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Block strength of internal combustion engine

Taking the internal combustion engine block as an example, this paper simulates its strength. Firstly the finite element model of diesel engine block is established on the basis of the simplified operation; Then makes its strength check to the block model, and obtains Stress distribution resultsÿWhich provides the basis for optimizing the block structure.

Key words: Internal Combustion Engine, Block, Finite Element Analysis

Introduction

One of the most important parts of the engine is the block, and its dynamic characteristics and strength is the guarantee for the engine to work normally. It is very important for guiding the design and improvement of the block to study on the structural strength of engine block and show the stress and deformation distribution accurately [1-4]. At present, the most effective and reliable method to study the stress problem of complex structure is finite element analysis [5-8]. Strength analysis of diesel engine block with ANSYS are carried out in this paper and has obtained the block's stress and strain nephogram at different working conditions, which can provide ground for structure optimization design of engine block.

1. Establish a FEM model

After a series of simplification of the complex body, the three-dimensional model is established, which is introduced into ANSYS, and then be divided the grid. The grid model is shown in Fig.1.

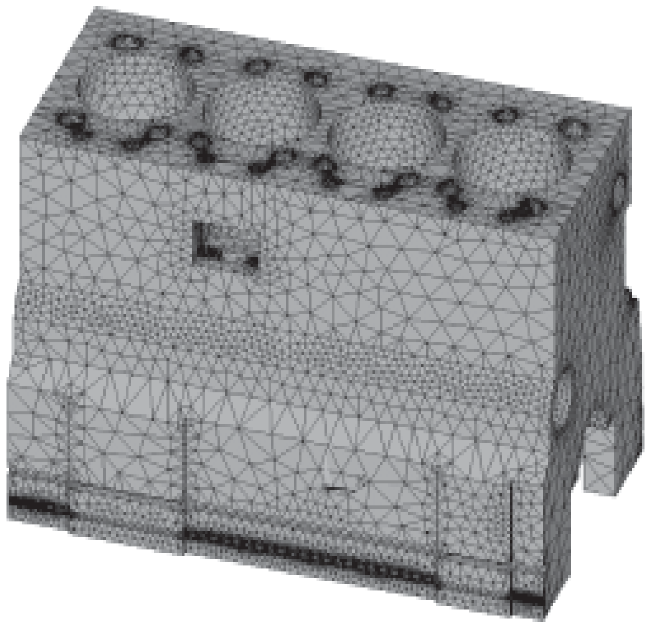

Fig.1 Diesel engine block's FEM

2. The block load calculation

In order to accurately simulate the stress distribution of the block in the actual working conditions of the engine, the applied force is required to simulate the actual working conditions as much as possible. The force on the engine block is very complex under operating condition, and it brings many difficulties in block's strength analysis. Therefore we must simplify the force which is applied on the diesel engine block. We have considered the gas force of the engine in the cylinder, the inertia force of piston connecting rod mechanism and the main bearing load, lateral force of the piston, axial load on the cylinder head bolt, which formed from itself on the basis of the actual response.

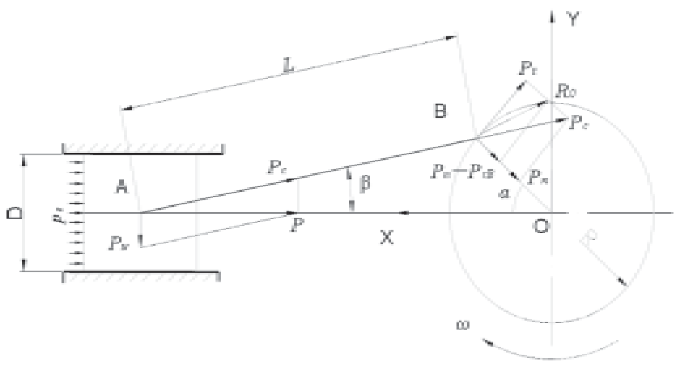

Fig.2 The connecting rod stress diagram

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2.1 The piston lateral force calculation

