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Characterisation of the sound field emitted by an electric spark source in air

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Summary
Electrical sparks are used as sound sources in air to generate short duration (30 μs) spherical waves. Sources with small gap between the electrodes have been used as impulse sources to study the acoustical properties of scaled models of halls. Sources with larger gap are used to produce high pressure (1000 Pa) N-waves for nonlinear applications. Some of the present authors have recently studied theoretically and experimentally the characteristics of high pressure N-waves emitted from a 17 mm gap spark source [1, 2]. These studies were dedicated to the dependance of the N-wave characteristics (maximum pressure, duration, rise time) with the propagation distance. However, the characteristics of the waves and the directivity of the source also depend on the electrode gap. In the present study, using 1/8 inch microphones, the field emitted by the spark source is studied experimentally for different electrode gaps (1-20 mm), propagation distances (0.15-1.5 m) and emission angles. Experimental data are compared to theoretical predictions. The influence of the limited frequency response of the microphones will be discussed. The present work is supported by the French International Program for Scientific Cooperation PICS and the French National Research Agency ANR SIMMIC project.

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1. Introduction

Electrical sparks can be used as sound sources in air to generate short duration (30 μs) spherical waves. Sources with small gap between the electrodes have been used as impulse sources to study the acoustical properties of scaled models of halls or of materials. Sources with larger gap are used to produce high pressure (1000 Pa) N-waves for nonlinear applications [3, 4]. The characteristics of such N-wave source have been studied experimentally by Wright [6, 5]. Some of the present authors have recently studied theoretically and experimentally the characteristics of high pressure N-waves emitted from a 17 mm gap spark source [1, 2]. Experiments and numerical simulations have been performed in order to obtain the dependance of N-waves characteristics (maximum pressure, duration, rise time) with the propagation distance [1]. A remarkable result of these previous publications is the measurement of the front shock of short duration N-waves thanks to the combination of the analysis of shadowgraphs and numerical simulation of sound and light propagation [2]. In these studies, the spark source was considered as a point source that genrerates spherical waves. However, the directivity of a spark source may vary with the gap between the electrodes and the source may differ from a point source at short distance from the spark.

The aim of the present communication is to analyse the modification characteristics of the waves and the directivity of the source for different electrode gaps. Using 1/8 inch microphones, the field emitted by the spark source has been measured for electrode gaps e varying from 1 to 20 mm. The wave characteristics (amplitude, duration, spectrum) variation has been measured for propagation distances increasing from 0.15 to 1.5 meter and for emission angles from 0^o to 80^o. A particular attention is paid to the influence of the limited frequency response of the microphones on the measured data.

2. Experimental setup

As demonstrated by Davy and Blackstock [3], short duration high pressure N-waves can be generated by

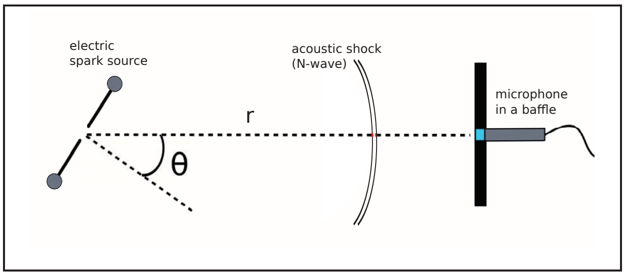

Figure 1. Definition of the emission angle θ and the source-microphone distance r.

using an electric spark source. The spark source used in the present experiment is made with two tungsten electrodes connected to a 15 kV electric supply. A sudden local heating and gas expansion occurs when the spark is generated. This induces the generation of a short duration and high pressure propagating pulse. Due to nonlinear propagation, the pressure pulse evolves towards an N-wave a few centimeters away from the electrodes. In the present experiment, the electrode gap between the electrodes is varied from 1 to 20 mm.

The waves are measured by using 1/8 inch microphones (Bruel & Kjaer Type 4138 or GRAS type 40DP) which grid has been removed. In order to limit the diffraction of waves on the edge of the microphones, the microphones are mounted in a baffle. The microphone is connected to its appropriate preamplifier, which is connected to a Bruel & Kjaer Nexus amplifier/conditionner which frequency response has been extended (140 kHz -1dB / 200 kHz -3dB). The conditioner output is then digitized using a National Instruments Data Acquisition System at a 10 MHz sampling frequency. The source is mounted on a turntable and both the source microphone distance r and the emission angle θ defined in figure 1 are computer controlled.

