



Method and system for evaluating acoustic directivity

Field of the Invention

5 The present invention relates to a method and system for evaluating acoustic directivity.

Background of the invention

10 A sound-emitting device, such as the diaphragm of a speaker or a musical horn, delivers wave energy by vibrating, and thereby projecting a sound wave forward in an acoustic transfer process. Acoustic projection is critical for most speakers as well as musical instruments, and it is a particularly great concern for small speakers. In many designs of sound emitting equipment, the delivery of the sound wave has to overcome a mismatch of medium impedances to produce an
15 audio signal of optimal quality. The efficiency of acoustic energy transmission may decrease in cases where only a small proportion of the longitudinal wave is transmitted into the air due to poor coupling. This phenomenon brings about absorption of audio waves and/or distortion of the original frequency distribution, which degrades the functional performance of the sound source.

20 Although there has been much progress in analyzing the air impedance experienced by audio waves by monitoring of the pressure variations, presently the preferred technique for effective characterization of sound propagation is active detection of air transmission velocity.

25 In designing an acoustic evaluation module, both the speed and accuracy of pressure sensing is of the utmost importance. These behaviors are influenced by environmental factors such as temperature, and humidity, which are likely to reduce the consistency of the measurement. Due to such considerations, localized pressure detection is advantageous as an absorption indicator to monitor the dynamic behavior of sound radiation.

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Summary of the Invention



The present invention relates to a new and useful method of acoustic characterization.

In general terms, the present invention proposes that a pressure field generated by a sound-emitting device (such as a speaker, or a musical horn) is
5 detected by a plurality of micro-sized capillary tubes, each coupled to a respective pressure detection device. The micro-sized capillary tubes enhance the sensitivity of pressure detection, so that local changes in sound emission behavior can be quantified on a distance scale corresponding the spacing of the capillary tubes.

10 This makes possible a sensing method which does not require a physical contact between a sensor and the sound-emitting device, and in turn makes possible effective mapping of sound propagation behavior, using an adaptable probing mechanism to fit the geometry of the sound-emitting device. This also makes possible study of the response of a sound wave from the mouth of the
15 emitting mechanism that is not otherwise easily evaluated when the amplitude of vibration is very small. The measurement system aims to analyze the pressure profile of sound wave, and to compute its propagation energy with regard to the environment conditions.

In use, the needle-like micro-sized capillary tubes (here referred to as
20 Pitot-tubes) are arranged in parallel in an array. The array is positioned at a specific distance in front of a sound emitting source. The size of the probe array may be selected depending on the vibration capacity of the sound source, to meet the required sensing resolution.

Various embodiments of the invention can be used for any general sound
25 emitting musical instrument or speaker system, such as to determine its acoustic directivity. In this methodology, the relationship between the air velocity to the pressure in relation to the sound baffle or source plane is identified. Subsequently, the directivity pattern of the acoustic transmission may also be identified as velocity vectors, such that the travel speed and direction of the air
30 particles are identified.

The probes permit the pressure to be measured a corresponding fixed sensing position in the acoustic field. The maximum change in air pressure quantifies the projected intensity of the sound emitting source, and this measured pressure level is also proportional to the travel velocity of the sound energy. This system enables the pattern of the sound radiation to be examined and modeled in 3-dimensions. The pressure measurements can be quantified and recorded over a long duration. The air impedance of a projected sound wave can be found from its local transmission velocity at the specific sensing positions.

Certain embodiments are arranged to assess the transmission efficiency of an audio wave as a function of its radiating frequency spectrum, which is useful for understanding the frequency response of the vibrating diaphragm in the speaker.

Brief description of the drawings

An embodiment of the invention will now be described for the sake of example only with reference to the following drawings, in which:

FIG. 1 shows schematically a portion of an embodiment of the invention in use for acoustic pressure sensing.

FIG. 2 shows a larger portion of the embodiment of Fig. 1.

FIG. 3 shows schematically a system for automated pressure sensing employing the embodiment of Fig. 1.

FIG. 4 shows the measured radiation profile of a typical sound emitting instrument, as derived by the embodiment of Fig. 1.

Detailed description of the embodiment

Referring firstly to Figs. 1 and 2, an embodiment of the invention is shown in use. The embodiment evaluates the sound field 105 in front of a diaphragm of a speaker 104 of an audio speaker system (though the speaker 104 may alternatively be any other sound-emitting device, such as a musical instrument), where the speaker 104 produces a longitudinal wave in the air. In the sound

transmission from the speaker 104, the interaction between static air and the dispersal vibration determines the transfer efficiency, so this dynamic air response indicates the performance and audio quality of the design of the speaker 104, especially when the amplitude of diaphragm vibration is very small.

The embodiment employs an array of multiple sensing elements, each comprising a Pitot-tube 101, which has an elongate through-hole in the centre of about 500 μ m in diameter. Fig. 1 shows a single one of these Pitot-tubes 101, while Fig. 2 shows how the plurality of the plurality of Pitot-tubes 101 are neatly arranged in parallel in a matrix formation 102, spaced apart perpendicular to the length direction of the Pitot-tubes 101, which itself is perpendicular to the vibration surface of the diaphragm of the speaker 104. The Pitot-tubes 101 are maintained in this configuration by a support structure (not shown). The open ends of the Pitot-tubes are in a single plane in the arrangement shown in Fig. 2, but other embodiments are not necessarily limited in this respect. Note that the optimal dimensions of the Pitot-tube 101 depend on the surrounding air conditions and the desired measurement precision. A smaller hole diameter provides a more localized detection sensitivity, but the cost may be higher. The outer diameter and the wall thickness of the tubes 101 are preferably small to avoid disturbing the air near their open end. Commonly a Pitot-tube 101 has an inner diameter of about 500 μ m (as mentioned above), and an outer diameter of about 1mm.