The piston lateral force is formed mainly by the interaction of reciprocating inertial force of the crank-rod mechanism and the gas force of the engine. The gas force P_g effecting on the piston is equal to the product of the piston crown area and the gas pressure difference between the upper and the lower sides of the piston. Formula 1 is the calculation formula of P_g [8].

$$P_g = (p - p')\frac{\pi}{4}D^2 \qquad \text{... (1)}$$

The gas pressure p in the cylinder changes with the crank angle can be obtained by indicator diagram. Crankcase gas pressure p for four stroke internal combustion engine generally takes atmospheric pressure. In working process the cylinder body's stress diagram is shown in Fig.2. Because there is a certain angle between connecting rod working and the direction of motion of the piston, which can produce certain piston lateral force P_H on the cylinder liner. λ = r/l, which is the ratio of the radius of the crank and the length of the connecting rod. According to the center crank connecting rod mechanism kinematic principles, we can determine the reciprocating inertial force on the piston pin:

$$P_j = -m_j R\omega^2(\cos\alpha + \lambda\cos 2\alpha) \qquad \text{... (2)}$$

In the formula, m_j – reciprocating inertial mass of the piston and connecting rod head

ω - angular velocity of the rotating crank

λ - ratio of the radius of the crank and the length of the connecting rod

α - angle of the crank

The interaction of gas cylinder pressure and piston reciprocating inertia force, lateral force P_H, can be expressed as:

$$P_H = (P_g + P_j)\tan\beta = (P_g + P_j)\frac{\lambda\tan\alpha}{\sqrt{1-\lambda^2\sin^2\alpha}} \qquad \text{... (3)}$$

In the formula, β – swinging angle of connecting rod $(\sin\beta = \lambda\sin\alpha)$

Force loaded on the crank P_c:

$$P_c = \frac{(P_g + P_j)}{\cos\beta} = \frac{(P_g + P_j)}{\sqrt{1-\lambda^2\cos^2 a}} \qquad \text{... (4)}$$

2.2 Main bearing load calculation

By the law of the crank-rod mechanism dynamics the force loaded on the crank P_c along the center line of the connecting rod reaches the center of the crank pin, it can be decomposed into two mutually perpendicular components P_t and P_n:

$$\begin{aligned} &P_t - P_c\sin(\alpha+\beta) \\ &P_n - P_c\cos(\alpha+\beta) \end{aligned} \qquad \text{... (5)}$$

Centrifugal inertia force of the big end of the connecting rod $P_{rB} = m_{CB}R\omega^2$. The quality of the big end of the connecting rod m_{CB}.

Multi-cylinder diesel engine has several main bearings, and each main bearing is influenced by adjacent two cylinders. Diesel engine is a four-stroke and four-cylinder machine, each cylinder ignition phase angle difference of 180 degree. So we can obtain the size of the two main bearings fore and aft:

$$P_1 = R_5 = \frac{1}{2}R_B = \sqrt{P_t^2 + (P_n - P_{rB})^2} \qquad \text{... (6)}$$

The direction is decided by both P_t and $(P_n – P_{rB})$.

Load of the middle main bearing:

$$R_{(i,i+1)} = \sqrt{P_{(i,i+1)}^2 + \left(P_{n(i,i+1)} - P_{rB}\right)^2} \qquad \text{... (7)}$$

In fact, the size of the bearing load is also affected by the factors such as oil film thickness, axis path, etc. The size and direction of the force on the main bearing seat is variable with crank angle. Due to the force is surface force, we can take it as a pressure to the relevant plane.

2.3 Bolt axial load calculation

In the finite element analysis carrying out on the body, the main consideration is axial force of bolts around the work cylinder, and the size of each axial force on the bolt is equal.

The changing relationship of the axial force on the bolts around the remaining three working cylinder is the same as the first cylinder bolts', and their phase angle differs by 180 degrees. The bolts between two cylinders are acted by two cylinders at the same time, so the forces on the two cylinders are added together when computing.

3. The block's strength check and analysis

Each cylinder's explosion pressure achieves the maximum When the engine is doing work, Table 1-4 shows the crankshaft angle, piston displacement, piston lateral force, main bearing load and gas pressure of each cylinder.

