has the advantages of fewer components, higher transmission efficiency, higher power density and easier production compared with the crank-connecting rod mechanism engine currently used.

2. Overall structure design of the dual-rotor engine driving by the elliptic gear
As shown in Figure 1, the overall structure of the dual-rotor engine driven by elliptic gears is illustrated. The names of the components are as follows: the cylinder block connecting bolt 1, the left
cylinder head 2, the left rotor 3, the intermediate transmission component 4, the right rotor 5, the cylinder block 6, the right cylinder head 7, the cylinder block connecting nut 8, the output shaft component 9, the spark plug 10. The initial phase difference between the left and right rotors is 90 degrees, and the symmetrical cylinder diaphragms are set 180 degrees apart from each rotor. Four separate spaces are formed between the two rotors and the cylinder block (corresponding to four cylinders of the traditional engine). Under the action of fuel combustion pressure in the cylinder, the left and right rotors are pushed, and the internal ring gears on the rotors drive the output shaft to turn through the intermediate transmission parts, and output power to the outside.

Figure 1. Overall structure.

Figure 2 shows the detailed structure of the output shaft component 9. The output shaft 91, the left elliptic gear 9A and the right elliptic gear 9B are arranged on it. The output shaft is arranged on the cylinder block with a pair of sliding bearings. Two elliptic gears are rigidly connected with the output shaft through a flat key to form a whole. Figure 3 shows the detailed structure of the intermediate transmission component 4, including the middle shaft 41 arranged on the cylinder block by the sliding bearings, the elliptic gear 4A, the elliptic gear 4B, the left circular gear 4C and the right circular gear 4. The elliptic gear 4A is rigidly connected with the left circular gear 4C while the elliptic gear 4B is with the right circular gear 4D. Both of them are supported on the middle shaft 41 through bearings.

Figure 2. Component structure of the output shaft.
Figure 3. Component structure of the intermediate transmission.

3. Transmission principle of the dual-rotor engine driving by the elliptic gear

After removing the cylinder head, the cylinder block and other components, the projection from the left side of the overall structure can be seen in Figure 4. It shows the transmission principle of the dual-rotor engine driving by the elliptic gear. The structural parameters of the left elliptic gear 9A, the
right elliptic gear 9B, the elliptic gear 4A and the elliptic gear 4B are exactly the same. The revolving centers are the right focus of the left elliptic gear 9A, the left focus of the right elliptic gear 9B, the right focus of the elliptic gear 4A and the left focus of the elliptic gear 4B, respectively. The left circular gear 4C meshes with the inner gear ring on the left rotor 3, and the right circular gear 4D meshes with the internal ring gear on the right rotor 5. According to Figure 2 to Figure 4, the gas pressure inside the cylinder drives the left rotor 3 to rotate, the internal ring gear on the left rotor 3 drives the left circular gear 4C to rotate, and the elliptic gear 4A which is rigidly connected to the left circular gear 4C drives the left elliptic gear 9A to rotate and then drives the output shaft 91 to rotate. At the same time, the gas pressure in the cylinder drives the right rotor 5 to rotate, and the internal ring gear on the right rotor 5 drives the right circular gear 4D to rotate. The elliptic gear 4B rigidly connected with the right circular gear 4D drives the right elliptic gear 9B and the output shaft 91 to rotate. Under the action of the in-cylinder pressure, the left rotor 3 and the right rotor 5 continuously drive the elliptic gears to rotate successively through the circular gears, and the output shaft can rotate continuously to output power.

In order to ensure the normal power transmission of the dual-rotor engine driving by the elliptic gear, reasonable meshing parameters must be designed. The left elliptic gear 9A, the right elliptic gear 9B, the elliptic gear 4A, the elliptic gear 4B's long half axle, a=100mm; the short half axle, b=80mm; the half focal length c=\sqrt{a \cdot a - b \cdot b}=60mm; the eccentricity, e = c/a = 0.6; the left circular gear 4C, the right circular gear 4D's indexing circle radius, r1 = a + c = 160mm; the left rotor 3 and the right rotor 5's indexing circle radius, r2=2*r1=320. The design parameters of the engine are a and e. The engine with different performances can be obtained by setting different long half axles and different eccentricities.

