19th International Symposium of Ballistics, 7–11 May 2001, Interlaken, Switzerland

THE ANALYSIS OF GUN PRESSURE INSTABILITY

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The stability of the pressure in a gun has traditionally been analyzed by Fourier transforms to seek the frequencies which carry the maximum energy. As different frequencies occur at various times during the interior ballistic cycle, the Fourier transform which averages the result over all time, does not identify the source of many instabilities. Windowed Fourier transforms, which are taken over a limited time window, do provide a better insight into the time of occurrence of instabilities. Wavelets transforms are calculated over all time and are selective in the frequencies studied in each transform. In the present study, the result of using the three methods to analyze the performance of a stepped chamber liquid propellant gun are given. It is shown that the wavelet method provides more information about the time of occurrence of frequencies, and hence possible source of the instabilities, than either of the Fourier transforms.

INTRODUCTION

During the development of the regenerative liquid propellant gun the possibility of some problems due to oscillations were suggested. These could arise due to the high pressure on the gun influencing the working system of the barrelprojectile integrity. The high pressure oscillations may be a threat to the projectile integrity and in addition may cause heating of the gun. The purpose of this work was an attempt to understand the source of these oscillations.

In order to obtain a better understanding of the combustion mechanism of the stepped chamber liquid propellant (LP) gun, pressure measurements were taken at various locations along the gun.

The usual method of analysis is using Fourier analysis to transform the signal from a time domain to a frequency domain in order to determine the predominate frequencies. This can often lead to finding the location of the source of the wave. One problem with regular Fourier analysis, is that the signal is integrated over all time and produces the average wave structure. This is overcome by using windowed Fourier transforms where the transform is performed for various time intervals Δt. The problem with windowed Fourier transforms is that a small window will not detect low frequencies and a large window will not recognize high frequencies.

The concept of Fourier transforms can be extended so that the window size may be adjusted to examine the signal at different levels. The method is known as wavelet analysis. This method is similar to Fourier analysis in that the same approach is used but the sine and cosine functions are replaced with wavelet functions. This method helps in detecting the source of the oscillations. In this procedure the signal is typically decomposed into 5 scales starting with 2^{-1} scale (highpass filter) and ending at 2^{-5} (lowpass filter).

METHOD OF SOLUTION

There were 8 pressure gage ports used on the experimental 40 mm bulk loaded liquid propellant gun (BLPG). The pressure gages are located, Figure 1, one in the booster, two in the combustion chamber, two in the barrel and one at the muzzle. The other two gages were used to establish the vibrational frequency of the gun fixture and were located in the side and top of the gun fixture but did not extend into the chamber or barrel.

Pressure measurements were made for twelve different configurations in order to examine the effects of various numbers of steps and step sizes. Wave deflectors were attached to the rear of the projectiles in order to examine the effects of these on gun performance. Typical pressure measurements are shown in Figure 1(a).

The first approach was to use standard Fourier transforms. The total transform, the sine transform and the cosine transforms were studied. As the total transform does not contain the sign of the transform it was decided to use either the sine or cosine transforms. The difference between these is that the cosine transform is appropriate if the function is even, that is f(-t)=f(t). Similarly if f(-t)=-f(t) then the sine transform is appropriate. As the experimental functions go to zero at t=0 then the sine transform would appear to be appropriate. Initially Fast Fourier transforms were used but it was found that the results were distorted when compared with integrating the function (slow transform). As the standard Fourier transform is integrated over all time it does not provide an indication of when events occur. The technique of shore time or windowed Fourier transforms has been developed. In this a time period is chosen and the transform performed over that time. If the time window is long then it can represent long wave length frequencies but the time is not accurately known. On the other hand if the window is narrow the time is known accurately but the long wave lengths are poorly represented. This is similar to the uncertainty principle in quantum physics. It has been found that for accuracy the relation between the window size Δt and the frequency range Δf such that

$$\Delta t \Delta f \geq \frac{1}{4\pi}.$$

A recently developed technique [2] which overcomes the problems connected with windowed Fourier transforms is that of wavelets. In the present work discrete wavelets transforms were used. In this a function $\psi(2^k t+l)$ where k and l are whole numbers is used as the integrating function instead of sine and cosine. Thus the transform becomes $\int f(t)\,\psi dt$. These orthogonal wavelets can be used to construct multiresolution transforms which use filters to obtain solutions at different frequencies. In the present study the filters used were the numerical filters by Daubechies using 20 coefficients.

RESULTS

The results of the Fourier sine transforms for typical data sets are shown in Figure 1b. The frequency of the initial wave can be measured but as this is averaged over the whole time the wave length is indeterminate .

