U.S. Patent 7,580,533 Particulate Flow Detection Microphone

Description and Discussion of Prototype One

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2 October 2009

Synopsis

The first prototype of a laser and smoke, no-diaphragm microphone based on U.S. Patent 7,580,533 was completed in September 2009. This device had a dynamic range of approximately 36 dB. The intent of the design was to evaluate aerodynamic, optical, and geometric parameters pertaining to the flow of smoke in the detection chamber.

Configuration

The microphone was constructed entirely of clear acrylic plastic tubing and sheet material. Refer to Figure 1 for its layout, dimensions and components. Generally, the device was composed of two concentric tubes, one inside the other. The outside tube supported a rectangular instrument stage near its top. The stage had mounting points for a photo-detector, a laser, and a laser beam gate. Above that, an exhaust fan was attached to a funnel. The inside tube had a nozzle at the top, straws in its upper section, and an enlarged tubular section at its base. Below the enlarged section at the base of the inside tube there was a synthetic smoke generator.

The top section of the outer tube formed the detection chamber. The chamber's walls had three holes: a pair across the diameter for the laser beam's path, and a larger hole for a sound input aperture, oriented perpendicular to the beam path. The inner tube's smoke nozzle was located in the center of the detection chamber, pointed up at the funnel's small end. The nozzle's rectangular outlet was immediately below the laser beam's path and aligned perpendicular to it.

Operation

The theory of operation was that a smooth ribbon of smoke flowing upwards from the nozzle would partially occlude the laser beam and be modulated by sound pressure waves that entered the detection chamber via the input aperture. Variations in the smoke ribbon caused by sound either scattered the laser beam or varied its power, causing the output of the photo detector to vary proportionately.

The 4.5 volt, 650 nm wavelength laser produced a circular 2.5 mm beam with a continuous output power of 5 milliwatts.

The microphone's photo detector output a uniform voltage between 0.5 and 2.0 volts in the absence of smoke, depending on the gain setting of its integrated amplifier. The noise floor of the photo detector was approximately 190 microvolts. The photo detector's peak sensitivity was at a wavelength of 1100 nm.

Smoke emitted by the nozzle partially occluded the laser beam during operation. The quantity of smoke production was controlled by varying the voltage of the smoke generator between 7 and 9 volts. The flow rate of the smoke was controlled by varying the voltage of the exhaust fan between 10 and 15 volts. Balancing the quantity of smoke versus fan speed provided some control over the density of the smoke ribbon. In no case was the output of the photo detector reduced more than 25 percent by occlusion or scattering.

The rate and volume of clean air flow in the annular space between the inner and outer tubes was critical. At high volume or at a rate much faster than the smoke ribbon, the clean air flow caused the smoke flow to become discontinuous or "torn." At low flow volume, friction between the faster moving smoke and the clean air caused the smoke flow to become turbulent. Turbulent flow created white noise in the microphone output signal. At extremely low clean air flow rates, such as when the annular air input was blocked, the smoke ribbon fanned out and lost density. In effect, the "stiffness" of the smoke ribbon was affected by the flow of clean air around it.

When the sound input aperture was left unscreened, any plosive or fricative voice sounds caused large displacements of the smoke ribbon, which resulted in popping noises. A single ply of bathroom tissue over the aperture was used to eliminate that effect.

The synthetic smoke generator produced inconsistent quantities of smoke even at a constant voltage due to depletion of fluid during operation. As the fluid level went down, smoke production increased as did noise from the smoke generator itself, which traveled up the tubes and into the detection chamber.

Unintended sound input via conduction through the walls of the tubes caused distortion. Reverberation of the tubes also contributed noise.

Ambient room light entered the photo detector and added noise. Consequently, the best audio results were obtained in a darkened room.

As the batteries in the laser depleted during operation, beam power and photo detector output declined.

Proposed Improvements and Modifications

1. Reduce the vertical height of the microphone structure. A 6-inch inner tube filled with straws will be sufficient to generate a laminar flow of smoke. The shorter length will improve suction, allowing a faster moving and denser smoke ribbon.

2. Construct the detection chamber out of low-Q materials.

3. Use acoustically non-conducting and low-Q tubing. Alternatively, cover the tubing with sound-deadening material.

4. Acoustically isolate the exhaust fan(s) from the detection chamber.

5. Increase the size of the sound input aperture and find a suitable pop screen material.

6. Power the laser externally from an adjustable voltage source.

7. Match the laser's wavelength to the photo-detector's sensitivity curve or vice versa.

8. Shape the laser beam with a lens and/or a gate.

9. Shield the photo-detector's input pathway and the detection chamber itself from ambient light.

10. Make the mounting points for the laser and the photo detector adjustable horizontally to support the non-occluded beam mode of operation.

11. Use a high-speed, high-resolution CMOS-type IC photocell. The digital output of the chip will require a data acquisition interface to the PC-based recorder or PA amplifier.

12. Control the flow rate of clean air to the detection chamber independently from the flow rate of the smoke-air mixture.

13. Isolate the smoke generator acoustically from the smoke tube.

14. Use a smoke or fog generator that has a constant output.

15. Modify the chemistry of the synthetic smoke or fog to produce the most dense, highly reflective or highly absorbent particles or droplets possible.

16. Implement water vapor-based system with downward oriented nozzle and flow direction.

17. Implement non-occluded, offset laser beam detection system in which the smoke ribbon or vapor stream impinges on the laser beam only when sound pressure waves cause it to do so.

18. Implement all-digital EQ, inversion, amplification and noise reduction on photo detector output signal.

19. Implement a closed loop, recirculating smoke, fog or vapor subsystem.