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# Strength analysis of diesel engine block based on multi-body transient dynamics

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**Abstract.** Based on the multi-body transient dynamics calculation method, the strength of a low-speed marine diesel engine block is analyzed. Firstly, UG software is used to simplify the whole machine and obtain the corresponding simplified model. Then, in ANSYS software, the corresponding loads and boundary conditions are applied to each component in the diesel engine model to simulate the normal working process of the diesel engine and calculate the structural strength of the engine block. It is found that the stress on the engine block is not constant, but changes with the rotation of the crankshaft and the explosion of each cylinder. The position of the maximum stress on the engine block appears at the bolt hole on the upper surface of the cylinder block, and is far less than the tensile yield strength of the material. Finally, the fatigue life of the computer block is calculated by importing three elements: stress distribution data, material properties and load spectrum. It is found that the mechanical fatigue life time of the engine block is much longer than the overhaul period of the diesel engine, which can be considered as infinite life.

**Keywords:**diesel engine block; strength analysis; 、 simulation calculation;transient dynamics; fatigue life.

## 1. Introduction

After more than 100 years of development, diesel engine has become one of the most widely used power machinery. Especially in the field of ship power, diesel engine has always been in the leading position. The main engine and auxiliary engine of mainstream oceangoing ships are diesel engines. Compared with other power plants, diesel engine has the advantages of high thermal efficiency, large power range and good mobility. It is very suitable to be used as marine power plant. In recent years, marine diesel engine is developing towards high burst pressure and high power density. High burst pressure means that the mechanical load borne by the diesel engine will increase, and high power density means that the weight of the diesel engine will decrease under the condition of constant power, which puts forward higher requirements for the structural strength and reliability of the diesel engine.

The engine block is an important part of the diesel engine. As the framework of the diesel engine, it is the basis for the installation and fixation of main components and accessories [1]. In the working process of diesel engine, the engine block will be in a very complex stress state, which requires it to have high strength and stiffness, and can’t produce cracks or large deformation [2]. The design of the engine block should not be too redundant, otherwise it will affect the power density index. Therefore, it is very important to analyze the strength of the block. So far, many scholars have analyzed and calculated the block through different methods. When studying the deformation of cylinder liner, FEV company adopts the finite element analysis method and the experimental measurement method of eddy current sensor respectively. It is found that the two methods obtain the same results [3]; S. Papez and M. birth took the lead in applying the finite element technology to the research of in-line 4-cylinder water-cooled engine block. When analyzing the static strength, the comprehensive influence of crankshaft and cylinder head is fully considered, and the error between the calculated stress value and the experimental value is within 9% [4]; Shi Xiuyong carried out stress finite element analysis for the pre tightening force state and maximum burst pressure state of the engine block, and put forward evaluation basis for various improvement

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schemes [5]; Xie Fulin combined with fatigue analysis experiment to accurately evaluate the structural strength of a vehicle diesel engine block [6].

At present, most studies use the finite element static strength analysis method, which needs to apply all the loads suffered by the diesel engine in the working process, including the additional loads generated in the working process, such as piston side thrust, which will make the simulation results have certain limitations. Therefore, according to the real operation process of in-line 6-cylinder diesel engine, the transient dynamic analysis method is used to analyze and calculate the strength of the engine block, obtain the deformation and stress nephogram, and complete the strength check.

## 2.Simulation calculation of engine block

### 2.1 Pretreatment of Model

This calculation takes a marine low-speed two-stroke in-line 6-cylinder diesel engine as the research object, with a cylinder diameter of 340mm and a rotating speed of 230rpm. According to the research needs, modeling and assembly are carried out in UG software, including engine block, cylinder liner, crankshaft, connecting rod and piston. Because the structure size of the block is very large, and there are large number of oil passage holes, threaded holes and other structures on the block, if the simulation calculation of the whole engine block is carried out, it will not only increase the difficulty of meshing, but also consume a lot of time. Therefore, it is necessary to appropriately simplify the engine block on the premise of meeting the calculation accuracy. It includes the following aspects[7]:

Ignore unimportant structures such as boss, oil passage and blind hole, and delete chamfer and cast fillet. These features have little impact on the overall stiffness and strength of the engine block, so ignoring these structures will not affect the simulation calculation accuracy of key parts of the engine block.

