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# Finite element analysis of cylinder stress and deformation of a small rotary engine

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**Abstract.** Compared with the traditional engine, the structure of rotary engine is compact, the power density is greatly reduced, the speed increases greatly, but its thermal load problem is more prominent. The finite element analysis software ABAQUS was used to simulate the stress and the axial deformation of the rotary engine cylinder. And then the influence of speed on cylinder stress was analysed. The results show that the area of the cylinder with large stress is located near the bolt hole of the cylinder, the stress and deformation of the cylinder increases with the increase of the engine speed.

## 1. Introduction

The demand for power sources that have long lifetimes and high energy densities has significantly increased in recent years[1]. Rotary engine has the characteristics of low weight, simple structure and small volume, having good application prospect in small equipment and aircrafts[2].

Despite the novel engine structure, the working cycle of rotary engine is the same as that of a four-stroke reciprocating engine, including four processes: intake, compression, combustion expansion and exhaust[3]. The four working processes of each combustion chamber are fixed to a particular area of the cylinder due to the working principle of the engine, the stress and thermal conditions of different areas of the cylinder are very different[4-5]. The engine temperature distribution is nonuniform. If the temperature difference in the cylinder is too large, there will be excessive thermal stress and very uneven thermal deformation, which may lead to cracking damage or serious leak problem[6-7].

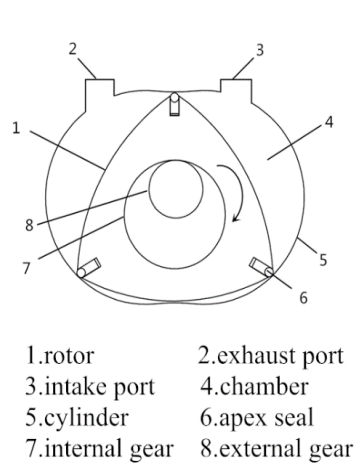
Analyze the stress and deformation of cylinder under thermo-mechanical coupling load can help improve the structure of the engine and is conducive to follow-up calculation of leakage analysis to guarantee the operation of the engine and improve the thermal efficiency and the engine performance[8]. In the field of stress and strain analysis of rotary engine, Guan used three-dimensional finite element model to analyze the micro-engine cylinder temperature field and deformation[9]. Zhang used the ANSYS thermal analysis module to simulate the rotary engine temperature at the maximum speed[10]. He analyzed a newly designed marine diesel engine piston by using a precise finite element analysis, including the lubrication, thermal, and structure[11].

In this paper, the cylinder stress and deformation of a small rotary engine will be studied using finite element method, the temperature, stress and deformation distribution will be discussed in detail. The influence of speed on the stress and deformation will be analyzed.



## 2. Engine structure and finite element model

The schematic sketch of a rotary engine structure is shown in Figure 1. Figure 2 shows the basic parts of a small rotary engine[12]. The rotary engine geometric parameters are shown in Table 1 respectively.



**Figure 1.** Schematic sketch of rotary engine.



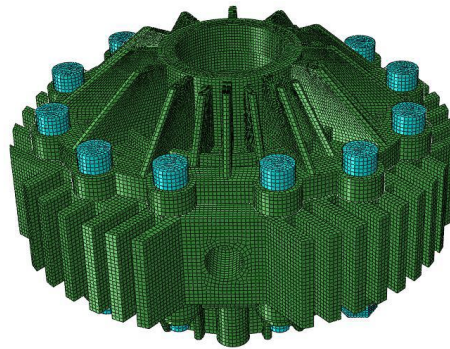
**Figure 2.** Basic engine parts.

**Table 1.** Geometric parameters.

Parameter	Value
Cylinder volume	4.97cc
Epitrochoid generating radius (R)	21mm
Compression ratio	8.4
Eccentric distance (e)	3mm
Thickness of cylinder (B)	14.5mm
rated speed	17000r/min

The cylinder is one of the most important components in the rotary engine, whose working condition is very poor, mechanical load and thermal load is the most serious.

Since the difference of temperature between the hot and cold area of the cylinder is very large, the large temperature gradients lead to large thermal stress in cylinder, which will result in extremely uneven thermal deformation, deteriorating the sealing performance. If the difference of temperature between the inner and outer surface of the cylinder is large, the thermal stress of the cylinder will be large, resulting in cracking and destruction. The finite element analysis software ABAQUS was used to calculate the stress of the rotary engine cylinder. Figure 3 is the grids model of the cylinder.



