SHOCK AND VIBRATION RESPONSE SPECTRA COURSE
Unit 5. Nonstationary Random Vibration

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Automobile Example

Consider that a vendor is developing a GPS navigation system for rental cars. The GPS system interfaces with a computer mounted underneath the dashboard. The computer has a small display screen with superimposed road maps so that the driver can navigate to his or her destination.

The navigation computer must be designed to withstand vibration. The engine, transmission, and aerodynamic effects are each sources of vibration. Nevertheless, the dominant source is vibration transmitted from the road, through the tires and suspension, and into the vehicle chassis.

Appropriate vibration test levels must thus be derived. The vendor begins by searching for reference data in MIL-STD-810E, SAE standards, and other sources. Although some useful data is available, the vendor reaches the inevitable conclusion that he must take field measurements to establish the maximum expected vibration level for his specific product.

The vendor thus mounts accelerometers inside a test car adjacent to the navigation system mounting location. A data acquisition system is used to monitor the data. A test driver then drives the car through a variety of roads, including city streets and highways.

What type of vibration is expected? The data will probably show that vibration is random. An exception might occur if a particular natural frequency is excited. This would be resonant excitation. The natural frequency would have a sinusoidal time history response. Even so, the amplitude of the sinusoid might vary in a somewhat random manner. For simplicity, consider that the response will be random vibration.

The next question is whether the random vibration "characteristics" vary with speed, road conditions, total vehicle weight, or other variables. The amount of variability will affect the amount of data which must be collected and analyzed.

A possible outcome is that the character of the random vibration might be reasonably consistent as the vehicle travels at 60 mph down a particular interstate highway. On the other hand, the character could vary considerably as the vehicle experiences stop-and-go driving over a city street filled with potholes, railroad tracks, and construction detours.

Definition

For simplicity, consider that random vibration can be "characterized" in terms of its statistical properties, such as mean value, standard deviation, and kurtosis.

The random vibration is "stationary" if these statistical properties remain constant with time. Otherwise, it is "nonstationary."

Stationary vibration is an idealized concept. All vibration is ultimately nonstationary. Nevertheless, certain types of random vibration may be regarded as reasonably stationary.

For example, the vehicle in the previous example experiences stationary vibration as it travels at a constant speed of 60 mph down a flat interstate highway. Or at least the vibration is stationary as long as the vehicle remains under those conditions.

The vibration during the stop-and-go city driving is clearly non-stationary, however. The vehicle experiences a series of transient vibration events as it crosses railroad tracks, encounters potholes and other obstacles. Transient vibration is nonstationary.

Rocket Vehicle Example

A rocket vehicle clearly experiences nonstationary vibration during its powered flight. A sample acceleration time history is shown in Figure 1.

