Airbag Noise Measurements

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When an airbag inflates rapidly during a car accident, the driver is exposed to a large impulsive sound pressure wave of short duration that could possibly damage human hearing. The time signals of these impulsive sounds were measured using transducers of various types and sizes in order to investigate the repeatability of measured results both for each transducer and between transducers. The aim was to find a suitable way for manufacturers to test airbags and to be able to make meaningful data comparisons.

Impulsive pressure waves can be measured with various transducers, but which provides the most realistic measurement? In this article we will try to answer this question by going into wave theory and clarifying the behavior of short impulsive waves from measurements with different transducer types on inflating airbags.

Airbag Signal Characteristics

The noise emitted during an airbag deployment is characterized as both an impulse with high frequency content and a pressure increase inside the vehicle compartment with low frequency content. While the determination of the low-frequency pressure signal is easily done using a standard microphone with a suitably low cut-off frequency, the measurement of the high-frequency content needs careful selection of microphone, preamplifier and data acquisition system.

The low-frequency content is caused by the expansion of the airbag inside the closed vehicle compartment and will be a function of airbag size, vehicle compartment internal volume and venting-time constant of the vehicle compartment. The pressure increase will therefore be reduced if, for example, a window is opened or other leaks are introduced. The following measurements focus on the high-frequency impulse and the measurements have been performed in free air so that no low frequency-pressure increase is observed.

The high-frequency impulse created by the inflation of the airbag is characterized by a very steep initial impulse which places great demands on the frequency response of the microphones and the signal handling capacity of the preamplifiers and data acquisition system. It is therefore necessary to consider factors such as diffraction around the microphone, frequency range, slew rate and sampling rates.

For an infinitely short pulse, the resulting spectrum will be broad band. If the pulse is transmitted through some linear system with frequency band limitation, the spectrum will be changed and, at the same time, the pulse shape will be changed.

Filtering the impulse through a band-limiting filter such as a single-order low-pass Butterworth filter, the peak of the pulse will be reduced. Figure 1 shows the resulting waveform of an impulse filtered through filters with different cut-off frequencies. Similarly the introduction of high-pass filtering will change the shape of the pulse but not the peak of the pulse.

Measuring a pulse with a microphone involves both high-pass and low-pass filtering. Due to the lower limiting frequency of the microphone itself and of the combination of microphone and preamplifier, the impulse will be high pass filtered with a cut-off frequency of around 1 to 5 Hz. This will, however, not change the peak value of the impulse, as mentioned above.

Similarly, due to the limited upper-frequency range of the microphone and preamplifier, the input pulse will be low-pass filtered, thus reducing the pulse peak if the bandwidth of the pulse is larger than the bandwidth of the microphone.

Transducer Selection

Choosing the right transducer for airbag noise measurements involves a number of compromises and considerations regarding dynamic range, frequency range, transducer size and type of response.

Microphone Dynamic Range. Airbag noise contains an impulse which requires a microphone with wide frequency range and the ability to handle high levels. The upper limit of the dynamic range of a measurement microphone, Figure 2, is directly related to the sensitivity of the microphone. For a typical 1/2-in. measurement microphone with a sensitivity of 50mV/Pa, the upper range of the dynamic range is limited to around 146 dB re 20 µPa. For a typical airbag with a peak impulse of 4000 to 6000 Pa, corresponding to 160 to 169 dB re 20 µPa, the microphone would be clearly overloaded as the expected output signal from the microphone should be around 200-300 V.

A typical 1/4-in. microphone with a sensitivity of 4 mV/Pa, would similarly give an output signal of around 16 to 24 V. This can easily be handled by the microphone, but may cause problems with the associated preamplifier. Preamplifiers of the IEPE type are normally limited by their peak handling capacity to around 10 to 12 V so, in this case, the preamplifier would be overloaded. Traditional types of microphone preamplifiers can normally be used with a supply voltage of ±60 V, and will be able to handle peak input signals up to around ±56 V. This will allow measurements of signals with peaks of up to around 14000 Pa or 176 dB re 20 µPa.

