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Recovery of Pyroshock Data From Distorted Acceleration Records

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and Space Administration

Scientific and Technical Information Branch

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LIST OF SYMBOLS

a_{Bias}	Signal bias pulse
A_o	Amplitude of pulse
t	Time
T_o, T_{o1}, T_{o2}	Decay time constants
a_{TOTAL}	Total signal
a_{True}	True signal
N, a_N, B_N	Constants
ω	Frequency
Y_{ACCEL}	Accelerometer transfer function
$F\{\ \}$	Fourier transform
$F^{-1}\{\ \}$	Inverse Fourier transform
Y_{TOTAL}	Total signal transform
Y_{TRUE}	True signal transform
ξ	Damping factor
ω_N	Resonant frequency

NASA TECHNICAL PAPER

RECOVERY OF PYROSHOCK DATA FROM DISTORTED ACCELERATION RECORDS

I. INTRODUCTION

High frequency shocks, such as those generated by pyrotechnic devices, often produce acceleration records (time histories) that are distorted. If the degree of distortion is great, the data is usually discarded as "bad" data. However, if the distortion is slight, the data is usually "cleaned up" by questionable, makeshift means. Often the "clean up" procedure introduces as much error as previously existed in the data. The purpose of this report is to outline techniques for "cleaning up" data so that a true signal is obtained and so that the "clean up" techniques will be reproducible in any laboratory.

The majority of ordnance shock data is distorted by either or both of the following: (1) Base line shift, or (2) accelerometer resonance. In the following sections, characteristics, correction methodology, and examples of data will be presented.

II. BASE LINE SHIFT

A. Characteristics

Base line shift occurs with piezoelectric accelerometers when shock levels approach 100,000 g's (this may occur at much lower levels depending upon the make and model of accelerometer). This effect usually appears as a signal envelope axis of symmetry shift, that is, the time history envelope is symmetric about an axis other than the zero base line. Also, this effect may appear as a signal superimposed upon an exponentially decaying pulse or upon a sine wave. Combinations of these two shift varieties also occur frequently.

It is believed by experts that saturation of charge amplifiers and/or temporary accelerometer crystal repolarization are responsible for inducing base line shifts.

B. Correction Methodology

Donald Baker Moore of Explosive Technology, Inc. (P.O. Box KK, Fairfield, California 94533), has begun experimentation in identifying and correcting distorted data. Accelerometer output (time histories) (Fig. 1) may be integrated once to obtain velocity time histories (Fig. 1) and twice to obtain displacement time histories (Fig. 3). If a residual velocity of great magnitude or a continuously increasing displacement exists after the shock, a base line shift is assumed. The shift may not always be visible in the acceleration time history. Figures 1, 2, and 3 represent a distorted or total signal and its derivatives. Figures 4, 5, and 6 represent a true signal and its derivatives. Notice that the velocity and displacement both go to zero after the shock.

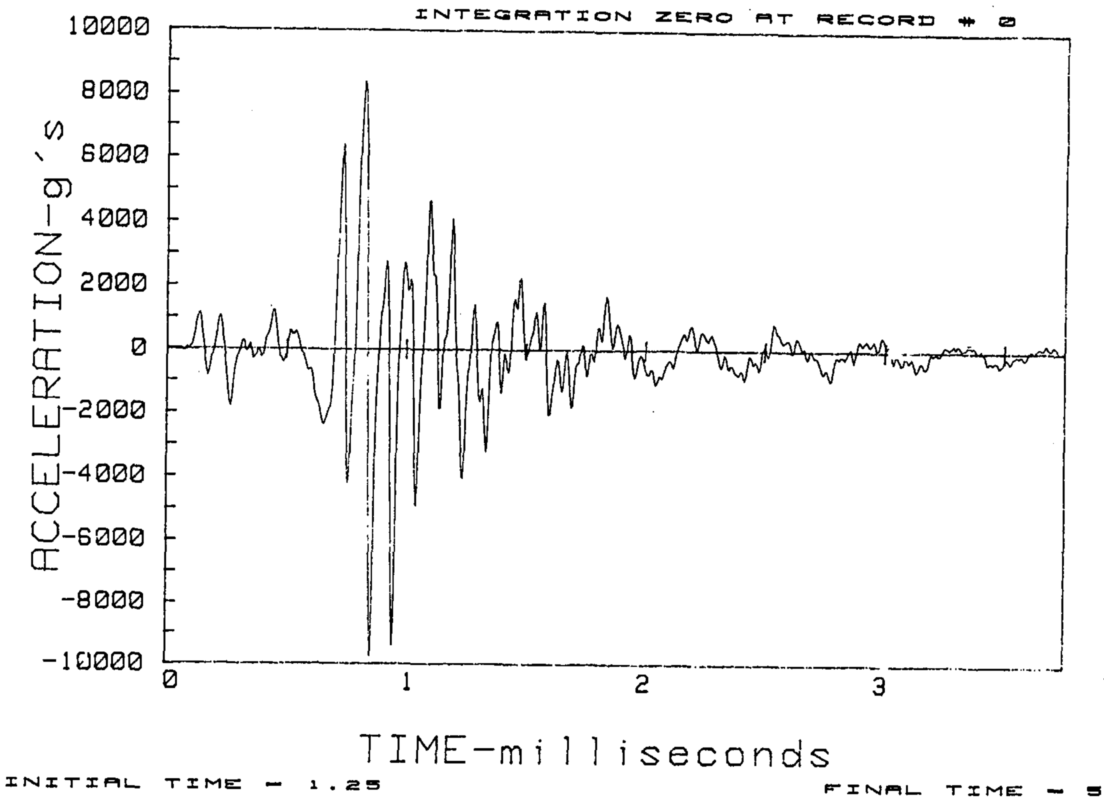

Figure 1. Acceleration time history.