3.1 Piston lateral force's stress analysis

The piston lateral force's acting surface where piston acts on the cylinder wall can be found according to the piston displacement of a moment, and then the pressure is applied on the surface. The pressure means uniform distribution load. The lateral pressure on the cylinder wall is evenly distributed within the scope of the cover angle 120 degree, and then we can obtain the stress nephogram of lateral force of each cylinder under the working condition of maximum explosion pressure, which is shown in Fig.3.

In the first cylinder which is under the maximum explosion pressure condition, we can see that the maximum stress appears in the role of the piston lateral force area from figure 3. It means that the piston lateral force has more influence on the first cylinder's stress, and has less influence on the other

Table 1: 1st Cylinder's parameters at maximum explosion pressure condition

Cylinder number	Cylinder 1 (inflation)	Cylinder 2 (exhaust)	Cylinder 3 (compression)	Cylinder 4 (inlet)
Crankshaft angle	390°	570°	210°	30°
Piston displacement (mm)	9	95	95	9
Gas pressure (Mpa)	11.6	0.95	0.16	0.15
Piston lateral force (Mpa)	3.04	-0.4	-0.19	-0.16

Main bearing number	Mbs1	Mbs2	Mbs3	Mbs4	Mbs5
Main bearing load (Mpa)	23	13	4	2.5	8

Table 2: 2nd Cylinder's parameters at maximum explosion pressure condition

Cylinder number	Cylinder 1 (compression)	Cylinder 2 (inflation)	Cylinder 3 (inlet)	Cylinder 4 (exhaust)
Crankshaft angle	210°	390°	30°	570°
Piston displacement (mm)	95	9	9	95
Gas pressure (Mpa)	0.16	11.6	0.15	0.95
Piston lateral force (Mpa)	-0.19	3.04	-0.16	-0.4

Main bearing number	Mbs1	Mbs2	Mbs3	Mbs4	Mbs5
Main bearing load (Mpa)	6	19	13	2.5	7

Table 3: 3rd Cylinder's parameters at maximum explosion pressure condition

Cylinder number	cylinder 1 (exhaust)	cylinder 2 (inlet)	cylinder 3 (inflation)	cylinder 4 (compression)
Crankshaft angle	570°	30°	390°	210°
Piston displacement (mm)	95	9	9	95
Gas pressure (Mpa)	0.95	0.15	11.6	0.16
Piston lateral force (Mpa)	-0.4	-0.16	3.04	-0.19

Main bearing number	Mbs1	Mbs2	Mbs3	Mbs4	Mbs5
Main bearing load (Mpa)	7.5	2.5	20	12	6

Table 4: 4th Cylinder's parameters at maximum explosion pressure condition

Cylinder number	cylinder 1 (inlet)	cylinder 2 (compression)	cylinder 3 (exhaust)	cylinder 4 (inflation)
Crankshaft angle	30°	210°	570°	390°
Piston displacement (mm)	9	95	95	9
Gas pressure (Mpa)	0.15	0.16	0.95	11.6
Piston lateral force (Mpa)	-0.16	-0.19	-0.4	3.04

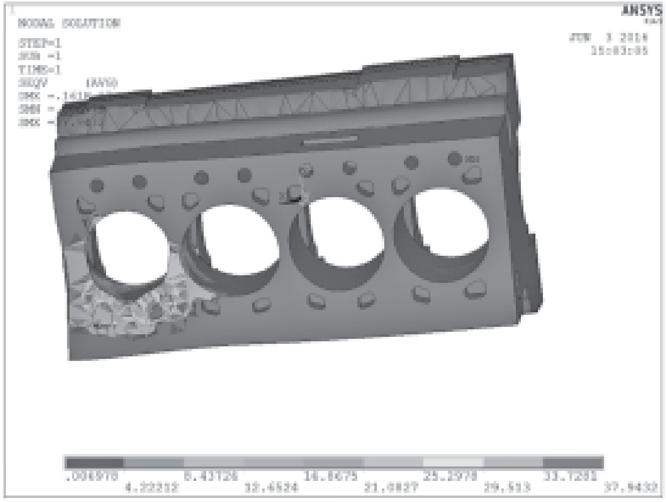
Main bearing number	Mbs1	Mbs2	Mbs3	Mbs4	Mbs5
Main bearing load (Mpa)	8	4	3	19	23

