Eight Degree of Freedom System

Introduction

An eight degree-of-freedom system has been designed and constructed to study the effectiveness of various vibration-based damage identification techniques. The system is formed with eight translating masses connected by springs. Damage is simulated by changing the stiffness characteristics of the spring joining two of the masses.

A schematic of the system is shown in Figure 1. Each mass is a disc of aluminum 25.4 mm thick and 76.2 mm in diameter with a center hole. The hole is lined with a Teflon bushing. There are small steel collars on each end of the discs. The masses all slide on a highly polished steel rod that supports the masses and constrains them to translate along the rod. The masses are fastened together with coil springs epoxied to the collars that are, in turn, bolted to the masses as shown in the Figures 1 and 2.

The undamaged configuration of the system is the state for which all springs are identical and have a linear spring constant. Two types of damage may be simulated, linear and non-linear. Either type of damage may be located between any adjacent masses in the system.

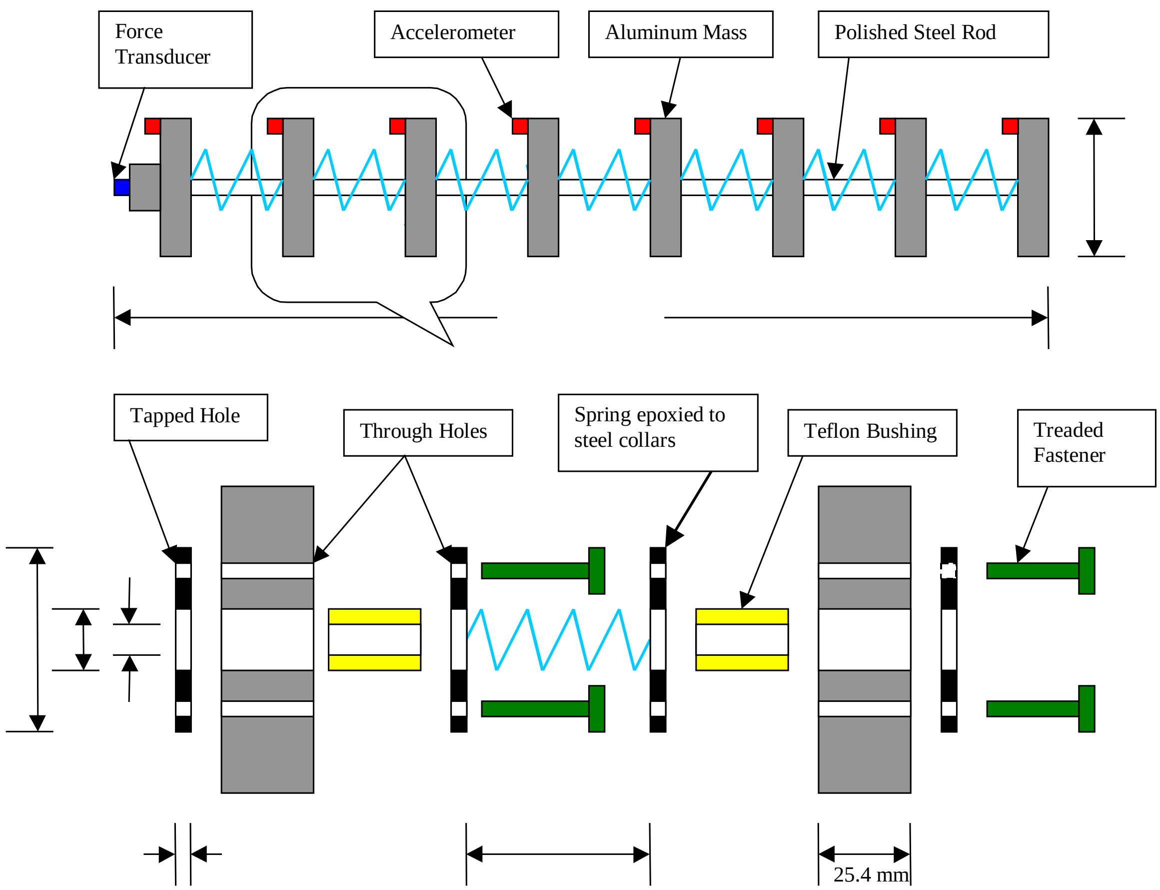

Fig. 1 Schematic diagram of the eight degree-of-freedom system.

