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FORCED VIBRATION AS A METHOD FOR DETERMINING STRUCTURAL INTEGRITY*

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A simple, quick, and reliable test method for determining the integrity of a structure has long been a goal for engineers. The development of such a test would allow easy periodic inspection of structures and devices with testing applications ranging from production quality control to evaluation of in-service and stockpiled items. Many nondestructive testing techniques have been developed, ranging from x-ray imaging to ultrasonic inspection. Vibration studies have been used in two different ways for damage assessment. The first use of vibration for damage assessment is through the detection of reduction in the resonant frequency of a specimen due to the decreased stiffness of the specimen resulting from the damage. This approach has been used by Adams, et.al. [1].

The second application of vibration analysis to damage assessment involves the measurement of material damping as an indication of damage level. The damping is monitored periodically, with increased damping corresponding to increased damage. This approach has been used widely for damage assessment and fatigue monitoring of fiber reinforced composite materials and, to a lesser extent, for isotropic materials [2,3]. Material damping in many materials is quite sensitive to stress amplitude; and, since the stress field near a crack is significantly higher than that for an undamaged specimen, material damping is sensitive to crack nucleation and growth [4].

The current work presents a method for determining material damping from forced vibration tests by measuring the driving force required at resonance. In addition, the force measurement is broken into its various frequency components which allows the investigation of the harmonic frequency generation associated with specific flaws. The test method is still in the development stage; however, there is promise that the additional information available from the frequency analysis, such as harmonic generation, will help to identify specific flaws from the test results.

The current test method, described in [5], utilizes a beam driven at its midpoint by an electrodynamic shaker giving, in essence, a double-cantilever beam system. The beam system is excited at a resonant frequency of the test system which includes the base clamping mass with the double-cantilever beam. This test condition leads to minimum driving force since the force at resonance is due only to damping and any nonlinear response of the beam system. The driving force and base acceleration are measured using piezoelectric transducers. The test setup is shown in Fig. 1. The material damping loss factor at any resonant frequency w is given by [5] as

$$\eta = \frac{F_o(w)\left|C_1\right|}{\ddot{y}_o\left(\frac{m_b}{4}\right)\left|C_2 + \left(\frac{2m}{m_b}\right)C_3\right|} \qquad (1)$$

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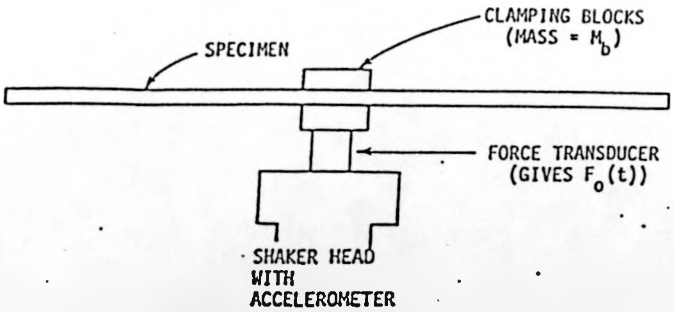

Fig. 1. Experimental setup.

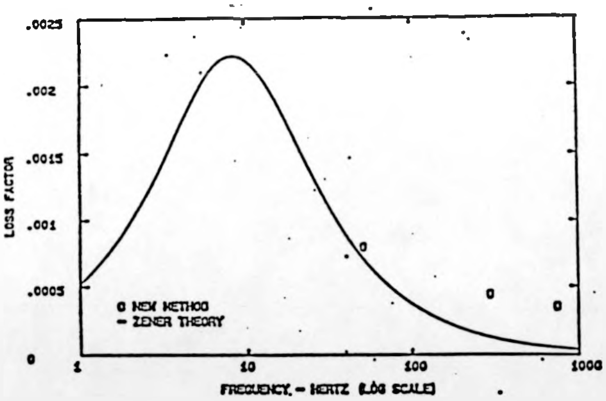

Fig. 2. Comparison of test results with Zener Theory.