The sensitivity of the microphone can be reduced further by using a stiffer microphone diaphragm, but this will usually be accompanied by an increase in diaphragm mass and therefore change in frequency response. The best result is obtained by decreasing the size of the microphone further, for example to 1/8 in. This can be made with a sensitivity of around 0.8 mV/Pa without sacrificing frequency range. With a sensitivity of 0.8 mV/Pa and a preamplifier signal-handling capacity of up to around ±56 V, the microphone can be used for signal peaks up to around 70000 Pa or 190 dB re 20 µPa.

Microphone Frequency Range. The ability of microphones to handle sound impulses with very steep rise and fall times is directly related to the frequency range of the microphone. An ideal infinitely short pulse will theoretically have a frequency spectrum covering an infinite number of frequencies from low to high. If the frequency range of the pulse is limited, the shape of the pulse will be changed and the peak will be reduced.

Another factor influencing the measurement results is the diffraction around the microphone. Diffraction is dependent on the size, shape and orientation of the microphone relative to the sound field. Normal measurement microphones are shaped as a cylinder with a flat end constituting the diaphragm. If the microphones are pointed towards the sound source, e.g. parallel to the propagation direction, the sound waves will be partially reflected by the presences of the microphone in the sound field. This will result in a pressure increase in front of the microphone (see Figure 3) and this increase will be measured by the microphone. The amount of pressure increase, or diffraction, in front of the microphone will depend on the size (diameter) of the microphone relative to the wavelength of the sound. Since the wavelength depends on the frequency, the diffraction will be frequency dependent. This means that, for a small microphone, the diffraction will be smaller than for a large microphone and the diffraction will be more pronounced at higher frequencies as indicated in Figure 4.

If the microphone is turned so that its diaphragm is parallel to the direction of propagation of the sound waves, no pressure increase in front of the diaphragm will occur. At higher frequencies, where the wavelength becomes small compared with the diameter of the microphone diaphragm, the microphone will underestimate the sound pressure. For example at 100 kHz, the wavelength is 3.4 mm and the effective diaphragm diameter of a typical 1/4-in. microphone is around 3.6 mm. This means that part of the diaphragm will be subjected to the under pressure of the sound