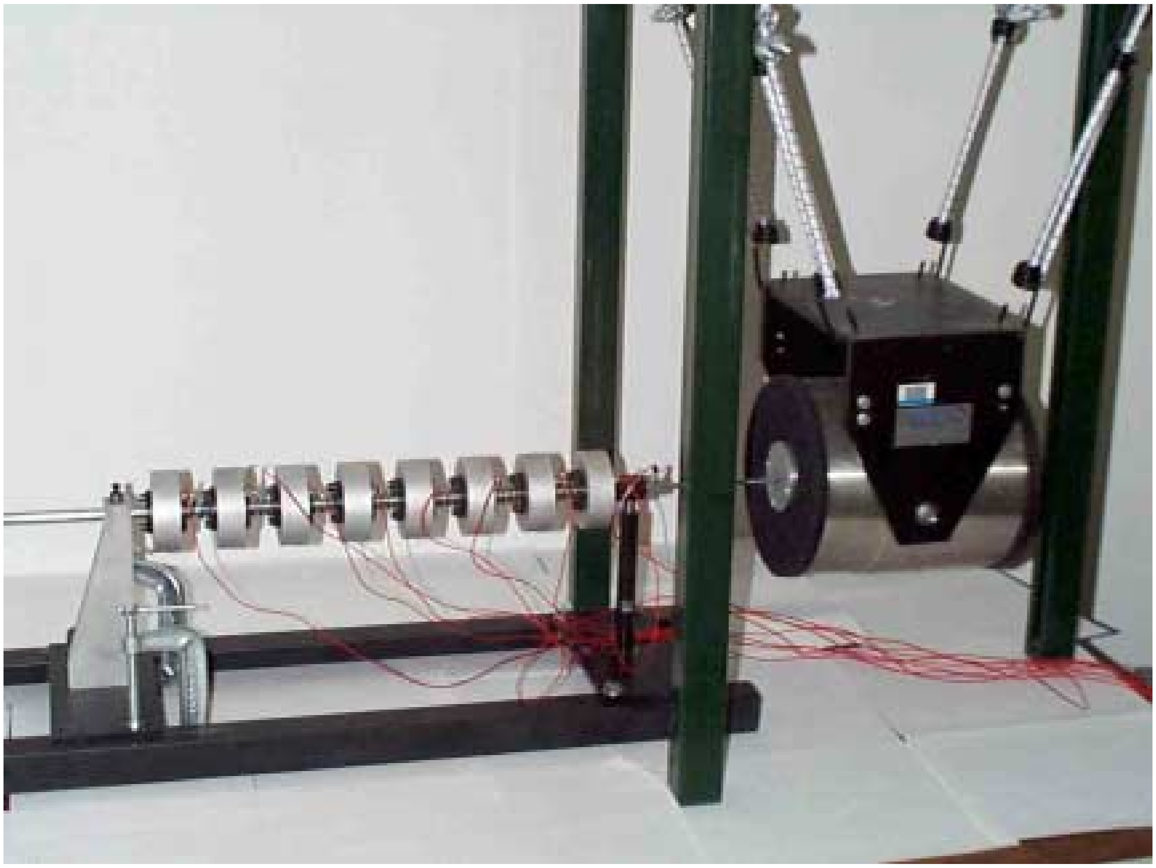

Fig. 2 Eight degree-of-freedom system attached to electro-dynamic shaker with accelerometers mounted on each mass.

1 Linear damage is defined as a change in the stiffness characteristics of the system such that the system can still be modeled by the standard linear differential equations of motion for a vibrating system after the damage. Linear damage in the model is simulated by replacing an original spring with another linear spring which has a spring constant less than that of the original. The replacement spring may be located between any adjacent masses, and thus simulate different locations of damage. The replacement spring may have different degrees of stiffness reduction to simulate different levels of damage.