three cylinders, which is not doing work. The maximum stress of the second cylinder appears near one side of the first cylinder. It can be seen that the maximum stress of the cylinder is caused by the deformation from the deformation figure of the cylinder when the first cylinder's explosion pressure achieved its maximum. The third cylinder's deformation is small because it lies in the greater distances from the first cylinder. So the third cylinder's stress is mainly affected by the piston's lateral force. Therefore, we can conclude that the stress of the cylinder which is doing work is mainly affected by the piston lateral force. For the non-working cylinder, its maximum stress appears near one side of the doing work cylinder if it is next to the doing work cylinder. If it is not next to the doing work cylinder, its stress is mainly affected by the cylinder piston's lateral force.

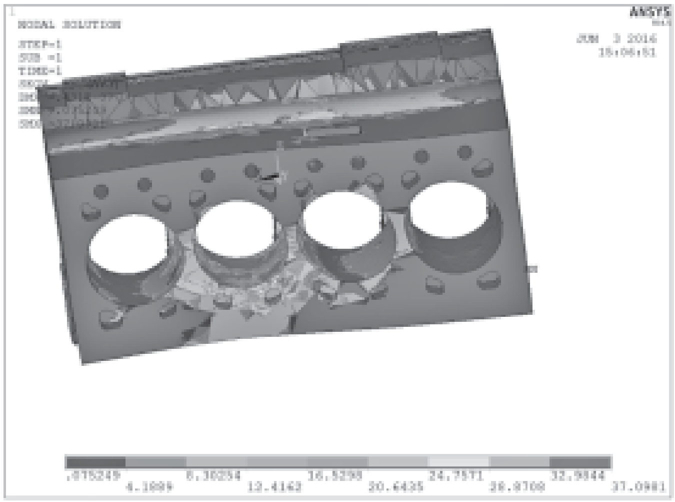
It can be seen that the maximum stress is 37MPa from figure 3, which appears at the moment when the fourth cylinder's explosion pressure achieved its maximum. It is far less than the material's ultimate strength 250MPa, so the block is safe.

3.2 Main bearing force analysis

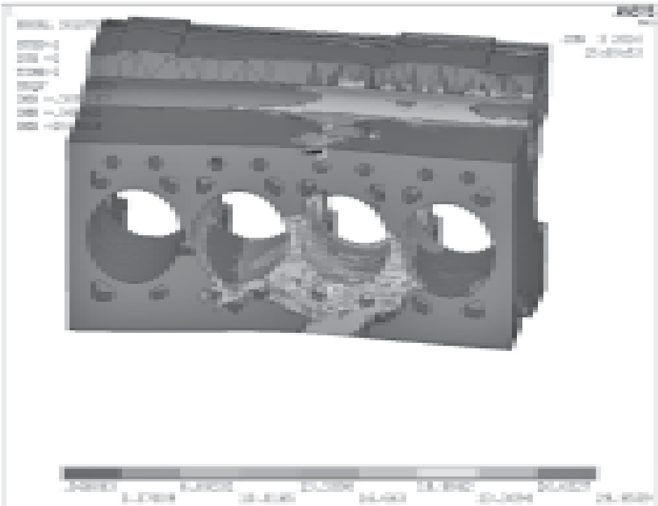
Main bearing load on the main bearing seat can be handled as cosine distribution load. Cosine function is $P = P_{max} \cos\varphi$. Stress distribution of the main bearing at each cylinder maximum explosion pressure condition is shown in Fig.4.