A typical windowed result is shown in Figure 2. The window size is 10^{-4} sec. and covers the times 0.9 to 1.0 ms of the results shown in Figure 1b. This does not satisfy the uncertainty criteria but it was found that it allowed the calculation of the principle wave velocity. Knowing the frequency of the waves and the chamber length for the arrival times at two positions in the barrel the wave velocity could be calculated for two cases. The wave velocities were typically 3820 m/s and 3460 m/s. This is the order of magnitude for the velocity of sound in water. Thus, it can be concluded that the wave is traveling through the very dense fluid possibly at supersonic speed.

However, very little can be determined about higher frequency waves. It can be seen that the wave originates in the booster. Although the booster wave does decrease a little with time, it still appears to have the same strength as the waves in the chamber. The conclusion from this work could be that the oscillations are driven by the booster. However this conclusion is not reached when wavelet analysis is undertaken.

The integration functions were Duabechies wavelet function. It was found by experiment that this produced the most useful results. Although all data sets were examined, only a representative one is presented here.

In the figure showing the wavelets, varying scales of wavelets are presented with decreasing levels of details. In order to simplify the discussion the bottom strip, which has a scaling factor of 2^{-5}, is referred to for case 1 as 1.1 and contains the long wavelength oscillations. The top strip at 2^{-1} is referred to as 1.5 and represents the highest frequency waves.

The waves in (A) Fig. 3, in the booster, continue for a longer time than in chamber 1. This suggests that the booster is not driving the low frequency waves. The waves in (D) Figure 4 in barrel 1, are smaller in amplitude than in either the booster or in chamber position 1. The first barrel position, (A) Figure 4, shows that the oscillations do not start until the projectile passes the pressure port. Thus the signal is being transmitted through the fluid and not through the gun structure. Examination of the wavelet signals at barrel 2 position, figure not included, showed that the high frequency signals arise from the time that the projectile starts moving through the barrel. Thus, it is reasonable to assume that these signals are transmitted through the structure. In barrel position 2, the high frequency signals have a sharp peak as the projectile moves across the sensor. At the muzzle, not shown, the high frequency signals have a maximum shortly after the projectile passes barrel 2 position at a time about 1100. This is all transmitted through the structure. The transducer in the side wall, not shown, the pressure signals only start after the projectile has passed the barrel 1 position. It thus appears that there are two problems. One due to oscillations being transmitted through the barrel and a second one due to the combustion process.

CONCLUSIONS

It has been shown that using both windowed Fourier and wavelet transforms that the differences in performance of the gun configurations can be seen in the wave analysis. Thus when the configuration is varied the results can be analyzed. For example when wave deflectors were used on the rear of the projectiles it was found that the wave patterns were similar with and without deflectors. This agreed with experiment.

REFERENCES

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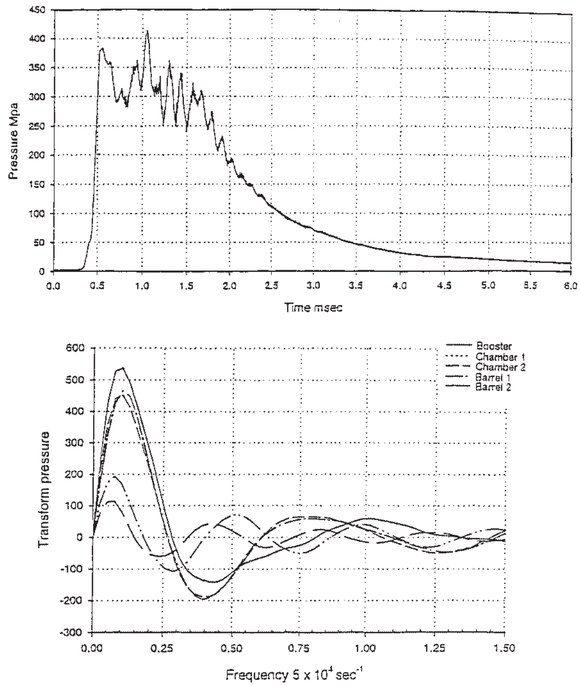

Figure 1. (upper) Pressure measurements in the booster (lower) Fourier sine transform (data set 9 [1]).

