FATIGUE ANALYSIS USING RANDOM VIBRATION

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ABSTRACT

The structural requirements for components are often defined in terms of random vibration specifications. However most present analysis methods are limited to approximating the structural capabilities by using static equivalent loads. In order to achieve correlation between the requirements and the analysis, an MSC/NASTRAN post-processing program has been written to calculate the fatigue life of a structure based on a random vibration input. This program is explained with a correlating example.

INTRODUCTION

Even though most structures fail due to fatigue conditions, most structural analyses are conducted using static equivalent loads. This is due to the fact that it is difficult to define and analyze dynamic environments. Some fatigue analysis attempts have been made summing damage due to block loadings or time history load inputs. Block loadings are independent of frequency, so the dynamic response of the structure is omitted from the calculations. The time history method is a refinement of this and is usually based upon stress calculations for the loadings at different points in time without using the displacement, velocity, and acceleration values at each node as an input for the next iterative step. Thus inaccuracies are incurred if the frequency range of the dynamic environment includes any resonant frequencies of the structure. Furthermore, the input files defining the load time histories can be very large, requiring calculations for thousands of time steps.

An alternative method for calculating fatigue life is to use the frequency domain rather than the time domain. For components and sub-systems where random vibration environments are defined by specification, the Power Spectral Density (PSD) plots can be used as an input for the calculations. Thus the analyses can be directly correlated with the test specifications and -- by remaining in the frequency domain -- the dynamic effects of the structure are included in the calculations. Furthermore, the input consists of a few PSD plots rather than a lengthy time history.

Thus the RANDFAT program was written to make fatigue calculations of structures based on random vibration inputs.

PROGRAM DEFINITION

The basic concept of this program is to evaluate the fatigue life of a component based on the input of random vibration PSD plots. The fatigue life capability is defined by strain vs $2N_f$ (number of full reversal cycles) curves for the materials involved. The calculated fatigue life is defined by strain vs number-of-applied-cycles curves (referred to as the "applied ε-n" curve) of each element in the model. For large models it is sufficient to calculate these curves for specific areas in the model. The RANDFAT program computes an applied ε-n curve for each desired loading condition. Using the applied ε-n curves, the RANDFAT program calculates the cumulative damage for elements of interest. The output of the RANDFAT program are files which can be input to a postprocessing program to make contour plots of fatigue life on the finite element model.

The structure to be analyzed is first defined using the standard MSC/NASTRAN input file format. Using this input file, an MSC/NASTRAN modal or direct frequency response analysis (SOL 108 or SOL 111) is performed with the results being written to an MSC/ACCESS database. The loading is usually in the form of base excitation, but other forms of input such as point forces or pressure loads can also be used. Multiple subcases may be used, typically to define the input in the three mutually perpendicular axes. In general, it is advisable to perform a modal analysis first, and use the computed natural frequencies to help set the data on the FREQ entries for the frequency to be used. The analysis frequencies in the frequency response analysis will also be the frequencies used in the random analysis portion the RANDFAT program. To aid the user, a program was written to automatically generate the FREQ entries using modal analysis output (SOL 103).

The MSC/ACCESS database which contains the model definition and the results of the frequency response analysis serves as the primary database for the RANDFAT postprocessor. The additional input to the RANDFAT program includes the stress vs $2N_f$ cycles curves defining the fatigue characteristics of the materials in the model; the input PSDs in the terms of the break points and time duration; and the stress bandwidths for the fatigue data reduction. Results in the MSC/ACCESS database exist for each of the subcases (typically the axis of the base input) in the frequency response analysis. Within the RANDFAT program, the user assigns input PSD spectra to the appropriate subcases. Note that the user is not limited to a single input spectra per subcase, but may have as many as ten. Likewise, the user is not limited to a single input spectra per subcase, in which case the subcase is simply ignored.