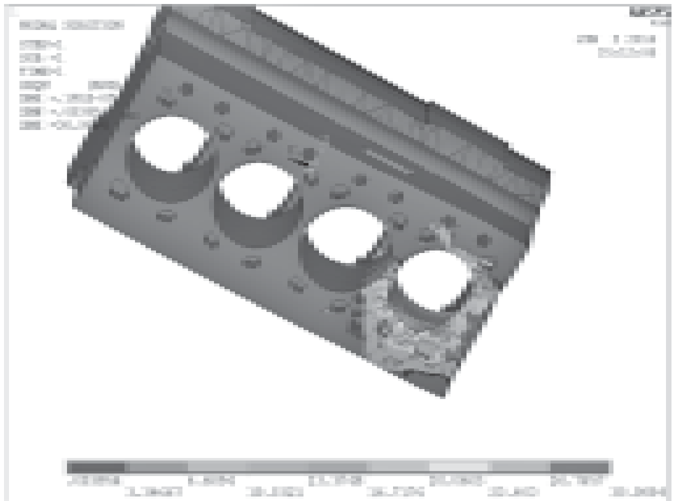
(a) cylinder 1



(b) cylinder 2



(a) cylinder 3



(b) cylinder 4

Fig.3 Stress distribution of the piston lateral force at each cylinder maximum explosion pressure condition

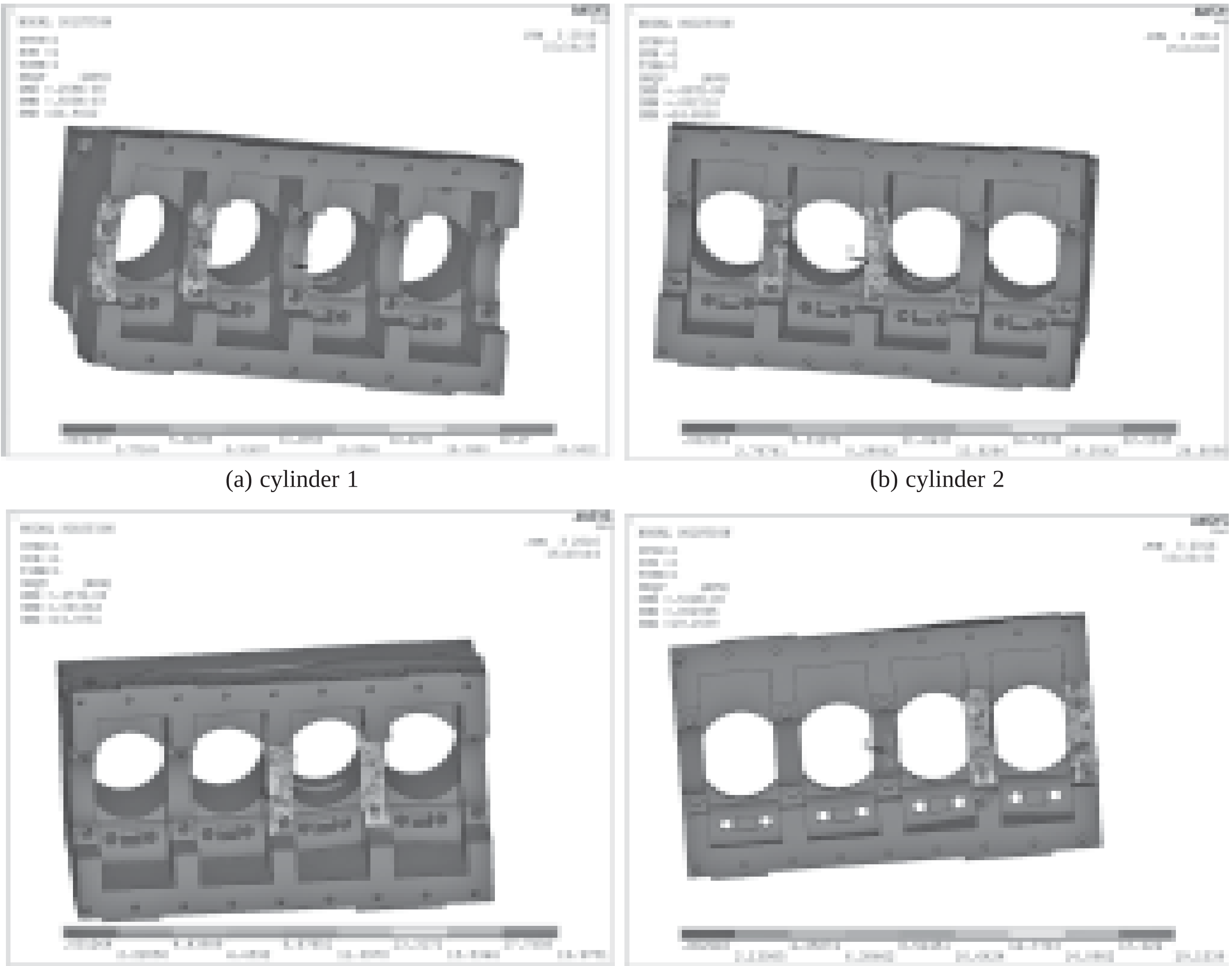
From Figure 4(a), in the first cylinder maximum explosion pressure condition it can be seen that the maximum stress appears at a pair of main bearing covers just below the power cylinder and the stress of the block's other main bearing covers is relatively small. It means that the load of the bearing cover is mainly caused by gas explosion pressure, gas pressure in the process of inlet and exhaust has little effect on the load of the main bearing cover. In the process of the calculation of multi-cylinder engine, we can ignore the non-power cylinder's gas pressure's influence on the load of the main bearing, which can save time.

