Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 47 (2012) 853 – 856

Procedia Engineering

www.elsevier.com/locate/procedia

Proc. Eurosensors XXVI, September 9-12, 2012, Kraków, Poland

# Flow Measurement Technique for Unknown Fluids Based on Hot Wire by Self-Calibration via Thermal Time-of-Flight (TToF)

E. Engelien*, H. Kirchgaesser, R. Viga, A. Grabmaier

*University Duisburg-Essen, Institute of Electronic Components and Circuits, Germany*

**Abstract**

For measurement problems with unknown fluids a new calibration-free volume flow measurement technique is developed. This measurement technique includes a controlled heat source associated with a minimum of two thermal sensors arranged downstream [5,6]. The heat source is used to generate a rectangular signal code [dT/dt] by injection of regulated thermal pulses into a flow line, the flow velocity being based on two measurands. Rapid changes in flow velocity are determined by the flow dependent variable (inversely proportional to the velocity) which is controlling the temperature of the filament. By analysis of the rising edge of the thermal signal of subsequent sensors the velocity can be measured less frequently but precisely and in unknown fluids (TToF) [6,7]. The combination of these two measurement techniques (hot wire and TToF) can be applied to both, liquids and gasses.



*Keywords:* volume flow meter; velocity measurement; hot wire anemometer; Thermal Time of Flight (TToF); crosscorrelation;

## 1. Introduction

The use of mass and volume flow measurement techniques is essential in industries for process control purposes. In recent years several different types of sensors were developed. Depending on the specifications, for example metering precision, flow ratio, permitted decrease of pressure and also for the cost of production, different measurement principles are applied [1,2]. The utilisation of these measurement systems is dependent on pressure, in the majority of cases temperature, density, viscosity

* Corresponding author. Tel.: +49-203-379-2728; fax: +49-203-379-2888.
*E-mail address*: Eberhard.Engelien@uni-due.de.


doi:10.1016/j.proeng.2012.09.281

and homogeneity of the fluid. At present, conventional flow sensors are restricted to the flowing medium that they are calibrated for.

Thermal flow sensors are commonly used due to their low cost and simplicity. Their measurement method is currently based on detecting the heat displacement from a permanently heating element (constant-current or constant-temperature) in dependence of the velocity of the passing fluid with known properties [3,9]. For this reason research is done to identify a media-independent, respectively calibration-free measurement principle. Current analysis shows that this can be accomplished thanks to the thermal pulse time delay method. However, this method does currently not lead to a measurement frequency of 10 Hz. Hence, sensors cannot sufficiently measure fluids with unknown properties or generate measurement results. Therefore, a volume flow measurement technique of the calibration-free TToF principle in combination with the conventional principle of hot wire anemometry is developed. This measurement technique is applicable to any kind of fluid with the variable measurement frequency.

## 2. Methods & Materials

In the following, the detection of flow velocity is presented as well the associated experimental setup for the investigation media air and water. The measurement technique consists of the principles of constant temperature anemometry (CTA) and ToF of heat pulses.