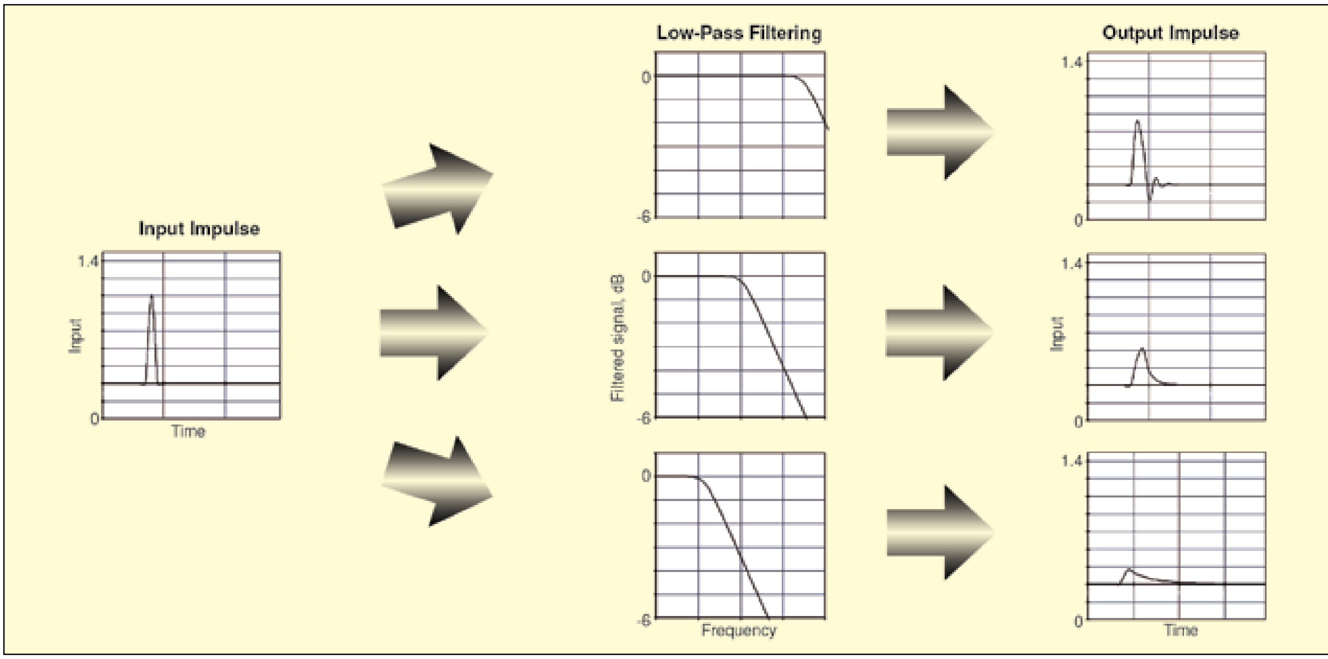

Figure 1. Low pass filtering of impulse.

Figure 2. Diffferent size measurement microphones.

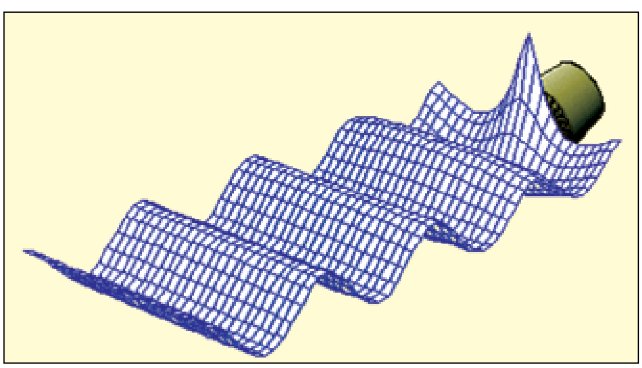

Figure 3. Pressure increase in front of microphone due to diffraction.

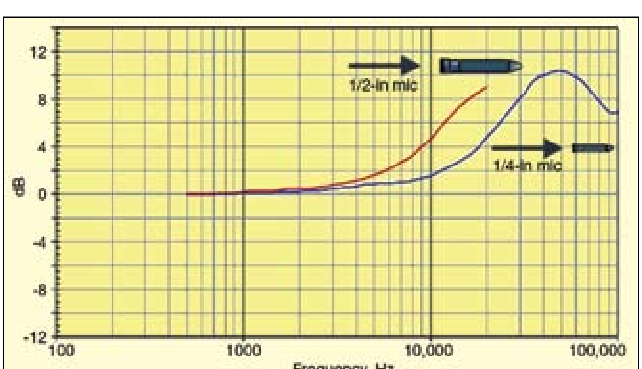

Figure 4. Diffraction for 1/2 in. and 1/4 in. microphones.

wave and at the same time another part of the diaphragm will be subjected to over pressure. The mean pressure over the full diaphragm will be close to zero and the microphone output will underestimate the true sound pressure of the sound wave.

For a short-duration pulse, its spatial length can be calculated from knowing the speed of sound. For example an impulse with duration of 0.005 ms will be 1.7 mm long, assuming a sound velocity of 340 m/s. Since this pulse is short compared with the effective diameter of the microphone's diaphragm, only part of the diaphragm will be excited by the impulse and as the nominal sensitivity of the microphone assumes an even excitation of the full diaphragm, the microphone will underestimate the impulse. So as the impulse travels across the diaphragm, different parts of the diaphragm will be excited (see Figure 5). This also means that it is not the duration of the pulse itself which is measured, but the time it takes for the pulse to travel across the diaphragm.