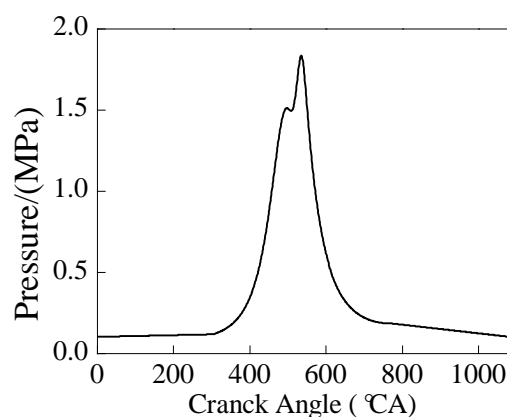
**Figure 3.** Finite element model.

### 3. Boundary condition

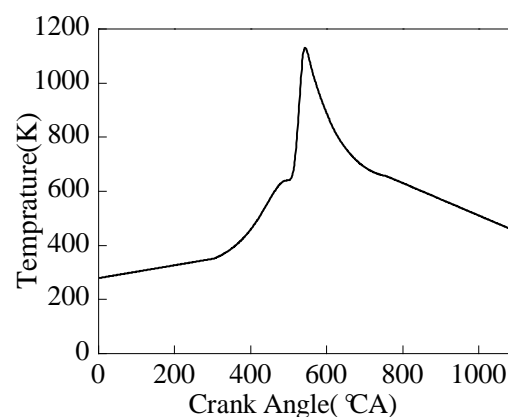
Due to the small size of the engine, pressure and temperature testing is very difficult. So in this paper gas temperature and pressure inner cylinder were calculated by MATLAB/Simulink. The pressure at the speed of 17000 r/min is shown in Figure 4. On the condition of 17000 r/min, the maximum pressure is 1.85MPa, and the gas pressure in the cylinder reaches the maximum around the crank angle of 560 °, in the combustion and expansion stroke.

In the intake stroke, the cylinder gas pressure is very small, close to the atmospheric pressure. In the compression stroke, the gas pressure in the cylinder increases rapidly. Due to the ignition of the mixture gas, the gas pressure gets sharply increased again after the compression TDC, and then the gas pressure drops rapidly. And in the exhaust stroke, the gas pressure in the cylinder is close to the atmospheric pressure.

The in-cylinder gas temperature at the speed of 17000 r/min is shown in Figure 5. The minimum temperature of the gas is 300 K, which shows up in the intake process. The maximum temperature is 1129 K, which appears in the combustion and expansion process. The temperature difference in the whole working process is 829 K.



**Figure 4.** Cylinder gas pressure.



**Figure 5.** Cylinder gas temperature.

## 4. Result and discussion

### 4.1. Stress calculation result

In the process of rotary engine operation, the cylinder bear different forces, generating corresponding stress.

1. The mechanical stress caused by the pressure of the gas.

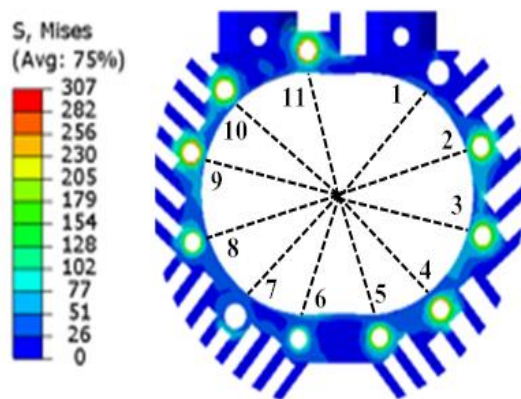
2. The thermal stress caused by difference temperature between the inner and outer surfaces of the cylinder wall.

3. Axial compression stress caused by cylinder bolt preload and thermal expansion.

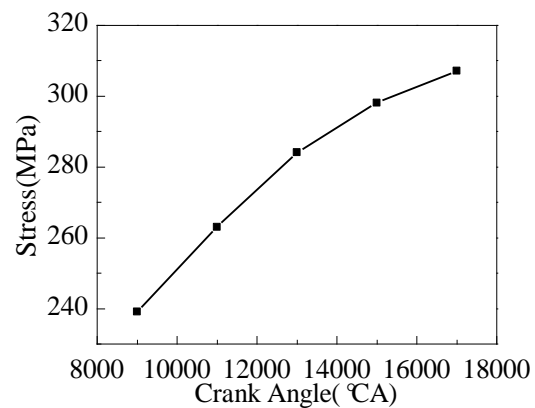
On the condition of 17000 r/min, the stress distribution of the cylinder is shown in Figure 6.

The area of the cylinder with large stress is located near the bolt hole of the cylinder, the cylinder maximum stress is 307MPa. The maximum stress of the cylinder is located in the bolt hole near the exhaust port, where the bolt preload is maximum. So large stress around the bolt hole is due to stress concentration.

