SHOCK AND VIBRATION RESPONSE SPECTRA COURSE
Unit 27. Sine Identification and Removal

By Tom Irvine
Email: tomirvine@aol.com

Introduction

Previous Units have given methods for identifying the amplitude and frequency of sine functions in measured data.

One method is the direct inspection. Another method is the Fourier transform.

A third method is a curve-fit method that is performed in the time domain. This method is useful for identifying the amplitude, frequency, and phase angle of a sine function. It is more accurate than either the direct inspection method or the Fourier transform.

Nevertheless, the curve-fit method requires initial estimates of the frequencies. Thus, it can be used in conjunction with the direct count or Fourier methods.

The time-domain curve-fit method is also useful for removing spurious sine signals from data. These spurious signals may be due to ground loops, eddy currents, and other electrical interference effects. In addition, analog tape records often introduce spurious sine signals.

The purpose of this Unit is to demonstrate the time-domain curve-fit method.

Method

The method is semi-automatic. The user must estimate the sine frequency, or frequencies. A computer program then uses random number generation to determine the best fit in terms of amplitude, frequency, and phase.

The steps are in summary:

1. The user estimates one or more sine frequencies. The user also specifies the number of iterations.
2. The computer program reads in the measured data signal and calculates its standard deviation amplitude.
3. The program generates a trial amplitude, frequency, and phase angle using a random number routine.
4. The program generates a trial signal based on the parameters in step 3.
5. The program subtracts the trial signal from the measured data signal and computes the error.
6. The program repeats steps 2 through 5 many times per the user's initial instructions.
7. The program then selects the amplitude, frequency, and phase angle which gave the lowest error.

The above steps are implemented in program sinefine.exe.

As an important note, this method works best when the measured data has a sine function with fairly constant amplitude. Also, it is appropriate for small segments of data, with less than 10,000 data points. These guidelines are not absolute requirements, however.

Example 1

Recall the sine.txt file from Unit2A. Again, this is measured data taken on a floor adjacent to a wafer polishing machine in a semiconductor facility. The measured time history is shown in Figure 1.

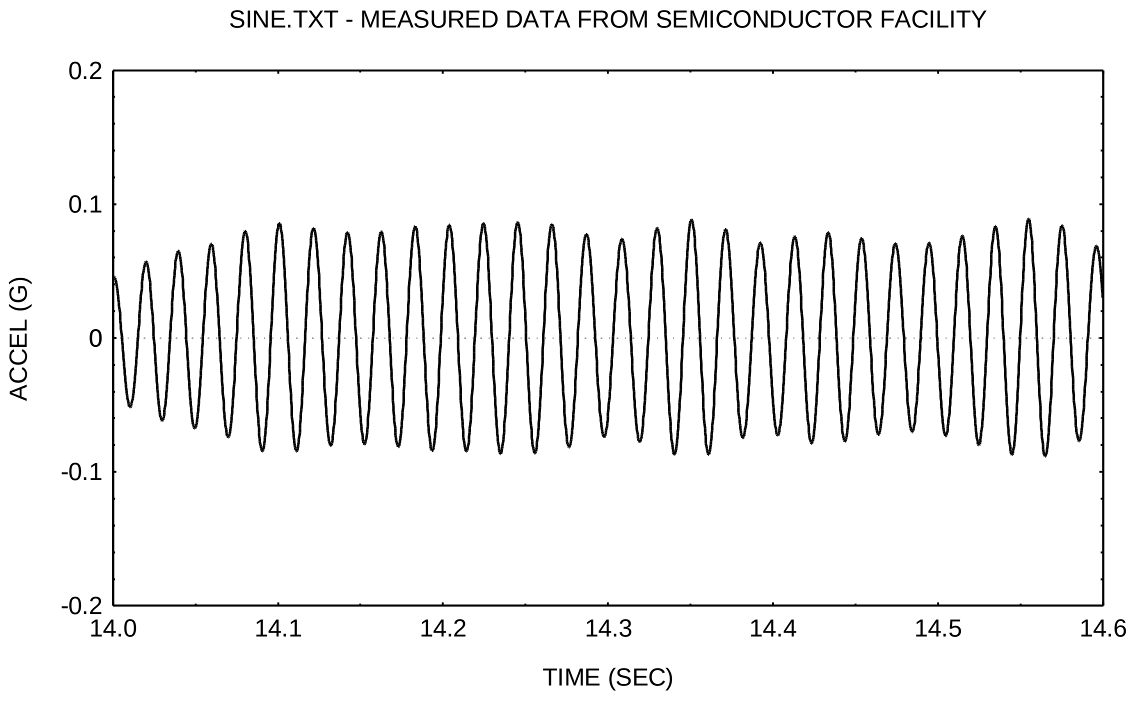

Figure 1.