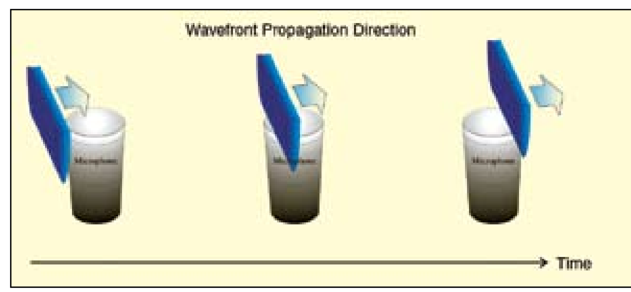

Figure 5. Impulse traveling perpendicular to the diaphragm.

Measurement Setup

An airbag under test was securely mounted on the back of a trailer, as shown in Figure 6, in a position 70 cm above ground The microphone stand, Figure 7, was placed in a horizontal line 80 cm from the center of the airbag to avoid direct impact from the airbag itself. The data acquisition system and the controlling computer were placed inside a container about 10 m away. The airbag deployment and the start of the data acquisition was controlled by a common trigger signal generated by the computer. An Olympus high speed video camera was placed around 3 m from the airbag to record the airbag inflation. The instrumentation chain is shown in Figure 8.

Measurements were performed with four different microphones from G.R.A.S. Sound & Vibration: 1/8-in. Pressure Microphone Type 40DP, 1/4-in. Free Field Microphone Type 40BF, 1/4-in. Pressure Microphone Type 40BP and 1/2-in. Free Field Microphone Type 40AF. The microphones were place in a line with 3 cm separation, on a common stand 70 cm above the ground, 80 cm away from the front of the airbag. The 1/4-in. Pressure Microphone Type 40BP was place with its diaphragm at a 90° angle to the incident wave front so that no pressure increase in front of the diaphragm from diffraction

Figure 6. Airbag mounted in front of microphones.

Figure 7. Microphone setup.

occurs. The other microphones were mounted with their diaphragms pointing toward the airbag. This combination gave measurement data from the small 1/8-in. microphone to the standard size 1/2-in. microphone and makes it possible to analyze the effects of microphone size, frequency range and diffraction effects.

The microphone capsules were powered by dual-channel supply modules, Type 12AA, and preamplifiers type 26AC. Data acquisition hardware used for recording and storage of the four input signals was a National Instrument PXI chassis 1042Q with a PXI-6120 16 bit, 4 analog input, simultaneous sampling data acquisition card. Data acquisition was controlled by a LabVIEW program, using the 64 MB onboard memory on the data acquisition card to measure the 4 channels simultaneously with a sampling frequency of 800,000 samples/sec/channel.

Before each measurement, the microphones were calibrated by a precision pistonphone Type 42AP. This pistonphone delivers a 250 Hz pure tone at 114 dB. The sound pressure inside the coupler is automatically corrected for ambient static barometric pressure. Correction values were implemented during later analyses of the results. Each airbag that was deployed was filmed by a high speed camera recording at 2000 images/sec.

Measurement Results

The deployment of a typical airbag is illustrated in Figure 9. The recorded acoustic pressure signal was synchronized with recordings from the high speed video camera and analyzed with the National Instrument Diadem Clip software for synchronizing movie files with test data. Initially, the airbag is at rest until the deployment starts and the airbag outer case starts to deform. About 2 msec later, the audio signal shows a large high-frequency peak and the airbag starts to fill and move outwards away from the steering wheel. 8 msec later the airbag stops its outward movement, accompanied by a negative pressure pulse. The airbag then continues to fill up radially for the next 60 msec until it is completely filled and starts to deflate.

The result shown in Figure 9 is for the 1/8-in. Pressure Microphone Type 40DP. Figure 10 shows a comparison of results from the other three transducer types. It can be seen that the response from the 1/4-in. Microphone Type 40BF is very similar to the result from the 1/8-in. microphone The main difference is under-estimation of the peak value by the 40BF while the signals from the other two microphones are very different from the first two signals.

