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Stiffness Evaluation and fast matching method of mechanical composite structure

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Abstract. Stiffness evaluation can improve the reliability and safety of combined machinery, which is often used to evaluate the performance of combined machinery. In order to study the stiffness evaluation method and rapid matching of mechanical composite structure, the composite machinery composed of high-power diesel is taken as the research object. The results show that the error between test mode and calculation mode is no more than 10%, indicating the reliability of finite element simulation model; two characterization methods of static stiffness and dynamic stiffness are determined, and the analysis methods of two characterization methods of combined machinery are discussed one by one. Taking the combined machinery of body, main bearing cap and oil pan as the research object, the overall stiffness characterization data of three parts are obtained one by one; finally, the principles of mechanical combination Stiffness Evaluation and rapid matching are summarized. This study provides a reference for Stiffness Evaluation and rapid matching of combined mechanical structures.

1. Introduction

With the rapid development of science and technology, the mechanical structure has gradually developed from single state to combined state. Combined machinery can effectively avoid the limitations of single machinery, improve labor production efficiency, simplify operation process and save labor cost. The stiffness of mechanical composite structure is the key to evaluate the reliability and safety of composite machinery[1]. There is a negative correlation between stiffness and deformation degree. When the deformation degree is greater, the plasticity is better and the stiffness is smaller. Especially for deformation sensitive components, the deformation amount needs to be controlled through stiffness. When the stiffness is exceeded, it will change from plastic deformation to rigid deformation and damage the machinery[2]. There are many factors to be considered in the structural stiffness evaluation of combined machinery due to different parts materials, different combination methods and different stress sensitivity.

The so-called fast stiffness matching means that for combined machinery, it is necessary to explore the force and deformation coordination between various parts, as well as the correlation between the whole combined machinery. When assembling machinery, one part is connected to another, and it is usually necessary to add "buffer parts"[3]. All walks of life have their own proprietary stiffness matching methods, such as the best stiffness matching structure of balance bearing and rotating mechanism shaft, which increases the working time of sliding surface; in order to reasonably match the suspension stiffness, it is suggested to give the optimization design scheme of heavy vehicle suspension system based on multibody dynamics simulation software; in order to solve the problem of

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asymmetry on both sides of bus body, it is suggested to use the stiffness matching optimization method of virtual parameters; in order to solve the reasonable deformation mode of automobile bumper anti-collision beam, the stiffness matching design of bumper is proposed, which effectively improves the anti-collision performance[4].

2. Experimental methods and materials

Using diesel engine as the research target, a single accessory of engine body, main bearing cap and oil pan is selected. In order to reduce the influence of unreasonable features on the result analysis, the solid model is simplified and the following measures are taken: (1) reducing bosses and screw holes; (2) Change the lubricating oil curve to straight; (3) Modify the main bearing cap to a flat rectangle (remove chamfers and transition fillets); (4) Planarization, conical surface, etc. The simplified model is simpler.



Fig. 1 Simplified model and exploded view

The goal of simplifying the model is to shorten the time of finite element calculation, put forward the corresponding parameters and facilitate the dynamic correction of the model. In addition, it can also realize the migration of similar model parameters and save the calculation time of the model[5]. The key model parameters proposed this time are: the number of cylinders is 12mm, the cylinder center distance is 190mm, the staggered distance is 36mm, the crankcase subsidence is 2mm. And the distance from the main bearing seat hole to the center is 236.5mm, the diameter of the main oil passage is 44mm, the diameter of the cylinder hole is 168mm, the wall thickness of the external water chamber is 12mm, the height of the sinking plate is 212mm, the width of the sinking plate is 24mm, the length of the main bearing cap is 344mm, the radius of the main bearing hole is 134mm. In addition, there is an oil pan parameter benchmarking table (Table 1)

Table 1 Comparison of oil pan parameters		
Symbol	Parameter name	Basic value /
		mm
L	Oil pan length	1343
D	Width of oil crust	448
Η	Oil crust height	114
Т	Oil crust wall thickness	7

3. Results and analysis

3.1. Principle of mechanical structure analysis

3.1.1. Static analysis of linear structures

Linear structural statics means that the model is subjected to a constant force under certain constraints. The principle is to solve the constitutive equation (stress and strain), motion equation (plane stress, plane strain and axisymmetric state) and equilibrium equation (stress tensor, volume force, internal **MAEIE 2021**

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force, external surface force, virtual displacement and virtual strain), and finally obtain a control procedure[6].

