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Simulation of heavy-duty engine based on flexible multi-body dynamics

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Abstract. For heavy-duty diesel engine, the structural flexibility of the crankshaft and the engine block has an important influence on the dynamic characteristics of the engine. The deformation and modal resonance generated at work must be considered. Therefore, the multi-body dynamic analysis of the crankshaft and the body structure is based on the flexible body model of the crankshaft and the body. In this paper diesel engine dynamics behaviour is analysed based on flexible multi-body method. The dynamic substructure condensation method is used to reduce the he shaft and the bearing block, obtain the flexible body model of the crankshaft and the body, reduce the computational solution scale, and improve the computational efficiency.

1. Introduction

With the continuous strengthening of engine, its speed, load and power density are gradually improved. The structural flexibility of the crankshaft and the engine block has an important influence on the dynamic characteristics of the engine [1]. The deformation and modal resonance generated at work must be considered in the analysis. Therefore, the multi-body dynamic analysis of the crankshaft and the body structure is based on the flexible body model of the crankshaft and the body. The research object of this paper is a six-cylinder v-type diesel engine. The flexibility of the crankshaft, the body and the connecting pairs is the main non-linear factor that needs to be considered [2].

Firstly, the finite element model of the crankshaft and body was established, and the principal degree of freedom node of the above model was defined, then the dynamic substructure condensation model of the crankshaft was obtained by calculation. After importing the quality matrix, stiffness matrix and geometry of the condensation, to the software of AVL EXCITE [3], the system parameters are defined in the POWER UNIT module, including the body element and the connection UNIT, the mechanical coupling relation, the engine structure parameters. According to the analysis needs, select the appropriate kinematics model, which is to select the different connection subunit models in the software. Considering the lubrication of oil film, the bearing adopts elastic hydrodynamic lubrication model (EHD2) to define the oil supply characteristics, oil tank and lubricating oil type of the bearing. The burst pressure curve of each cylinder is imported into the software, which is applied to the engine dynamics model as the load. The simulation control parameters are set in the software, including simulation iteration step, iteration precision, result storage information and integral method. After completing the calculation, the desired results are extracted and the results are processed [4].

2. Dynamic substructure condensation

The mesh model of the body was established by HYPERMESH finite element pre-processing software, the condensation process is accomplished by ABAQUS finite element software.

2.1. Substructure condensation model of crankshaft

The substructure condensation model of crankshaft is condensed from the finite element model (FEM) of the crankshaft assembly, which including crankshaft, flywheel and balance weight, as shown in Figure 1. The FEM of crankshaft assembly is composed of hexahedral mesh, in order to facilitate the definition of the connecting between main bearing and connecting rod large end bearing.

6 layers of hexahedral elements are arranged along the length direction of the main journal, in which the size of the middle 4 layer element equal to 1/4 size of main bearing width. 10 layers hexahedral elements are arranged along the length direction of the crank pin, in which the thickness of the middle 8 layer grid is the 1/8 size of the width of the bearing of connecting rod. For both main journal and crank pin, 48 grid elements are arranged in the circumferential direction. At the same time, it is necessary to ensure that there are nodes in the center of each layer of the main journal and crank pin length direction [5], so as to facilitate the binding of RBE2. The model has 25,914 units and 32,768 nodes.