The dominant frequency is approximately 50 Hz, as estimated by counting the peaks and then divided by the duration. Use the curve-fitting method to determine the amplitude, frequency, and phase angle.

The following estimate is thus obtained using program sinefind.exe.

$$y(t) = A \sin\left(2\pi f\, t - \phi\right)$$

where

$A = 0.0812$ G

$f = 48.381$ Hz

$\phi = 6.173$ radians

(1)

The input parameter to program sinefind.exe were:

40000 trials per frequency,
nominal frequency = 50 Hz with a tolerance of ±5 Hz.

Equation (1) is shown superimposed on the sine.txt time history in Figure 2. The agreement is good. The error signal is shown in Figure 3.

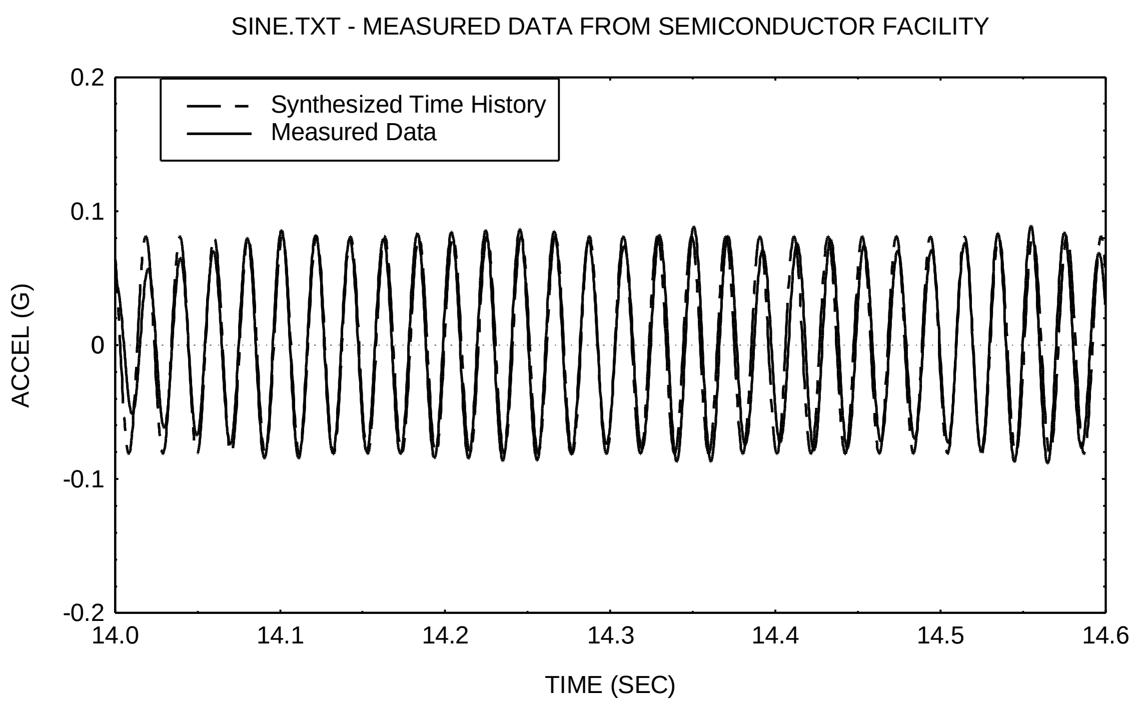

Figure 2.

