

MEASURING WAVE FRONTS OF INFLATING AIRBAGS

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Abstract

When an airbag inflates rapidly during a car accident, the driver is exposed to a large impulsive wave of sound pressure of short duration that could possibly damage human hearing. The time signals of these impulsive were measured using transducers of various types and sizes in order to investigate the repeatability of the measured results both for each given 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.

1. INTRODUCTION

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

2. AIRBAG SIGNAL CHARACTERISTICS

The noise emitted during an airbag deployment is characterized by 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 suitable 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 the airbag size, the vehicle compartment internal volume and the 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 a broad band spectrum. If the pulse is transmitted through some linear system with 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. Similarly the introduction of highpass filtering will change the shape of the pulse but not the peak of the pulse.

Measuring a pulse with a measurement 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.

3. 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.

3.1 Microphone dynamic range

The 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 is directly related to the sensitivity of the microphone. For a typical $\frac{1}{2}$ -inch measurement microphone with a sensitivity of 50 mV/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 200-300V.

A typical ¹/₄-inch microphone with a sensitivity of 4mV/Pa, would similarly give an output signal of around 16 to 24V. This can easily be handled by the microphone, but may cause problems with the associated preamplifier. Preamplifiers of the IEPE type are normally limited in their peak handling capacity to around 10 to 12 V so in this case the preamplifier would be overloaded. The traditional types of microphone preamplifiers can normally be used with a supply voltage of ±60V, and will be able to handle peak input signals up to around ±56V. This will allow measurements of signals with peaks of up to around 14000Pa or 176dB 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 $\frac{1}{8}$ -inch. This can be made with a sensitivity of around 0.8 mV/Pa without sacrificing frequency range. With the 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.

3.2 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. The 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 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.

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-inch microphone is around 3.6 mm. This means that part of the diaphragm will be subjected to the under pressure of the sound wave and at the same time another part of the 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.

4. MEASUREMENT SETUP

The airbag under test was securely mounted on the back of a trailer, in a position 70 cm above ground and the microphone stand was placed in a horizontal line 80 cm from the centre of the

airbag to avoid direct impact from the airbag itself. Having 4 microphones measuring simultaneously made it possible to compare data even though not measuring at the exact same position. The distance between each microphone was 3 cm.

Measurements were performed with four different microphones from G.R.A.S. Sound & Vibration: ¹/₈-inch Pressure Microphone Type 40DP, ¹/₄-inch Free Field Microphone Type 40BF, ¹/₄-inch Pressure Microphone Type 40BP (90 degree angle to the incidence wave front) and ¹/₂-inch Free Field Microphone Type 40AF. This combination gave us measurement data from the small ¹/₈-inch microphone to the standard size ¹/₂-inch microphone. Diffraction around the measurement microphone and also the upper-frequency limitations are parameters that influence the recording. Analyses of the measured signal will be made to study the most suitable microphone type for measurements on short, high level impulses.

The microphone capsules were powered by dual-channel supply modules, Type 12AA, and preamplifiers of types 26AL and 26AC. Data acquisition hardware used for recording and storage of the four input signals was a National Instrument PXI box 1042Q with acquisition card PXI-6120. All channels were synchronized to measure the 4 channels simultaneously. The sampling frequency was set to 800000 samples per second, to make sure we got enough data for the analyses. When an airbag is set off, each channel measures a signal of 2 seconds duration. A trigger signal is generated from the computer to activate data sampling and also to set off the airbag. The data acquisition card begins the recording 100ms before the airbag is set off and data are stored onboard the PXI-6120 card in a cycling buffer that writes to the disk every 2 seconds.



Figure 1. Microphone setup



Figure 2. Airbag mounted in front of microphones

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



Figure 3. Measurement chain

5. MEASUREMENT RESULTS

The deployment of a typical airbag is illustrated in Figure 4. The recorded acoustical pressure signal was synchronized with recordings from a 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 ms 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 ms 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 ms until it is completely filled and starts to deflate.



Figure 4. Airbag deployment

The result shown above is for the ¹/₈-inch Pressure Microphone Type 40DP. Figure 5 shows a comparison of the results from the other three transducer types. It can be seen that response from the ¹/₄-inch Microphone Type 40BF is very similar to the result from the ¹/₈-inch microphone, the main difference being the under-estimation of the peak value by the 40BF, while the signals from the other two microphones are very different from the two first signals.



Figure 5. Signals from 4 different transducers

Analyzing the signals with the Short-time Fourier Transform program in the National Instruments Sound and Vibration package for Labview gives detailed information about the signals both in the frequency and time domains.

It can be seen that the ¹/₈-inch 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 of even higher frequencies, but it is not very likely that it will contain much energy above the present frequency range.

The 40BF ¹/₄-inch Microphone in figure 6b is limits measurements up to around 80 kHz, while the 40BP and 40AF records very little of the impulse in the signal. Looking closer at the time signal around the impulse for the four transducer signals as in figure 7, reveals details about signals measured by the different transducers.



Figure 6. Colourmap of STFT for four different transducer signals



Figure 7. Time signals from 4 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-inch microphone estimates a peak value of 1345 Pa, while the 40BF ¹/₄-inch microphone gives 943 Pa. This is caused by limited bandwidth of the 40BF ¹/₄-inch microphone and not problems with handling the dynamic range of the impulse.

The steep pulse measured by the $\frac{1}{8}$ -inch microphone has a duration of around 5µs corresponding to a wave front width of around 1.7mm, assuming a sound velocity of 340 m/s. This means that the wave front will travel across the diaphragm of the 40BP $\frac{1}{4}$ -inch microphone. 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.

5. CONCLUSION

To measure the steep impulse of an airbag deployment requires a small transducer able to handle very high frequencies. A ¹/₈-inch measurement microphone has a size and frequency range able to measure the very short wave fronts and capture the high frequencies.