Technology Offer

Carbon Nanotube Fiber Hot-Wire Anemometer

Ref.-No.: 1402-6469-FG

Abstract

This invention relates to a high-performance hot-wire anemometer utilizing a carbon nanotube fiber (CNF) as the sensing element for fluid velocity measurement. The CNF replaces conventional metallic wires, offering significantly lower electrical resistivity combined with a positive thermal coefficient of resistivity. This enables highly sensitive detection of flow-induced temperature changes while operating at reduced voltages. The probe consists of a CNF suspended between two prongs, forming a robust and miniaturized sensing structure. The invention addresses limitations of conventional and metal-coated CNT probes, particularly in durability, cost, and signal resolution. Its improved mechanical strength and thermal stability allow reliable operation in harsh and particle-laden environments. This technology is particularly suited for advanced fluid dynamics research, industrial flow monitoring, and high-frequency turbulence measurements.

Background

Hot-wire anemometers are widely used for measuring fluid velocities by correlating heat transfer from a heated wire to flow characteristics. Conventional probes typically use metallic wires, which provide predictable electrical behavior but suffer from limited mechanical robustness and sensitivity at small scales. Recent developments introduced carbon nanotube-based probes, often coated with metals to enhance conductivity. However, such composite structures are prone to abrasion, increased manufacturing complexity, and high costs. Additionally, metal coatings dominate electrical conduction, limiting the intrinsic advantages of CNT materials. Thin probes are desirable for high spatial and temporal resolution but are particularly vulnerable to mechanical damage and instability in harsh flow conditions. Therefore, there is a need for a durable, highly sensitive, and cost-effective hot-wire probe that leverages the intrinsic properties of carbon nanotube fibers without reliance on metal coatings.

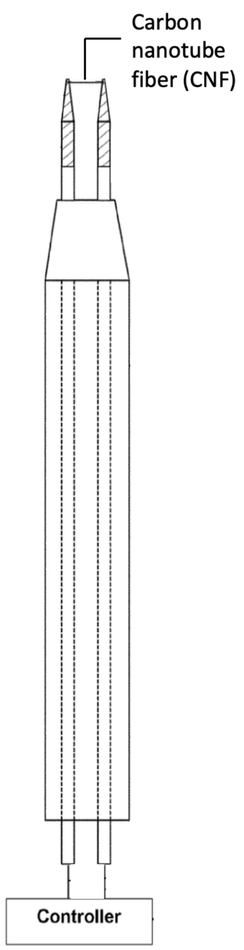

Figure 1: Schematic representation of a hot-wire anemometer with a carbon nanotube fiber (CNF) suspended between two prongs as the sensing element.

Technology

The invention relates to a hot-wire anemometer comprising two conductive prongs and a hot-wire probe formed by a carbon nanotube fiber (CNF) spanning between the prong tips. The CNF serves as the active sensing element over its entire length and is directly exposed to the fluid flow. It exhibits an electrical resistivity of not more than 25 $\mu\Omega \cdot m$ and a positive thermal coefficient of resistivity of at least 1×10^{-3} K^{-1}, enabling a strong and predictable resistance response to temperature variations induced by fluid velocity.

The carbon nanotube fiber is uncoated and free from metallic layers, ensuring that electrical conduction occurs intrinsically within the nanotube structure. This design avoids the limitations of metal-coated CNT wires, such as abrasion-induced degradation and dominance of metallic conduction pathways. The fiber typically has a diameter in the range of 5-20 µm and an active length between 0.2 mm and 5 mm, allowing high spatial and temporal resolution in flow measurements.

The CNF is mechanically and electrically connected to the prongs by embedding its ends into solder applied to the prong tips. The prongs may be made of stainless steel and can be pre-treated, for example by tinning, to

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improve solder adhesion. This configuration ensures a stable electrical interface and robust mechanical fixation, even under mechanical stress.

The carbon nanotube fiber is produced via wet spinning from a solution of carbon nanotubes, followed by coagulation, drying, and thermal annealing at temperatures of at least 400°C in an oxygen-free environment. This annealing process removes volatile dopants and stabilizes the electrical properties, resulting in a thermally stable sensing element with reproducible behavior over repeated temperature cycles.

Advantages

- Significantly lower electrical resistivity enables reduced operating voltage and simplified, cost-efficient electronic circuitry.
- Uncoated carbon nanotube fiber eliminates abrasion issues and enhances durability in particle-laden or harsh flow environments.
- High positive thermal coefficient of resistivity improves sensitivity and accuracy of flow velocity measurements.
- Superior mechanical strength of CNT fibers prevents breakage and extends operational lifetime compared to metallic wires.
- High temporal resolution with cutoff frequencies up to ~99 kHz supports advanced turbulence and transient flow analysis.

Potential applications

- High-resolution fluid dynamics research, including turbulence and boundary layer measurements in aerodynamics.
- Industrial process monitoring involving gas or liquid flow in harsh or particle-containing environments.
- Environmental sensing systems for wind, airflow, and pollutant dispersion measurements.
- Microfluidics and precision flow measurement in laboratory-scale or biomedical systems.
- Aerospace and automotive testing where robust, high-frequency flow sensing is required.

Patent Information

Application pending in EP, US (*EP4655598A1*; 22.01.2024)

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