2 Non-linear damage is defined as an occurrence of impact between two adjacent masses. It is simulated by placing rods (impactors) on one mass that limit the amount of motion that mass may move relative to the adjacent mass. Figure 3 shows the hardware used to simulate non-linear damage. When the distance between mass and the ends of the rods is equal to the initial clearance, impact occurs. This impact simulates damage caused by spring deterioration to a degree which permits contact between adjacent masses, or in a simplified manner, the impact from the closing of a crack during vibration. The degree of damage is controlled by changing the amount of relative motion permitted before contact, and changing the hardness of the bumpers on the impactors.

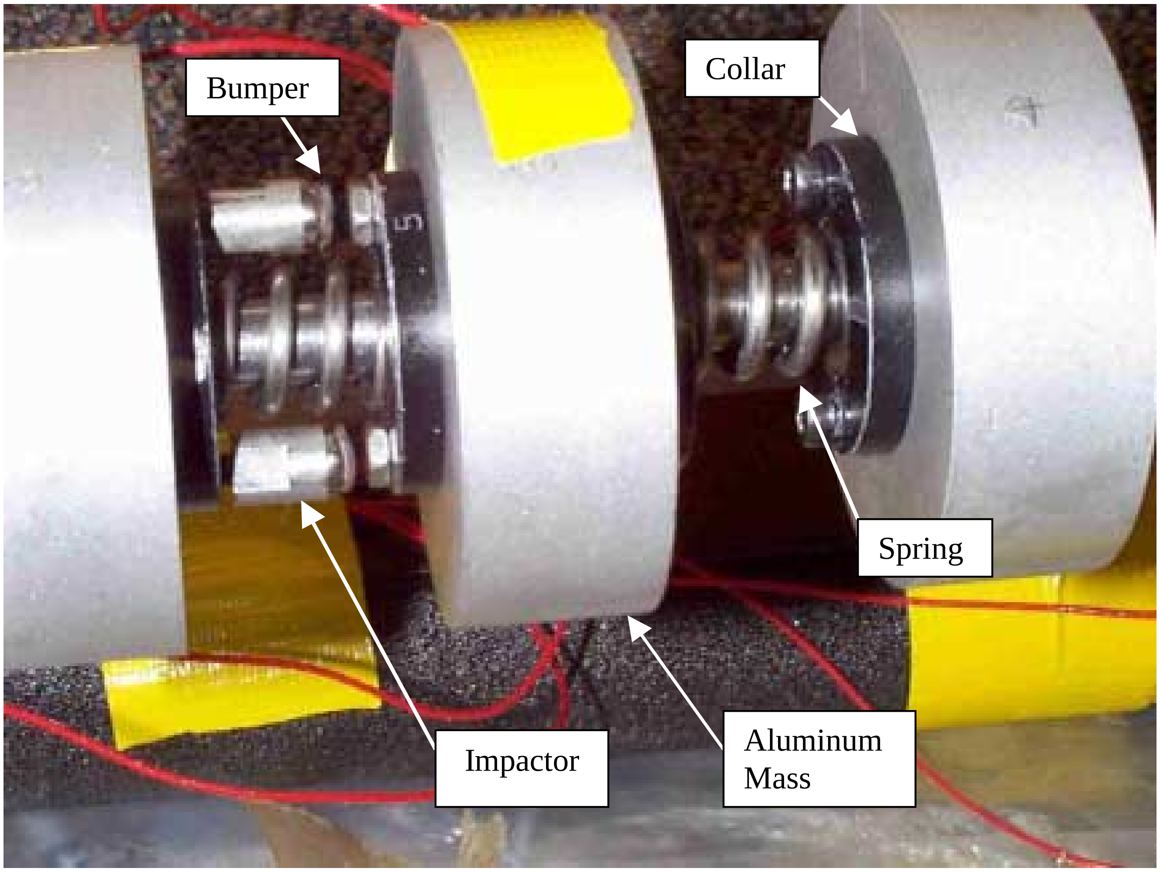

Fig. 3 Impactors and bumpers used to simulate nonlinear damage.

The nominal values of the system parameters are as follows:

Mass 1: 559.3 grams (This mass is located at the end where the shaker is attached. It is greater than the others because of the hardware needed to attach the shaker.)