3. Results

For each position (r, θ), one hundred waves are measured and the recorded signals are analysed. The parameters discussed hereafter are the maximum positive peak pressure P_{max} and the duration of the positive part of the wave, called the half-duration T.

3.1. Variable electrode gap, normal incidence

Waveforms have been measured for different electrode gaps e at one meter in the case $\theta = 0^o$ (normal incidence). Pressure waveforms and corresponding spectra estimated from the microphone output are given in figure 2. These figures show that the peak pressure and the wave duration decreases with the electrode gap. The waveform seems to be more symmetric when e decreases. However, it is clear from the spectrum that the limited frequency bandwidth has a great influence on the measurement. The cut-off frequency of the measurement system is around 140 kHz. The low-pass filtering is clearly seen on the spectra of figure 2. This limited frequency response has several consequences. First is the huge overestimation of the front shock rise time, that is estimated to be of the order of 2.5 μs from the microphone signal, while optical methods have shown that it is of the order of 0.1 μs [2]. Thefore, this parameter is not discussed hereafter. As it can be clearly seen on the waveforms, the low-pass filtering also induces oscillations that are related to the cut-off frequency of the measurement system and not to the electrode gap. When the electrode gap is decreased from 20 mm to 1 mm, the spectrum is shifted towards high frequencies, thus a larger and larger part of the spectrum is outside the measurement system bandwidth. Consequently, the real pressure waveforms for short electrode gaps should differ significantly from the waveforms deduced from the electric output of the measurement system. The situation is even much more critical if the pressure waves are measured using 1/4 inch microphones because their cut-off frequency is lower. Additional error is done for non normal incidence of the wavefront on the microphone membrane because the responsivity of microphones decreases significantly with the angle of incidence at high frequencies.

Additional measurements showed that the peak pressure decrease with the distance r at $\theta = 0^o$ does not vary with the electrode gap e.

3.2. Variable electrode gap, source directivity

Figure 3 shows waveforms measured at one meter of the source with the electrode gap $e = 20$ mm. They have been measured for emission angles $\theta = 0, 30, 50, 70^o$. Similarly to the observation of Wright [5], as the emission angle increases, the waveform evolve from an N-wave at $\theta = 0^o$ towards a waveform with a zero-pressure interval near the center of the waveform. When the emission angle increases from 0^o to 70^o, the negative peak pressure decreases. A second positive pressure peak appears on some waveforms. The time interval between the two positive peaks corresponds to the electrode gap e. Therefore the spark source should be considered as a line source rather than a point source.

In figure 4 are plotted the maximum peak pressure and the half duration of the wave as functions of the emission angle θ. Mean values are computed over 100 waves and are nomalized by the values obtained at $\theta = 0^o$. These curves show how the peak pressure differs from an ideal point source. In the case of an electrode gap of 1 mm, the peak pressure and the half-duration are nearly constant up to 45^o, while the behavior is clearly different for larger gaps. Note that the definition of the half duration is no more valid at large emission angles for the larger gaps because of

