CTHWA DYNAMIC RESPONSE EFFECTS ON TURBULENCE MEASUREMENTS IN TURBOMACHINERY FLOWS

Elissavet Boufidi
"Jacques Chauvin" Laboratory
von Karman Institute
for Fluid Dynamics
Rhode-St-Genèse, Belgium
boufidi@vki.ac.be

Mattia Cottes
Polytechnic department of
engineering and architecture,
University of Udine, Italy
cottes.mattia@spes.uniud.it

Fabrizio Fontaneto
"Jacques Chauvin" Laboratory
von Karman Institute
for Fluid Dynamics
Rhode-St-Genèse, Belgium
fontaneto@vki.ac.be

ABSTRACT

This paper examines the effect of the dynamic response of Constant-Temperature Hot-Wire Anemometers (CTHWA) on the measurement of turbulence, especially for the case of turbomachinery flows where large fluctuations are present. Errors in the measurement of turbulence quantities stemming from the dynamic behavior are often neglected. The aim of this work is to highlight them and, when possible, propose ways to correct them.

INTRODUCTION

A CTHWA system is composed of a hot-wire probe and an electronic unit, which consists of a Wheatstone bridge (the hot wire is part of the active leg of the bridge) and a feedback loop which adjusts the current in order to keep the temperature of the wire constant. The dynamic response of the system is, therefore, defined by the thermal inertia of the wire and the response of the electronics. Nevertheless, it is common practice to optimize the system's response for one operating point using the well-known square wave test and use static calibration laws to retrieve the instantaneous velocity, assuming a flat frequency response. This practice neglects the following sources of potential errors:

- The attenuation of fluctuations due to the heat conduction to the wire supports
- The fact that the square wave test doesn't guarantee a flat frequency response up to the cut-off frequency and can result in amplification or damping of fluctuations
- The non-linear nature of the governing equations which should not be neglected for large fluctuations.

RESULTS AND DISCUSSION

In the present work, the numerical model proposed by Freymuth [1] is employed to investigate the dynamic behavior of CTHWA under different flow perturbations. The original model has been modified to take into account also heat conduction effects and the variation of flow temperature and density. The distortion of the output signal is examined for different model inputs. The following cases are simulated: uniform flow with different levels of turbulence, and rotor wakes with different blade passing frequencies and velocity deficits.

Under the small-fluctuations assumption, the effect of the heat conduction to the wire supports and the non-flat response before the cut-off, can be corrected by applying a transfer function in the frequency domain. This allows the correction of the turbulent spectrum up to a frequency which is limited by the signal-to-noise ratio of the system. This practice is no longer relevant when large fluctuations are present (as in the case of rotating wakes): large deviations from the optimized operating point lead to a different response (amplification or attenuation of the signal before the cut-off frequency) and the generation of higher harmonics due to parametric excitation leads to signal distortion. The latter may not have a significant influence on the turbulence intensity measured, but strongly affects odd moments like the skewness, as has been demonstrated also by Weiss et al. [2]. The only method available for correcting all non-linearity effects has been developed for Constant-Voltage Anemometry (CVA) by Berson et al. [3]. No similar method exists for the moment for CTA, to the authors' knowledge, but modelling could be a first step towards such a development. In the meantime, experimentalists should be aware of the limitations of the technique and should be able to estimate the effect of the dynamic response on their measurements.

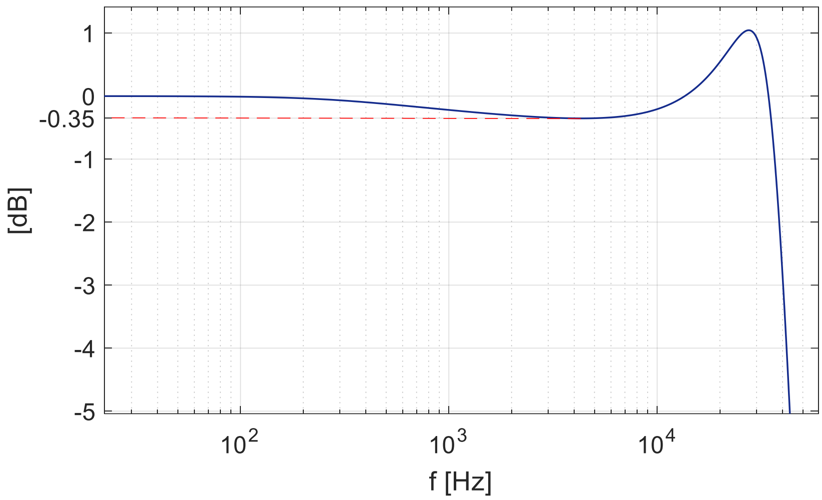

Figure 1. CTHWA amplitude transfer function: attenuation at low frequencies due to heat conduction effects and amplification before the cut-off frequency due to non-optimal system tuning.

REFERENCES

[1] P. Freymuth, (1977), Further Investigation of the Nonlinear Theory for Constant-Temperature Hot-Wire Anemometers, Journal of Physics E: Scientific Instruments 10.

[2] J. Weiss, A. Berson, G. Comte-Bellot, (2013) Investigation of Non- Linear Effects in Constant Temperature Anemometers, Measurement Science and Technology 24.

[3] A. Berson, P. Blanc-Benon, G. Comte-Bellot, (2009), A Strategy to Eliminate All Nonlinear Effects in Constant-Voltage Hot-Wire Anemometry, Review of Scientific Instruments 80.