1988

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THE THEORETICAL ANALYSIS AND EXPERIMENTAL INVESTIGATION ON THE NATURAL FREQUENCIES AND VIBRATION PATTERNS OF COMPRESSOR REED VALVES

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ABSTRACT

It is well known that the natural frequencies and vibration patterns are necessary for the computer simulation of compressor reed valve , the analyses of flow, noise and stress in the valves, and the design of backer plates. By the finite element method, this paper has analysed the free vibration of suction and discharge reed valves, and presented the vibration patterns and natureal freqencies for the first, second and third orders under the following boundary conditions: the valve plates are assumed with one end fixed and the other free, or with one end fixed and the other hinged. Through the acoustic activation to the valves, the vibration patterns for the first and second orders have been photograghed by laser hologram. There exists a good agreement between the theoretical and experimental results.

INTRODUCTION

To analyse the dynamic characteristics of compressor flexible reed valves, it is necessary to obtain the information about their natural frequencies and vibration patterns at first. Therefore, the study concerning these aspects is very important, and has been holding the attention of many experts all over the world.

Some essential data of natural frequencies and vibration patterns /1/ were reported for the mathematical simulation of compressor reed valves to predict if the valve plates quiver in operation, and are disclosed and closed punctually, and to predict their interactions with gas pulsation. The knowledge should be mastered of the natural frequency of reed valves to indentify the peak of sound pressure spectrum. If the vibration patterns are solved, the stress distribution of valve plates will be known /2/, for the stress is directly relative to the deflection curves, and for the deformed shapes of valve plate are very similar to the first order vibration pattern. The profile design of backer plates greatly affects the impact velocity and the service life of reed valves /3/. The optimal design to the backer plates of discharge valves should be that, the backer profile is identical to the first order vibration pattern of reed valve plates from the root end through the port centre, and is less curved than the pattern from the port centre through the other end.

Becouse of the structure complexity of compressor reed valves and different boundary conditions, it is very formidable to obtain their vibration patterns through analytical and experimental methods. Sands and salt crystals /4/, and hologram method /5/ were utilized in experiments to picture the vibration pattern nodes. In this paper, the finite element method and laser hologram with acoustic activation are applied to the theoretical and experimental studies on the vibration patterns and natural frequencies of reed valves.

THE FINITE ELEMENT ANALYSES

With the damping negligible, the natural frequencies and the correspondent vibration patterns can be determined by:

$$\det([K] - \omega^2 [M]) = 0 \tag{1}$$

$$([K] - \omega^2 [M]) \{\delta\} = 0 \tag{2}$$

where, [K] total stiffness matrix

[M] total mass matrix

ω natural circular frequency to be determined

{δ} vibration pattern vectors to be determined

The problem like this is named characteristic value problem in Mathematics. There exist many solution methods and the correspondent computer programmes, which are different only on the solution manners. The method in this paper is characterized for adopting a series of effective means to make rapid the convergence: For matrix [M], a consistent mass matrix was adopted, and the quantities at the diagonal line were amplified under the condition of constant total mass; and after the Cholesky's Decomposition to [M], the problem of generalized eigenvalue was changed into a problem of standard characteristic value; according to Givens-Householder's Method, a series of orthogonal transformation converted the new matrix in the standard eigenvalue equation into a triple diagonalmatrix; the QR method was applied to transform the triple diagonalmatrix into an upper triagular matrix, and all the characteristic values were at the diagonal line. The drift coordinate method was also utilized in the iterative process to shorten the time of convergence.

In this paper, the finite element analyses are carried out to the natural frequencies and vibration patterns of suction and discharge reed valves with an air compressor typed 2V-0.6/7. The layout of finite elements is shown in Fig. 1. Considering their symmetry, half of the suction valve plate and one fourth of the discharge are calculated, and divided into ten elements respectively. Each of them is isoparametric element with eight nodes. There are 53 nodes and 159 degrees of freedom in the suction valve plate, and 45 nodes and 135 degrees of freedom in the discharge valve plate.

There exist two kinds of boundary condition during the operation of suction valve plate: the plate is assumed one end fixed and the other free, or called the First Kind of Boundary Condition, if the plate is in the process from the beginning of operation to the moment it barely wraps the backer plate; and at the moment the valve plate wraps the backer plate, it is assumed one end fixed and the other hinged with point contact at node 1, or called the Second Kind of Boundary Condition. There exists only the First Kind of Boundary Condition for the discharge valve plate.

EXPERIMENTAL APPARATUS

To obtain the precise natural patterns, the laser hologram method with acoustic activation was applied to measure the vibration parameters of the tested reed valve plate, a very light and thin spring-steel plate. Becouse the acoustic excitation does not contact the tested plate, no additional mass will be brought out. Through the laser hologram, the whole distribution of vibration amplitude can be obtained with the precision in the order of wavelenghth.