Use smooth round holes instead of threaded holes and smooth cylinders instead of bolts. In actual production, the geometry of the contact part between bolt and threaded hole is very complex. If it is not simplified, it will increase the contact relationship and increase the amount of calculation, which is easy to lead to non convergence of calculation.

Replace the cylinder head with a simple cylinder. The purpose of this paper is to analyze the structural strength of the engine block. The function of the cylinder head is to transmit the explosion pressure to the engine block and provide the contact surface of the bolt preload between the cylinder head and the engine block, so the structure of the cylinder head will not affect the simulation results of the engine block.

After simplification by the above method, the model required for calculation is shown in Figure 1.

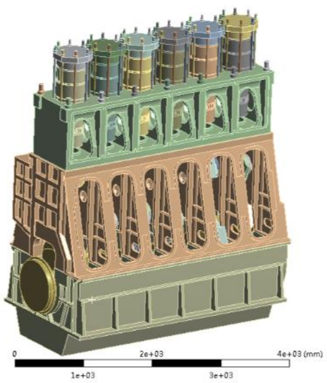


Figure 1. Simplified 3D model

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## 2.2 Selection of Calculation Model

Transient dynamic analysis is a method used to determine the dynamics corresponding to any time-varying load, which can determine the time-varying stress and strain of the structure under any combination of loads.

The basic equation of transient dynamic analysis is

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=\{F(t)\}$$

In this function, $[M]$ is mass matrix, $[C]$ is damping matrix, $[K]$ is stiffness matrix, $\{\ddot{u}\}$ is nodal acceleration vector, $\{\dot{u}\}$ is node velocity vector, $\{u\}$ is node displacement vector.

In this paper, the complete method is used for simulation calculation, while allowing large deformation in nonlinear characteristics. The advantage of this method is that it is easy to use and allows various types of nonlinear characteristics; the complete matrix is adopted, and the approximation of the mass matrix is not involved; all displacements and stresses can be obtained by one analysis; it is allowed to apply any load on the real 3D model.

## 2.3 Analysis of Grid Independence

Import the simplified engine block model into the transient structural module of ANSYS Workbench, and define the material for the engine block as Carbon Steel RQT501. The main parameters of the material are shown in Table 1.

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TABLE I. Material properties

| Name of Material | Value | | |
|---|---|---|---|
| | Tensile yield strength ( $MPa$ ) | Density ( $kg \cdot m^{-3}$ ) | Young's Modulus ( $Pa$ ) |
| Carbon Steel RQT501 | 472 | 7850 | $2 \times 10^{11}$ |

Before the simulation calculation, the model needs to be meshed, and the grid size needs to be determined after the grid independence analysis. Otherwise, the grid size is too large, resulting in inaccurate calculation results and large errors. If the grid size is too small, it will consume a lot of additional calculation time and obtain calculation results with almost the same accuracy.

In this paper, the grid size is determined by comparing the simple static calculation results. When the static calculation results gradually converge and the error between the static calculation results and the previous grid size calculation results is less than 5%, the grid size used in this calculation is the required value of this engine frame simulation calculation. Grid size and static stress results are shown in Table 2.

TABLE II. Results of grid independence analysis

| Grid Size (mm) | Value And Grade | | |
|---|---|---|---|
| | Number of units | Stress ( $MPa$ ) | Grid quality |
| 95 | 206283 | 90.23 | low |
| 85 | 228873 | 100.29 | medium |
| 75 | 261020 | 115.64 | medium |
| 65 | 314534 | 120.33 | high |
| 60 | 352737 | 121.46 | high |

It can be seen from table 2 that when the mesh size changes from 75mm to 65mm, the stress result increases by less than 5%. When the mesh size changes from 65mm to 60mm, the stress result increases by only 0.94%. Therefore, the mesh size of 65mm is selected and the tetrahedral element is used to mesh the engine block. There are 615208 nodes and 314534 units in the grid division. The quality of the grid division is good and meets the calculation requirements.