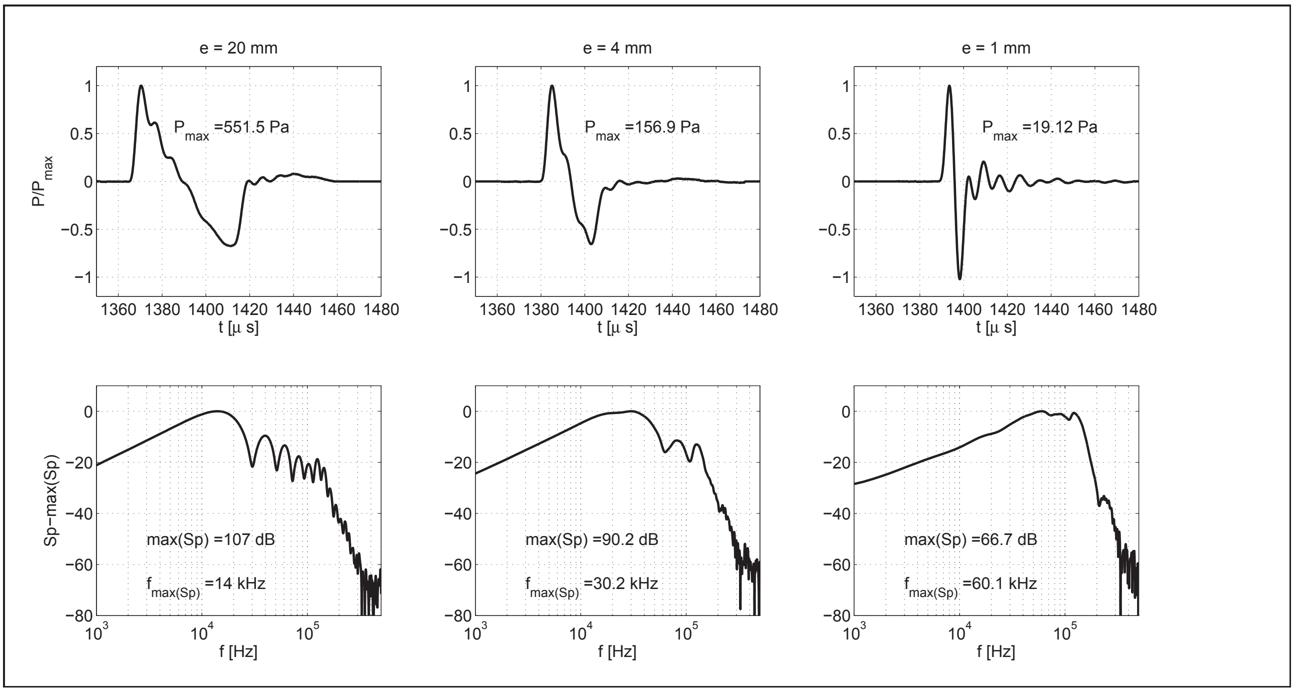

Figure 2. Waveforms and corresponding spectra measured at 1 m from the source for three electrode gaps. Spectra are normalized by their maximum value, given in dB, ref. 2.10^{-5} Pa. The frequency $f_{max(Sp)}$ corresponds to the maximum of the spectrum.

