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Dynamic Analysis and Optimization of Vibration isolation system for refrigerator Compressor

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Abstract: Fully enclosed reciprocating compressor is the core component of refrigerator, and also an important research object in the design of refrigerator vibration and noise reduction. This paper aiming at the engineering research of vibration isolation design and structure optimization of refrigerator compressor, the dynamic characteristics of refrigerator compressor vibration system are analyzed by theoretical modeling calculation and vibration modal test, and the parameters of the system force transfer rate are optimized, which provides a reference for the design of vibration and noise reduction of compressor. First of all, according to the structure and working principle of refrigerator compressor, the compressor is simplified as a dynamic model of 3-DOF two-layer vibration isolation system, the vibration differential equation is established by Lagrange equation. The three order natural frequency of the compressor isolation system is calculated by using the mathematical software MATLAB, it is 3.4236Hz, 14.7469Hz and 63.5231Hz, respectively. The expression of force transfer rate of compressor system is derived. The curve of force transfer rate is plotted, and the influence of various parameters on force transfer rate is analyzed. Secondly, in order to improve the effectiveness of optimal design and avoid blindness of optimization, the sensitivity analysis of the parameters in the formula of force transfer rate is carried out. The sensitivity parameters: support spacing, eccentricity, damping and shell mass are selected as optimization variables, with the minimum force transfer rate at the working frequency as the optimization objective function, the optimization mathematical model is established and the genetic algorithm in the MATLAB optimization toolbox is used to optimize the calculation. The third order peak value of the force transfer rate curve is reduced by 0.7 dB, 0.5dB and 1.1dB, respectively, which provides a reference for the optimal design of the refrigerator compressor. Thirdly, dynamic characteristic analysis of refrigerator compressor whole machine and pump body by using finite element software ANSYS Workbench. The natural frequency of the first three steps is low, and the vibration modes is the whole vibration form; and the second three order modes are shown as the vibration form of the internal exhaust pipe. The first four natural frequencies are in the frequency range of 50 Hz, so we should pay special attention to the occurrence of

resonance; And after the fifth order, the natural frequency higher. Finally, vibration and test system LMS Test. Lab is used to test the compressor by hammering method. Compared with the natural frequency of finite element analysis, the minimum error is 1.18% of the first order and the maximum error is 5.65% of the 5th order. The corresponding theoretical calculation of the third-order natural frequencies is 3.502Hz, 14.263Hz and 61.354Hz, respectively, and the error is 2.24%, 3.39% and 3.54%, respectively, the accuracy of the finite element simulation and the reliability of the mechanical model are explained within the allowable range.
Keywords: refrigerator compressor, vibration isolation, parameter optimization, modal analysis.

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1. SENSITIVITY ANALYSIS AND STRUCTURAL PARAMETER OPTIMIZATION OF COMPRESSOR VIBRATION ISOLATION SYSTEM

When the complex structure of the compressor is optimized, some structural parameters of the compressor should be modified to improve the dynamic characteristics of the compressor structure and reduce the transmission of the vibration. There are many factors affecting the vibration of the compressor, and the optimization analysis of the compressor structure is very large. The optimization design based on experience will be due to lack of theoretical support, and it has a certain blindness, which can not reach the optimal effect. Before optimizing the design, the sensitivity analysis of the structural parameters of the compressor is carried out to determine the sensitivity of the structural parameters, that is to find out the parameters which have great influence on the system force transfer rate as the optimization design variable. On this basis, the optimization design of the compressor structure can not only avoid the blindness of the optimal design, but also shorten the calculation. Quantity and design cycle to improve the efficiency of the whole machine structure optimization. Sensitivity analysis is also helpful for a better understanding of the structural performance when optimizing the design of the complex structure of the compressor.