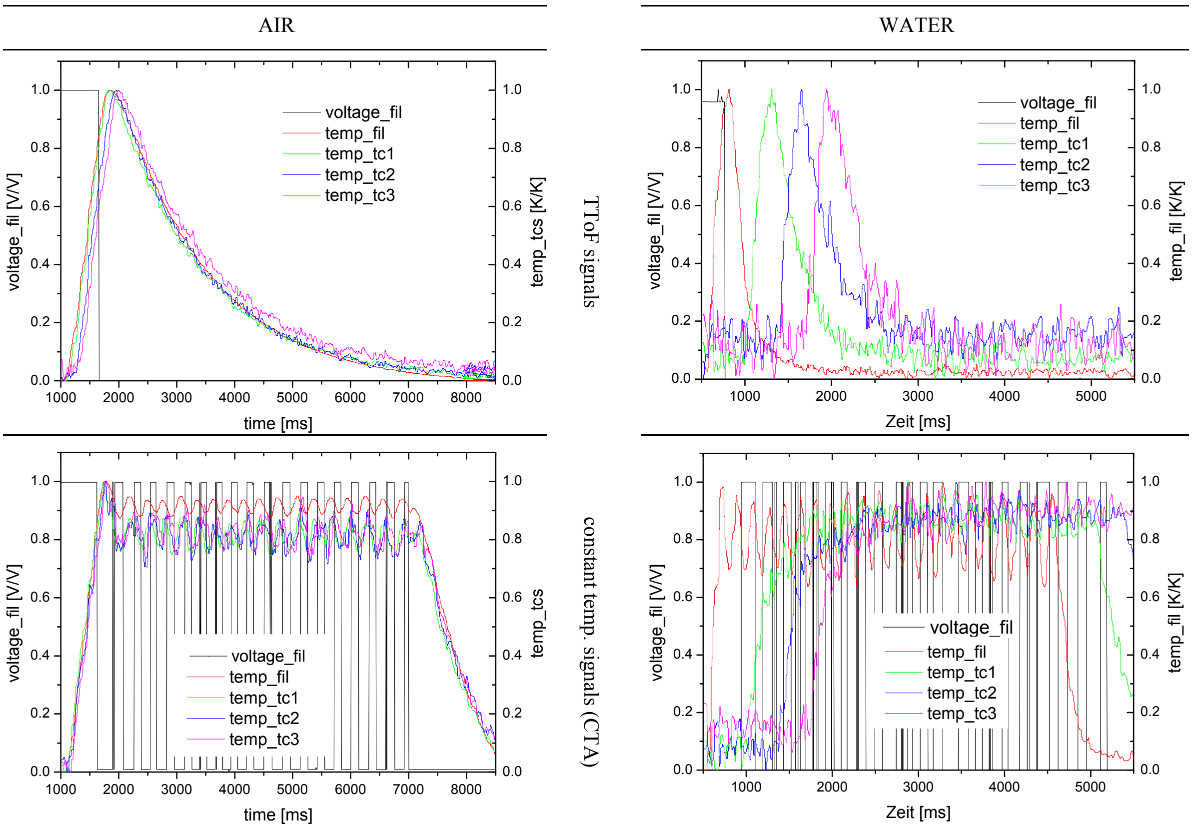


Fig. 1: Filtered, offset corrected and normed signal for the flow velocity measurement by TToF and constant-temperature-anemometry of air and water.

### 2.1. Experimental Setup

The experimental setups contain a conveyer for the respective flowing medium (air & water), a reference flow sensor (air: hot-wire anemometer of the Testo company / magnetic-inductive flowmeter of the Krohne company) and a specifically constructed sensor consisting of a filament to generate the heat pulses and four thermocouples type K (Ø = 50 µm) arranged at the filament and downstream [7]. Considering the pipe's diameter, the filament and the thermocouples are vertically plugged into the middle of the pipe. The thermal signals are sampled at a frequency of f = 100 Hz with a resolution of ΔT = 0.01 K.

### 2.2. Signal Processing

The volicity at a certain point in time is measured by CTA. The temperature at the filament is detected by an adjacent thermocouple and controlled by a PID-controller. To calibrate the CTA values the TToF principle is applied. For this purpose the values are sampled at a 100 Hz rate and filtered due to the effects of thermal and electrical noise by Chebyshev-filter. In the following the signals (fig. 1) are offset correlated and normalised. For the calculation of the time delays $\tau_{12}$ and $\tau_{13}$ the two cross-correlation functions $Rx_{T1}x_{T2}(\tau)$ and $Rx_{T1}x_{T3}(\tau)$ are obtained [6,7].

## 3. Results & Discussion

For measurement purposes the velocity vector $v_{max}$ is detected in the centre of the pipe. Therefore the filament creates heat pulses with dT of 4 K in water and ΔT of 10 K in air.

In the analysis (fig. 2a,b) the respective values of the CTA measurement principle are related to the values of the TToF principle and are represented according to the reference.