The experiment was conducted with laser holographic interferometer on an apparatus with gas shockproof, as shown in Fig. 2. In Fig.2, the units numdered from 1 to 8 are the laser device and lights system, 9 is the tested plate, 10 is the holographic negative, and from 11 to 16 are the acoustic activation and vibration pick-up systems.

The tested plate 9 was installed firmly according to the two kinds of boundary condition in operation respectively. The acoustic activator 13 stimulated the plate 9 to vibrate, and the vortex flow transducer 14 sensed the vibration parameters. In order to find the accurate resonance frequency, an oscillograph was applied to monitor the exciting vibration and the actual vibration. And meanwhile the laser interferometer photographed the tested plate continuously. The holographic picture of vibration pattern at resonance was treated to make clear the interferent streak caused by the interference of the tested plate with laser. According to the order of interferent streak, we can determine the vibration amplitude, for the amplitude transmissivity is directly proportional to the exposure.

CALCULATED AND EXPERIMENTAL RESULTS

In Tables 1 and 2, we present the theoretical data by finite element method and the tested results concerning the natural frequencies of suction and discharge reed valve plates.

Table 1. The Theoretical and Experimental Results of the Natural Frequencies for Suction Valve Plate

Types of Boundary Condition	The Sources of Results	Natural Frequencies (Hz)		
		1st order	2nd order	3rd ord
The First Kind of Boundary Condition	Theoretical	24.2	93.4	178.9
	Experimental	22.8	77.7	
The second Kind of Boundary Condition	Theoretical	93.4	128.2	342.2
	Experimental	80.7	140.0	

Table 2. The Theoretical and Experimental Results of the Natural Frequencies for Discharge Valve Plate

Types of Boundary Condition	The Sources of Results	Natural Frequencies (Hz)		
		1st order	2nd order	3rd order
The First Kind of Boundary Condition	Theoretical	302.7	655.8	1261.1
	Experimental	304.0		

The computed results to the vibration patterns of suction valve plate are shown in Fig. 3, where a, b and c represent the vibration patterns for the first, second and third orders respectively under the First Kind of Boundary Condition, and b, d and e the vibration patterns for the first, second and third orders respectively under the Second Kind of Boundary Condition.

The experimental results of vibration patterns to suction valve plate are shown in Fig. 4, where a and b represent the vibration patterns for the first and second orders respectively under the First Kind of Boundary Codition, and b and c the patterns under the Second Kind of Boundary Condition.

In Fig. 5 are shown the theoretical and experimental results of vibration patterns of discharge valve plate, where a, b and c are the theoretical results for the first, second and third orders, and d is the holographic picture of the first order vibration pattern.

CONCLUSIONS

In this paper, we have descrbed theoretical and experimental methods, i.e., the finite element method and the laser hologram with acoustic activation, to analyze the natural frequencies and vibration patterns of compressor reed valves. Through these methods, we have obtained satisfactory results, and can supply the reliable and essential data necessary to the dynamic analyses of reed valves. The requirement can also be met only by the computer programme about finite element analyses if no experimental means available.

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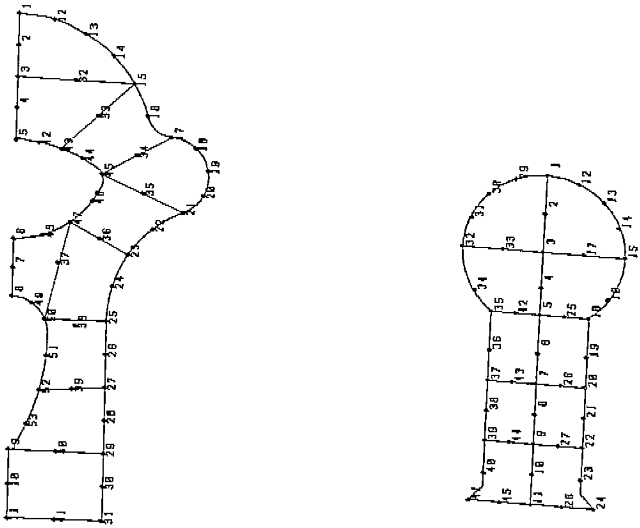
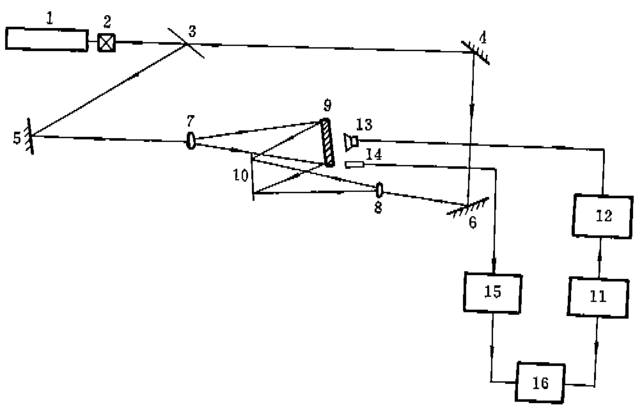