3.1.2. Linear structural dynamics analysis

When a component deforms, the deformation energy will be transformed into internal energy, but some internal energy can be saved, and some internal energy will appear "violent resistance", which is called inertial force term. The key of dynamic analysis is the setting of damping, which is divided into direct mode damping, Rayleigh damping and compound mode damping. The value range of direct modal damping is 1% - 10%; rayleigh damping shall not exceed the maximum damping value (10%); composite modal damping is suitable for composite structural systems of various materials.

3.2. Research on Stiffness Evaluation and matching of mechanical structure

3.2.1. Evaluation method of static stiffness of mechanical structure

The characterization parameters of static stiffness analysis include stress, strain and displacement. For static stiffness, the greater the deformation displacement under the same load strength, the greater the plastic strength, the smaller the stiffness; for different blocks of the same material, small deformation means large regional stiffness, and vice versa

Static stiffness calculation includes four aspects: body static stiffness calculation, main bearing static stiffness calculation, oil crust static stiffness calculation and overall static stiffness calculation. 20KN load is applied on the left and right sides of the body. The results show that the displacement of the third and fourth transverse compartments is the largest, indicating that their stiffness is the smallest; the maximum principal strain is located at the position where the water chamber of the engine block is connected with the outer wall of the cylinder. The same load is applied on both sides of the main bearing cap. The results show that the central displacement of the bearing hole is the largest, and the maximum principal strain is located at the threaded hole close to the bearing hole. Because the oil crust belongs to thin shell, it only plays the purpose of sealing oil storage, so it has low requirements for its stiffness, Therefore, the static stiffness is not analyzed this time. Finally, the static stiffness of the combined machinery composed of the body, main bearing and oil crust is evaluated. The results show that the maximum deformation is located between the 6th and 7th diaphragms, and the maximum principal strain is located between the transmission box of the body and the oil crust. Compared with a single machinery, the deformation variable of a single machinery is greater under the same load, the combined machine can disperse the load. Compared with the single machine, the shape variable is smaller. However, due to the differences between different parts, the position of the maximum principal strain is inconsistent, which is mostly concentrated in the connection position of the parts. The structural differences between parts lead to the difference of static deformation

3.2.2. Evaluation method of dynamic stiffness of mechanical structure

With the operation of the combined machinery, the dynamic load occurs all the time. The biggest harm to the combined machinery is resonance. When the modal frequency is close to the dynamic load to a certain extent, resonance will occur, resulting in great damage to the combined machinery. The dynamic stiffness calculation includes direct frequency response method and modal frequency response method, The difference between them is that the direct frequency response method directly solves the motion process, but the calculation process is cumbersome, time-consuming and labor-consuming, but the accuracy is higher than that of the modal frequency response method; the modal frequency response method has high efficiency and saves time and energy, but the accuracy is worse than the direct frequency response method. Therefore, the appropriate dynamic stiffness calculation method should be selected according to the design requirements.

Like the static stiffness evaluation, the dynamic stiffness evaluation is also calculated from three aspects: the dynamic stiffness of the body, the dynamic stiffness of the main bearing and the dynamic stiffness of the oil crust. In the first step of the stiffness analysis of the engine block, the modal

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parameters are obtained first, and the maximum displacement response frequency is determined by analyzing the first-order bending model and the first-order torsional modal displacement versus frequency response curve of the engine block. The corresponding frequency of the maximum displacement of the first-order bending mode is 163hz, the corresponding frequency of the maximum displacement of the first-order bending torsional mode of the body is 784hz, and the maximum displacement is located in the water chamber; the maximum displacement of the first-order torsional mode of the engine block. The modal frequency of the first-order torsional mode is located at the side wall of the lower crankcase of the engine block. The modal frequency of the first-order torsional mode is 240Hz. Since the oil pan is 221hz, and the modal frequency of 200Hz is applied. The results show that the frequency of the maximum displacement response of the first-order bending mode of the maximum displacement is in the right longitudinal waterway zone; the maximum stress of the first-order bending mode of the whole machine is located at the lower crankcase and the oil pan, because the oil pan bears a considerable part of the weak zone.