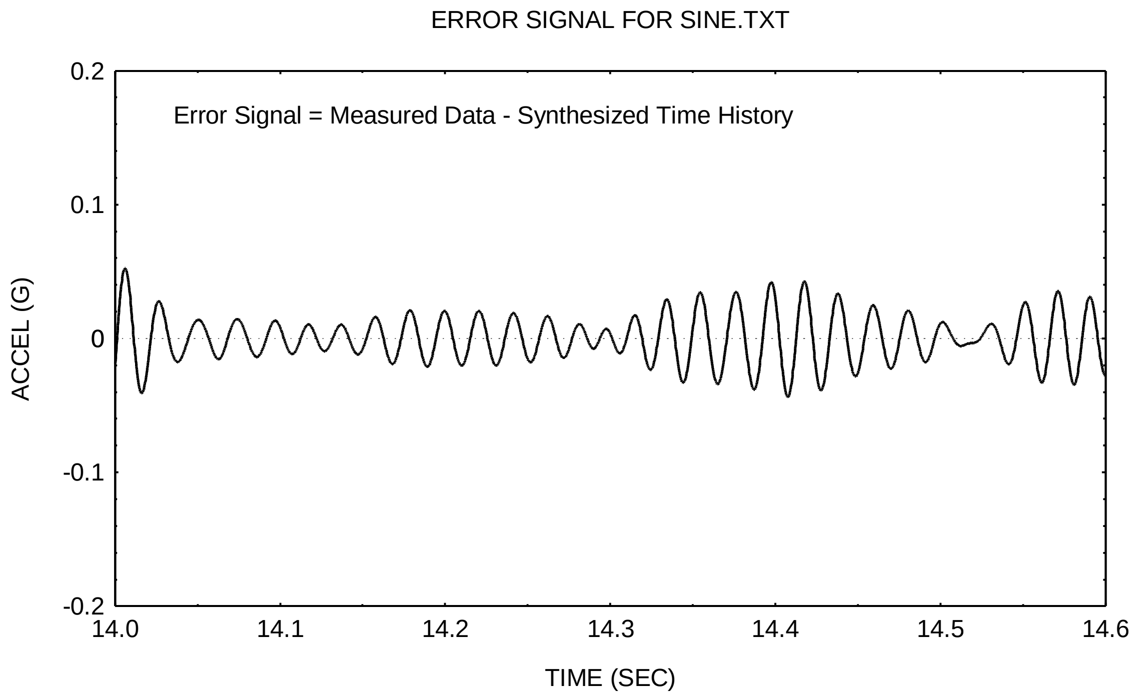

Figure 3.

Example 2

Note that the time history in Figure 1 has a slight beat frequency effect. Thus, repeat the analysis using two frequencies.

The following estimate is obtained using program sinefind.exe.

$$y(t) = \sum_{i=1}^{2} A_i \sin\left(2\pi f_i t - \phi_i\right)$$

where

$$A_1 = 0.0812 \text{ G} \qquad A_2 = 0.0179 \text{ G}$$
$$f_1 = 48.381 \text{ Hz} \qquad f_2 = 46.176 \text{ Hz}$$
$$\phi_1 = 6.173 \text{ radians} \qquad \phi_2 = 3.394 \text{ radians} \tag{2}$$

The input parameter to program sinefind.exe were:

40000 trials per frequency,
nominal frequency 1 = 50 Hz with a tolerance of ±5 Hz,
nominal frequency 2 = 50 Hz with a tolerance of ±10 Hz.

Equation (2) is shown superimposed on the sine.txt time history in Figure 4. The agreement is very good. The error signal is shown in Figure 5.

