Vol. 9 №. 3 Trans. Nonferrous Met. Soc. China Sep. 1999

Article ID: 1003 - 6326(1999)03 - 0566 - 06

Experimental modal analysis on damage of skeleton in brake of airplane①

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Abstract: The relation between damage and modal parameters of skeleton has been discussed and analysed. Some significant results for detecting damage have been obtained by using experimental data of ω_{di} and ζ_i. Then, the modal experiments of four type of skeleton have been performed, the modal bifurcation phenomenon is discovered. It follows that this method for studying skeleton damage is a very promising method through theoretical and experimental analysis.

Key words: damage; skeleton; modal analysis; bifurcation **Document code: A**

1 INTRODUCTION

The skeleton is a ring plate with many holes. The conventional quality control check of skeleton is mechanical strength and hardness testing, it is a destructive one and sample check can only be utilized, thus, its failure is unavoidable. Ultrasonic testing can not be performed because of sonic interfere of holes of skeleton. Now an effective method to detect flaw of skeleton is magnetic powder explore method by using high-quality explore instrument, but it is a probable estimation for skeleton damage according to magnetic powder accumulation, the remainder lifetime of skeleton and influence of residual stress on skeleton quality can not be answered yet. Due to the development of new dynamic analysis technique of fatigue, fracture and modal analysis etc, it provides a new research method for skeleton damage. In recent years, there has been a considerable demand and development to detect and locate damage in structure[1~10] by using experimental modal analysis. In this paper, the ensemble average frequence spectrums of four sorts of skeleton have been measured by using impulse excitation and the modal parameters have been obtained by using global fitting method. Through the theoretical and experimental analysis, it is evident that the method of experimental modal analysis afford promise to detect and locate skeleton damage.

2 RELATION BETWEEN DAMAGE AND MODAL PARAMETERS

According to testing, the modes of skeleton are rarely spaced in the frequency domain, each mode of skeleton can be regarded as a single degree of freedom system. From single free vibration, we may know

$$M_i\ddot{x} + C_i\dot{x} + K_i x = 0 \tag{1}$$

where M_i — ith modal mass, C_i — ith modal damping coefficient, K_i — ith modal stiffness.

Eqn. (1) can be written as

$$\ddot{x} + 2\zeta_i\omega_i\dot{x} + \omega_i^2 x = 0 \tag{2}$$

where ζ_i — ith modal damping ratio, ω_i — ith undamping natural frequency.

For the testing skeleton, ζ_i is very small and $\omega_{di} = \sqrt{1 - \zeta_i^2}\,\omega_i$, we obtain

$$\zeta_i = \frac{C_i}{2\sqrt{K_i M_i}} \tag{3}$$

$$\omega_{di}^2 \approx \omega_i^2 = \frac{K_i}{M_i} \tag{4}$$

From Eqns.(3) and (4), because skeleton

① Project supported by Powder Metallurgy Research Institute of Central South University of Technology
Received Dec.10, 1998; accepted Apr.14, 1999

is always rubbed, its mass is certainly to be a decrement and the residual stress will be produced by heat caused by friction in brake. According to theoretical analysis and testing results[7], the natural frequencies of skeleton may be increased under the influence of residual tensile stress, we obtain following results by using experimental data of modal parameters, ω_{di} and ζ_i etc.

(1) A decrease in modal frequency ω_{di} combined with a decrease in the damping ratio ζ_i of ith mode means that a loss of stiffness and a decrease of damping C_i occur in the skeleton.

(2) A decrease in modal frequency ω_{di} combined with an increase in the damping ratio ζ_i of ith mode means that a loss of stiffness, an increase of damping C_i and possibly a decrease in mass occur in the skeleton.

(3) An increase in modal frequency ω_{di} combined with a decrease in the damping ratio ζ_i of ith mode means that residual tensile stress, a decrease of damping C_i occur in the skeleton.

(4) An increase in modal frequency ω_{di} combined with an increase in the damping ratio ζ_i of ith mode means that residual tensile stress, an increase of damping C_i and possibly a decrease in mass occur in the skeleton.

3 EXPERIMENTAL MODAL ANALYSIS AND RESULTS

Skeleton was divided into four types of skeleton: A, B, C and D. Modal experiments of their new and old skeleton were performed. Firstly, the frequence spectrums of over sixty points were measured using CRAS random signal and vibration analysis system with an impact hammer and accelerometer. Then, the ensemble average frequence spectrum were obtained by adding all frequence spectrums. Finally, first six or seven order modal frequencies, damping ratios and shapes were obtained by using global, real modal and cursor line fitting method. Through comparison the experimental results are given by Tables 1 ~ 6 and Figs.1 ~ 4.