3.3. Induction of stiffness matching principle

Compared with a single component, stiffness matching is for combined machinery, which not only evaluates the stiffness of a single component, but also includes the relationship between components. At present, the applicable scenarios of stiffness matching analysis include aircraft wing and vehicle engine set. Considering the stiffness analysis results of a single component and the whole machine, as well as multiple influencing factors in the stiffness calculation process, five kinds of methods and principles for rapid stiffness matching are summarized:

1) Fully consider the deformation of the first-order torsion and first-order bending of the whole machine mode. The deformation can be subdivided into vector direction, three-dimensional coordinate (XYZ) direction and main direction. Generally, the amount of deformation depends on the displacement value. In fact, because the degrees of freedom of the research target are infinite, the corresponding modal order is also infinite. However, compared with the whole machine, there is a lack of excitation of high-order frequency, so more attention is paid to the previous modes. In particular, the first-order bending and first-order torsion modes are more valuable, which can characterize the characteristics of the structure to a certain extent.

2) Fully consider the correlation of modal frequencies of single accessories. The modal frequency parameters are used to evaluate the stiffness of the whole machine and a single part, and the absolute value difference of hierarchical frequency is used to evaluate the participation stiffness contribution of a single part in the whole machine, so as to clarify the basic characteristics of the stiffness of the whole machine. In the previous cognition, carry out dynamic parameter correction for the single part with the greatest contribution, and increase the stiffness of the whole machine on the premise of ensuring the quality of the whole machine, so as to achieve the design of stiffness matching.

3) Carry out detail optimization of weak areas with structural stress concentration. Engine and other combined machinery have a high probability of fault zone after long-time operation, and the corresponding weak zone such as stress concentration occurs in the process of simulation analysis. Facing this situation, we try to increase the stiffness of the combination by distributing stiffeners, stiffeners and increasing the wall thickness.

4) Response sensitivity analysis is used to optimize design objectives. Sensitivity analysis can screen the variables that have the greatest impact on the object from many influencing factors, and sort the impact contribution rate of each variable synchronously. Using this method to optimize the most sensitive design variables and apply them to the optimization design can improve the efficiency of the optimization design and provide important gradient parameters for the subsequent optimization and maintenance of the structure.

5) The incremental ratio of frequency to mass is used as the characteristic parameter to evaluate the stiffness of the structure. Generally speaking, the structural mass is positively correlated with modal

frequency and structural strength. The increase of structural mass will increase the structural strength. Therefore, it can be considered to increase the stiffness by increasing the increment ratio of the two.

4. Conclusion

Based on the concept of structural stiffness, this paper comprehensively discusses the influencing factors of mechanical composite structure stiffness, the characterization and analysis method of structural stiffness, and the stiffness matching principle of composite structure. Through the complete machine composed of three parts of diesel engine body, main bearing cap and oil pan, the modal analysis is obtained one by one, the experimental modal discussion of engine body and oil pan parts is carried out one by one, and compared with the corresponding finite element simulation modal analysis results. The results show that the error between test mode and calculation mode is no more than 10%, Furthermore, the accuracy of the finite element simulation model is proved; based on the macro and micro definitions of stiffness, the influencing factors and characterization methods of stiffness are discussed, and further comparative analysis is carried out from the two aspects of static stiffness and dynamic stiffness. The methods and methods of static stiffness and dynamic stiffness analysis of composite structure are discussed one by one. Taking the composite structure as the research goal, the characterization parameters of static and dynamic stiffness of each fitting and the whole machine are obtained one by one. Finally, this paper makes full use of the previous understanding, summarize the stiffness analysis method of the composite structure, calculate the relevant parameters of the composite parts according to the stiffness evaluation standard, discuss the stiffness matching relationship between the composite parts combined with the parameters, summarize the principle of stiffness matching, clarify the stiffness evaluation criteria of the composite structure, and discuss the stiffness matching of the simulation model.

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