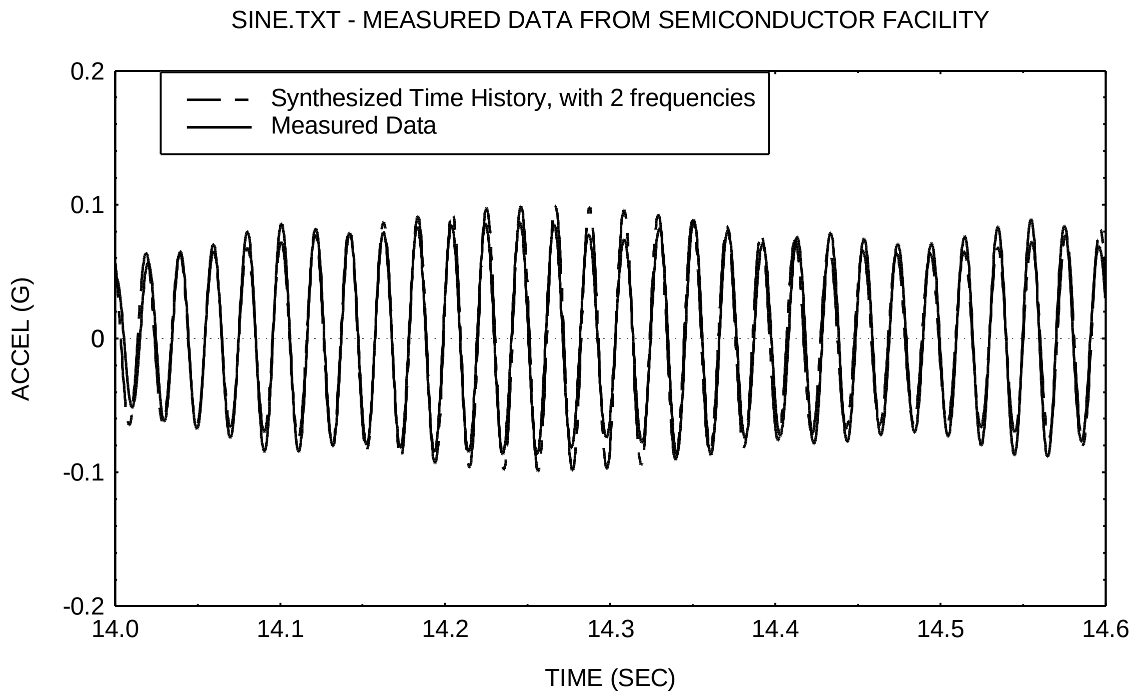

Figure 4.

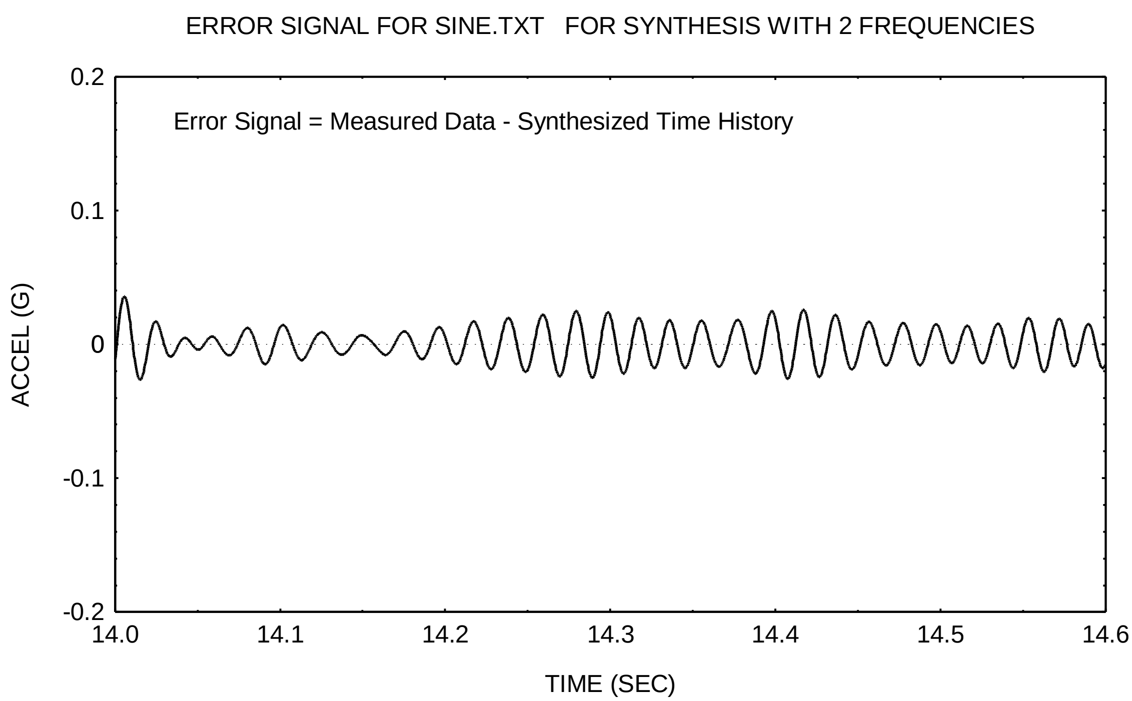

Figure 5.

Obviously, this synthesis process could be repeated for additional frequencies in order to reduce the error.