a. Suction Valve Plate

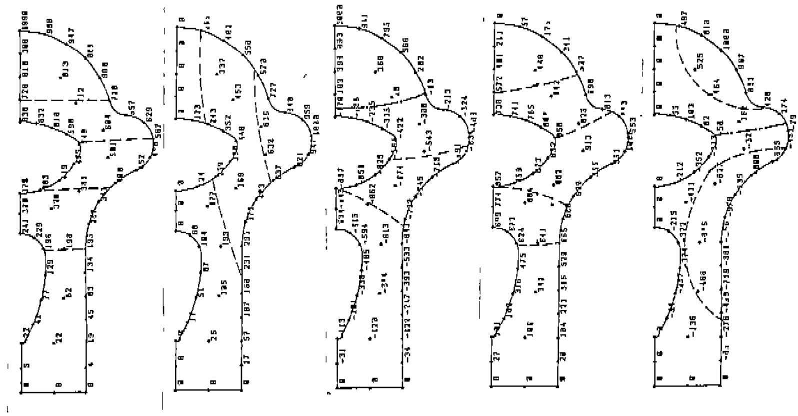
b. Discharge Valve Plate

Fig.1 The Layout of Finite Elements for Suction and Discharge Valve Plates



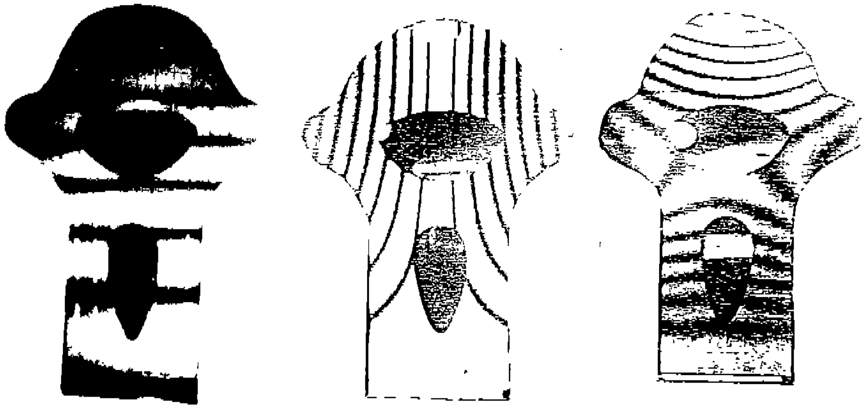
1. Laser Device 2. Switch 3. Spectroscope 4,5,6 Total Reflector 7,8 Diffussion Mirrors 9. Test Plate 10. Holographic Negative 11. XD2 Signal Generator 12. Power Amplifier 13. Acoustic Activator 14. Vibration Pick-up 15. WFC-1 Vibration Meter 16. Oscillograph

Fig. 2 The Sketch of Experimental Apparutus



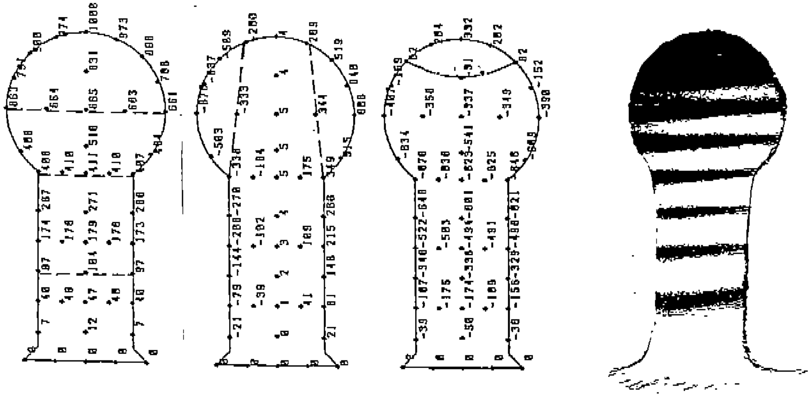
I. 24.2 Hz (a) I. II. 93.4 (b) I. 178.9 (c) II. 128.2 (d) II. 342.2 (e)

Fig.3 The Computed Results for Vibration Patterns of Suction Valve



I. 22.8 Hz (a) I. 77.7/II. 80.7 Hz (b) II. 140.0 (c)

Fig.4 The Holographic Pictures of Vibration Patterns for Suction Plate



302.7 Hz (a) 655.8 Hz (b) 1261.0 Hz (c) 304.0 Hz (d)

Fig.5 The Thoeretical and Experimental Results of Vibration Patterns of Discharge Valve Plate