Analyzing the signals with the Short-Time Fourier Transform (STFT) program in the National Instruments Sound and Vibration

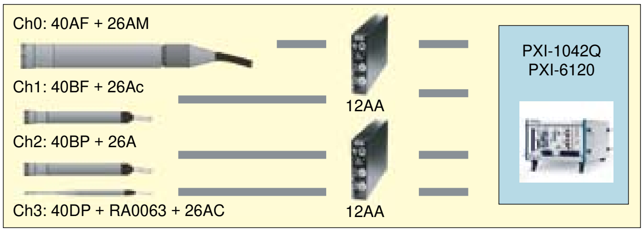

Figure 8. Measurement chain.

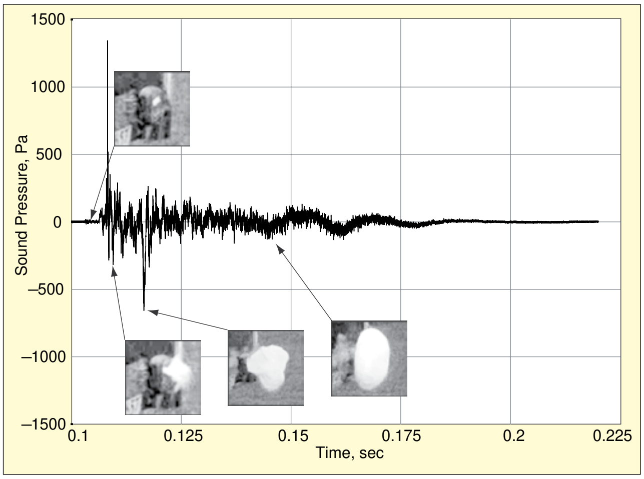

Figure 9. Airbag deployment.

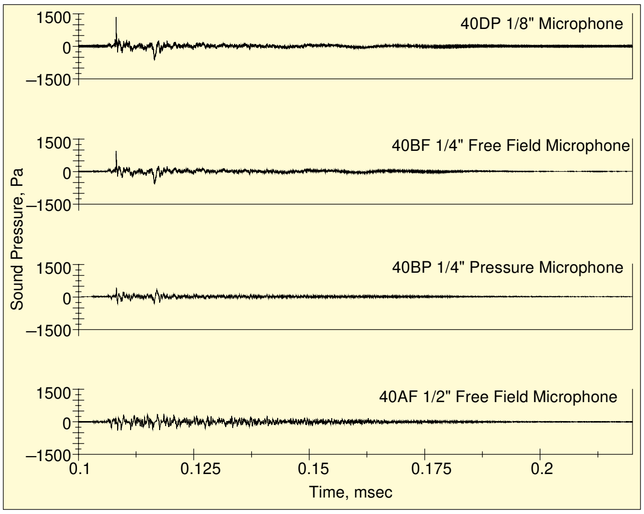

Figure 10. Signals from four different transducers.

package from LabVIEW gives detailed information about the signals both in the frequency and time domains.

It can be seen that the 1/4-in. microphone measures the impulse with a frequency range up to 140 kHz, covering essentially the full useful frequency range of the microphone. It might be that using a microphone with an even wider frequency range would reveal frequency content in the pulse at even higher frequencies, but it is not very likely that it will contain much energy above the present frequency range.

The 40BF 1/4-in. microphone in Figure 11b has upper frequency limits around 80 kHz, while the 40BP and 40AF microphones do not respond significantly to the impulse in the signal. Looking closely at the time signal around the impulse for the four transducer signals shown in Figure 12 reveals details about the response of the different transducers.

In general, the signals from the four transducers follow the same trend. The biggest difference occurs at the peak, where the 40DP 1/8-in. microphone estimates a peak value of 1345 Pa, while the 40BF 1/4-in. microphone gives 943 Pa. This is caused by the limited bandwidth of the 40BF 1/4-in. microphone and not problems with handling the dynamic range of the impulse.