Figure 5 shows the performance curves of the rotation angles and velocities of the left rotor 3 and the right rotor 5 varying with the rotation angles of the output shaft when the long half-axis a is 100mm and the eccentricity e is 0.6mm. In a cycle, the left and right rotors rotate 360 degrees, the output shaft rotates 720 degrees, and the transmission ratio is 1:2. During the rotation cycle of 360 degrees, the rotation angles and rotational speeds of the left rotor 3 and the right rotor 5 vary periodically every 90 degrees. Within the range of 0 to 90 degrees, the left rotor speed is fast in the early stage and slow in the late stage. In the range of 90 to 180 degrees, the right rotor speed is fast in the early stage and slow in the late stage. The range of 180 to 270 degrees and the range of 270 to 360 degrees alternate in turn. The volume of four "cylinders" formed by the three parts: the left rotor 3, the right rotor 5 and the cylinder block 6, also changes periodically, and each cylinder completes four working strokes of intake, compression, work and exhaust in turn. Rotors rotate 2 turns, the engine works 4 times, and the output shaft rotate 2
turns. Compared with the traditional crank-connecting rod engine, it can greatly reduce the volume and improve the transmission efficiency.

Figure 5. Graph of the rotor transmission.

4. Performance comparison of different elliptic parameters
In order to further optimize the transmission characteristics of the dual-rotor engine driving by the elliptic gear, the design calculation is carried out for different elliptic parameters. When the long half-axis a is 100mm and the eccentricity e is 0.4mm, 0.6mm or 0.8 mm, the rotation angles and velocities of the left and right rotors are shown in Figure 6 and Figure 7 respectively. When the eccentricity e increases from 0.4mm to 0.8mm, the greater the difference of rotation angle and velocity of left rotor 3 and right rotor 5, the larger the maximum and minimum corresponding cylinder volume. Compression ratio = maximum cylinder volume/minimum cylinder volume. Therefore, the larger the eccentricity, the larger the compression ratio of the corresponding engine, the higher the raising power, and the better the output of the whole engine performance. RR represents the right rotor, and LR represents the left rotor in Figure 6 and Figure 7.

Figure 6. Rotor angle at different centrifugal rate.
5. Conclusion
In view of the shortcomings of the existing crank-connecting rod mechanism engine, the dual-rotor engine driving by the elliptic gear proposed in this paper has fewer components, no eccentric motion of the rotor in the shell and low vibration noise. The isolation space formed by the two rotors is equivalent to a four-cylinder engine. When the rotor rotates one turn and the output shaft rotates two turns, the power density is higher than that of the traditional engine; the pressure arm of the rotor is long; there is no side pressure and "dead point"; the operation efficiency is high. The engine with different power output can be serialized by changing the eccentricity $e$ and the long half axle $a$. Cooling, lubrication, intake, exhaust and oil supply systems of the engine are basically the same as those of the traditional engine. Therefore, dual-rotor engine driving by the elliptic gear proposed in this paper can make good use of the mature technology of the existing engine and then greatly improve the performance of the engine.

Acknowledgments
This work was financially supported by the Scientific Research Team Project of Nanning University (No.2018KYTD06).

References
[1] Martins D, Frank T, Simas H, et al. (2018) Structural analysis, survey and classification of kinematic chains for Atkinson cycle engines. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 40(2): 52.
[2] Johnson T, Joshi A. Review of vehicle engine efficiency and emissions. (2018) SAE International Journal of Engines, 11(2018-01-0329): 1307-1330.
[3] Ali M K A, Fuming P, Younus H A, et al. (2018) Fuel economy in gasoline engines using Al2O3/TiO2 nanomaterials as nanolubricant additives. Applied energy, 211: 461-478.
[4] Şahin Z, Durgun O, Tuti M. (2018) An Experimental Study on the Effects of Inlet Water Injection of Diesel Engine Heat Release Rate, Fuel Consumption, Opacity, and NOx Emissions//Exergetic, Energetic and Environmental Dimensions. Academic Press, 981-996.
[5] Evelyn E, Aziz A R A, Firmansyah F, et al. (2018) A review on the operating characteristics of free piston engine and its recent developments//AIP Conference Proceedings. AIP Publishing, 2035(1): 030007.

[6] Jain A, Jalanapurkar M, Tandel D, et al. (2018) Comparative Study of Friction & Wear behavior with different materials of Segmented Piston Ring Cylinder Liner of IC Engines using Linear Reciprocating Tribometer. International Journal of Innovative Knowledge Concepts, 6(Special: 2): 143-151.

[7] Jia B, Mikalsen R, Smallbone A, et al. (2018) A study and comparison of frictional losses in free-piston engine and crankshaft engines. Applied Thermal Engineering, 140: 217-224.

[8] Leboeuf M, Dufault J F, Nickerson M, et al. (2018) Performance of a Low-Blowby Sealing System for a High Efficiency Rotary Engine. SAE Technical Paper.