## 2.4 Definition of Boundary Conditions

Based on the analysis of multi-body transient dynamics method, to simulate the real operation of diesel engine, it is necessary to add corresponding joints to the engine block, crankshaft, connecting rod and piston.

Firstly, considering the fixing requirements of the whole machine, the fixing constraint with the ground is imposed on the bottom of the oil pan. At the same time, in the working process of diesel, the relative movement between oil pan, frame and cylinder block can be regarded as not occurring. Therefore, fixed constraints are also imposed between oil pan and engine frame, engine frame and cylinder block. Then, apply the rotating pair between the crankshaft and the bearing seat, and apply two rotating pairs between the connecting rod and the crankshaft and piston pin; Finally, the reciprocating motion pair between the piston and the cylinder liner is applied.

In this calculation, only external loads need to be applied to the engine block, namely bolt preload, cylinder burst pressure and gravity. For the bolt preload, two groups of bolts are considered: the bolts on the cylinder head and the upper part of the cylinder block, with a diameter of 34mm and

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a bolt preload of 65000N; The diameter of the bolt between the cylinder block and the engine frame is 64mm, and the bolt preload is 590000N.

At the beginning of the calculation, the speed of the diesel engine directly changes from 0 to the rated speed, which will produce great numerical stress concentration and affect the results. Therefore, the total simulation time is 0.52174s, that is, the crankshaft angle of the diesel engine is 720 °. To sum up, the time of applying cylinder pressure to the upper surface of the piston is also two cycles, and the maximum burst pressure is 18.478mpa. The curve of cylinder pressure changing with time is shown in Figure 2.

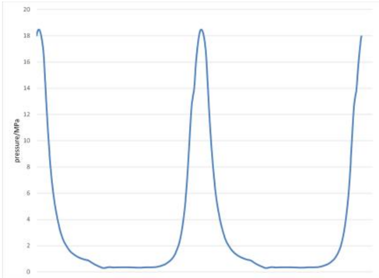

Figure 2. Curve of cylinder pressure

## 3.Analysis of Strength Simulation Results

In this paper, the strength analysis of the engine block is mainly based on the fourth strength theory, that is, the shape ratio theory, and the size of the equivalent stress of the analysis paradigm. The theory fully considers the influence of three principal stresses on material strength, that is, no matter what state, once the specific energy of the material reaches the limit value, the material will yield.

### 3.1 Stress Analysis of the Whole Engine Block

The stress distribution of the whole engine block is shown in Figure 3. Since the speed of the diesel engine directly changes from 0 to 230 rpm at the beginning of the calculation, resulting in great stress concentration, which is not in line with the actual situation, this paper only analyzes the calculation results of the crankshaft angle of the diesel engine within 360 ° - 720 °. It can be seen from the figure that during the operation of the diesel engine, the stress borne by the engine block is not constant, but changes with the rotation of the crankshaft and the explosion of each cylinder.

In the analysis period, the stress distribution area mainly appears near the through bolt hole, each diaphragm of the engine frame and the bearing seat of the engine base. The maximum stress borne by the engine block appears at the bolt hole on the upper surface of the cylinder block, with a size of 156.34MPa, which is lower than the yield strength of the material. The stress distribution in the figure is consistent with the actual situation, and the stress is far lower than the yield strength of the material.