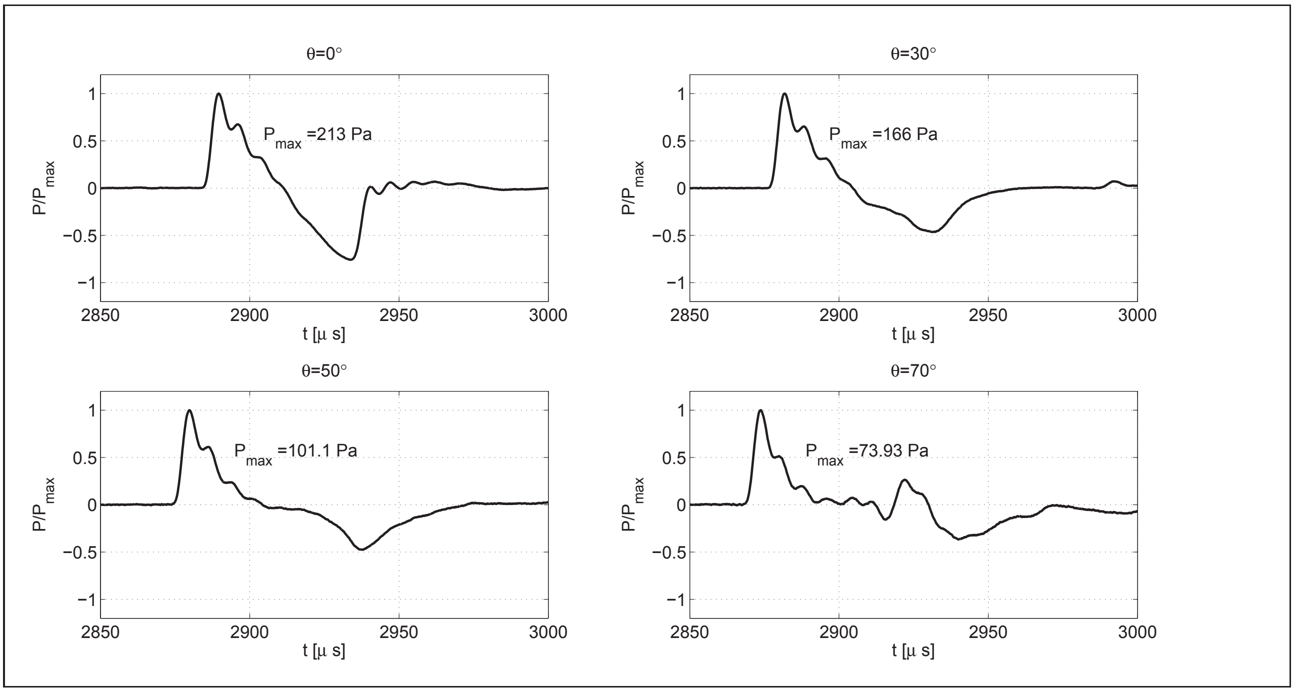

Figure 3. Waveforms measured at 1 m from the source with the electrode gap $e = 20$ mm. Waveforms are normalized by their maximum value P_{max}.

the appearance of the zero-pressure interval near the center of the wave. This remark explains why the estimation of the half duration varies greatly at emission angles greater than 60^o.

Despite the wave behavior vary greatly with the emission angle, at $\theta = 0$ the peak pressure decrease with the distance r does vary with the electrode gap e, suggesting a spherical-like behaviour of the wavefront on the source axis.

4. Conclusion

The characteristic parameters of short duration pressure N-waves generated by a spark source have been

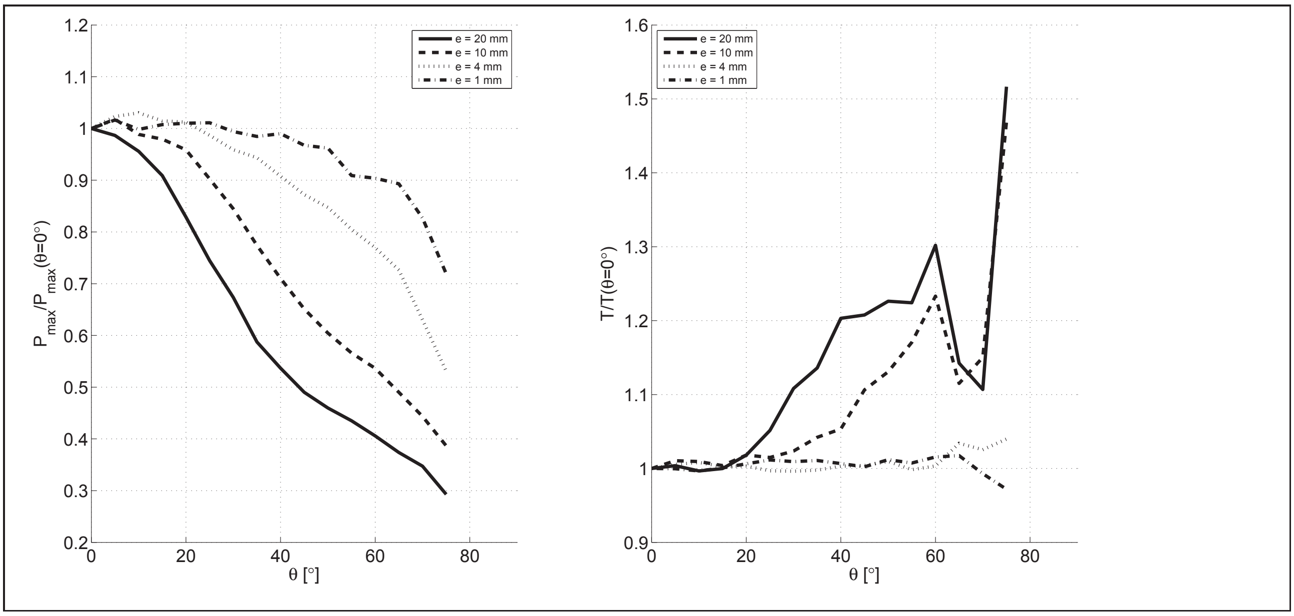

Figure 4. Evolution with the emission angle θ of the peak pressure and the half-duration of the waveform, measured at 1 m from the source for different electrode gaps. P_{max} and T are normalized by their value at 0

measured for various source-microphone distances and emission angle. The dependance of the peak pressure and the duration of the positive pressure interval have been analysed. Results suggest that the spark source should be considered as a line source rather than a point source for non normal emission angles. The great influence of the low-pass filtering induced by the limited frequency response of the measurement system has also been outlined.

Acknowledgement

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