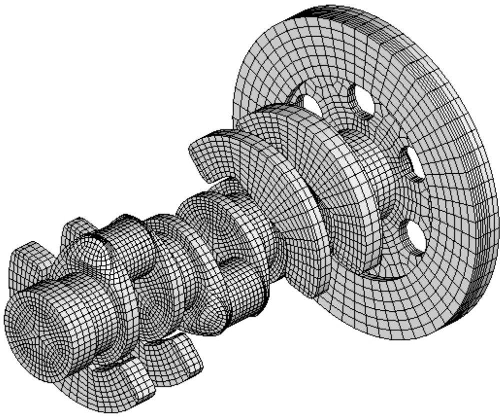

Figure 1. FEM of crankshaft

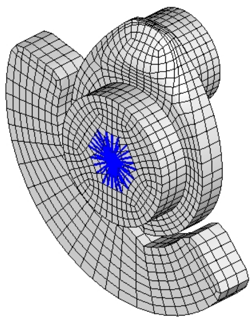

Figure 2. The RBE2 connection at the centre of the main journal

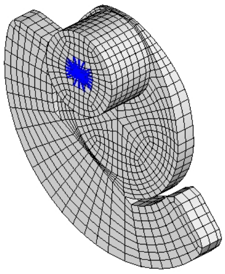

Figure 3. The RBE2 connection at the centre of connecting rod shaft

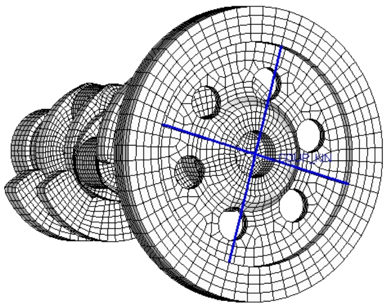

Figure 4. The RBE2 connection at the centre of the flywheel

5 nodes at the center of main journal section are defined as master nodes, while 2 nodes at the center of crank pin section are defined as master nodes. The six degrees of freedom (DOF) between the master node at the center of the section and the slave nodes within the radius of 1/2 of the surrounding section are coupled by the DOF coupling element RBE2, as shown in Figure 2 and Figure 3, in which the master nodes are the main DOF nodes and the slave nodes are the subordinate nodes. Master nodes are also defined on the flywheel, inertia body and shock absorber body, which are shown in figure 4. The master node on the flywheel is used to load torque, and the master nodes on the inertial body and the shock absorber body are used to characterize the dynamic behavior of the torsional damper.

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It is necessary to ensure that the addition of RBE2 connections does not affect the stiffness and mode of the original model, as they directly control the torsional vibration and fillet stress of the shafting. In order to ensure the accuracy of the calculation results, the model compliance must be verified. The crankshaft finite element model and the original model must have the same dynamic characteristics. Table 1 introduces the modal frequencies of the crankshaft model before and after the RBE2 coupling connection. The result shows that the addition of RBE2 has little effect for the crankshaft modal, therefore the modified model has the same dynamic characteristics as the original model.

Table 1. The modal analysis result of the crankshaft before and after set contrast RBE2

Modal order	Modal frequency（HZ）（nonRBE2）	Modal frequency（HZ）（RBE2）	Error（%）
7	95.418	97.91	2.61
8	100.76	103.8	3.01
9	218.16	223.62	2.50
10	244.71	246.41	0.69
11	270.82	277.25	2.37
12	386.66	394.31	1.97
13	436.26	448.42	2.78
14	549.29	555.83	1.19

2.2. Engine Block Dynamic Substructure Condensation

The engine block include the body, the oil pan, the main bearing cover and other parts, and the cylinder block and the main bearing are also installed on the body, as shown in figure 5. The cylinder sleeve, bearing and bearing backing by 8 node hexahedron unit, and the rest of the 10 node tetrahedral two unit. The width direction of the bearing shell divided into 4 equal parts, and the main journal consistent. The total number of nodes in the finite element model is 341391, and the number of elements is 188492. 8 nodes hexahedron element is 20352, and 10 node tetrahedron element is 168140.