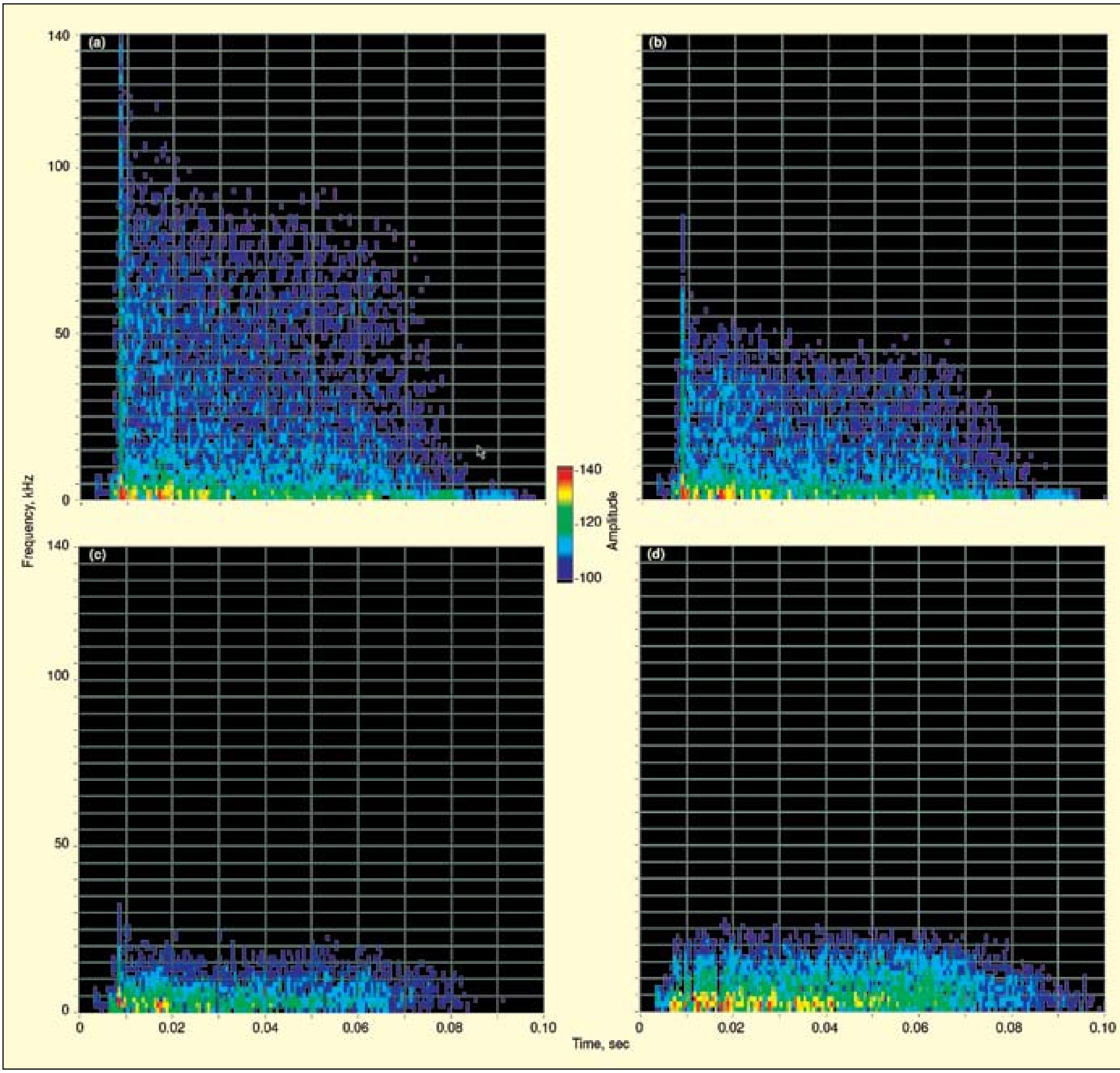

Figure 11. Colormap of STFT for four different transducer signals: a) 40DP 1/8 in. microphone; b) 40BF 1/4 in. microphone; c) 40BP 1/4 in. microphone; and d) 40AF 1/2 in. microphone.