From Tables 1 ~ 6, it can be seen that the damage to the skeletons causes detectable frequency shifts. Generally speaking, the shifts tend to decrease for A type of old skeleton and the ones tend to increase for B type of old skeleton except nodal circle mode.

Table 1 Comparison of ensemble average frequency of A type skeleton

Skeleton case		Modal order						
		1	2	3	4	5	6	7
New	1	105.0	291.2	366.2	550.0	852.5	902.5	
	2	106.2	292.5	368.8	553.8	856.2	907.5	
Old	1	103.8	290.0	372.5	543.8	555.0	850.0	906.2
	2	105.0	290.0	366.2	543.8	551.2	850.0	902.5
Relative frequency of old to new skeletons		Decrease	Decrease		Mode bifurcation		Decrease	

Table 2 Comparison of modal frequency of A type skeleton

Skeleton case		Modal order						
		1	2	3	4	5	6	7
New	1	103.96	290.01	367.91	540.85	845.67	894.91	
	2	106.80	291.03	370.59	548.95	853.54	898.46	
Old	1	103.15	290.57	374.09	545.15	552.89	849.96	904.50
	2	104.96	289.56	363.81	544.21	549.92	849.95	905.15
Relative frequency of old to new skeletons		Decrease	Decrease		Mode Bifurcation			

Table 3 Comparison of modal damping ratio of A type skeleton

Skeleton case		Modal order						
		1	2	3	4	5	6	7
New	1	0.011 3	0.004 9	0.004 9	0.007 9	0.011 3	0.010 9	
	2	0.001 5	0.005 4	0.005 4	0.011 9	0.006 0	0.011 5	
Old	1	0.001 5	0.001 5	0.004 5	0.003 0	0.004 9	0.001 5	0.003 0
	2	0.006 4	0.003 9	0.006 9	0.001 5	0.006 4	0.001 5	0.004 5
Relative frequency of old to new skeletons		Decrease	Decrease		Mode bifurcation	Decrease	Decrease	Decrease

Table 4 Comparison of ensemble average frequency of B type skeleton

Skeleton case		Modal order					
		1	2	3	4	5	6
New	1	120.5	325.0	391.2	598.8	652.5	925.0
	2	122.5	328.0	385.0	603.8	650.0	932.5
Old	1	120.5	330.0	388.8	607.5	656.2	938.8
	2	127.5	335.0	368.8	613.8	641.2	945.0
Relative frequency of old to new skeletons		Increase	Increase	Decrease	Increase		Increase

Table 5 Comparison of modal frequency of B type skeleton

Skeleton case		Modal order					
		1	2	3	4	5	6
New	1	119.77	325.57	393.61	598.96	653.80	920.36
	2	122.88	330.07	386.57	604.50	649.02	931.26
Old	1	121.39	328.31	386.70	606.38	659.99	932.65
	2	128.36	333.65	369.35	616.47	641.09	943.16
Relative frequency of old to new skeletons		Increase	Increase	Decrease	Increase		Increase

Table 6 Comparison of modal damping ratio of B type skeleton

Skeleton case		Modal order					
		1	2	3	4	5	6
New	1	0.005 4	0.001 5	0.006 9	0.001 5	0.002 5	0.009 4
	2	0.003 9	0.004 9	0.004 5	0.002 0	0.002 5	0.002 0
Old	1	0.009 9	0.005 4	0.006 8	0.002 5	0.007 9	0.011 3
	2	0.007 9	0.004 5	0.001 5	0.006 4	0.001 5	0.003 0
Relative frequency of old to new skeletons		Increase	Increase	Decrease	Increase	Increase	Increase