Example 3

Again, measured data often contains spurious signal due to electromagnetic interference. Data recorded in analog form on magnetic tape is particularly vulnerable. Consider the time history in Figure 6, which was measured during a rocket fairing separation test. The separation event consists of two pulses. The first is at time zero. The second is at 0.080 seconds.

The overall signal-to-noise ratio in Figure 6 is marginal. A "noise floor" is evident both before and after the event. The noise floor appears to consist of broadband random noise superimposed on a 30 Hz sinusoidal signal. The task is to remove the spurious sinusoidal signal in order to clarify the data. Program sinefind.exe is used to perform this task. The synthesized signal is shown in Figure 7. The error signal is shown in Figure 8. The error signal is equal to the raw signal in Figure 6 minus the synthesized signal in Figure 7. The error signal is retained as an estimate of the true measured signal.

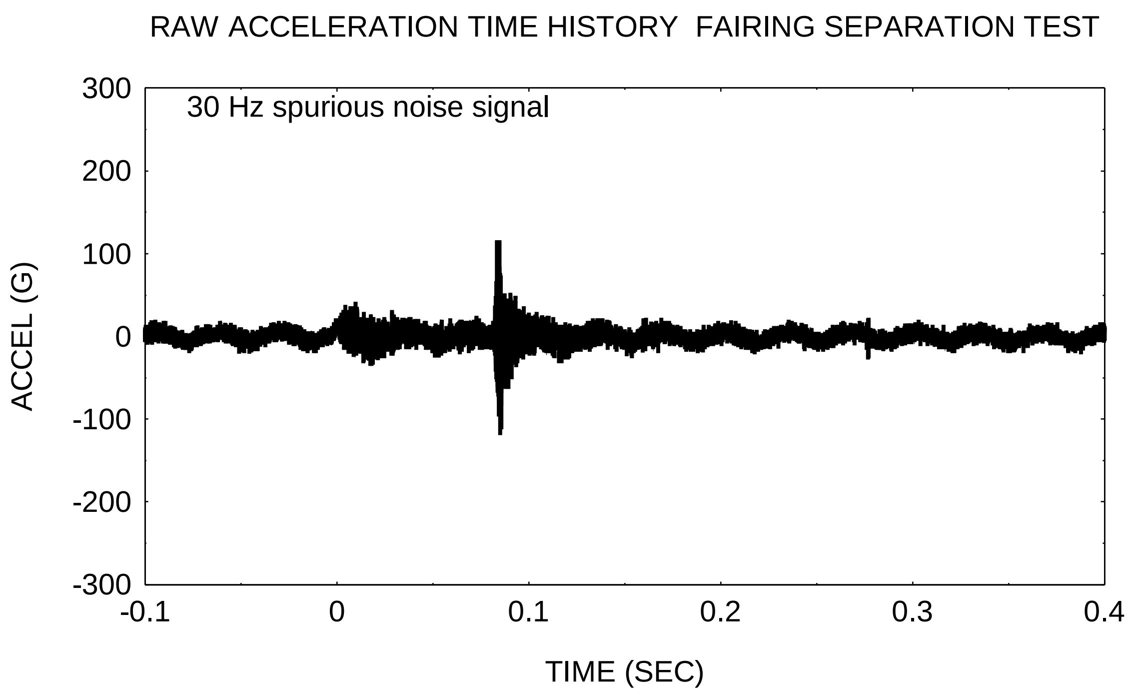

Figure 6.

