On a high-resolving LCA
Laser Cantilever Anemometer

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1 Introduction

Based on Patent application DE 198 22 125.8-52 (Peinke et al. 1998), we present a description of a first prototype of a high resolving anemometer. The principles and first results are shown.

Hot wire anemometers have been used for a long time as suitable velocity detectors [1][2]. Heated by a current, such a sensor is cooled by convection in the flow. In constant-current mode the necessary voltage will give a measurement of the flow velocity. The low heat capacity allows a high dynamic response up to some kHz. The disadvantage is the extreme mechanical sensitivity for such high resolving probes. Furthermore, it works partly as an antenna. Thus electromagnetic radiation has to be minimized during the measurement. For measurements in liquid fluids like water, the hot wire is coated with a thin quartz layer to provide corrosion and to guarantee electrical isolation. This leads to a loss in sensitivity.

Another often used one-point measurement technology is the Laser-Doppler-Anemometry (LDA) consisting of two crossing laser beams. The advantage of the LDA is that it is a non contact measurement technology that needs no calibration. The detected velocity is only dependent on the particle velocity and the distance between the fringes which are completely determined by the wavelength of the laser light and the angle between the two beams. The disadvantage of the LDA is the relative large measurement volume. This leads to an increase in noise. Another disadvantage is the discontinuity of the measured time series.

2 Principles of Function

Based on the new technique for Atomic Force Microscopes (AFM), we present here a new anemometer (Laser Cantilver Anemometer LCA). The sensor is a
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cantilever, with a typical length of 200µm, a width of 10µm and a thickness of 1 – 5µm, normally used to resolve atomic distances and forces. It is arranged perpendicular to the flow and scanned by a laser-pointer. Inserted into a flow the cantilever is bent. As a result of that, the light-pointer moves, this is detected by a PSD (Position Detector). Due to the fact that the LCA was produced to resolve atomic forces it is sensitive enough to be displaced by air flow of moderate velocities (a few mm/s).

Anemometers like hot-wire or LDA can not distinguish between forward or backward flow. For LDA an optic-acoustical cell can be used to prevent this problem by shifting the interference fringes. This presupposes that the mean flow velocity and the range of fluctuations must be known before measuring. The LCA has an intrinsic detection of the direction of the flow because the cantilever will be bent in forward or backward direction.

3 Calibration

In contrast to the LDA both measurement techniques, the hot-wire or the LCA, need a calibration of the system. This is usually performed in a laminar flow. In contrast to the King’s law for the hot wire, where the signal $U[V]$ is a function of the velocity $v[m/s]$, $U \propto v^4$, the LCA follows the relationship of a bended cantilever

$$s \propto l^3 \cdot F = l^3 \cdot p \cdot A = l^3 \cdot \frac{1}{2} \cdot \rho \cdot v^2 \cdot A,$$

(1)

where $l$ is the length of the cantilever and $F$ is the force perpendicular to the surface $A$, $p$ is the pressure and $\rho$ the specific density. Because the deflection is the observed quantity we get only a dependency of $v^2$, so the nonlinearity is strongly reduced. Note that the nonlinearity effects the binary resolution of the system. In figure 1 a calibration curve is shown.

![Figure 1: Calibration function of LCA, dots represent measured data, solid curve fitting function $\propto x^{0.5}$](image)

4 First experiments and results

We compare LCA-measurement with the hot-wire anemometry. (We used Dan-tec Streamline with probes 55P01 (air) and 55R01 (water).) The first measurements were performed in a turbulent free-jet, with water in water and air in air. The power spectrum of the water free-jet (figure 2, left picture) shows, that the dynamical range of the cantilever anemometer is about one order of magnitude larger than the hot-wire. In the air experiment (figure 2, right picture) we got close to the dynamical resolution of the hot-wire. As one can see, there are a lot of interfering signals in the hot-wire signal at high frequencies, which don’t appear in the cantilever-signal.

![Figure 2: Power spectrum of the water experiment (left plot, cantilever: solid line, hot-wire: open symbols) and the air experiment (right plot, cantilever: black line, hot-wire: gray line).](image)

The following results are based on the air experiment, with the following parameters: Nozzle-diameter $d = 8mm$, measurement at a distance of $37.5d$, velocity $v = 32.8m/s$ at the nozzle ($0d$), $Re = 17493$. For further investigations, we consider the probability density functions ($pdfs$) at three different length-scales, see figure 3. These length-scales are marked with arrows in the spectrum (figure 2, right picture) and labeled as a,b and c.

The power spectrum indicates a worse resolution of the LCA for frequencies above $10^4Hz$ (here structures are less then $0.5mm$). If this deviation is due to fundamental limitations of the method, one expects rising Gaussian noise. Surprisingly the pdfs become much more intermittent, see figure 3. We interpret this effect as a sign, that here features of the turbulent flow situations are still measured. We should note that the actually used tip of our sensor is not optimized to scales below $2mm$ (support of commercial cantilevers are used). Thus these deviations may be an effect due to the perturbation of the flow. As a further investigation of the statistics of our measured data, the sixth order structure function is plotted over the third order one. This leads to the Kolmogorov constant $\mu$ of intermittency: $\mu = 0.25$ for the hot-wire and $\mu = 0.4$ for
the cantilever.

Figure 3: Probability density functions at the different length-scales defined in figure 2 (top=a, middle=b, bottom=c). The grey pdfs are from the hot-wire data and the black pdfs represent the cantilever data.

5 Conclusion

A new type of anemometer based on micro-structured cantilevers was presented. First measurements of a prototype were compared with hot-wire anemometry. The resolution for an air flow is comparable to those of commercial ones. The measurement in water indicates an achievable augmentation in the resolution.

The authors acknowledge the financial support by the DFG (grant no.: Pe478/7)

References