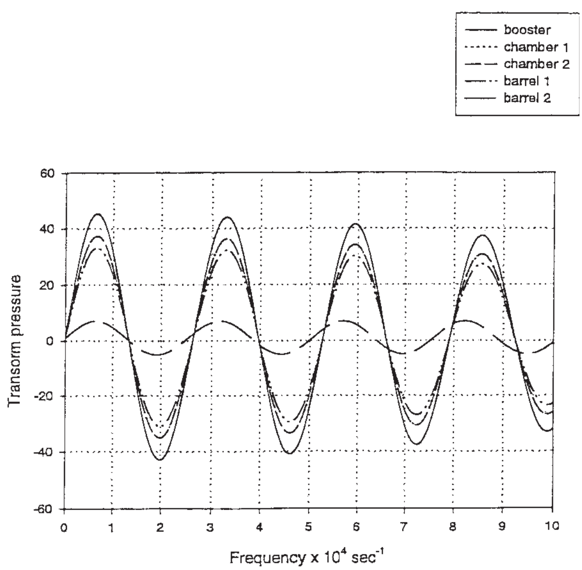

Figure 2. Fourier window transform 0.9–1.0 ms (data set [1]).

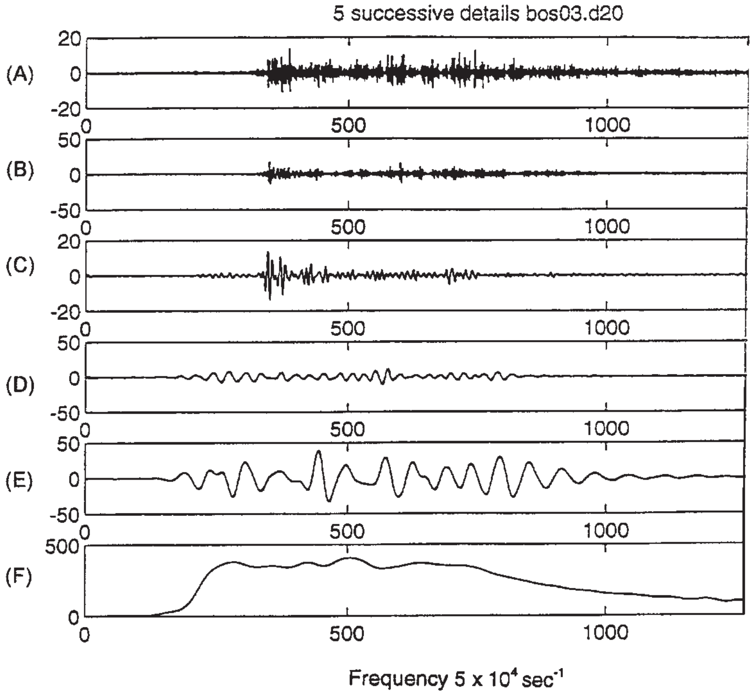

Figure 3. Booster multiresolution wavelets at varying resolution.
(A) One half of the sample data used (2^{-1})
(B) One quarter of the sample data used (2^{-2})
(C) One eigth of the sample data used (2^{-3})
(D) Data sample (2^{-4})
(E) Data sample (2^{-5})
(F) Wave reconstruction using (A)–(D)

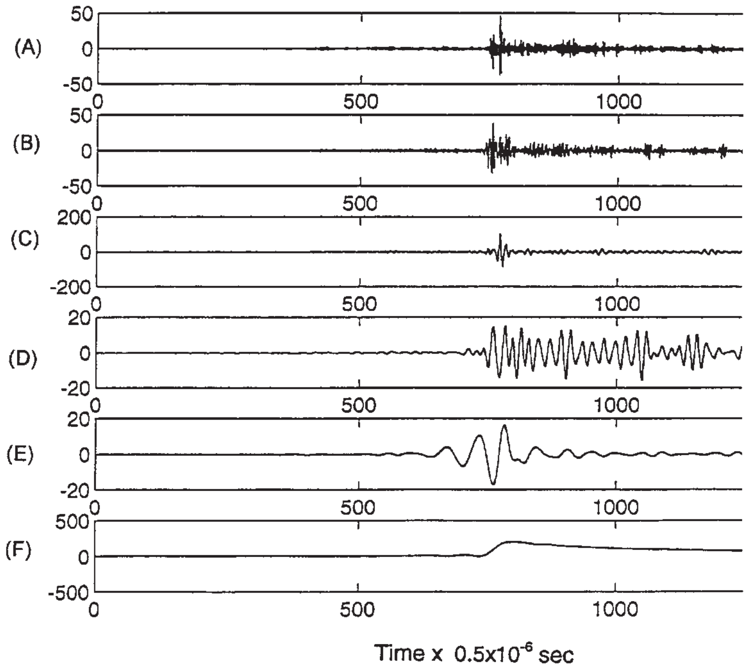

Figure 4. Barrel position 1 multiresolution wavelets at varying resolution.
(A) One half of the sample data used (2^{-1})
(B) One quarter of the sample data used (2^{-2})
(C) One eigth of the sample data used (2^{-3})
(D) Data sample (2^{-4})
(E) Data sample (2^{-5})
(F) Wave reconstruction using (A)–(D)