(a) CA 360 (b) CA 450

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(c) CA 540 (d) CA 720

Figure 3. stress distribution of engine block under different crankshaft angles

### 3.2 Stress Analysis of Cylinder Block

The stress distribution of the cylinder block is shown in Figure 4. Due to the large bolt preload near the through bolt hole and the small contact area between the nut and the upper surface of the cylinder block, the high stress has been maintained near it, with the maximum value of 156.34MPa Stress in the range of 15-20MPa is also distributed near the threaded hole of the connecting bolt between the cylinder head and the cylinder block. This is due to the bolt preload of the connecting bolt, which makes the cylindrical surface of the threaded hole subject to upward shear stress, resulting in obvious stress in these areas. The stress in the range of 10-15MPa is distributed in the contact area between the cylinder block and the cylinder liner, because when the piston moves back and forth, it will produce side thrust on the cylinder liner, and the cylinder liner will contact the cylinder block and then be transmitted to the cylinder block.

In the through bolt hole, the stress on the cylinder block gradually decreases from top to bottom, and the stress near the bolt hole on the lower surface of the cylinder block is much less than that on the upper surface. This is because the contact area between the lower surface of the cylinder block and the upper surface of the engine frame is large. After the pressure generated by the nut on the upper surface of the cylinder block is transmitted, the stress distribution will be more uniform.

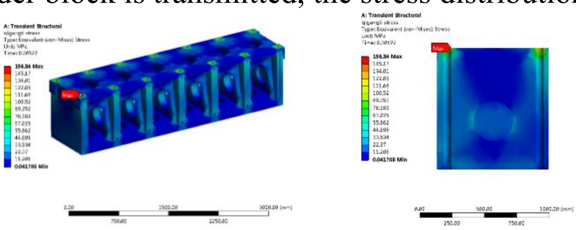

Figure 4. stress distribution of cylinder block

### 3.3 Stress Analysis of Engine Frame

The stress distribution of the engine frame is shown in Figure 5. It can be seen from the figure that the diaphragm is the main stress area in the frame. The intersection of stiffeners outside the frame and the corner area of the structure are also subject to stress ranging from 20-30MPa. The maximum stress of the frame appears at the transition fillet, with a size of 89.951MPa, which is lower than the yield strength of the material. This is because the diaphragm is near the through bolt hole, and the thickness of the diaphragm is very thin compared with other parts of the frame, so it will produce greater stress. The intersection of stiffeners and transition fillets will also produce stress concentration due to large mesh density and sharp corners, which are reasonable phenomena. In the bolt hole, the stress increases gradually from top to bottom, which is due to the obvious stress concentration near the thread position due to the pre tightening force of the bolt.

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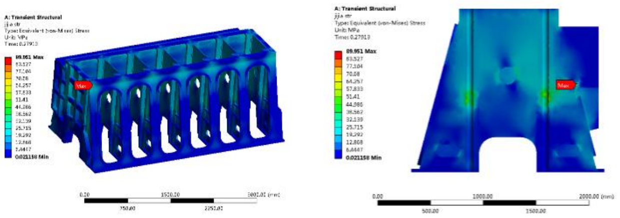

Figure 5. stress distribution of engine frame

### 3.4 Stress Analysis of Engine base

The stress distribution of the engine base is shown in Figure 6. As shown in the figure, the main stress bearing area in the engine base is located near each bearing seat, and the stress condition of each bearing seat is different, which is corresponding to the rotation of the crankshaft and the explosion of each cylinder. The maximum stress of the engine base appears at the contact position between the bearing base and the engine base, which is 67.05MPa, which is less than the yield strength of the material.

During the operation of the diesel engine, the burst pressure of the cylinder acts on the piston. After passing through the connecting rod and crankshaft, the bearing seat will be under pressure. In addition, during the rotation of the crankshaft, inertial force will also act on the bearing seat, so there will be stress concentration at the bearing seat. Because the oil pan is mainly affected by gravity and is not directly affected by other external forces, the stress on it is very small in the whole calculation cycle.