1.1 Principle of sensitivity analysis

First, the mathematical method is used to establish the function relation between the design variable and the performance index. According to the function relation, the sensitivity (first derivative or partial derivative) of the structure static and dynamic performance changes with the structure design variable is calculated, and then the influence degree of the design variable quantity on the performance index is determined according to the sensitivity value. Thus, the influence degree of the design variable quantity on the performance index is determined. Structural improvement or optimization design by adjusting the design variables[1].

The sensitivity function expression in mathematical sense can be expressed as:

$$S(x_i) = \frac{\partial f(x_1, \cdots, x_i, \cdots, x_n)}{\partial x_i}$$

Formula: F (XI) - the function parameter is a function of the design parameters of the structure, and the performance parameter is the force transfer rate in the compressor vibration isolation system.

Xi - structural design parameters, the main parameters of the design parameters in the compressor vibration isolation system are stiffness, damping, eccentricity, spring spacing and the quality of the shell.

In order to solve the mathematical model of the design system, priority should be given to the optimization methods and calculation procedures with good reliability, fast convergence speed and good algorithm stability. Based on the idea of numerical fitting, a parameter (such as stiffness K1) is changed each time in the design of the system, and the other parameters remain unchanged, and the partial derivative of the parameter is obtained, that is, the sensitivity of the parameter [2-3].

1.2 Sensitivity analysis of structural parameters

According to the derivation order of a parameter in the force transmissibility formula, it is divided into first order sensitivity and higher order sensitivity [34]. In this paper, we only do first-order sensitivity analysis, using direct derivation method in local sensitivity analysis. As the pump body is simplified as the rigid body mass M1, it is difficult to modify the overall quality of the components, and the overall distance of the spring spacing of the upper vibration isolator remains unchanged (l=l1+l2), and the other one of the variables is determined accordingly. So only the parameters in the force transfer rate formula Tf: support spacing L1, eccentricity e, shell mass m2, vibration isolator stiffness K1, K2 and damping loss factor ETA 1, ETA 2 are solved. In order to facilitate calculation and analysis, the logarithm of sensitivity is lg| gamma. The sensitivity curves of each parameter in the force transfer rate are plotted using MATLAB software, as shown in Figure 1-1.

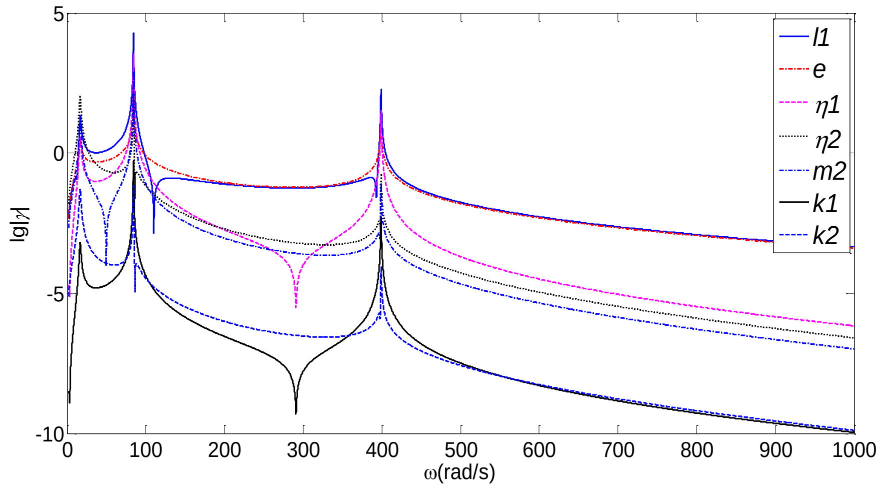

Fig. 1-1 Sensitivity curve of parameters

It can be seen from the sensitivity curve of each parameter in the diagram that the sensitivity fluctuates greatly around the second order natural frequency, which indicates that resonance is easy to occur near this frequency. The sensitivity value of the eccentricity of the exciting force and the distance between the supporting springs is larger, and the sensitivity of the mass and damping of the shell is the second, and the sensitivity of the stiffness is the minimum. Through the sensitivity analysis of the system parameters, the influence degree of different parameters on the transfer rate is seen, the parameters are sorted according to the degree of influence, and the sensitive parameters are selected to optimize the parameters, which can not only prevent the selection of unrelated parameters, but also prevent missing important parameters. The preliminary preparation for the optimal design of the compressor structure is provided. At the same time, the dynamic characteristics of the compressor vibration isolation system can be accurately evaluated by the sensitivity curve of different parameters of the force transfer rate. It provides a theoretical reference for the vibration noise reduction and optimization design of the system.

