Converting sunlight into audible sound: Some practical measurements on the Heliophone

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Abstract

This paper presents measurement results obtained with a device called Heliophone. The Heliophone collects and converts sunlight to sound without electronic amplification. Sunlight is focused to a photoacoustic piston surface in the photoacoustic cavity by means of a compound parabolic collimator, and its intensity is modulated by a mechanical chopper. The photoacoustic cell is connected to an acoustic horn, which acts as an impedance matching device between the cavity and the open air environment, making the sound audible. Acoustic measurements are presented, using sunlight to drive the Heliophone.

Keywords: photoacoustic; carbon black; soot; horn; sunlight
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1 Introduction

In this work people from the artistic work environment and from the academic work environment collaborated to design and develop a new device to convert sunlight into audible sound, called Heliophone. Both artistic aspects as well as academic aspects are involved in this work. From an academic point of view, the work is interesting because of the photoacoustic effects involved. A good physical understanding of these phenomena is not very easy, and described in detail in another publication of the authors [1]. One interesting aspect, as described this this reference, is the crucial importance of the use of soot. Also the design of the horn-cavity combination is important. However, the focus of this paper is not so much about these aspects, as well as on some practical measurement results that were obtained with a Heliophone prototype.

The interested reader can get more information about this project at the website www.heliophone.earth.

2 Device description and measurement results

This paper discusses some practical in-situ measurement results using a device called Heliophone, earlier described by the authors [1]. In the device (Figure 1), sunlight is focused by means of a compound parabolic collimator (CPC) onto a photoacoustic cell (detailed in Figure 2), in which a candle soot carbon blackened copper coated Kapton® foil is heated by the sunlight. This foil acts as a photoacoustic transducer. The collimated sunlight is modulated by means of a rotating mechanical chopper. Due to optical absorption by the carbon black, a periodically varying heat flux is induced into the air above the surface. This causes pressure variations in the cell cavity at the chopper frequency and its harmonics. The cavity had a small opening where it is connected to an acoustic horn, which acts as an impedance matching device between the cavity and the open air environment, making the sound audible.
Figure 1: Final realization of the Heliophone (CPC = compound parabolic collimator). Photography by Neil Karia.

The body of the photoacoustic cell was made of Plexiglas (see Fig. 2), to allow the chopped light beam to illuminate the carbon blackened copper coated Kapton foil. The foil (width of 9 mm) was placed in the middle of the spherical cell cavity (inner diameter 15 mm). As the width of the foil was smaller than the diameter of the cell cavity, the lower and upper half of the cell cavity can communicate with each other, allowing the pressure being generated at the side where the light beam entered the cavity to reach the side at which the horn was mounted. The thicknesses of the Kapton and copper layer were 65 µm and 35 µm respectively. The copper-Kapton layer was purchased from the Dupont® company (material trade name: Pyralux®). The candle soot layer was deposited by swinging the Pyralux foil slightly tilted back and forth in the flame of an ordinary candle, with the copper side oriented to the flame.

Figure 2: Schematic representation of the Heliophone, (a) total assembly (CPC = compound parabolic collimator), (b) detail of chopper, photo-acoustic cell and horn, (c) photo-acoustic cell with Kapton foil seen from the side of the acoustic horn opening (carbon blackened surface at the other side of the Kapton).
In the following we discuss a measurement with the Heliophone that was carried out around noon time on a sunny day in May. The acoustic pressure was measured at the end of the horn. The Heliophone as shown in Fig. 1 was used for this purpose, sweeping the chopper blade from a maximum achievable rotational speed down to stand-still. The slits in the chopper blade (Fig. 2b, chopper with 31 slits) had a slightly angle-dependent width, resulting in faint, periodical chopping frequency modulations during its rotation, and thus resulting in a specific sound being generated by the Heliophone. The spectrogram (Fig. 3) illustrates this specific sound, showing multiple discrete frequencies (sub-tones) being generated. The spectrogram also illustrates that the fundamental frequency is the strongest, followed by the third, the fifth and the seventh harmonic, as expected.

Figure 3: Swept sine spectrogram of acoustic pressure of a Heliophone using sun light. Measurements performed in front of the horn. The color bar indicates the single sided power spectrum in dB, ref 20 µPa.

Figure 4 (dotted line) shows the frequency dependency of the sound pressure level of the fundamental Fourier component, extracted from the spectrogram. During the beginning of the sweep (i.e. for $t < 13$ s, at a rotational speed of about 1050 rpm, fundamental frequency equal to 540 Hz), the sound pressure in front of the horn was measured to be 78 dB(A) (main frequency component 540 Hz).

Compared to laboratory measurements with a (artificial) light source with a known strength (in detail described in [1]), it could be inferred that the collected sunlight power was about 2 Watt. Using a numerical model for the photoacoustic effect (for details see [1]), the sound pressure at the end of the horn could be estimated. As compared to the numerical prediction (dashed line), the measurements in-situ compare well in terms of their shape and amplitude, although at lower frequencies the predictions are largely overestimated because viscous losses that are not taken into account in the model.

A further improvement of the optical path (i.e. of the CPC, the compound parabolic collimator) might improve the amount of sun light power incident upon the photoacoustic cell, and will thus also increase the outputted sound pressure levels for future versions of the developed
Heliophone.

Figure 4: (color online) Fundamental component of the sound pressure level in front of the horn, measured in-situ using sunlight (green dashed line), and predicted using a volume velocity source $Q=1.5482e-07m^3s^{-1}$ (blue solid line).

3 Conclusions

By using an acoustic impedance matching horn connected to a small photoacoustic cavity, audible sound was generated with a sound pressure level of 79 dB(A) ref 20 $\mu$Pa was measured in front of the horn, using sunlight that was collimated by a compound parabola.

At present work is being done to improve the optical part of the current prototype of the Heliophone, which might result in a higher solar energy that is incident upon the photoacoustic cell, and thus in a higher sound levels radiated by the device.

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References