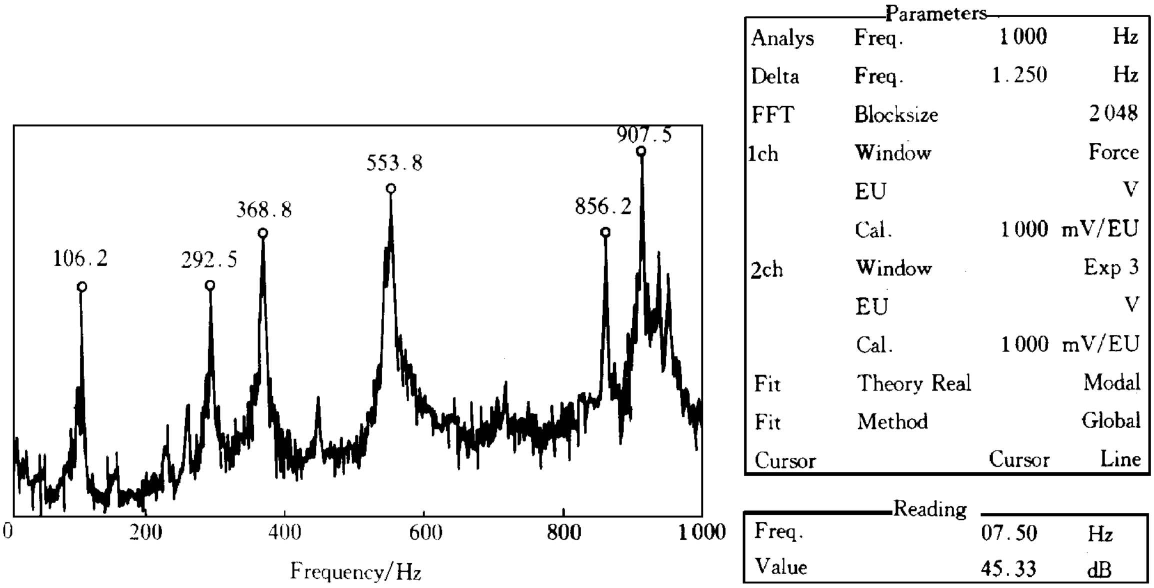

Fig.1 Ensemble average frequency spectrums of A type new skeleton

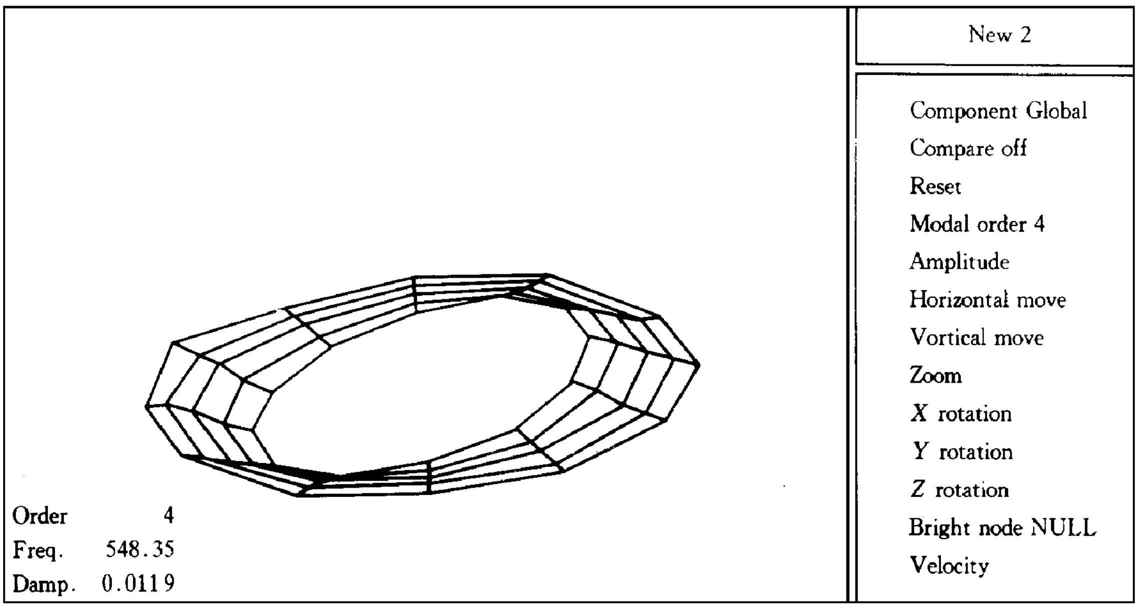

Fig.2 4th mode shape of A type new skeleton

From Figs.1 ~ 4, it can be obtained that the modal shapes do not change generally with increasing the level of skeleton damage and the modes of new and old skeletons may be paired, but the mode bifurcation occurs in A type skeleton.

4 CONCLUSIONS

The damage to the skeletons will cause detectable frequency shifts, it will provide a basis for statistical evaluation. The damage to A type skeleton occurs easily in braking process, it is coincided with above analysis, i.e. the frequency shifts tended to decrease. The mode bifurcation has been discovered in A type skeleton, it is probably caused by a change in quality with very small change of structural parameters.