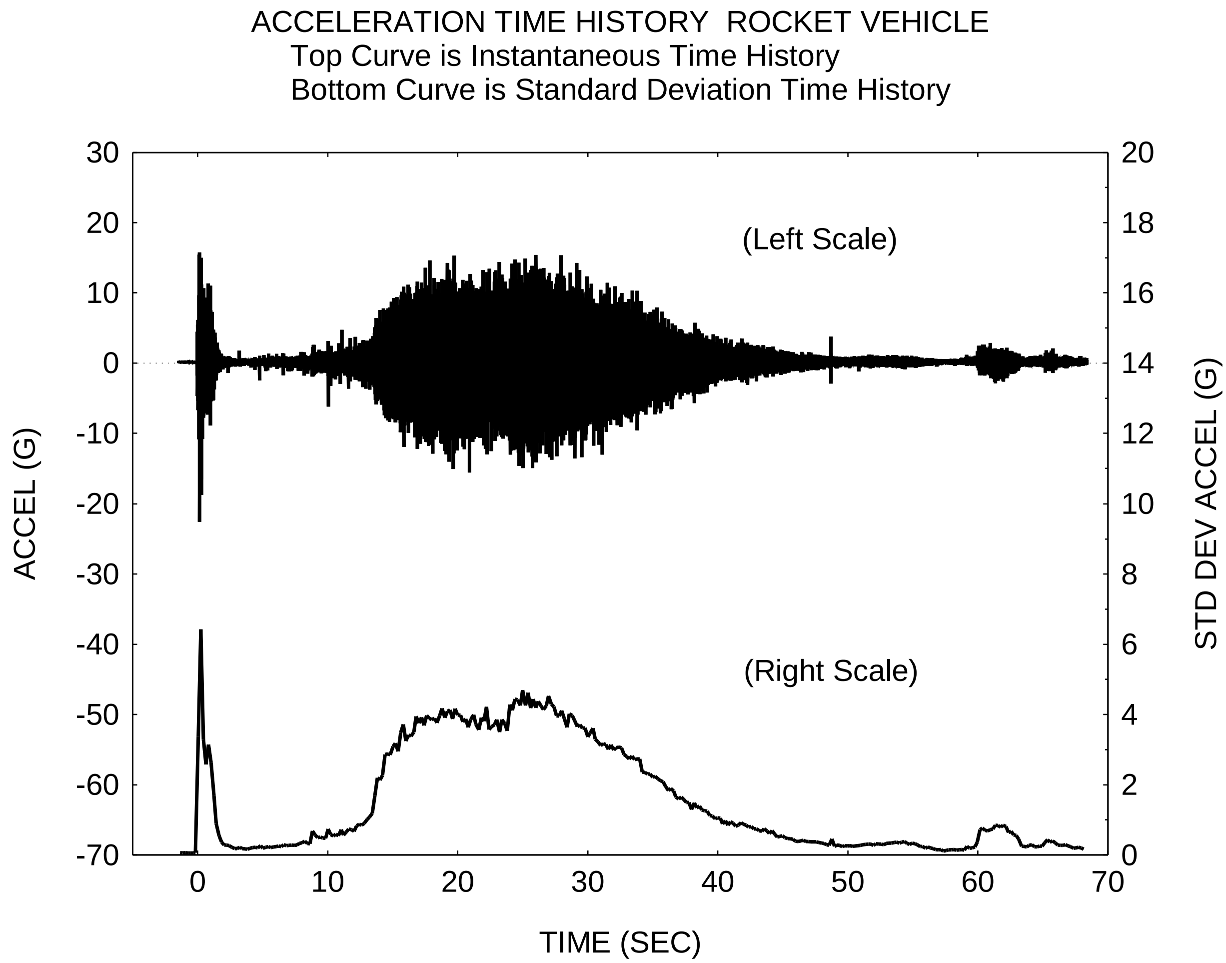

Figure 1.

Note that Figure 1 is a double-Y plot which contains two time history curves. The upper curve is an instantaneous time history, as measured directly by the accelerometer. The bottom curve is a standard deviation time history. For this example, a standard deviation value was calculated for every 0.2 second interval.

There are several reasons for computing a standard deviation time history.

1. An instantaneous time history may have well over 100,000 data points. Plotting this complete set may be impractical depending on the available computer hardware and graphing software. On the other hand, the standard deviation calculation can reduce this set to a 100 or so points. Thus, the standard deviation time history is a "data reduction tool."

2. The standard deviation time history can be used to check whether a signal is stationary. The example in Figure 1 is clearly nonstationary judging from the instantaneous time history. Nevertheless, there may be other cases where the distinction is subtle.

3. The standard deviation time history can be used to clarify sinusoidal signals which are masked by random vibration. The standard deviation of a sine function is 0.707 times the peak value. On the other hand, the standard deviation of random vibration may be 0.30 times the peak value. Thus, the standard deviation calculation favors sine vibration.

Qualitative Description of the Rocket Example

The acceleration time history in Figure 1 is measured data from a ground-launched rocket vehicle. The rocket experience motor ignition vibration and launch acoustics effects during the first few two seconds.

Thereafter, the vibration level decays to a relatively benign level for several seconds. During this phase, the rocket is traveling at a subsonic speed. The main vibration source at this time is the motor burn.

At 14 seconds, the vibration level abruptly increases. The vehicle is accelerating through the transonic velocity. Shock waves form around the vehicle. Furthermore, the vehicle passes through its "maximum dynamic pressure" condition. Thus, aerodynamic buffeting effects become the dominant vibration source. The aerodynamic effects continue until about the 40 second mark.

The motor burn ends near the 60 second mark. Note that the vehicle has attitude control thrusters. The thrusters use bursts of nitrogen gas to correct the orientation of the vehicle. The thrusters were the main source of vibration from 60 to 65 seconds.

Homework

1. The file: rocket.txt is included. This is the data from Figure 1. Use program maxfind.exe to check the descriptive statistics of the file. Note the number of samples. Judge whether your graphics program is capable of plotting the instantaneous time history. If so, plot the data. Otherwise, proceed to the next problem.

2. Program sstt.exe can be used to generate a standard deviation time history. The convention is:

```
sstt rocket.txt 0.2
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Note that the filename is specified in the command line. The number 0.2 directs the program to calculate a standard deviation time history for every 0.2 second interval. This number can be varied.

Actually, program sstt.exe generates three output files:

sa.dat - mean value vs. time
ss.dat - standard deviation vs. time

s.dat - four columns: time, mean, std dev, RMS.

The homework problem is to practice plotting these files. Also, experiment with various time interval values. For example, change 0.2 to 0.1 and repeat the calculation.

3. Is kurtosis a useful parameter for evaluating nonstationary random vibration? Recall the kurtosis value from problem 1.

4. Use program generate.exe to synthesize a white noise time history.

   Set the duration to 12 seconds.
   Use a sample rate of 500 samples per second.
   Set the standard deviation value to 1.
   Call the output file: white.out

   Now use program sstt to calculate the standard deviation time history of the white noise time history. Use an interval of 1.

```
sstt white.out 1.
```

   Does the standard deviation time history tend to shown that the white noise time history is stationary or nonstationary? For the purpose of this problem, assume that the signal is stationary if the standard deviation values are within, say 20% of one another.