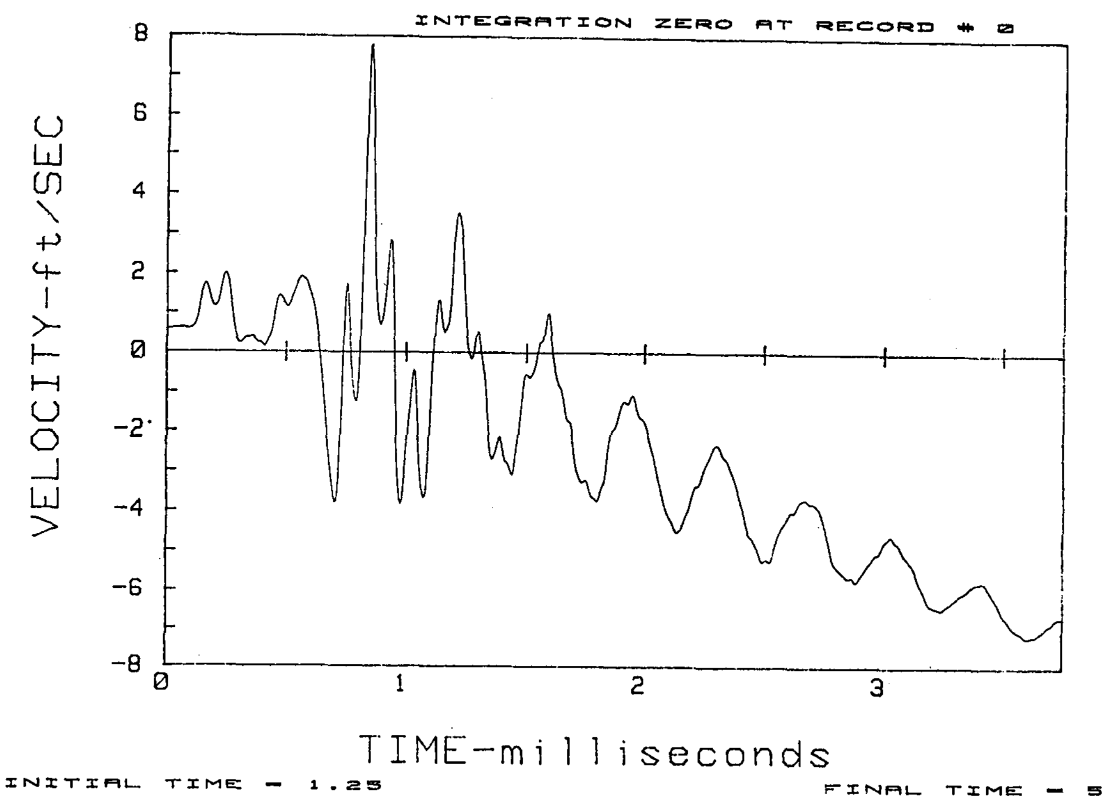

Figure 2. Velocity time history.

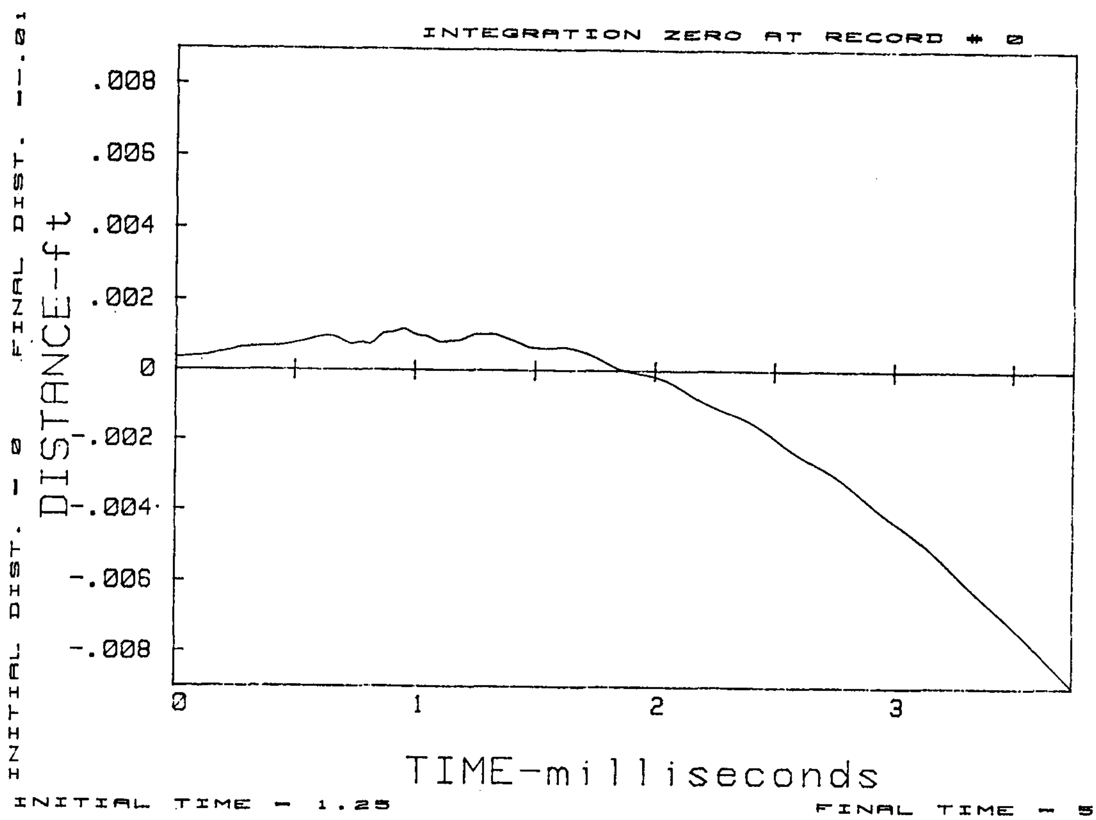

Figure 3. Displacement time history.