3.3 The axial force analysis on the bolt

Ignore the influence of bolt pre-tightening force, uniform load is applied on six threaded holes around each cylinder head in the calculation. For example, in the first cylinder maximum explosion pressure condition, we have obtained axial force's stress nephogram of the bolt, which is shown in Fig.5. From that, it can be seen that the maximum stress of the bolt hole is 116 Mpa. It doesn't exceed the material's tensile strength 250 Mpa, so the bolt hole is safe.

4. Conclusion

The stress of the block affected by axial force on the cylinder head bolt, lateral force of the piston and the main bearing load is obtained by using ANSYS to simulate. By analyzing the block's strength, we can draw the conclusion: 1) under the condition of a cylinder maximum explosion pressure, the cylinder piston's lateral force is the largest, and the maximum stress of the block's cylinder wall appeared at the moment of piston's site of action. 2) The piston lateral force of the adjacent cylinder is greatly influenced by the power cylinder, and the stress appears near one side of the power cylinder. 3) When a cylinder under the working condition of maximum



(a) cylinder 1 (b) cylinder 2

(a) cylinder 3 (b) cylinder 4

Fig.4 Stress distribution of the main bearing at each cylinder maximum explosion pressure condition

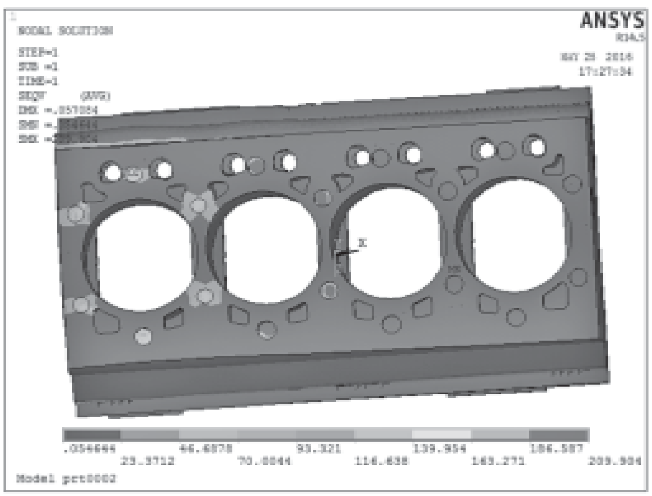


Fig.5 Stress distribution of the roof bolt hole at the 1st cylinder maximum explosion pressure condition

explosion pressure, the force on the main bearing seats which just under the power cylinder is the largest, the load of the rest of the cylinder's main bearing seats is smaller. 4) The bolts around the power cylinder bear stress evenly, and the force on the surface of the piston crown is equally split among them.

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