Masses 2 through 8: 419.4 grams

Spring constants:	56.7 kN/m	(322 lb/in)	(undamaged)
	43.0 kN/m	(244 lb/in)	(24% stiffness reduction)
	49.0 kN/m	(278 lb/in)	(14% stiffness reduction)
	52.6 kN/m	(299 lb/in)	(7 % stiffness reduction)

Spring locations are designated by a sequential number with the spring closest to the end of the system where the excitation is applied designated as “No. 1.”. The “damaged” spring location is given by a number, counting from the excitation end.

Damping in the system is caused primarily by Coulomb friction. Every effort is made to minimize the friction through careful alignment of the masses and springs. A common commercial lubricant, Tri-Flo, is applied between the Teflon bushings and the support rod.

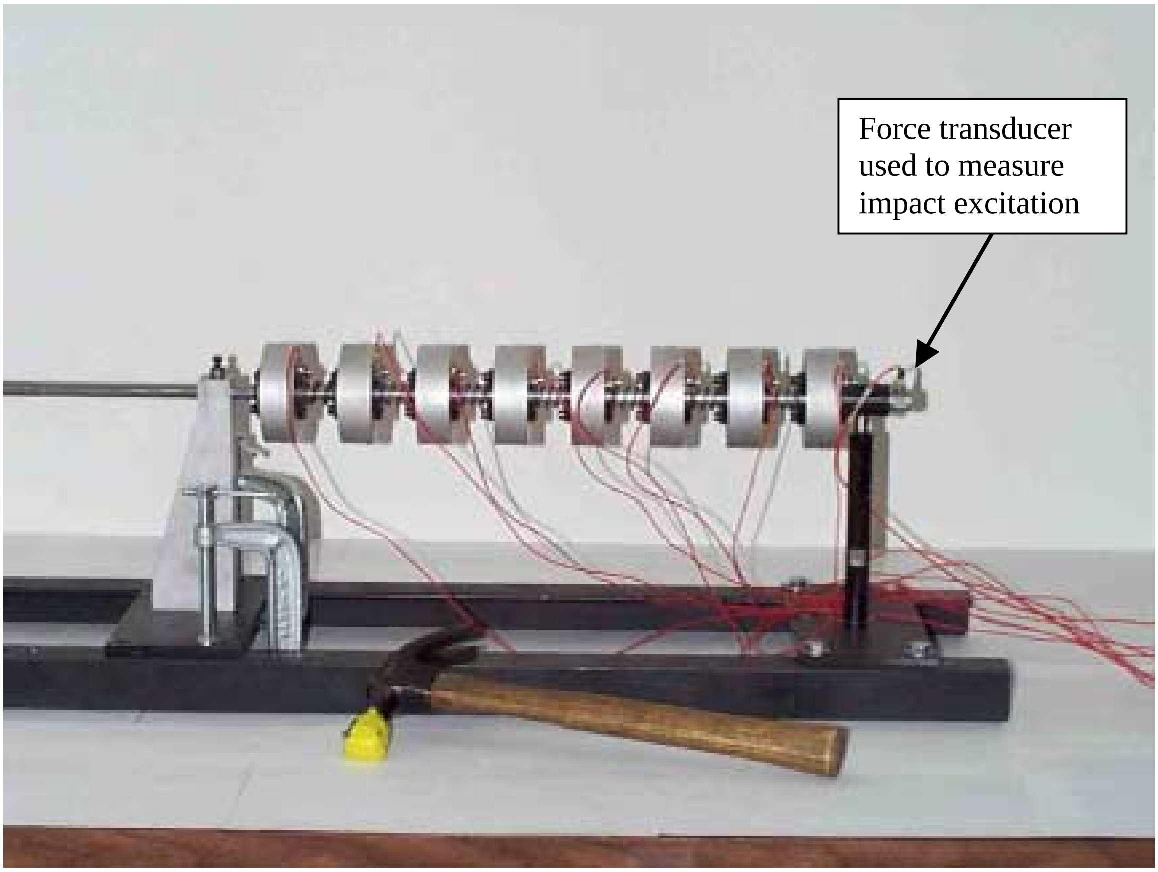

Fig. 4 Eight degree-of-freedom system shown with hammer used to apply impact excitation.