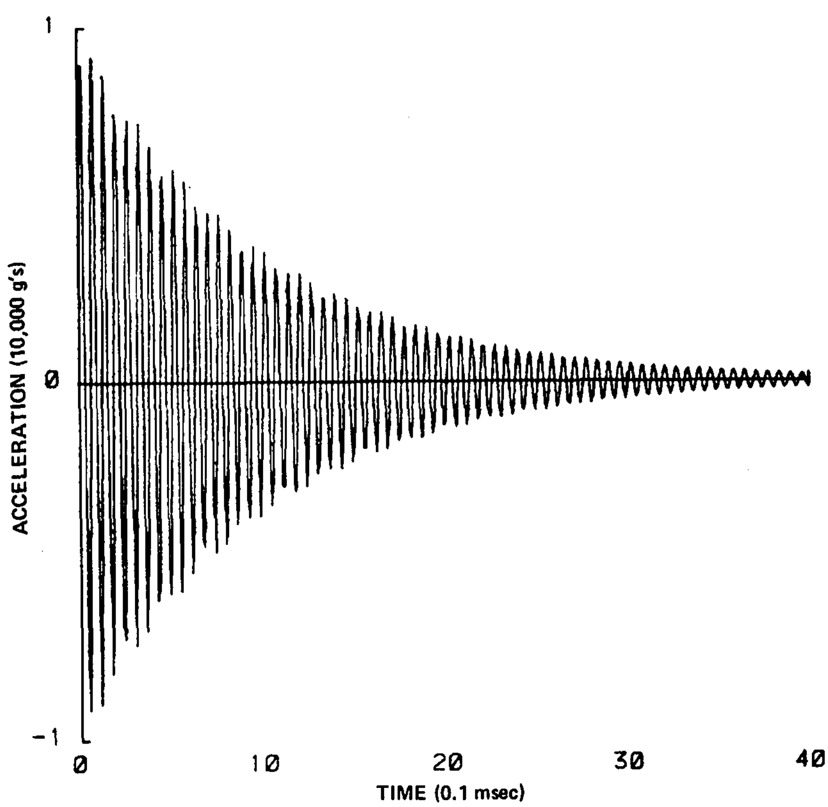

Figure 4. Acceleration time history.

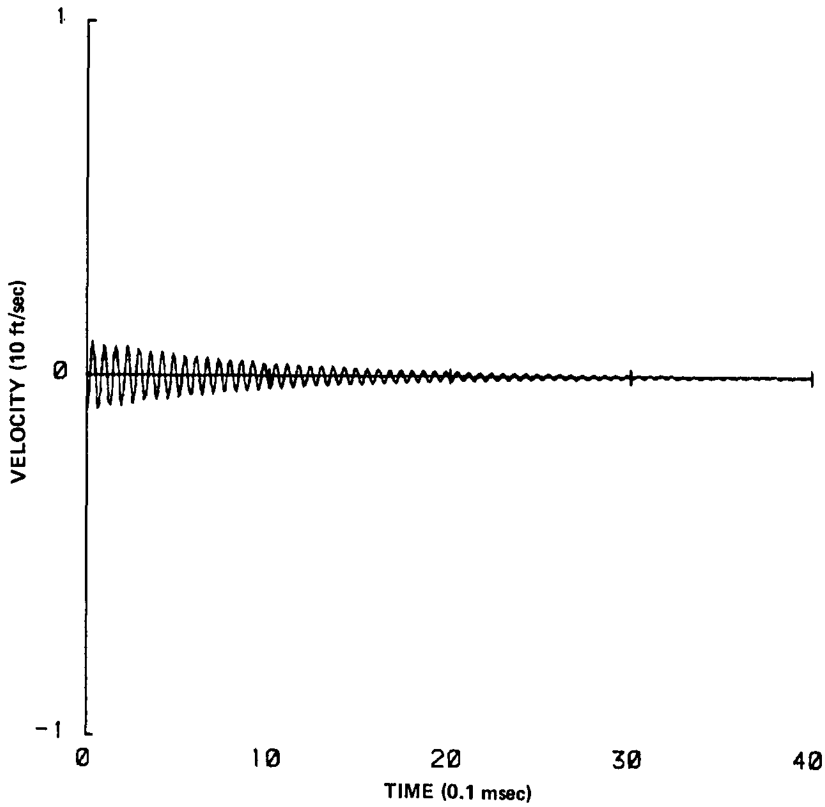

Figure 5. Velocity time history.

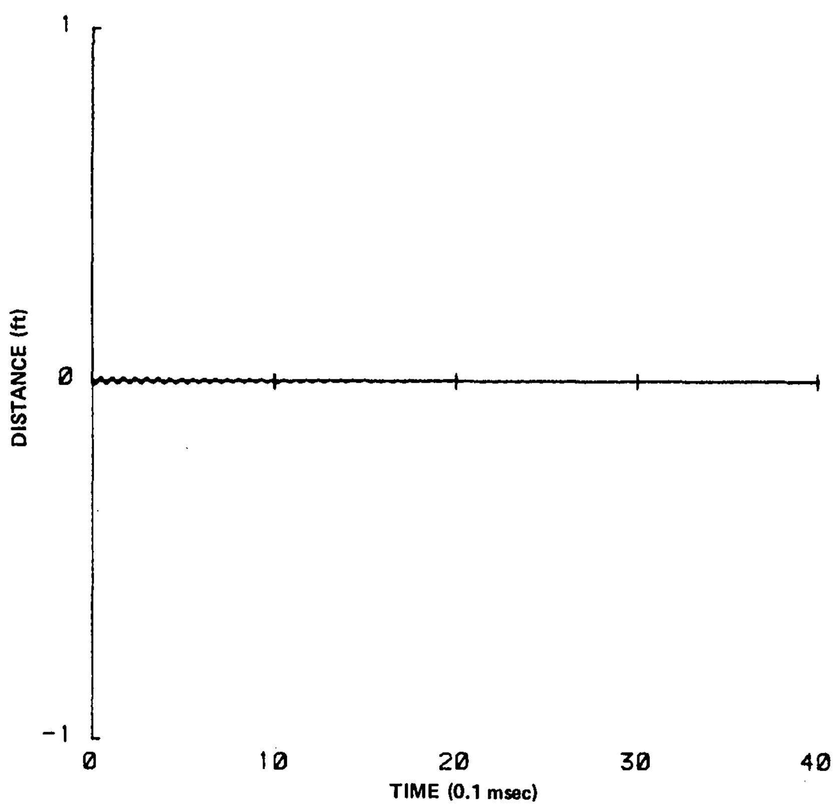

Figure 6. Displacement time history.