SYNTHESIZED SIGNAL   FAIRING SEPARATION TEST

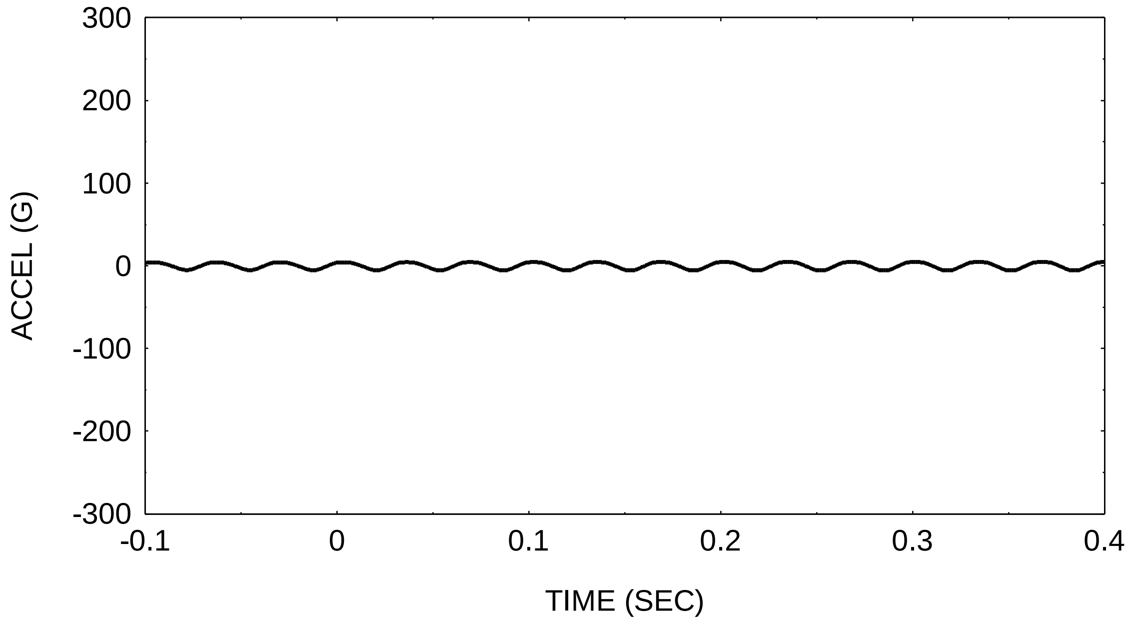

Figure 7.

PROCESSED ACCELERATION TIME HISTORY FAIRING SEPARATION TEST

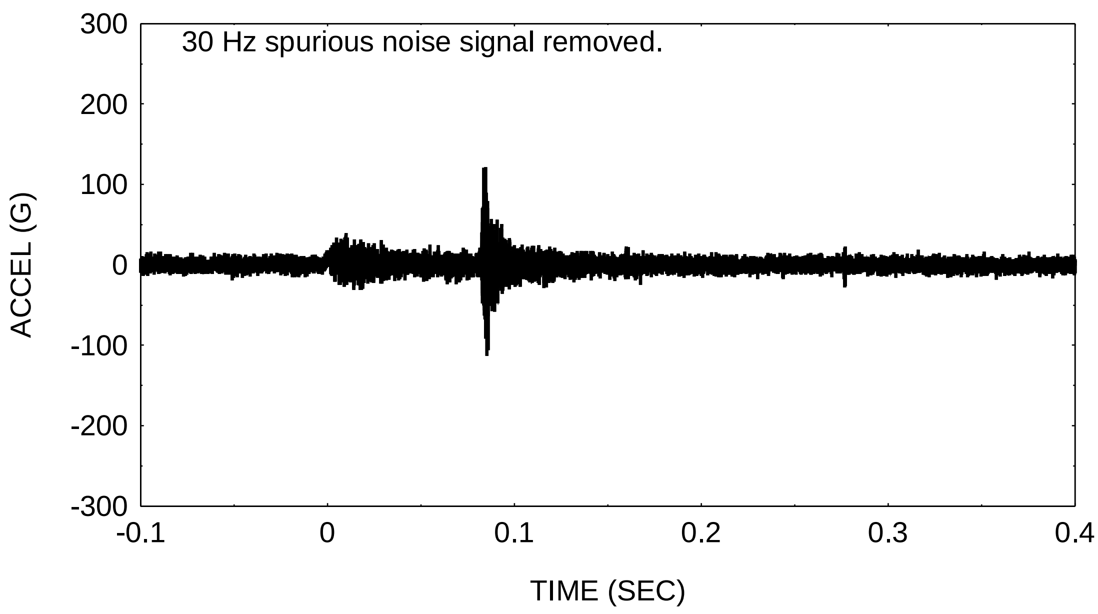

Figure 8.

The synthesized time history in Figure 7 is given by the following equation, with coefficients found via program sinefind.exe.

$$y(t) = \sum_{i=1}^{2} A_i \sin\left(2\pi f_i t - \phi_i\right)$$

where

$A_1 = 4.66$ G $\quad A_2 = 0.790$ G

$f_1 = 30.314$ Hz $\quad f_2 = 29.619$ Hz

$\phi_1 = 5.612$ radians $\quad \phi_2 = 3.522$ radians

(3)

The absolute shock response spectra of the raw signal and the processed signal are shown in Figure 9. The need for accurate spectra drives the sine removal effort.