Measurements made during damage identification tests are the excitation force applied to mass 1 and the acceleration response of all masses. Excitation is accomplished with either an impact hammer (shown in Figure 4) or a 215-N (50 lb) peak force electro-dynamic shaker (Figure 2).

The data acquisition equipment used in this study and shown in Figure 5 was a Hewlett- Packard 3566A data acquisition system. This system is composed of a model 35650 mainframe, 35653A source module, 4 35653A 8-channel input modules (which provided power for the accelerometers and performed an 8 bit A/D conversion of the transducer signals). A 35651C signal-processing module performs the necessary FFT calculations. A laptop computer was used for data storage and as the platform for the software for controlling the data acquisition system. The force transducer used was a PCB type 204 (nominal sensitivity of 100 mv/lb), and the accelerometers were Endevco type 2251A-10 (nominal sensitivity of 10 mv/G).

Table I shows the data that have been obtained and used to study the various damage identification methods. Each file is a universal data file (type 58) containing the frequency response functions, input power spectral density, response power spectral densities, cross-power spectra and coherence functions. If multiple measurements were averaged, all spectral functions are the averaged quantities. The final, windowed time history is also stored in these files.

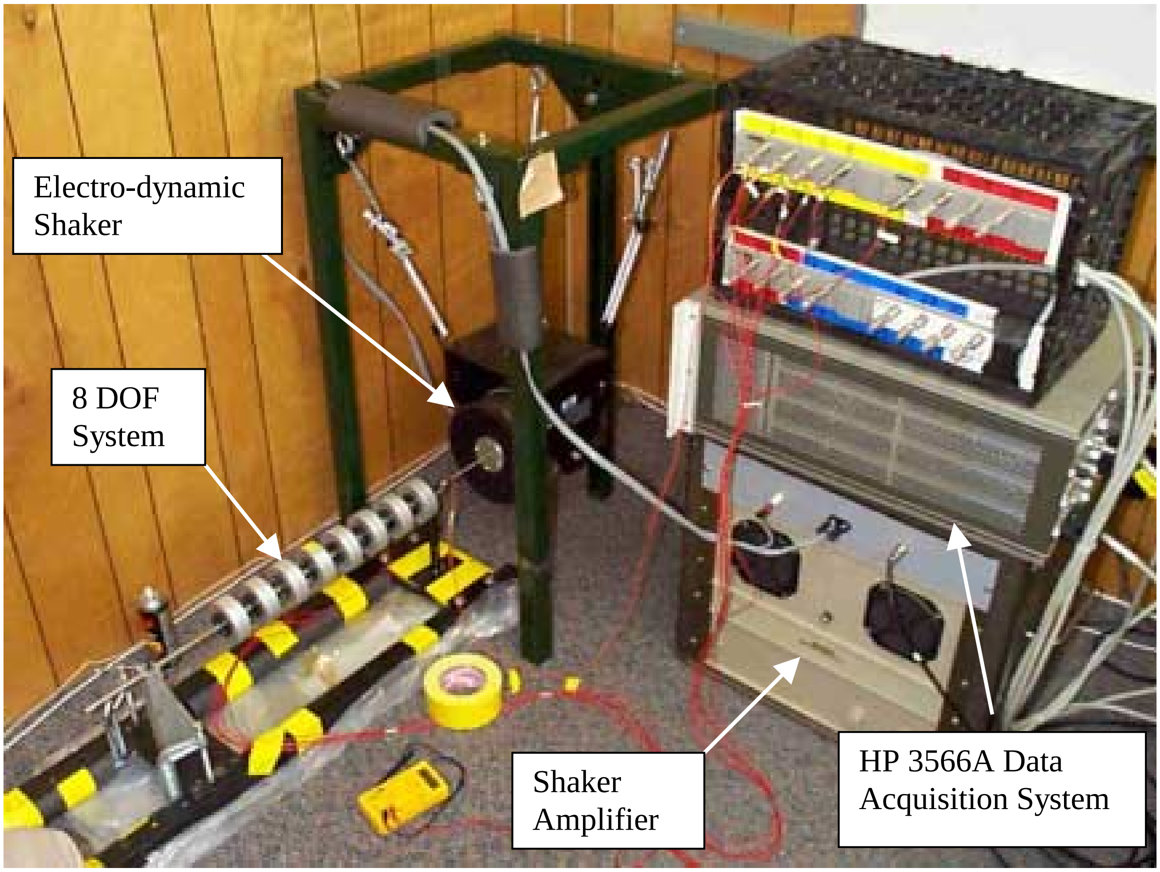

Fig. 5 Data acquisition system.

TABLE I

DATA FILES OBTAINED FROM THE EIGHT DOF SYSTEM

Filename	Contents of File				
	No of Tests	Damage Description	Test Data File	Type of Excitation[1]	Notes[2]
Jan298m1	1	Undamaged	Jan298m1	Impulse	Window: Uniform
Feb198	8	Undamaged	Feb198u4	Random, 3 v	Window: Hanning No. of averages: 40
			Feb198u3	Random, 4 v	
			Feb198u2	Random, 5 v	
			Feb198u1	Random, 6 v	
		14% damage at Location 5	Feb198d5	Random, 3 v	