The distortion source can be assumed to be an erroneous bias pulse of the following form:

$$A_{Bias} = A_o \exp(-t/T_o) \quad .$$

If the bias is a pure direct current shift, $T_o \rightarrow \infty$, and $a_{Bias} = A_o$ = a symmetric shift. Suitable values may be selected for the parameters, thus forcing the velocity and displacement values toward reasonable levels. Often the bias terms are so obvious that the constants A_o and T_o may be chosen by inspection. When this is not possible, mathematical averaging techniques may be employed to derive the constants. The total signal may be written as follows:

$$a_{TOTAL} = a_{TRUE} + a_{BIAS} \qquad \text{or} \qquad a_{TRUE} = a_{TOTAL} - a_{BIAS} \quad .$$

Any true pyroshock pulse may be expressed as follows:

$$a_{TRUE} = \sum_{N=1}^{\infty} [\exp(-a_N\, t) \sin(b_N\, t)] \quad .$$

Once the bias term, a_{BIAS}, has been derived, the true signal may be easily extracted. The total signal with bias may be written as follows:

$$a_{TOTAL} = \left[\sum_{N=1}^{\infty} [\exp(-a_N\, t) \sin(b_N\, t)] \right] + A_o \exp(-t/T_o) \quad .$$

C. Examples

There are five commonly occurring cases of base line shift (including the case when $a_{BIAS} = 0$).

Case No. 1: A true signal, no adjustments are necessary (Fig. 7).

$$a_{BIAS} = A_o = 0$$

$$a_{TRUE} = a_{TOTAL} \quad .$$

Case No. 2: A simple direct current shift where $T_o \rightarrow \infty$ and $A_o = N$ (Fig. 8).

$$a_{BIAS} = N$$

$$a_{TRUE} = a_{TOTAL} - N \quad .$$

Case No. 3: A combined or complex shift, multiple adjustments are necessary. At $t = 0$, $a_{BIAS} = N$, or $A_o = N$. By inspection the bias contains two exponentials, one forcing the signal toward zero from above, and one forcing the signal to zero from below. A computer curve fill will determine T_{o1} and T_{o2} (Fig. 9).

$$a_{TRUE} = a_{TOTAL} - [\exp(-t/T_{o1}) + \exp(-t/T_{o2})] \quad .$$

Case No. 4: By inspection it may be seen that the signal is stacked upon a sine wave. There is no direct current shift (Fig. 10).

$$a_{TRUE} = a_{TOTAL} - \sin(-t/T_o) \quad .$$

Case No. 5: By inspection it may be seen that the signal is direct current shifted and stacked upon a sine wave. Combine case No. 4 and case No. 2 (Fig. 11).

$$a_{TRUE} = a_{TOTAL} - N - \sin(-t/T_o) \quad .$$

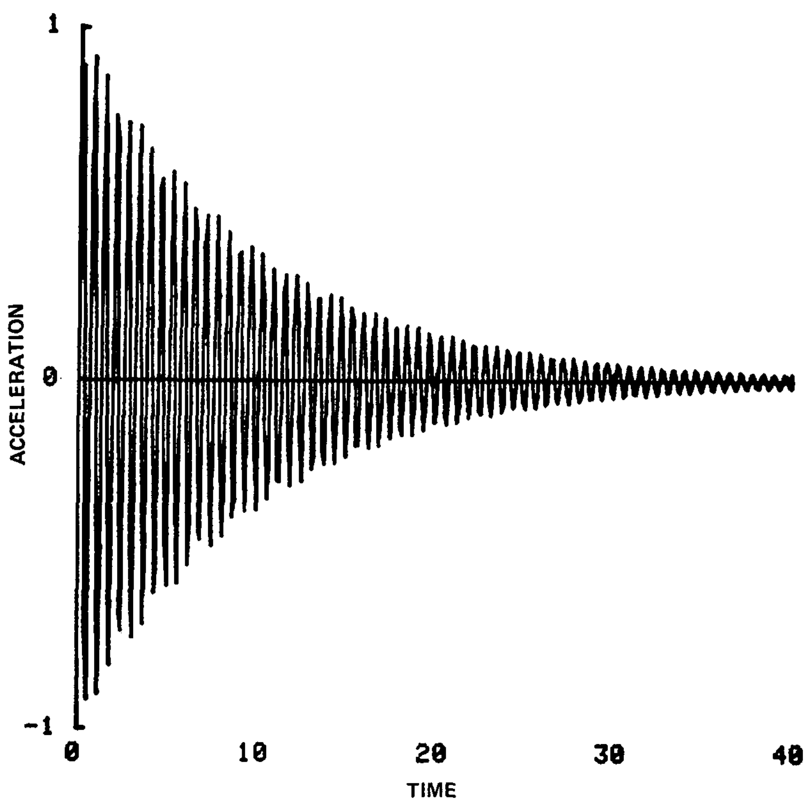

Figure 7. True acceleration time history.

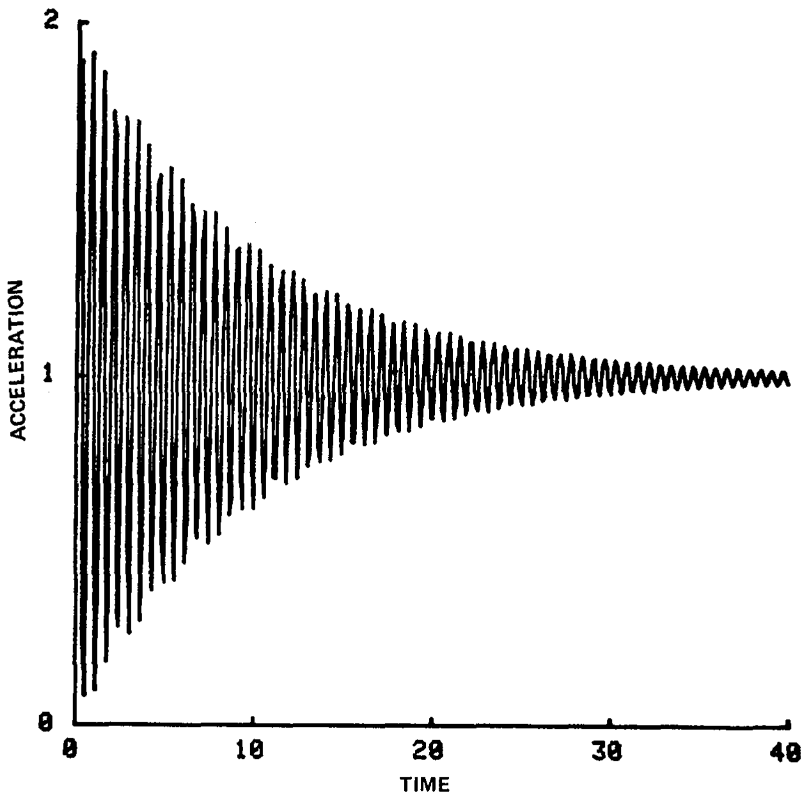

Figure 8. Direct current shifted acceleration time history.