For each of the input spectra, the RANDFAT program computes the output PSD in terms of σ^2/Hz for each of the requested elements in the model. After an output PSD in computed for an element, the stress RMS value of the element is obtained. This stress RMS value is used to derive a pseudo RMS vs frequency curve for the element using the equation:

$$RMS_{BAND} = C \sqrt{\frac{PSD_{BAND}}{PSD_{PEAK}}} * RMS_{TOTAL}$$

where C = User Defined Scale Factor

PSD_{BAND} = Average PSD within the Band

PSD_{PEAK} = Peak PSD for the Curve

RMS_{TOTAL} = RMS Value for the Curve

A frequency band is defined as the region between the analysis frequencies as entered in the MSC/NASTRAN FREQ entries. This results in a histogram of σ_{RMS} values at frequency intervals over the full range of the input PSDs. Note that the frequency intervals used for this step are not necessarily the same size and are based on the resonances of the structure, thus eliminating any variations due to input PSD definitions.

The frequency values corresponding to the center frequencies of the bands are multiplied by the time duration for each random input to obtain tables of ε_{RMS} vs number of cycles for each element of interest in the model. These tables are then reduced by summing the number of cycles experienced at each stress level, based on the stress bandwidths which were input. This results in the "applied ε-n (stress versus number of cycles) curve" for each element over the full range of the input PSDs. The applied ε-n curves are then combined by summing the number of cycles for each of the input PSDs for each element of interest. This results in combined applied ε-n curve tables for each element of interest in the model.

The damage for each element of interest in the structure is then calculated based on the Palmgren-Miner rule of linear cumulative damage. For each frequency band, the damage is calculated based on:

$$D_i = 2N / 2N_f$$

where 2N is from the "combined applied ε-n curve" tables and $2N_f$ is from the input definition of the material fatigue characteristics. The overall cumulative damage is then calculated from the equation:

$$D_o = \Sigma D_i$$

This information is then put into a format for making color contour plots of the overall cumulative damage, with $D_o > 1.0$ being unacceptable.

EXAMPLE

At the present time only preliminary runs have been made using RANDFAT. A speed control bracket was used for correlation of the analytical method with test results. This bracket is shown in Figure 1. The bracket is mounted to a vehicle at its top with a single bolt and at its back with a tongue inserted in a slot. For the finite element model the two mounting locations were joined together for a base excitation input. A concentrated mass representing the speed control unit was attached to the bracket using an RBE3 from the CG of the unit to its three mounting points on the arm of the bracket.

The input consisted of nine PSDs -- three each in the x, y, and z axes. These spectra were developed from road test data of the vehicle and represent a durability lifetime for the bracket. These spectra are presented in Table 1. These same spectra were used for conducting vibration tests on the bracket. Several samples each of two configurations of brackets were tested. All of the baseline configuration samples experienced cracking during the lab test; none of the modified configuration samples experienced cracking. This correlates with the results obtained from durability road tests on full-up vehicles. The baseline configuration bracket was used for the preliminary runs using RANDFAT. During vibration testing the bracket experienced cracking at the lower end of the bend where the arm joins the back. This is correlated by the output of the computer run, as shown in Figure 2.

CONCLUSIONS

The initial results of the RANDFAT program show that it is possible to determine the fatigue life of a structure using a frequency domain input. Efforts are underway to develop to is method further by analyzing other structures which were subjected to random vibration laboratory tests.

REFERENCES

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[2] Tustin, W., "The Future of Random Vibration Screening and Testing in Automotive engineering", Society of Automotive Engineers, April 1987.

[3] Shaklee, F.S., "Fatigue Life Estimation for Design Engineers", Unpublished, October 1981.

X -AXIS RANDOM VIBRATION INPUTS								
SPECTRUM X1			SPECTRUM X2			SPECTRUM X3		
Hz	g^2/Hz		Hz	g^2/Hz		Hz	g^2/Hz	
5	.0009		5	.004	0.886 g_{RMS}	5	.017	1.913 g_{RMS}
24	.003	0.722 g_{RMS}	10	.02		10	.08	
30	.11		40	.013		40	.08	
36	.003		180	.00006	423.7 Minute	55	.006	52.5 Minute
138	.00025	83.4 Minute	500	.00006		153	.001	
142	.001					500	.001	
149	.0002							
210	.00004							
500	.00004							