1.3 Optimization design of vibration isolation system for compressor

Optimization design is the best design scheme to determine the structure. The purpose is to reduce the amount of material, reduce the cost of the project, simplify the process and improve the structure performance of [35]. The formula of the force transfer rate derived above indicates the ratio of the amplitude of the resultant force to the excitation force of the vibration source, which means that the vibration of the vibration isolation system caused by the excitation is transferred to the base, and the better the effect of the system is the effect of the force transfer rate. Therefore, the vibration isolation system is optimized and the force transmissibility is reduced, so as to achieve the purpose of vibration reduction and noise reduction.

Compared with the traditional optimization method, the genetic algorithm has the advantages of stable operation, global convergence, no guidance and fast running speed. The genetic algorithm is used in this paper to optimize the algorithm.

1.3.1 Introduction of MATLAB genetic algorithm toolbox

The optimization design is widely used in the production practice. MATLAB provides a powerful optimization toolbox , has a variety of powerful functions to optimize the design, and also has a very convenient and practical GUI form of optimization tools.

Genetic algorithm is a method of imitating the process of biological evolution. A genetic algorithm is a population of the potential solution set of the problem, and the population is composed of individuals encoded by a certain number of genes. Each individual is an entity with a chromosome feature. The chromosome is the main carrier of the genetic material, that is, a collection of multiple genes, and its inherent expression (genotype) is a combination of some genes. It determines the external manifestation of the individual shape, [4].

At the beginning, mapping from phenotype to genotype is needed, that is, coding. Gene coding is very complicated. We usually simplify it, such as binary encoding. After the generation of the first generation population, the approximate solution is evolved from generation to generation according to the principle of survival of the fittest and the survival of the fittest. In each generation, the individual is selected according to the adaptation degree of the individual in the problem domain, and the genetic operators of genetics are used to combine, cross and mutate to represent the new population of the solution set. The process is like the natural evolution of the population, and the progeny population is more adaptable to the environment than the previous generation. The optimal individual in the last generation can be decoded and can be used as the optimal solution for the problem. Genetic algorithm includes three basic operations: selection, crossover and mutation. These basic operations have many different methods, [5].

The optimization design includes: objective function, optimization variable and constraint condition. The objective function usually selects the response of the system, such as the transfer rate, the power flow and the acceleration. The optimization variables generally choose the properties of the material, such as stiffness, damping or position size, etc. the constraints can choose the boundary conditions of the variables, and the stress and frequency can also be selected. The essence of the optimization design of the vibration isolation system is the essence of the system. It is to reduce the transmission of vibration energy to the foundation, so as to achieve the purpose of vibration and noise reduction [6].

The main operation steps of the optimization tools include: (1) select the solver solver and the optimization algorithm; secondly set the target function; (3) select the optimized parameters; (4) set the optimization options; (5) click "Start" button to solve the operation; (6) observe the running state and operation results of the solver; and I export the operation result [6].

1.4 Optimization of structural parameters of compressor

Objective function

The value of the force transfer rate of the system is an important index to evaluate the vibration characteristics of the mechanical system, which reflects the vibration isolation performance of the system. The better the performance of the system is, the better the performance of the vibration isolation system. Therefore, the optimized objective function selects the force transfer rate Tf derived from the previous chapter.