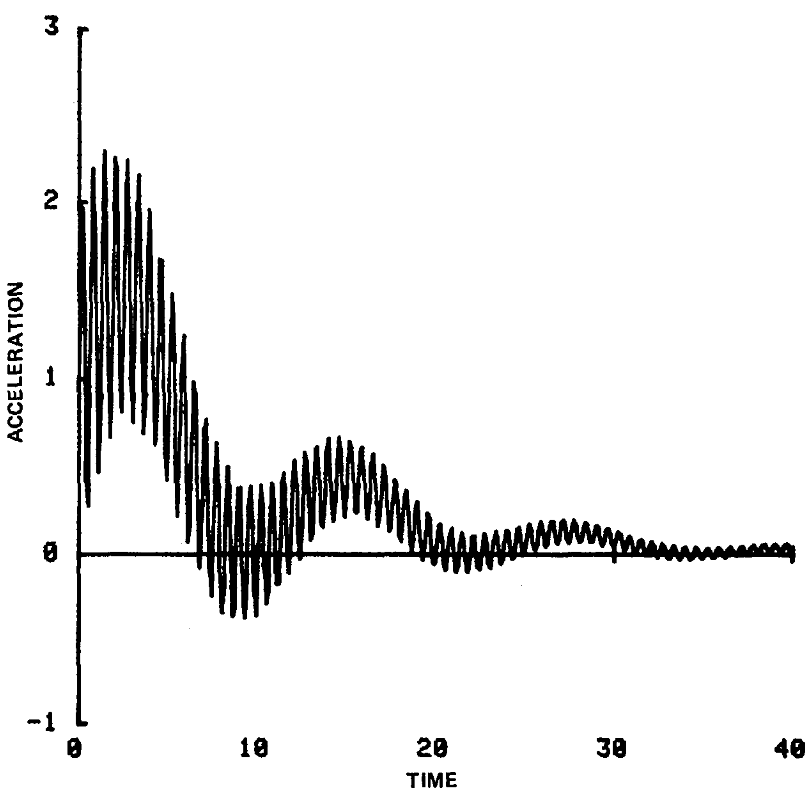

Figure 9. Complex biased acceleration time history.

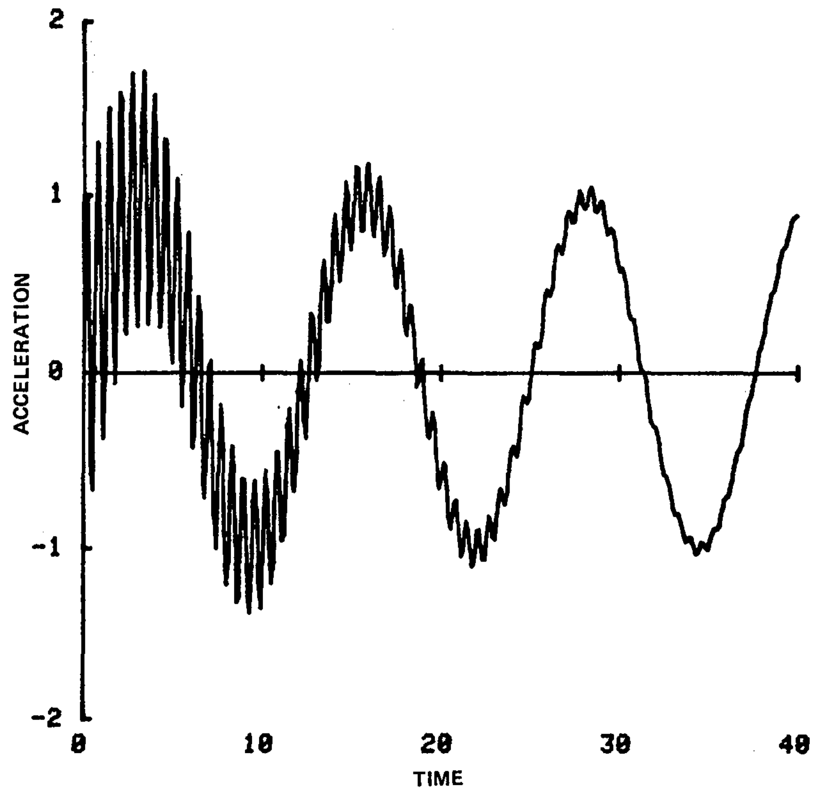

Figure 10. Sine distorted acceleration time history.

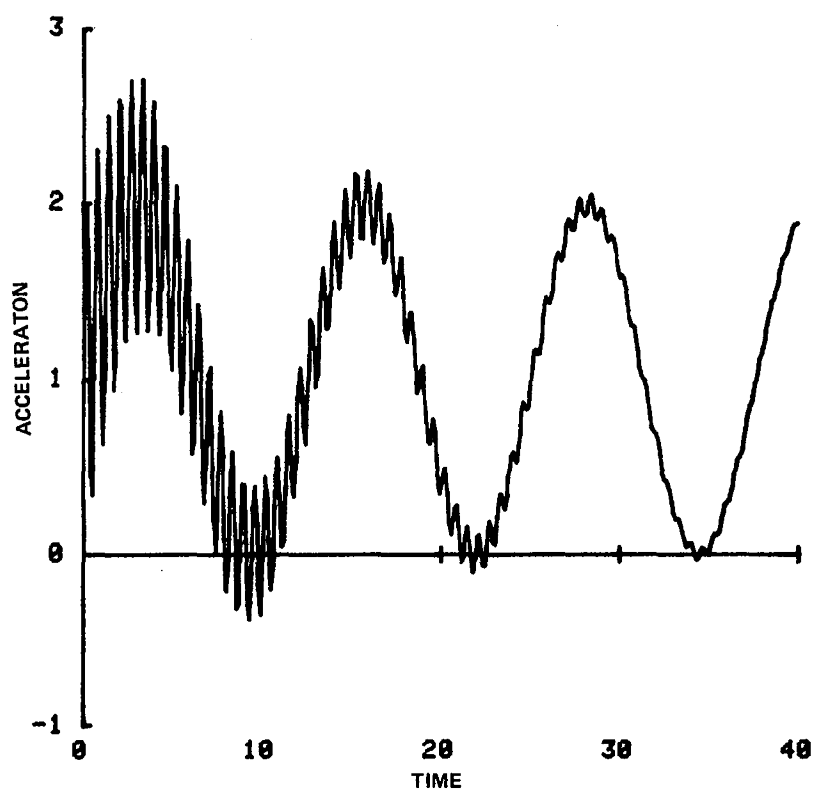

Figure 11. Direct current-sine distorted acceleration time history.

