The Thermal and Mechanical Coupling Finite Element Analysis of the Cylinder Head of an 8 Cylinders 265 Diesel Engine

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ABSTRACT: This article described the thermal mechanics coupled analysis of a cylinder head. The mainly considered forces were heat load, bolt preload and the in-cylinder explosion pressure. In the analysis, the thermal calculation was coupled with mechanical force. According to the obtained equivalence stress of the cylinder head from the coupling field simulation, we can find the stress distribution and dangerous position in the cylinder head. From the simulation results, the comprehensive stress of cylinder head is less than 160MPa, the amount of deformation is tiny, and the structural safety of cylinder head meets the design requirements.

1 INSTRUCTIONS

Cylinder head is the most important and complicated part in diesel engine, and its working condition is very poor for it stands for the high temperature and high pressure of burned fuel. Heat load mainly influences the bottom (fire surface) of the cylinder head, forms an uneven temperature and structural stress distribution in cylinder. In some cases, local stresses are too high. Furthermore, the combustion pressure constantly impact on the cylinder head. So, the cylinder head sustains both the thermal load and the mechanical load. The safety of cylinder head is our concern in this research.

Table 1. Main parameters of 8L265 diesel engine.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>General type</td>
<td>8 cylinder, L type, four stroke</td>
</tr>
<tr>
<td>Bore×Stroke/mm×mm</td>
<td>265×300</td>
</tr>
<tr>
<td>Rated power (Speed) /kW(r/min)</td>
<td>2330(1000)</td>
</tr>
<tr>
<td>Mean effective pressure at rated power/MPa</td>
<td>2.1</td>
</tr>
<tr>
<td>Max combustion pressure/MPa</td>
<td>16.5</td>
</tr>
</tbody>
</table>

With the improvement of computer simulation technology, the finite element analysis method is used spread. It can shorten the development time, reduce the cost, and provide theoretical support for engine test. A cylinder head of 8L265 diesel engine was analyzed in this paper, and the cylinder head temperature field was simplified as a steady-state style. The simulation is based on Steady-State Thermal model and Static Structure model of the commercial software ANSYS Workbench. The main parameters of 8L265 diesel engine are listed in table 1.

2 THERMO-MECHANICAL COUPLING ANALYSIS

The thermo-mechanical coupling analysis of the cylinder head in ANSYS Workbench include two step, first step is the solution of the temperature field and thermal stress, the second step is the solution of stress distribution of cylinder head applied by mechanical load. Then, connect two steps by transferring the thermal stress data of temperature field into the second step to solve the combination stress distribution of cylinder head.

Figure 1 shows the schematic diagram of coupled thermo-mechanical analysis of ANSYS Workbench. In the schematics, the model A part deals with the CAD modeling and post-processing work, model B part focus on the analysis of temperature field of cylinder head, and the function of model C is analyzing the mechanical stress of the cylinder head. In figure 1, the analysis results of temperature field are transported into the setup function of mechanical stress analysis step, which means the coupling of thermal and mechanical analysis. After the transfer of thermal results, executing the Import Load command in Static Structural model to finish the datum transmission.
3 THE CAD MODEL AND FINITE ELEMENT MODEL OF CYLINDER HEAD

The 3D solid model of the cylinder head of 8L265 type diesel engine is created by Pro ENGINEER software. The CAD model of cylinder head is simplified to increase the efficiency of meshing generation and finite element analysis. The simplification should not affect the temperature distribution in cylinder head. The CAD model appearance and finite element model are shown in figure 2 & 3. The cylinder head is made by vermicular graphite cast iron, this metal is treated as isotropic material in the simulation, and assumed that the material properties is constant during temperature variation. The material properties of vermicular graphite cast iron is shown in table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data</th>
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<tbody>
<tr>
<td>Coefficient of thermal conductivity</td>
<td>36.6</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>7.05</td>
</tr>
<tr>
<td>Coefficient of linear expansion (1/°C)</td>
<td>1.10E-05</td>
</tr>
<tr>
<td>Elasticity modulus (MPa)</td>
<td>1.47E+05</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>Yield limit (MPa)</td>
<td>220</td>
</tr>
</tbody>
</table>

4 BOUNDARY CONDITION

4.1 Displacement boundary condition

In 8L265 diesel engine, the cylinder head is unibody type, each cylinder head is connected by screw bolt to the cylinder liner of the block. According to the domestic and foreign research results [1-3] on the constraint of cylinder head, the general application of constraint is used in the interface between cylinder head and block. Since the thermal expansion effect of cylinder head, the contact surface should not be constrained completely. The contact surface has no expansion in normal direction, so the displacement constraint in normal direction can be applied in the contact surface between cylinder head and block. At the same time, symmetrical displacement constraint should be applied on the symmetrical plane of the cylinder head.
4.2 Force boundary condition

The mechanical forces imposed on cylinder head mainly include three kinds: bolt preload, interference load of valve seat, and in-cylinder explosion pressure. Among of them, the calculation of bolt preload is the most complicated. The next part will introduce the calculation methods and results of these 3 kinds of forces.

4.2.1 Bolt preload

As shown in figure 4, the cylinder head is fastened to the cylinder liner of the block by four m48 type screw bolt.