where

F_0 = the magnitude of the driving force

$\ddot{y}_0$ = the magnitude of the base acceleration

$C_1 = \beta L\ (1 + \cos \beta L \cosh \beta L)$

$C_2 = (\beta L)^2\ (\sin \beta L \cosh \beta L - \cos \beta L \sinh \beta L)$

$C_3 = (\cos \beta L \sinh \beta L + \sin \beta L \cosh \beta L) - 2\beta L \cos \beta L \cosh \beta L$

m_b = the mass of the clamping base

$2m$ = the mass of the beam not contained within the base

βL = the eigenvalue of the system obtained from

$$2m_b w^2 (1+\cos \beta L \cosh \beta L) + \frac{4mw^2}{\beta L}(\cos \beta L \sinh \beta L+\sin \beta L \cosh \beta L)=0 \quad (2)$$

This test method was used to measure the material damping of an aluminum specimen for which the material damping could be modeled using the Zener Thermal Relaxation Theory [6]. The material damping was obtained from the driving frequency components of the force and acceleration signals and is plotted along with the Zener Theory predictions in Fig. 2. The comparison shows that the test results agree quite well with the theoretical predictions, showing the proper decrease in damping with frequency and are nearer the theoretical values than those obtained from other test methods. In addition, the damping of aluminum is quite low and the good comparison with theory indicates that the test method is sensitive to damping.

The effect of the tightness of the base clamping blocks on the driving force is shown in Figs. 3 and 4. The second harmonic of the driving frequency is seen to increase dramatically when the clamping blocks are loosened. This effect is due to the relative motion between the beam and the blocks. When tightly clamped there is very little relative motion and little energy loss. However, when the blocks are loosened, the relative motion and energy loss increase. This effect occurs at the second harmonic frequency because the friction between beam and block occurs twice per cycle, once against the top block and once against the bottom block. Thus, the force component at the second harmonic frequency is a good indicator of loose clamping at the driving point.

Currently, further development work using this technique is being pursued. Preliminary test results on a soft-supported, free-free beam with masses bolted near the free ends indicate that loosening of the bolted joints has a significant effect on the driving force. This effect appears to be strongest at the driving frequency and is thought to be associated with the sliding friction between the loosened mass and the beam which occurs at the driving frequency.

The measurement of the driving force required at resonance shows great promise as a nondestructive evaluation tool for investigating the integrity of structures. The test method requires only limited instrumentation and appears to be quite sensitive to loosened joints. Further work on this technique is required to determine its ability to identify flaws and damage levels for imperfections such as cracks, voids, delaminations, and loosening joints.

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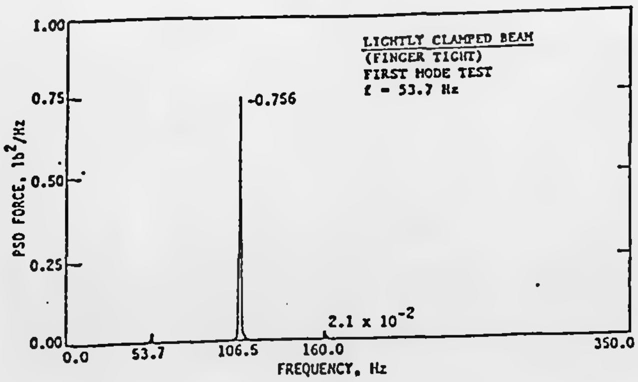

Fig. 3. Power spectrum of force signal for the loosely clamped case, mode 1.

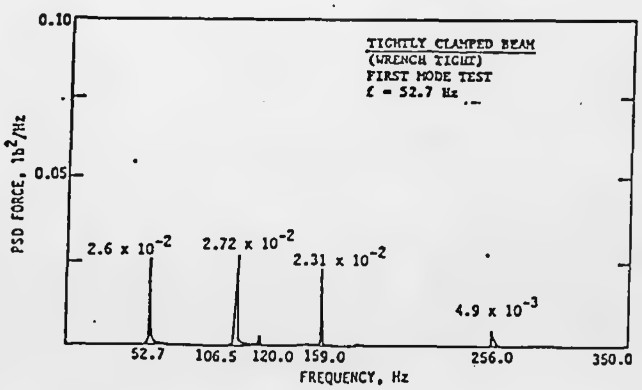

Fig. 4. Power spectrum of force signal for the tightly clamped case, mode 1.