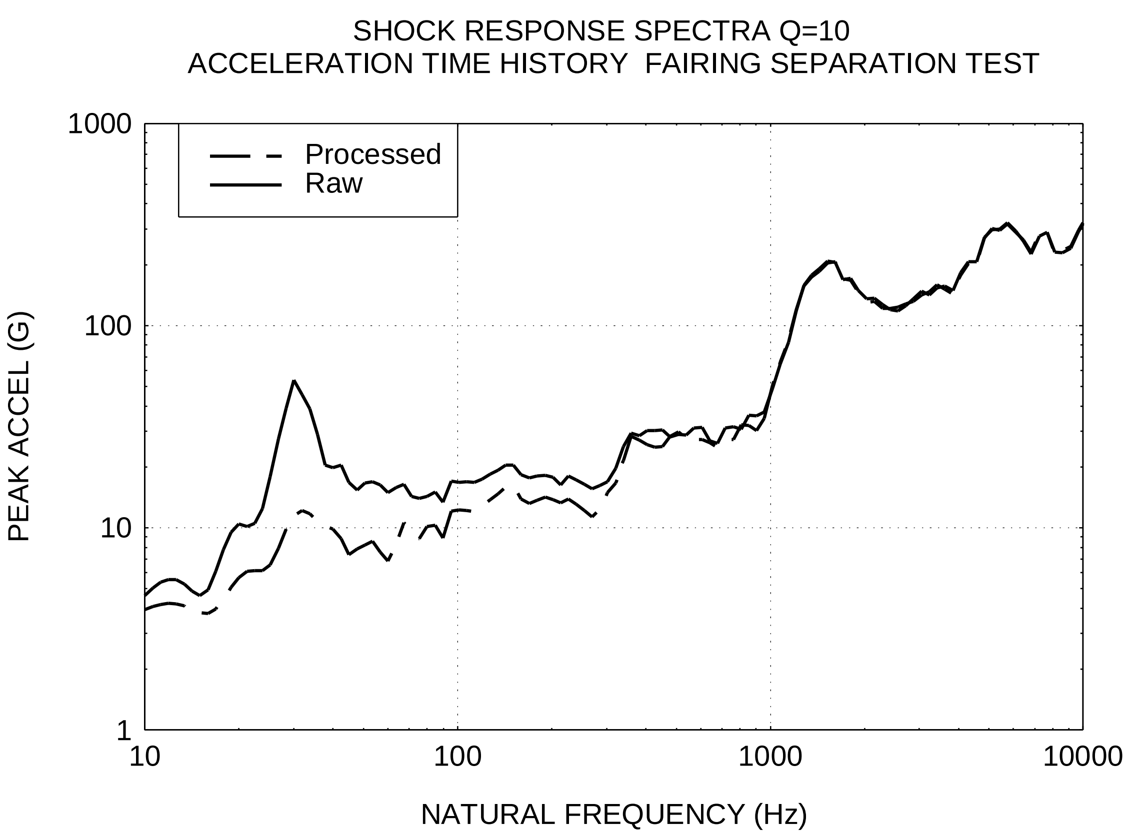

Figure 9.

Both the processed signal in Figure 8 and the spectral comparison in Figure 9 reveal that further refinement could be made.

<u>Homework</u>

Use program sinefind.exe for the following problems. A good number of iterations per frequency is 40000.

A good tolerance for the frequency estimate is 5 Hz or 10 Hz.

Note that program sinefind.exe runs rather slowly. A few minutes may be required for each frequency, depending on the number of data points and iterations.

1. Recall file trailer.txt from Unit2B. This is actual data measured on a semi-trailer during a proving ground test. Use program poweri.exe to calculate the power spectral density. Plot the result. Identify the dominant frequency below 100 Hz.

2. Take the frequency determined in problem 1 as an estimate. Use two estimates of this value within program sinefind.exe. Plot the raw signal and the synthesized signal.

3. The time history in Figure 6 is given in file fairing.txt. Repeat Example 3 as given in the text but use three or four frequencies near 30 Hz to achieve a more thorough removal of the spurious signal. Perform a shock response spectra comparison to verify the removal. Use program qsrs.exe for the spectral calculation.