III. ACCELEROMETER RESONANCE

A. Characteristics

Any environment with significantly high g levels at high frequency will excite an accelerometer into producing a resonant response. This response may appear as a high frequency wiggle superimposed upon the lower frequency real signal, or it may be completely hidden in the real signal. In reality, all frequency components of the acceleration signal above one-tenth of the resonant frequency of the accelerometer will be amplified by the accelerometer response function. The accelerometer can be mathematically approximated by a very lightly damped simple harmonic oscillator. The accelerometer response function (accelerometer frequency transfer function) is prescribed if the damping factor ξ, and resonant frequency ω_N are known. The transfer function may be written as follows:

$$Y_{ACCEL}(\omega) = \frac{1}{1 + \frac{2\,i\,\xi\,\omega}{\omega_N} - \frac{\omega^2}{\omega_N^{\,2}}}\;, \quad \left|Y_{ACCEL}(\omega)\right| = \sqrt{Y_{ACCEL}(\omega)\cdot Y^{*}_{ACCEL}(\omega)}$$

$$= \sqrt{\frac{1}{1 + 2\,(2\epsilon^2-1)\left(\frac{\omega}{\omega_N}\right)^2 + \left(\frac{\omega}{\omega_N}\right)^4}}$$

The total signal is, in fact, a convolution of the real signal (true signal) with the accelerometer impulse response function (transfer function) in the time domain.

B. Correction Methodology

The major problem in correcting data is determining the accelerometer transfer function. The damping factor and resonant frequency of any given accelerometer may be determined by testing and analyzing the resulting data. Also, many accelerometer manufacturers provide characteristics for their instruments. Once the accelerometer frequency response transfer function is derived, the remaining process is straight forward.

First, deconvolve the total signal by Fourier transforming the time signal into the frequency domain as follows:

$$Y_{TOTAL}(\omega) = F\left\{a_{TOTAL}\right\}$$

Next, divide the total signal by the accelerometer transfer function to yield the true signal as follows:

$$Y_{TRUE}(\omega) = \frac{Y_{TOTAL}(\omega)}{Y_{ACCEL}(\omega)}$$

Finally, use the inverse Fourier transform to convert the true signal back into the time domain as follows:

$$a_{TRUE} = F^{-1}\left\{Y_{TRUE}(\omega)\right\}$$

The complete process can be summarized as follows:

$$a_{TRUE} = F^{-1}\left\{\frac{F\{a_{TOTAL}\}}{Y_{ACCEL}(\omega)}\right\}$$

The complete process is easily accomplished by computer using Fast Fourier Transform (FFT) techniques.

C. Examples

For simplicity let the accelerometer have a damping factor of $\xi = 0.1$ and a resonant frequency of $\omega_N \doteq \omega_A$. Therefore we have the following:

$$Y_{ACCEL}(\omega) = \frac{1}{\sqrt{1 + 2[2(0.2)^2 - 1]\left(\frac{\omega}{\omega_A}\right)^2 + \left(\frac{\omega}{\omega_A}\right)^4}} = \frac{}{\sqrt{1 - 1.96\left(\frac{\omega}{\omega_A}\right)^2 + \left(\frac{\omega}{\omega_A}\right)^4}}$$

$$Y_{ACCEL}(t) = a_{ACCEL} = F^{-1}\{Y_{ACCEL}(\omega)\} = 1.005\,\omega_A\, e^{-0.1\,\omega_A t} \sin 0.995\,\omega_A t$$

(See Fig. 13.)

By examining the total signal (Fig. 14), one may observe that it may be described as follows:

$$Y_{TOTAL}(t) = a_{TOTAL} = \omega_A\,[0.3328\, e^{-0.1\,\omega_A t} \sin(0.995\,\omega_A t - 14.5)$$
$$+ 0.6204\, e^{-0.005\,\omega_A t} \sin(0.5\,\omega_A t - 7.228]$$

NOTE: For convenience ω_N of the system was described as a function of ω_A.

Deconvolve the signal by transforming into the frequency domain as follows:

$$Y_{TOTAL}(\omega) = F\{Y_{TOTAL}(t)\} = \frac{1}{\sqrt{\left[1 - 1.96\left(\frac{\omega}{\omega_A}\right)^2 + \left(\frac{\omega}{\omega_A}\right)^4\right]\left[1 - 7.998\left(\frac{\omega}{\omega_A}\right)^2 + 16\left(\frac{\omega}{\omega_A}\right)^4\right]}}$$

Next, divide the total signal by the accelerometer signal as follows:

$$Y_{TRUE}(\omega) = \frac{Y_{TOTAL}(\omega)}{Y_{ACCEL}(\omega)} = \frac{1}{\sqrt{1 - 7.998\left(\frac{\omega}{\omega_A}\right)^2 + 16\left(\frac{\omega}{\omega_A}\right)^4}}$$

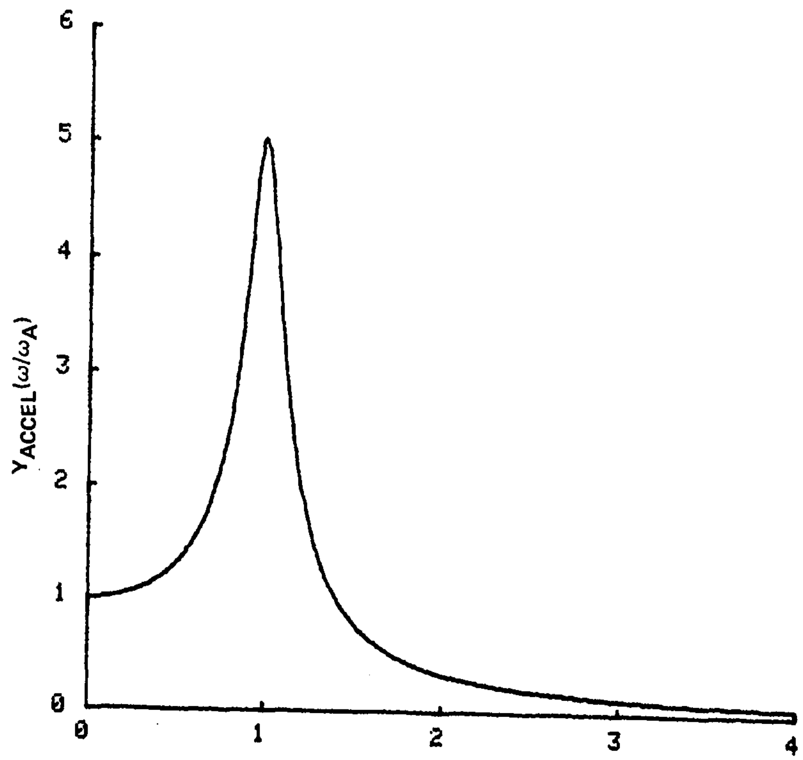

Figure 12. Accelerometer transfer function (ω/ωA).