On the basis of the formula of force transfer rate of the two-stage vibration isolation model of the refrigerator compressor, the minimum objective force transfer function at 50Hz of the working frequency is taken as the optimization objective function.

$$T_f = \frac{K_2^*[K_1^{*2}l^2 + K_1^*(l_1 - l_2)m_1 e\omega^2 - 2K_1^* J\omega^2]}{K_2^* K_1^{*2} l^2 - K_2^* K_1^* (l_1^2 + l_2^2) m_1\omega^2 - K_1^{*2} l^2 m_2 \omega^2 - 2K_2^* K_1^* J\omega^2 + K_1^*(l_1^2 + l_2^2) m_1 (m_2 - m_1)\omega^4 + K_2^* m_1 J\omega^4 + 2K_1^* m_2 J\omega^4 - m_1(m_2 - m_1) J\omega^6} \quad (3\text{-}1)$$

Optimal variable

In the front of the parameters, the sensitivity analysis is carried out. When the parameters are optimized, the parameters with large sensitivity should be selected first, which can not only provide the accuracy of the optimization, but also avoid the blindness of the optimization. The parameters are selected from the analysis results: the support spacing L1, the eccentricity e, the damping loss factor ETA 1, the ETA 2 and the shell mass M2 as the optimization variables, and the value space of the variables is shown in Table 1-1.

Constraint condition

When setting the boundary conditions of the parameters, it is mainly based on the type of isolator, the maximum value of the product manual, the dimension theory and the practical experience of Engineering [41-42]. The parameters are explained: the spring support spacing is L1, as the overall distance of the bottom spring of the pump body is l=l1+l2=86.5mm, the maximum theory value is 86.5mm; the eccentricity e, the influence curve of the eccentricity to the force transfer rate shows that the reverse hour reduction is beneficial to reducing the transfer rate, and the maximum value of the eccentricity is -5.57mm and the negative number table. The eccentric position is on the other side of the center of mass; the mass of the shell is m2, according to the engineering optimization, generally increasing the thickness of the shell to improve the vibration isolation efficiency, so the value of the M2 is increased as the boundary condition; for the vibration isolator, the damping is generally increased to reduce the vibration, but the resistance to the general assembly makes the isolator not satisfied with the support. Therefore, the boundary conditions are set according to the type and function of the isolator.

Optimization mathematical model

From the preceding objective function, optimization variables and constraints, the mathematical model of the vibration isolation system parameters optimization can be obtained.

$$\min \quad f(x) \qquad (1\text{-}2)$$
$$\text{s.t.} \quad u_i \le x_i \le v_i$$

In the model, f (x) represents the objective function, namely the force transfer rate Tf, UI and VI respectively denote the lower bound and upper bound of the optimization variable.

In the MATLAB software work directory, the target function M files myfun.m and NonCon.m are created, and the system force transfer rate formula is programmed and processed into the above two m files respectively. Then the MATLAB optimization toolbox is run: the GA solver is selected in the Solver drop-down menu; the target function input: @myfun; the number of input variables: 5; the input boundary condition; the input of the nonlinear constraint function: @NonCon; the other parameters are set as the default values. Click "Start" to start to solve [43]. The results of the 51 iterations are shown in Table 1-1, and the parameter values before and after the optimization are replaced in the force transfer rate function, and the force transfer rate curve before and after optimization is shown as shown in Figure 1-2.