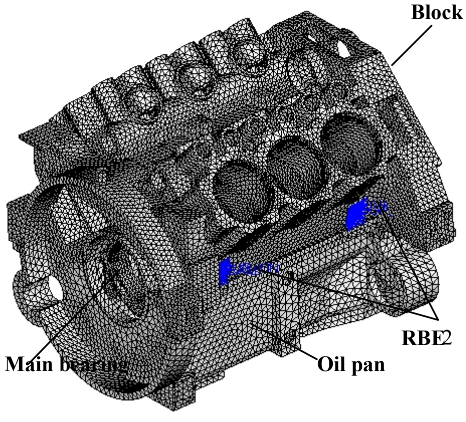

Figure 5. Mesh model of engine Block

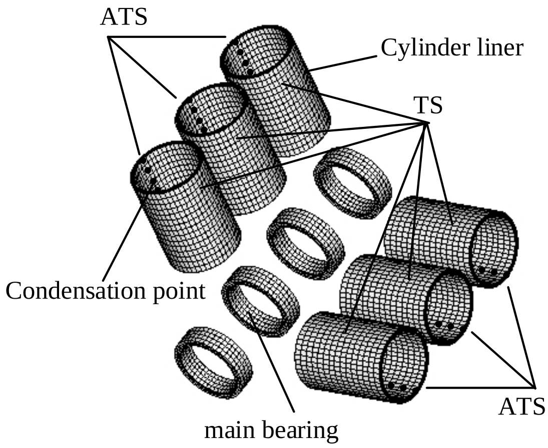

Figure 6. Engine model after condensation

2.3. Substructure condensation model of cylinder liner

In the condensation process of the cylinder liner, 10 main degrees of freedom nodes are defined on the TS and ATS sides of each cylinder sleeve to establish a coupling connection with the mass point at the small end of the connecting rod, as shown in Figure 6.

3. The establishment of dynamic model of the engine

3.1. The condensation dynamic model of the engine

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The resulting sub-structure condensation file is imported into AVL EXCITE, and the condensation dynamic model of the whole engine is obtained as shown in Figure 7.