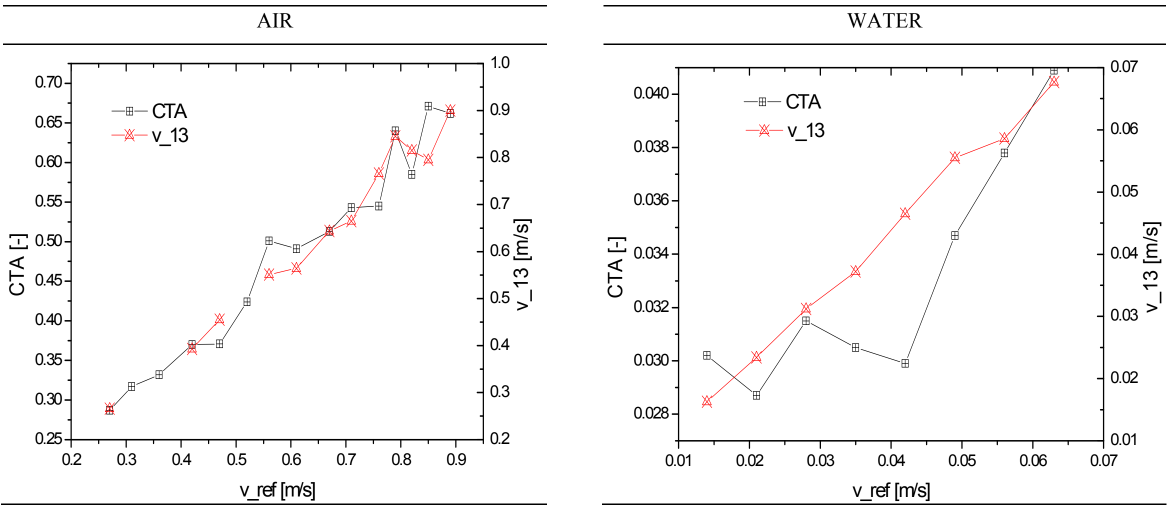


Fig. 2: Gemessene Geschwindigkeit mittels TToF and CTA of Air and Water über die jeweilige referenzgeschwindigkeit

At lower velocities as chosen as a basis for water, the applied CTA measurement technique shows greater deviations due to the chosen parameter of the PID controller. For medium to high velocities, as shown in particular in fig. 2 (air) for the range of defined parameter, a linear dependence can be observed. This means that for future measurements the parameters of the PID controller should be adapted dynamically to the velocity in order to allow larger measurement ranges. This would also be a key condition for application to diverse media as the parameters differ by media, as in this case for air and water.

## 4. Conclusion

The current works aim at developing a measurement method for velocity detection of flowing media. For this purpose a combined measurement technique of the calibration-free TToF principle and the constant temperature anemometer principle for high frequency measurements is applied. With the measurement results shown in fig 2a,b the approach of the combined measurement is confirmed. Therefore the basis for a simple, cost-efficient and calibration-free measurement technique is created.

## 5. Subsequent Work

The work completed so far on temperature-controlled signals has proven that the hotwire anemometer in combination with the TToF measurement principle is a simple solution for calibration-free volume flow measurement. For this purpose the increase and the pulse width of the thermal signals were analysed. Subsequently completed analysis of thermal pulses will show that the decreasing constant allows conclusions on the properties of the flowing medium.

## Acknowledgements

This work is supported by the German research association (Deutsche Forschungsgemeinschaft, DFG) and is part of the funded project ANTEMES.

## References

[1] Fiedler O. *Strömungs- und Durchflussmesstechnik*, R. Oldenbourg Verlag, ISBN 3-486-22119-1, 1992.

[2] Baker, R.C.: *Flow Measurement Hand-book, Cambridge University Press*, Cambridge, ISBN 521-48010-8, 2000.

[3] Cao Y et all, *Flow Rate measurement System Using thermal Air Flow Sensor*, 9th ICEMI, IEEE 987-1-4244-4864-8, 2009.

[4] Ecin O, Engelien E et all, *Modelling Thermal Time-of-Flight Sensor for Flow Velocity Measurement*, COMSOL Conference 2009, Milan.

[5] Engelien E, Ecin O et all, *Sensor Modelling for Gas Flow Measurement using Thermal Time-of-Flight Method*, 15th ITG-/GMA-Fachtagung, Sensor&Test 18.-19.05.2010, p. 1-8.

[6] Engelien E, Ecin O et all, *Calibration-Free Volume Flow Measurement Principle Based on Thermal Time-of-Flight (TTOF) for Gases, Liquids and Mixtures*, AMA-Fachtagung, Sensor&Test 7.-9.06.2011, p. 1-6.

[7] Engelien E, et all. *Calibration-Free Volume Flow Measurement Principle Based on Thermal Time-of-Flight (TToF),* Eurosensors Athen, pp. 1-4, 2011.

[8] Frey T, Bossert M, *Signal- und Systemtheorie*, Vieweg+Teubner Verlag, ISBN 978-3-8351-0249-1, 2008.

[9] Oliveira A. et all, *Compensation of the Fluid Temperature Variation in a Hot-Wire Anemometer*, IEEE IMTC, Ottawa, May 19-21, pp. 1377-1380, 1997