Y-AXIS RANDOM VIBRATION INPUTS								
SPECTRUM Y1			SPECTRUM Y2			SPECTRUM Y3		
Hz	g^2/Hz		Hz	g^2/Hz		Hz	g^2/Hz	
5	.004	5.715 g_{RMS}	5	.04	4.186 g_{RMS}	5	.0025	0.662 g_{RMS}
11	.23		14	.20		12	.013	
500	.04	26.4 Minute	58	.20	115.9 Minute	34	.013	350.7 Minute
			95	.013		71	.0018	
			500	.013		85	.0001	
						500	.0001	

Table 1. -- Random Vibration Inputs

Z-AXIS RANDOM VIBRATION INPUTS								
SPECTRUM Z1			SPECTRUM Z2			SPECTRUM Z3		
Hz	g^2/Hz		Hz	g^2/Hz		Hz	g^2/Hz	
5	.004	0.867 g_{RMS} 67.4 Minute	5	.00042	1.123 g_{RMS} 396.7 Minute	5	.04	3.698 g_{RMS} 81.2 Minute
21	.0031		14	.09		12	1.0	
29	.07		60	.002		25	.10	
35	.0028		500	.0002		123	.01	
51	.0022					500	.01	
57	.018							
66	.0019							
82	.0015							
86	.0103							
92	.0013							
110	.00101							
115	.007							
120	.00093							
235	.00022							
238	.00051							
241	.00020							
278	.00012							
500	.00012							

Table 1. -- Random Vibration Inputs -- Continued

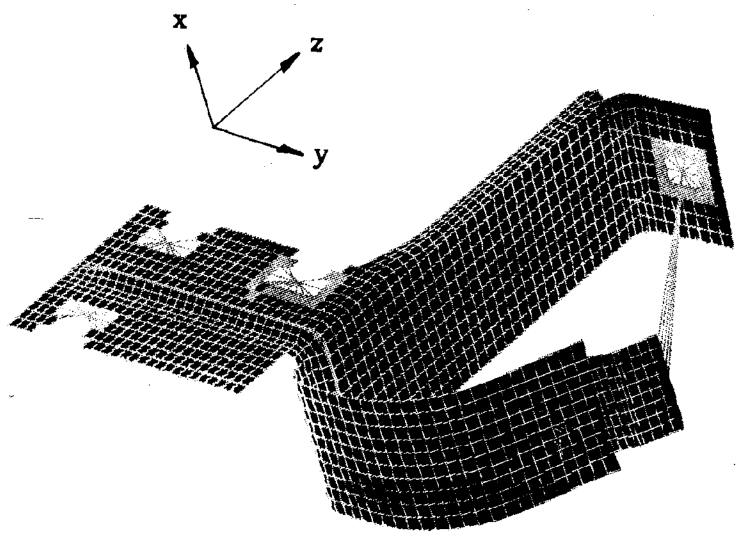

Figure 1. -- Finite Element Model of Speed Control Bracket.

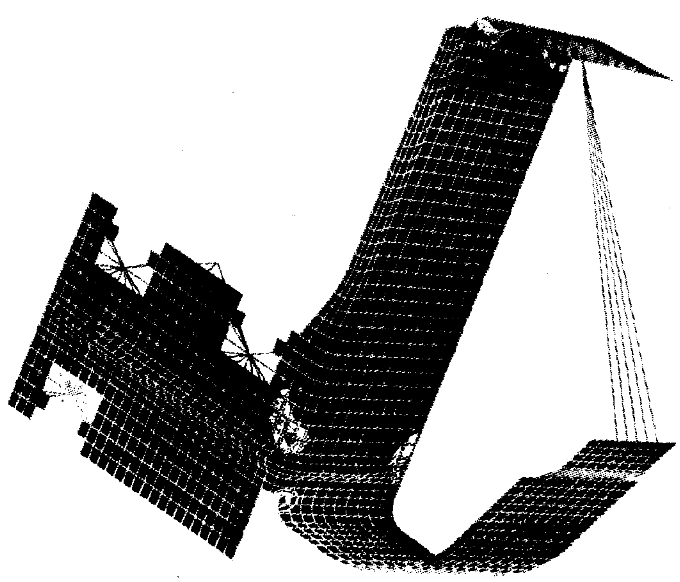

Figure 2. -- Fatigue Life Contour Plot of Random Vibration Input