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VIBRATION FATIGUE LIFE OF ALUMINUM STIFFENED PLATE SUBJECTED TO RANDOM LOADING

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ABSTRACT

Vibration fatigue tests were carried out on four types of stiffened aluminum plate with clamped boundaries under random base excitation. Based on the strain history, the accumulation of fatigue damage of the stiffened plates was estimated by means of the rainflow cycle counting technique and the Miner linear damage accumulation model in the time-domain. Utilizing the change of natural frequencies, a nonlinear model was fitted for predicting the fatigue damage of stiffened plate and then the foregone failure criterion of reduction in natural frequency is improved. Meanwhile, The influence of section and spacing of the stiffeners on the fatigue behavior of the aluminum plate was investigated.

Keywords: stiffened plate, vibration fatigue, vibration test, fatigue life.

INTRODUCTION

Aluminum alloys are widely used in aeronautic engineering in types of plate structure. The vibration fatigue failure must be considered during the structural design process, and the fatigue property should be tested or predicted. Random vibration testing is common for estimating the vibration fatigue durability of materials and structures. The methods for predicting fatigue life can be divided into time domain and frequency domain based by the data and parameters used in the analysis. The time domain method has been accepted widely for fatigue life prediction, however, calculating the cycles of vibration loading process is very time consuming. Modal analysis has been widely used for damage evaluation by the parameters of natural frequency and some researchers pointed out that the defects in structures can be detected by the natural frequencies. Some investigations showed that the relationship between the loading cycles and the relative changes of natural frequency was non-linear, and natural frequency decreases dramatically in the end stage of fatigue life.

This paper outlines the relationship between the cumulative fatigue damage in time domain and the natural frequency changes are analyzed. The failure criterion of 5% reduction in fundamental frequency is validated by several random vibration fatigue experiments of stiffened 2024-T3 plate. The factors of crossing shape and spacing which influence the enhanced effort of the stiffeners are discussed using the results of vibration fatigue test.

RESULTS AND CONCLUSIONS

Table 1 shows the mean fatigue life (in seconds) for each group of specimen obtained in form of seconds during relevant loading duration in the time domain. It can be found that since the reduction in natural frequency is about 2.8% when the specimen failure, the threshold of 5%

can be improved. In order to get the relationship between the fatigue damage and the reduction in natural frequency, a nonlinear fitting was used. In the present work it seems that the definition of fatigue damage variable D can be described as

$$D = 1 - \left(\frac{\Delta F_n}{\Delta F_0} \right)^a \tag{1}$$

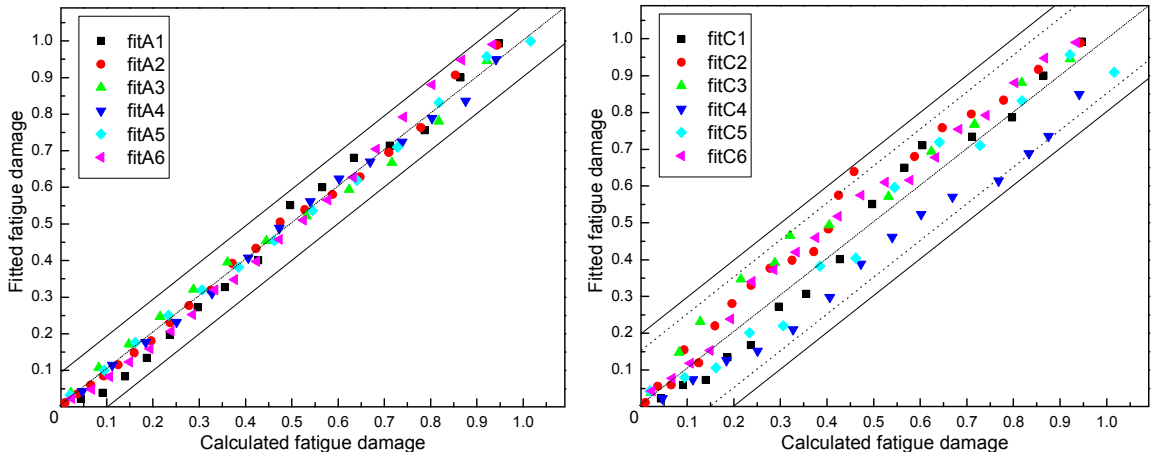
$$\Delta F_n = F_n - F_f \,;\, \Delta F_0 = F_0 - F_f \tag{2}$$

where F_n is the natural frequency of the plate in the current fatigue damage state, F_f is the natural frequency of the failed specimen, and F_0 is the initial natural frequency, undamaged plate specimen. Then the Eq.(1) can be used to predict the fatigue life of plate. Fig.1 illustrates the predicted and calculated experimental fatigue lives where a good agreement can be achieved when a=1.925 and the agreement fall due to the increased stiffeners.

The natural frequency of the stiffened plate is increased. With the same cross-sectional area of stiffener, the T section stiffened plate has longer fatigue life than L section stiffened plate due to more enhancement of T section stiffener to the stiffness of plate. Besides, the spacing between neighboring stiffeners also plays an important role in the vibration fatigue behavior of stiffened plate in the form that the smaller stiffener spacing, the longer vibration fatigue life.

Table 1 - Mean fatigue life of each groups

Group	cross section of stiffener	Spacing	Mean results by time domain	Mean results of reduction in natural frequency
A	—	—	4847s	2.76%
B	L	150mm	5026s	2.80%
C	T	150mm	5362s	2.83%
D	T	132mm	5879s	2.82%



(a) group A (b) group C

Fig. 1 - Comparison of calculated experimental results with fitted results

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