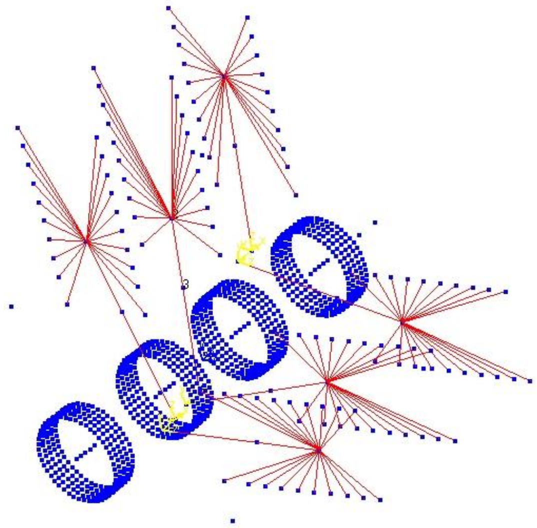

Figure 7. The condensation dynamic model of the whole engine

3.2. The flexible multi-body dynamic model of engine

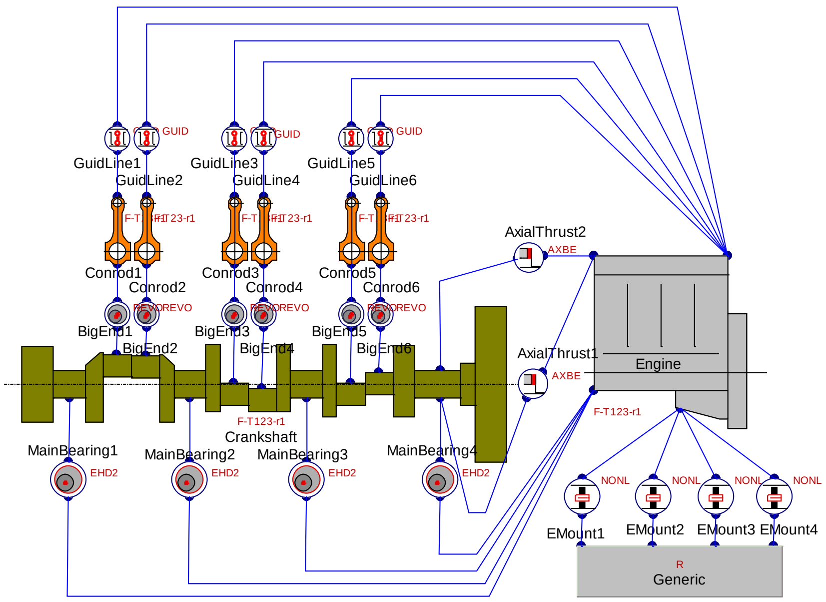

Figure 8. The condensation dynamic model of the engine

Through the POWER UNIT module in AVL EXCITE, a flexible multi-body dynamic model of a six-cylinder high-power diesel engine is established. The model fully considers the major components of the elastomer nonlinear link element interaction between deformation and elastomer. The connections between the various moving parts are defined in the POWER UNIT module of AVL EXCITE, as shown in Figure 8.

The component parameters and global parameters of the model are analyzed, and the analysis step parameters are defined. Each working condition is defined as three cycle simulation calculations, and the simulation results of the second cycle are extracted as the analysis data. In the analysis process, the iteration step value is 0.0625 degree, the minimum iteration step is 0.015625 degree, and the maximum iteration step is 0.5 degree.

3.3. Connection definition of main bearing

An elastic hydrodynamic lubrication bearing model (EHD2) is used to connect the main bearing pairs [6]. The lubrication model can describe the axle neck and bearing elastic deformation, bearing clearance, axis of mass conservation (non-cavitation model), the supply of the lubricating oil (oil tank, oil hole and line etc.) and other factors, is a more accurate to obtain the bearing pressure distribution model. The parameters of main bearing are shown in table 2 [7].

Table 2. Parameters of Main bearing EHD2 model

Parameter	Value	Parameter	Value
Main bearing width	30mm	Oil type	SAE5W-30
Main bearing diameter	108mm	Oil supply pressure	4.6 bar
Radial clearance	0.025mm	Cavitation pressure	0.6 bar
Modulus of elasticity	0.008	The coefficient of friction	0.05
The root-mean-square root of the peak surface of crankshaft	0.4	The average height of the main shaft neck	0.3
The mean-square root of the peak roughness of the bearing surface	0.8	The average peak point height of the bearing	0.5
Oil temperature	100 ℃	Oil groove position	315°~135°

4. Flexible multi-body dynamic Simulation

The flexible multi-body dynamics model of journal bearing is driven by the explosion pressure curve of the cylinder. The burst pressure curve in this paper is obtained through the actual engine cylinder pressure measurement experiment [8], which is shown in figure 9.

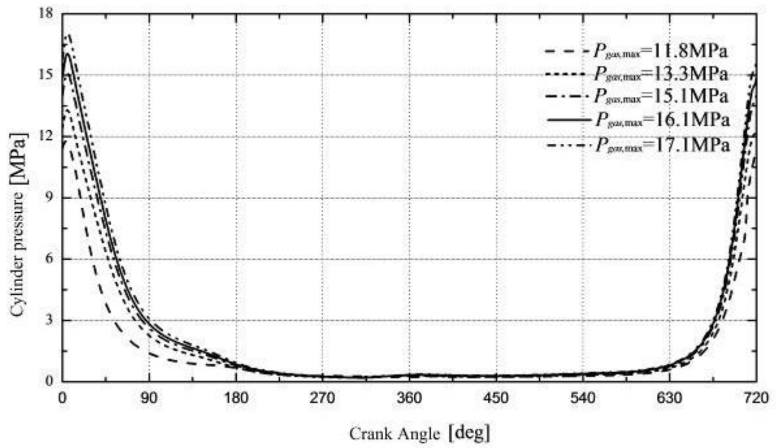

Figure 9. The explosion pressure curve of the cylinder of engine.