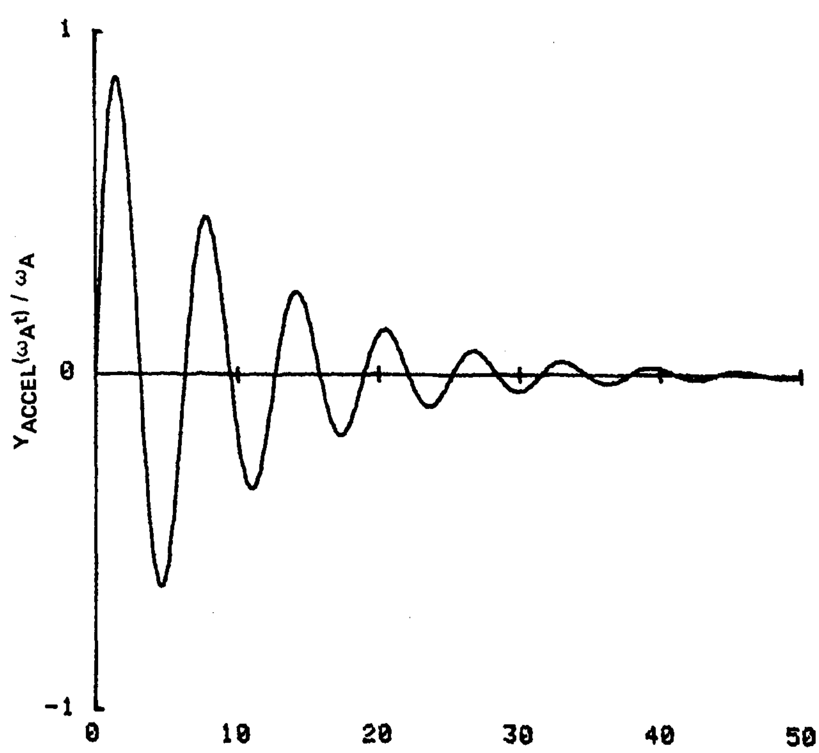

Figure 13. Accelerometer transfer function ($\omega_A t$).

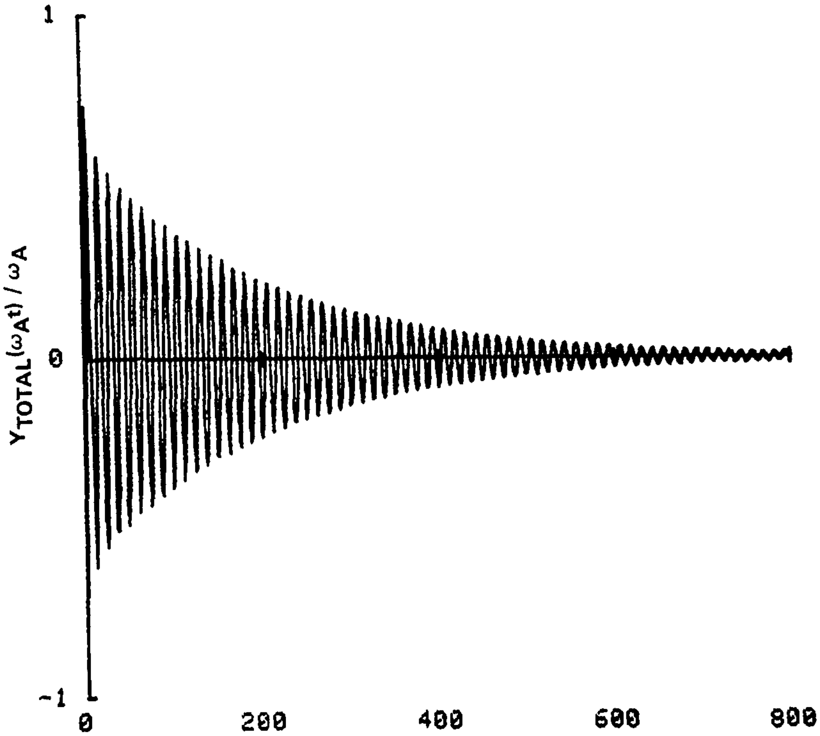

Figure 14. Total signal ($\omega_A t$).

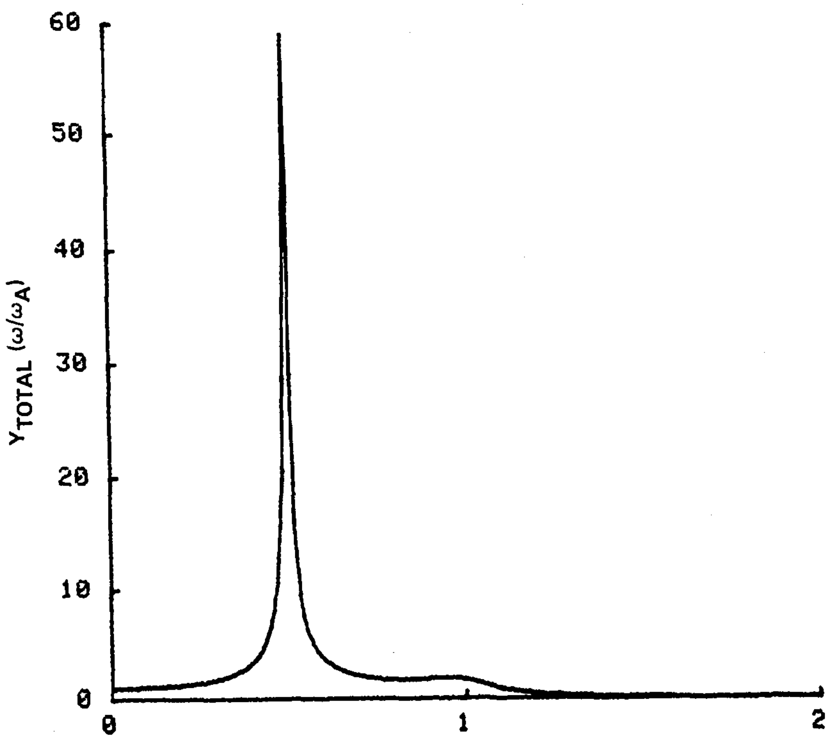

Figure 15. Total signal (ω/ω_A).