![Figure 4. The stereogram of bolt connection on cylinder head.](image)

4.2.2 In-cylinder explosion pressure

According to the related literatures [4, 5], the explosion pressure in cylinder can be simplified as uniform distribution force acted on the fire surface of cylinder head in mechanical analysis. The aim of the mechanical analysis is to find the dangerous area of the cylinder head and propose an improvement scheme. The usual method to choose the explosion pressure in the mechanical analysis is using the maximum explosion pressure. In this research, the maximum explosion pressure of 8L265 engine in cylinder is 16.5MPa at the rated power condition, and this explosion pressure will be used in the simulation.

4.2.3 Interference load of valve seat

The interference load of valve seat can be obtained by calculating the magnitude of interference between valve seat and cylinder head. In general, the interference load of valve seat is very small compared to in-cylinder explosion pressure or other forces, and has little influence to stress distribution of cylinder head. So, the interference load of valve seat is omitted in this simulation.

5 THE ANALYSIS OF THERMAL-MECHANICAL COUPLING CALCULATION

5.1 The results of the mechanical stress analysis

This mechanical finite element simulation only considers the bolt preload and in-cylinder explosion pressure without taking account of the thermal load. Figure 5 & 6 show the equivalent stress distribution nephograms of the cylinder head only with the action of the mechanical forces.

![Figure 5. Bottom view of mechanical stress distribution on cylinder head.](image)

![Figure 6. The profile section map of mechanical stress distribution on cylinder head.](image)

Figure 5 shows the equivalent stress distribution of the bottom of the cylinder head. From figure 5, we can draw a conclusion that the influence of mechanical stress to the cylinder head mainly locates in the area near the bolt-hole and the fire surface, mechanical stress has little affection on other part of the cylinder head. The maximum equivalent mechanical stress of the cylinder head is 102.2MPa.
The high mechanical stress on the fire surface is mainly caused by the explosion pressure in cylinder.

Figure 6 shows the profile section diagram of the equivalent stress distribution of the cylinder head under the action of the mechanical forces. Because the bolt preload is increasing continuously as the depth of bolt-hole is added, the mechanical stress of the side face of cylinder head is gradually rising from up to down near the bolt-hole. The max mechanical stress distributes around the annular region of the surface of cooling channels. In general, the mechanical stress is smaller than the thermal stress, and has little influence on the cylinder head.

5.2 The results and analysis of thermal-mechanical coupling calculation

The simulation in this part is to calculating the equivalence stress distribution of cylinder head in the thermal load, bolt preload, and in-cylinder explosion pressure coupled situation. The figures 7-10 show the equivalence stress distribution nephograms of cylinder head in different locations under the action of coupled forces.

Figure 7. Bottom view of coupling stress distribution on cylinder head.

As shown in figure 7, the equivalence stress mainly distributes in the bridge zone of the fire surface of the cylinder head, the maximum of equivalence stress is 156.2MPa. The stress below the exhaust duct is obviously higher than the stress in other area. This phenomena is mainly made by the high thermal stress associated with the high temperature difference between the exhaust dust and the cooling channel below it.

Figure 8 shows the equivalence stress distribution of thermo-mechanical coupling of the top side of the cylinder head. The equivalence stress around the exhaust duct side of the cylinder head. The equivalence stress around the exhaust duct is obviously higher than the equivalence stress of other part in the cast iron structure of the cylinder head. This is caused by the high thermal stress around the exhaust duct.

According to the equivalence stress distribution diagrams list above, we can draw a conclusion that, in general, the equivalence stress around the surface of the cylinder head is still in the material safety limitation, the maximum equivalence stress area is in the bridge zone of the fire surface, especially in the bridge zone between inlet duct and exhaust duct, and the bridge zone in the two inlet ducts. In these bridge zone, the temperature difference is huge, that leads to the high thermal stress and high integral stress.
Figure 10 shows the equivalence stress distribution in the profile section along the middle line of the cylinder head. From figure 10, we can draw a conclusion that the equivalence stress inside the cylinder head is comparatively small and has a little influence to the structure of cylinder head, the equivalence stress is gradually reduced from the fire surface to the interior of cylinder head. Concentration of stress occurs in the convergence area of two exhaust ducts, for the thermal stress mainly gathers there.

6 CONCLUSION

This research is a comprehensive stress analysis to the cylinder head under thermo-mechanical coupling load, conclusion is derived as follow by this research:

1. When considering mechanical load only, the equivalence stress of the cylinder head mainly distributes in the area near the four bolt-hole of the bottom of the cylinder head, and the maximum of equivalence stress is 102.2MPa.
2. When considering the thermo-mechanical coupling load, the equivalence stress distribution is changed correspondingly. In general, the equivalence stress mainly distributes in the bridge zone of the fire surface of the cylinder head, especially in the bridge zone between inlet duct and exhaust duct and the bridge zone between the two inlet ducts. The maximum equivalence stress is 156.2MPa.
3. When considering the thermo-mechanical coupling load, the maximum amount of deformation of cylinder head is about 0.66mm, and locates in the end of exhaust duct. The amount of deformation of the fire surface which is the crucial concern of the cylinder head, is no more than 0.22mm.

In summary, the cylinder head’s comprehensive stress is no more than 160MPa, the amount of deformation is small in regular working condition. The structural safety of cylinder head meets the design requirements.

REFERENCES