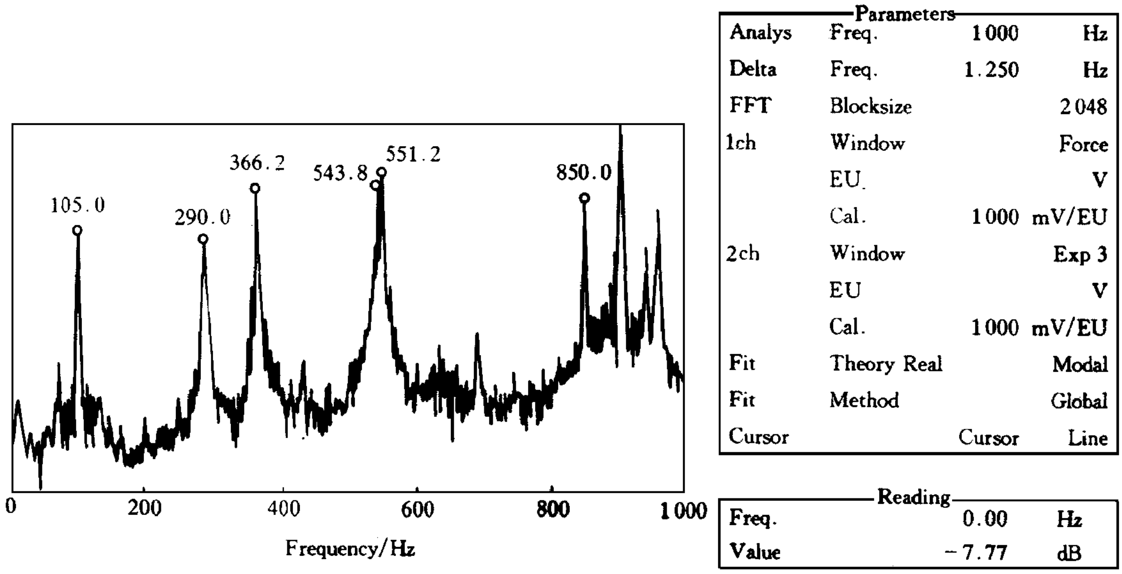

Fig.3 Ensemble average frequency spectrums of A type old skeleton

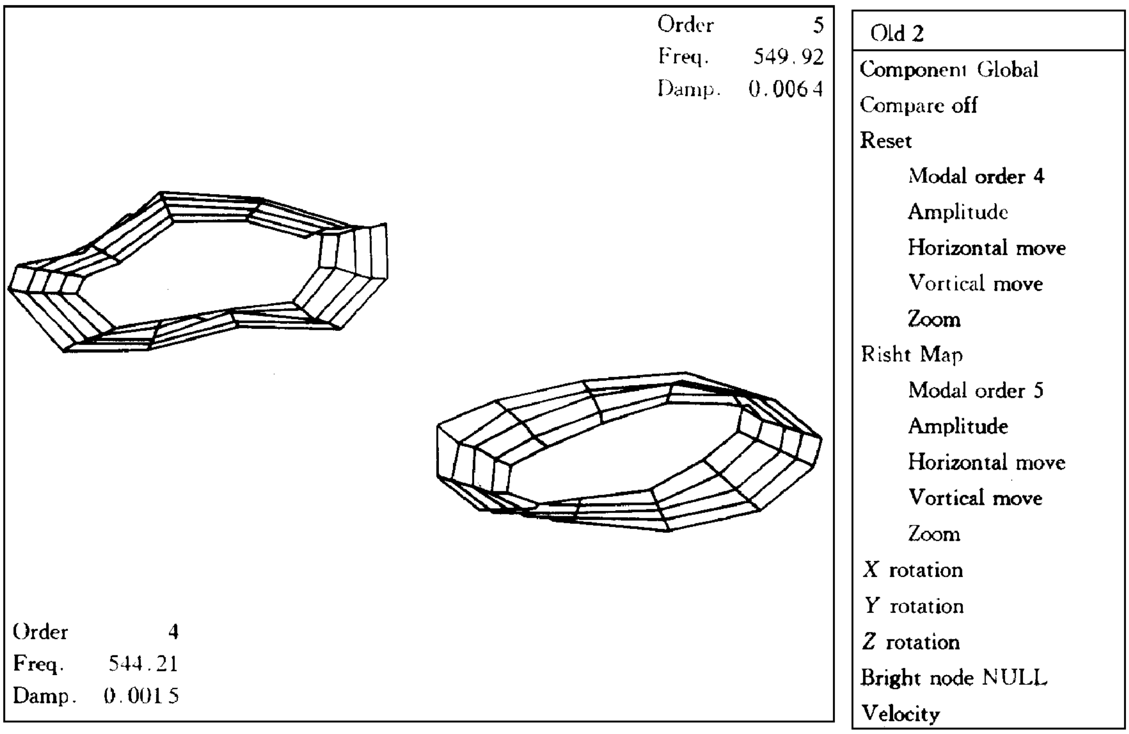

Fig.4 Mode bifurcation of A type old skeleton

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(Edited by Yuan Saiqian)