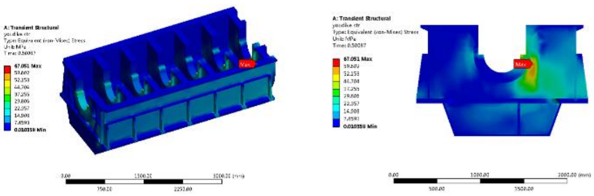

Figure 6. stress distribution of engine base

## 4.Fatigue Life Analysis of Engine Block

### 4.1 Theory of Fatigue Life Calculation

Under the cyclic action of alternating stress, although the maximum cyclic load does not exceed the ultimate load of the material in the tensile limit test, the material failure finally occurs, which is called fatigue failure. Therefore, although in the above analysis, the maximum stress of the engine block is far less than the tensile yield strength of the material, it is still necessary to analyze the mechanical fatigue life of the engine block to judge whether fatigue failure has occurred.

In the calculation of fatigue life, S-N standard measurement is widely used, and S-N curve represents the stress amplitude $\sigma$ and limit number of fracture cycles $N_f$ relationship. This curve is obtained from the axial tensile test using the standard specimen. The fatigue life N can be obtained by applying the stress range S. Since the stress on the engine block does not exceed the yield strength of the material, the S-N criterion is applicable in calculating the fatigue life.

### 4.2 Analysis of Fatigue Life of Engine Block

In this paper, the nCode module in ANSYS Workbench is used to calculate the fatigue life of the block, which requires three elements: engine block stress distribution data, material properties and load spectrum. Firstly, by coupling the nCode module with the transient structural module mentioned above and updating the result data, the block stress distribution data and material

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properties will be transferred to the nCode module. Then, because the data of the first cycle of diesel engine rotation is inconsistent with the actual situation, the data calculated in the second cycle of rotation (360 ° - 720 ° crankshaft angle) is selected for the load spectrum. In this paper, the material of the engine block is defined as Carbon Steel RQT501, and its S-N curve is shown in Figure 7.

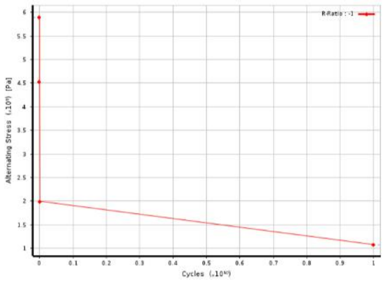


Figure 7. S-N curve of material

The fatigue life diagram of the engine block is shown in Figure 8. The whole block is dark blue with a service life of $8.583\times10^{14}s$, the shortest service life is $4.412\times10^{14}s$, namely $1.15\times10^{11}h$, compared with the overhaul period of $10^{5}h$ for low-speed diesel, can be considered as infinite life. Therefore, through analysis, it is found that the maximum stress of the engine block is not only less than the yield strength of the material, but also will not produce fatigue failure due to high cycle fatigue.

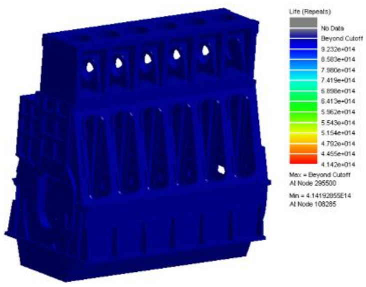


Figure 8. Fatigue life of engine block

## 5.Conclusion

This paper mainly simplifies a marine low-speed two-stroke diesel engine, and calculates the strength of the engine block based on the multi-body coupling transient dynamics calculation method, and obtains the stress distribution diagram of the engine block. Then, the mechanical fatigue life of the block is calculated and its fatigue life diagram is obtained.

In the working process of diesel engine, the stress on the engine block is not constant, but will change periodically with the rotation of crankshaft and the explosion of each cylinder. The maximum stress of the engine block is 156.34MPa, which appears at the bolt hole of the cylinder block. The material of the engine block is Carbon Steel RQT501 and the tensile yield strength is 472MPa, so the engine block will not undergo plastic deformation during operation.

The minimum fatigue life of the block is $1.15\times10^{11}h$, far exceeding the design service life of low-speed diesel engine. If the diesel engine operates normally, it can be considered as infinite service life.

The engine block has great redundancy in stress and fatigue life. In the follow-up research, the structure of the engine block can be properly optimized, the weight of the engine block can be reduced and its power density index can be increased.

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