			Feb198d8	Random, 4 v	
			Feb198d9	Random, 5 v	
			Feb198d10	Random, 6 v	
Apr23pr	10	Undamaged	Apr23pr1	Impulse	Window: Uniform No. of averages: 10
			Apr23pr2		
			Apr23pr3		

			Apr23pr4		
			Apr23pr5		
		14% damage at Location 5	Apr23pr6	Impulse	
			Apr23pr7		
			Apr23pr8		
			Apr23pr9		
			Apr23pr10		
Non_linear_ undam	10	Undamaged	r7_15u5a.unv	Random, 3 v	Window: Uniform Test date: 7/15/98 No. of averages: 10
			r7_15u5b.unv	Random, 3 v	
			r7_15u5c.unv	Random, 3 v	
			r7_15u5d.unv	Random, 3 v	
			r7_15u5e.unv	Random, 3 v	
			r7_15u5f.unv	Random, 5 v	
			r7_15u5g.unv	Random, 5 v	
			r7_15u5h.unv	Random, 5 v	
			r7_15u5i.unv	Random, 5 v	
			r7_15u5j.unv	Random, 5 v	
Non_linear_ dam1	8	Damaged. Impactor at location 5	r7_15d5a.unv	Random, 3 v	Test date: 7/15/98 Window: Uniform No. of averages: 10 See notes 3,4
			r7_15d5b.unv	Random, 3 v	
			r7_15d5c.unv	Random, 3 v	
			r7_15d5d.unv	Random, 3 v	
			r7_15d5e.unv	Random, 3 v	
			r7_15d5k.unv	Random, 5 v	
			r7_15d5l.unv	Random, 5 v	
			r7_15d5m.unv	Random, 5 v	
Non_linear_ dam2	7	Damaged. Impactor at location 5.	r7_15d5n.unv	Random, 5 v	Window: Uniform No. of averages: 10 See notes 3,4
			r7_15d5o.unv	Random, 5 v	
			r7_15d5p.unv	Random, 5 v	Window: Uniform No. of averages: 10 See notes 3,5
			r7_15d5q.unv	Random, 5 v	
			r7_15d5r.unv	Random, 5 v	
			r7_15d5s.unv	Random, 5 v	
			r7_15d5t.unv	Random, 5 v	

1. If the excitation is random, the voltage to the shaker supplied by the HP source module is also shown.

2 The instrument set-up parameters are as follows unless noted in this column.

Maximum frequency	200 Hz
Number of frequency lines	1600
Record length	8 sec
Sample rate	500 Hz
Number of data points	4096

3 Tip of impact rod has a soft rubber cover about 2.0 mm thick.

4 Initial clearance of the rod and mass is about 0.2 mm (1/4 turn from contact).

5 Initial clearance of the rod and mass is about 0.4 mm (1/2 turn from contact).