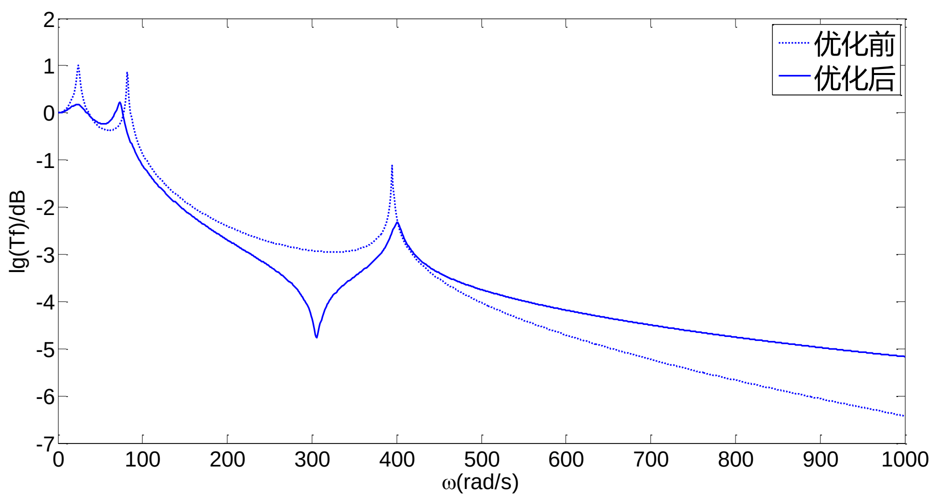

Fig. 1-2 Comparison of optimization results

Table 1-1 Data contrast of parameter optimization

Optimal variable	Spacing l1/mm	eccentricity e/ mm	Damp η1	Damp η2	Shell mass m2/kg
Variable lower bound	0	-5.57	0.001	0.1	2.5
Variable upper bound	86.5	5.57	0.1	1	5.0
Original parameter value	48.4	5.57	0.001	0.1	2.5
result	34.1	-2.13	0.016	0.887	3.5

As can be seen from Table 1-1, compared with the original parameter values, the optimized support spacing decreases, the eccentricity reverse decreases, and the shell mass increases, while the largest change is the damping, in which the spring damping increases 16 times of the original value. The rubber damping increased by 8.87 times of the original value. The optimization results correspond to the analysis results of the effect of parameter changes on the force transfer rate in chapter 2, which verifies the correctness of the theoretical modeling, which is in accordance with the actual engineering situation and shows the reliability of the optimization.

From the optimized simulation curve 3-2, it can be seen that in the middle and low frequency band, the overall force transfer rate decreases and the optimization effect is good, especially the resonance peak decreases obviously, and the resonance peak decreases by 0.7 dB / 0.5 dBU 1.1 dB, respectively. The first and second order resonance peaks are slightly shifted to low frequency. The compressor can cross the resonance frequency better, the force transfer rate between the second and third order resonance frequency decreases obviously, especially the antiresonance peak appears near the working frequency 50Hz, which is very favorable to the compressor vibration reduction, which shows the effectiveness of the optimized results. However, after the third order peak, the force transfer rate of the middle and high frequency band increases, and the optimization effect is not obvious. Excellent The result can provide data reference for the structure improvement and vibration reduction and noise reduction of refrigerator compressor.

1.5 Conclusion

The main contents are as follows: (1) in this chapter, the sensitivity of the parameters of the force transfer rate formula is analyzed firstly, and the sensitivity parameters are selected to optimize, which not only improves the efficiency of the optimization design, but also avoids the blindness of the optimization. The parameters such as support spacing, eccentricity, damping loss factor η 1, η 2 and shell mass m 2 are selected as optimization variables, and the optimal mathematical model is established with the minimum force transfer rate at working frequency as the optimization objective function.

(2) the genetic algorithm in the MATLAB optimization toolbox is used to optimize the calculation, the optimal solution of each parameter is obtained, and the contrast diagram before

and after optimization is obtained in the simulation of substitution force transfer rate formula. The support spacing and eccentricity decrease in varying degrees, the damping and shell mass increase, especially the spring damping is the largest, which is consistent with the previous analysis of the influence of the parameters on the force transfer rate, which shows the correctness of the theoretical modeling. The force transfer rate curve has been decreased in the range of power frequency, especially the third order peak value has decreased 0.7 dB ~ 0. 5 dB ~ (-1) dB respectively, especially the antiresonance peak appeared near the working frequency, the optimization effect is obvious. The effectiveness of the optimization results provides a reference for the design of vibration and noise reduction of refrigerator compressor.

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