Figure 7 shows the stress regulation in rotary engine cylinder at different speed. The area of the cylinder with large stress is located near the bolt hole of the cylinder, and the maximum stress of the cylinder increases with the axis speed up. With the increase of speed, the maximum pressure of the cylinder is increase, as well the mechanical stress. The temperature of the cylinder gets raised, resulting in the increase of thermal stress with the increase of the speed. The stress of the cylinder increases with the increase of the speed under the combined action of the high thermal stress and the mechanical stress.



**Figure 6.** Cylinder stress distribution.

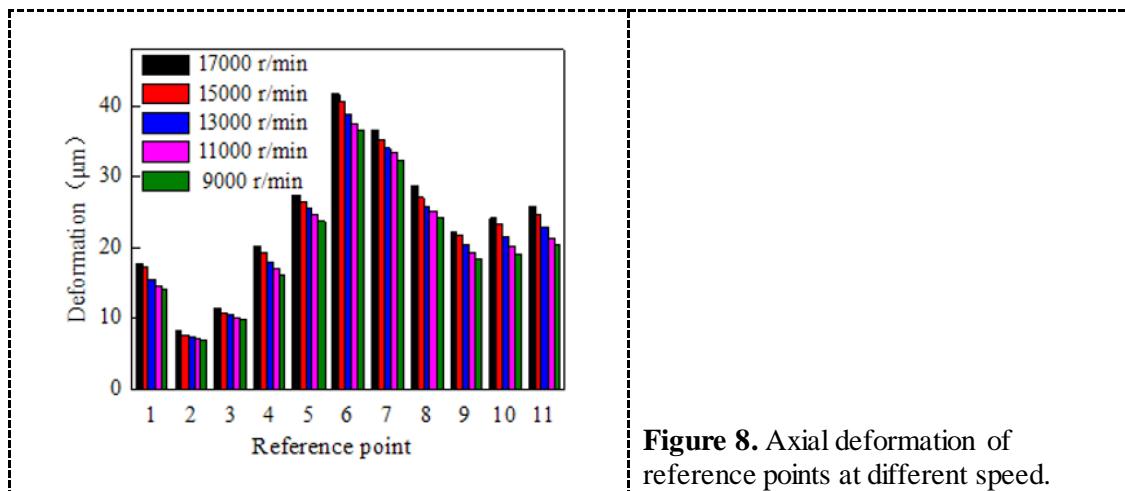


**Figure 7.** Cylinder stress at different speed.

#### 4.2. Deformation calculation result

Take the point 1-11 near the bolt hole on the edge of the cylinder inner wall as the reference points to analyze the deformation of the cylinder in the axial direction. The axial direction is perpendicular to the plane of the paper. The reference points are shown in Figure 6.

The axial deformation of the reference points at various speed is shown in Figure 8. The deformation of the cylinder increases significantly with the increasing temperature.



**Figure 8.** Axial deformation of reference points at different speed.

The change trend of the axial deformation of the cylinder at different speed is generally the same, and the axial deformation of the cylinder increases with the increasing of the speed.

The large temperature difference causes a very uneven thermal deformation of the cylinder. In addition, the cylinder is also constrained by the front and rear covers as well as the bolt preload torque.

When the speed is 17000r/min, since the temperature near the intake port of the cylinder is still high, the axial deformation of the reference point 1 is still as large as 17  $\mu\text{m}$ , despite that it is always in contact with cool gas. While the axial deformation of the reference point 2 is small, due to contact with the low-temperature mixed gas continuously.

With the rapid increase of the cylinder temperature and pressure, the deformation of the cylinder increases rapidly from the reference point 2 to the reference point 6. The axial deformation of the reference point 6 is about 4 times of the reference point 2.

The reference point 6 is located near the top dead center, where the cylinder temperature and the gas pressure is the highest. So the axial deformation of the reference point 6 is also the maximum. After the reference point 6, the deformation of the cylinder rapidly declines. The axial deformation of the reference point 9 is about half of the reference point 6.

Since the temperature of the in-cylinder gas is still high during the exhausting process, the temperature increases significantly near the exhaust port of the cylinder. Therefore, the axial deformation increases again after the reference point 9.

## 5. Conclusions

In this paper, the stress and deformation of the cylinder were calculated by finite element method, and the influence of speed on the stress and deformation of the cylinder was analyzed. The simulation results show that:

(1) The maximum stress of the cylinder is located in the bolt hole near the exhaust port, where the bolt preload is maximum.

(2) The area of the cylinder with large stress is located near the bolt hole of the cylinder, and the maximum stress of the cylinder increases with the increase of the speed.

(3) The area near the cylinder short axis shows the maximum axial deformation, which is around the glow plug; the minimum deformation of the cylinder is in the intake area. The largest deformation difference is between the reference points 6 and 2, which reaches 33  $\mu\text{m}$  at 17000 r/min.

(4) The axial deformation of the cylinder increases as the speed increases. The axial deformation difference between the speed of 9000 r/min and 17000 r/min is about 17%.

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