The steep pulse measured by the 1/8-in. microphone has a duration of around 5 μs corresponding to a wave front width of around 1.7 mm, assuming a sound velocity of 340 m/s. This means that the wave front will travel across the diaphragm of the 40BP 1/4-in. microphone as this microphone was placed perpendicular to the wave front direction. The microphone has an effective back plate diameter of approximately 3.5 mm, so the wave front will excite only a small part of the diaphragm. The impulse as recorded with the 40BP will therefore be a 'smoothed' version of the peak.

The 1/2-in. free field microphone type 40AF misses the impulse completely. Partly because the frequency range of the microphone is limited to 20 kHz and partly because the diaphragm area is large compared to the length of the wavefront. The very short wavefront causes the diaphragm to "break up," so that the diaphragm does not move in a well-defined pattern. Different parts of the diaphragm move in chaotic patterns at high frequencies. This can be seen as a very high frequency ripple or noise on the signal from the 40AF shortly after the impulse signal.

The peak value measured for the steering wheel type airbag was measured to 1345 Pa. Much higher peak values were measured for a passenger side airbag. As shown in Figure 13, the full airbag deployment takes about 75 msec with peak values up to

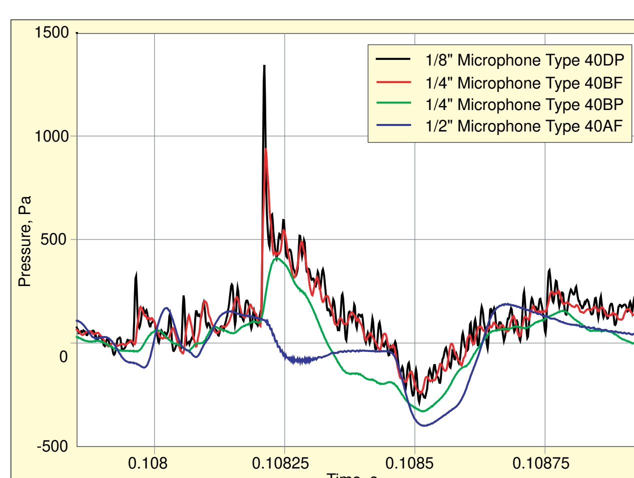

Figure 12. Time signals from 4 different transducers.

6000 Pa. The initial part of the airbag signal is characterize by a general pressure increase superimposed with a number of short

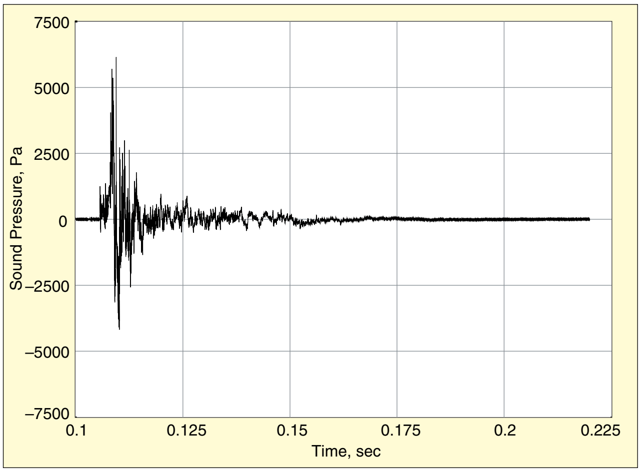

Figure 13. Airbag deployment time history.

impulses. The initial pressure increase is followed by a negative pressure superimposed with a high positive peak impulse. While the impulses are very high, they are still well below the handling capacity of the microphone and preamplifier of up to around 70.000 Pa or 20 dB higher.

Conclusions

Measurement of the steep impulse of an airbag deployment requires a small transducer able to handle very high frequencies. A 1/8-in. measurement microphone has the size and frequency range capability to measure the very short wave fronts and capture the high frequencies. The use of high speed simultaneous sampling and effective data processing tools enables detailed investigation of the signal and correlation with the physical phenomena and high speed recordings.

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