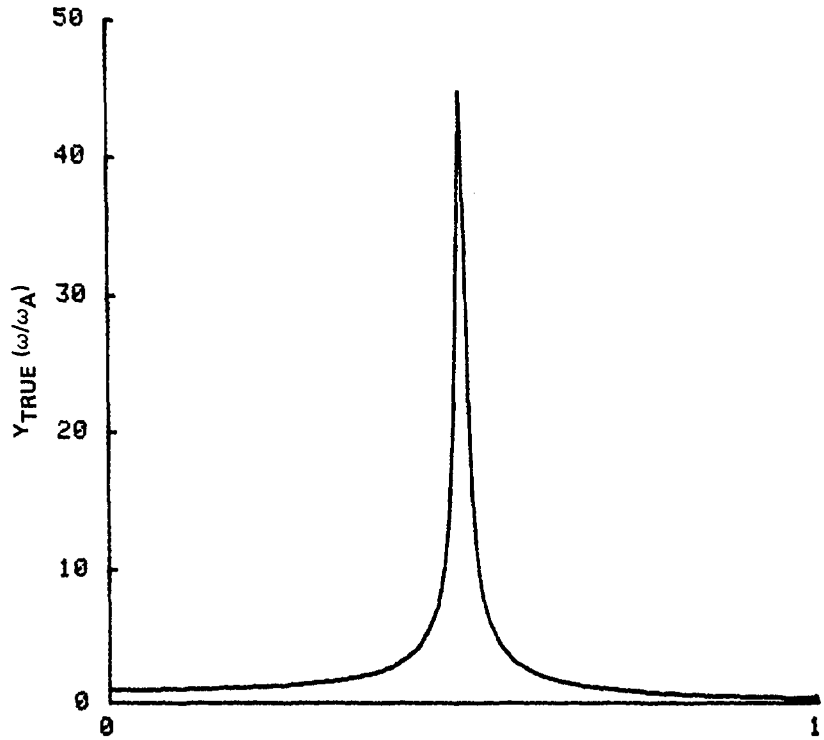

Figure 16. True signal (ω/ω_A).

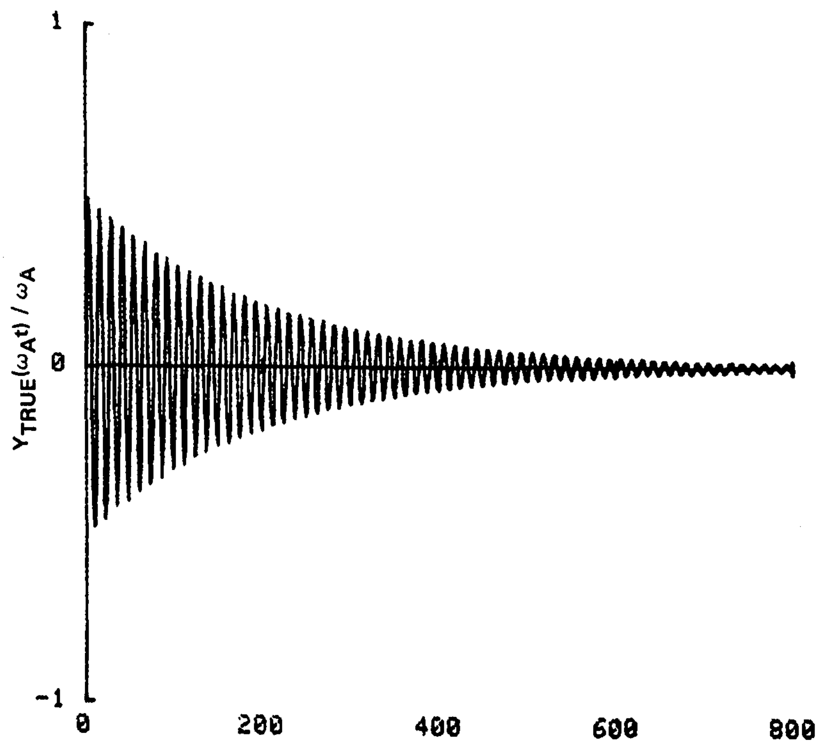

Figure 17. True signal $(\omega_A t)$.

This should be the true signal. Finally, transform back into the time domain to obtain the "true" time signal as follows:

$$Y_{TRUE}(t) = a_{TRUE} = F^{-1} \{Y_{TRUE}(\omega)\} = 0.5\ \omega_A\ e^{-0.005\ \omega_A t} \sin 0.5\ \omega_A t$$

(See Fig. 17.)

IV. SUMMARY

In the past much usable data has been discarded or erroneously cleaned up. Now, it is possible to systematically and correctly clean up data so that the clean up procedures are reproducible.

The two major sources of data distortion are accelerometer resonance and base line shift. These distortions may or may not be readily observable. In theory, they may be identified and removed yielding true data.

V. CONCLUSIONS

In theory distorted data may be readily corrected upon investigation by removing bias terms or accelerometer transfer functions or both. These clean up procedures remain to be proven in the laboratory or applied sense.

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16. ABSTRACT

In the past, distorted pyrotechnic shock time history data has been discarded completely or "cleaned up" by questionable means. Too often the "clean up" procedures introduced as much error into the data as previously existed. The purpose of this paper is to outline techniques for data recovery so that true signals are obtained and so that these recovery procedures will be completely reproducible by any scientist in any lab. Most ordnance shock data is distorted by baseline shifts or accelerometer resonances. The methodology of recovering true signals from these two types of distortion is discussed.

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