The outburst pressure curve of the pressure Pgas,max=11.8MPa was obtained through the test experiment of the pressure test of the prototype cylinder under the rated speed of 2200rpm. The peak burst pressure Pgas,max was 13.3MPa, 15.1MPa, 16.1MPa and 17.1MPa. The pressure curve was obtained through the GT Power calculation on the basis of the burst pressure curve of the experimental test and the parameters of the known engine oil injection volume and the intake and exhaust Angle.

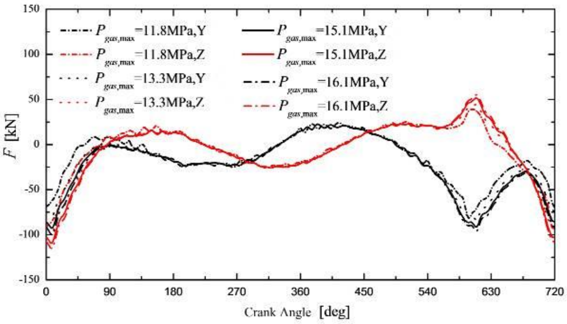

Figure 10. The response situation of the bearing force of the 1st bearing is given by different outburst pressure curve

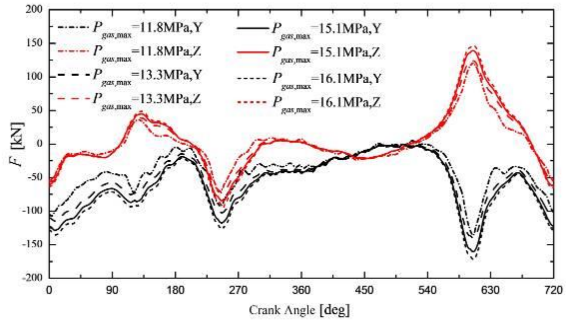

Figure 11. The response situation of the bearing force of the 2nd bearing under different outburst pressure curve

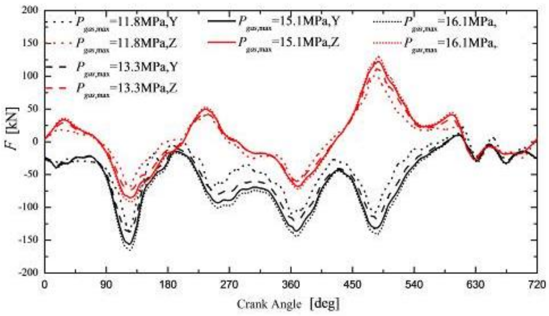

Figure 12. The response situation of the bearing force of the 3rd bearing under different outburst pressure curve

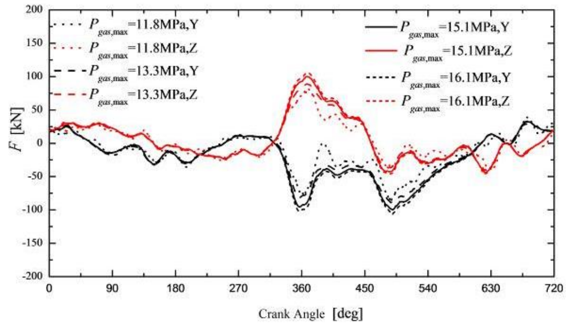

Figure 13. The response situation of the bearing force of the 4th bearing under different outburst pressure curve

5. Conclusions

The structural flexibility of the shaft and the bearing block has an important influence on the dynamic characteristics of the engine. The following conclusions can be obtained through the above analysis:

- The dynamic substructure condensation method is useful to reduce the computational solution scale, and improve the computational efficiency.
- The main bearing force of the two sides of the body is relatively small, while the main bearing force of the middle partition is larger
- The main bearing is mainly affected by adjacent explosion pressure of the cylinder, not adjacent to each cylinder explosion pressure on the main bearing force effect is small.
- With the increase of engine outbreak of peak stress, peak bearing force of the bearing is also increasing, of which the second and third main bearing of the bearing force was bigger.

Acknowledgments

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