As shown in Fig. 1, a respective pressure sensor 102 is provided at the end of each Pitot-tube 101. The pressure sensor 102 has high sensitivity for capturing the air movement 105. Individual flexible rubber tubing elements 103 are provided to seal the junction between each Pitot-tube 101 and the respective sensor 102.

The arrangement and layout of the probes 101 is carried out taking into account the geometric configuration of the speaker 104, and the number of sensing points is adjusted according to the required resolution. The configuration and the spacing between the tubes can be tuned for optimal

acoustic transmission mapping; smaller pitches and denser sensing points allow the air movement due to an acoustic wave to be measured with finer resolution. The probes are positioned uniformly such that their open tips form a plane in front of a sound emission source. The probing distance 100 from the surface of diaphragm may be varied during the measurement to identify the change in energy profile from the sound source. Since the width of the tip of the Pitot-tubes 101 is very small, each Pitot-tube 101 is unlikely to cause interference to the sound propagation in the air, nor impair the sensitivity of the sensing mechanism. The probes are spaced apart by a distance much greater than their individual width, so as not to cause obstruction to the acoustic wave.

The sensor 102 may take the form of a piezo-electric sensing cell (although in other embodiments it may be a fluid manometer or a PVDF sensor). The piezo-electric material generates an electrical output when it is subject to external compressive stress. The sensing cell can be designed to have a desired sensitivity by a selection of the stress-voltage ratio. If this is high, a small change in the air pressure on the piezo-material caused by an audio wave may trigger a significant electrical signal. The layout of the sensor cell array 202 is also designed taking into account the presence of the rubber tubing elements 103 on the Pitot-tubes 101.

The cells 102 are uniform and have identical sensitivity so that a pressure distribution profile can be mapped when sound wave 105 is transmitted to the Pitot-tubes 101. As shown in Fig. 3, the sensor cells 202 are connected to a data-logger 303 that records every fluctuating value of electrical voltage from each individual sensor independently. The voltage variations are also provided to a computer 304, which reproduces the acoustic pressure by plotting the digital detected values via a user-friendly processing system as a pressure distribution plot. This produces a geometric model as shown in FIG.4, for identifying the vibration and transmission behavior of the sound wave.

Fig. 4 shows a distribution plot produced by an embodiment which is a 3-D mapping of the acoustic transmission profile. The array of the Pitot tubes forms a 2-D planar distribution of sensing points that are parallel to the perimeter area of the speaker. When sound is projected from the speaker, the

pressure detected at every sensing point varies according to the distance from centre of speaker. The maximum air pressure is measured at the centre of the cone-like peak 401 observed on the 3-D mapping.

According to fluid mechanics theory, the velocity of air can be obtained from the pressure value at a specific position. Considering the air flow to be incompressible, and the static pressure to be very small compared to the projected acoustic pressure, Bernoulli's equation is given by:

$$\frac{P}{\rho} = \frac{V^2}{2} \quad (1)$$

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where P denotes the transmitted air pressure [Nm^{-2}];
 ρ denotes the air density, 1000 [kgm^{-3}];
 V denotes the velocity of air [ms^{-1}]; and

15 By taking square root of the ratio of detected pressure (P) over the density of air, the average velocity (V) of each air particle is obtained from equation (1) as:

$$V = \sqrt{\frac{2P}{\rho}} \quad (2)$$

Air vibration slows and weakens gradually over time, and this transition is reflected by the change in the velocity obtained from equation (2). Calibration for the change in voltage with standard acoustic projection towards the probing sensors is carried out to identify the loss in energy. This comparison is particularly useful in determining the absorption level of the sound wave in air that results from impedance in the intended audio frequency spectrum.

25 Although only a single embodiment of the invention has been described in detail, many variations are possible within the scope of the invention as defined in the claims, as will be clear to a skilled reader.

Claims

1. A pressure-measurement device for characterization of the sound-field generated by a sound-emitting device, comprising:
 - 5 (a) an array of Pitot tubes, each including a small through hole having an open end; and
 - (b) for each Pitot tube, a respective pressure sensor, for measuring the pressure at the other end of the respective Pitot tube.
- 10 2. A pressure-measurement device according to claim 1 in which the pressure sensors are selected from group consisting of: hydro-manometers, piezo-electric sensors, and PVDF sensors.
- 15 3. A pressure-measurement device according to claim 1 or claim 2, further comprising a plurality of flexible rubber tubing elements, sealing the connection between respective Pitot tubes and the respective pressure sensors.
- 20 4. A pressure-measuring system for acoustic characterization of a sound source comprising a pressure-measuring device according to any preceding claim, and a processor coupled to receive the output of the pressure sensors and perform an acoustic characterization calculation.
- 25 5. A method of monitoring the sound-field generated by a sound-emitting device, the method comprising:
 - (a) locating a plurality of Pitot tubes in relation to the sound-emitting device, each Pitot tube including a small through hole, for capturing of incoming pressure, a first end of the through hole being open and directed at the sound-emitting device.
 - (b) using a respective pressure sensor for each Pitot tube to measure the
30 pressure at a second end of the Pitot tube.

6. A method according to claim 5 in which the sound-emitting device is a stationary sound emitting baffle.
7. A method according to claim 3 in which multiple Pitot-tubes are arranged
5 in parallel in a regular array, spaced apart pairwise by uniform distances.
8. A method according to any of claims 5 to 7 further including transmitting the output of the sensors to a processor arranged to receive the output of the pressure sensors and perform an acoustic characterization calculation.