Colegrove, P., "Wire + arc additive manufacturing," Mater. Sci. Technol. 836(March), 1743284715Y.000 (2015).

10329-66, Session 15

Noninvasive seedingless measurements of the flame transfer function using high-speed camera-based laser vibrometry

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Lean combustion by means of swirl-stabilized flames is a priority of industries development, in order to reduce pollutant emissions and to increase the efficiency of jet engines or stationary gas turbines. This combustion exhibits instabilities based on flame oscillations due to thermos-acoustic fluctuations of pressure and heat release rate [1], which potentially result in failure of the device. Therefore, the characterization of the combustion during the industrial development process is inevitable. To this aim, the flame transfer function (FTF) is measured, which is the ratio of the average heat release rate inside the flame and the average flow velocity at the combustor outlet and the temporal fluctuations of both quantities, respectively [2]. Measurements of the FTF can be obtained by a multi-microphone-method [3], but the technique allows no spatially resolved data inside the flame volume. Field measurements of the heat release rate can be achieved using chemiluminescence, but only under the condition of adiabatic flames [4], which is not fulfilled at technically premixed flames. Measurements of the flow velocity inside the flame can be realized using well known techniques such as particle image velocimetry or Doppler global velocimetry [5]. Yet, both techniques require the usage of tracer particles, which influences the thermodynamic behavior of the flow.

Simultaneous seedingless measurements of both, the heat release rate and flow velocity can be achieved using multiple laser-vibrometers and signal correlation [6]. The measurement is based on the linear relation between the heat release rate and the change of the refractive index inside flames. Such fluctuations of the refractive index can be detected integral along the laser beam of a standard pointwise laser-vibrometer. Using multiple laser-vibrometers it is furthermore possible to measure the flow velocity inside the flame due to the phase delay between two vibrometer signals and the known distance between the measurement positions. However, no simultaneous field measurements have been done and, thus, the detection of complex spatio-temporal flow behavior is not possible.

In order to overcome these limitations, a high-speed camera-based laser-vibrometer is designed for non-invasive seedingless measurements of the FTF inside swirl-stabilized technically premixed flames. The laser-vibrometer offers single pixel resolution with measurement rates up to 40 kHz at an image resolution of 128 x 64 px. Based on a comparison with a standard pointwise laser-vibrometer the new system is validated and a detailed discussion of the measurement uncertainty is presented. Spatially resolved measurements of the heat release rate and its temporal fluctuations inside a swirl stabilized flame are demonstrated for the first time. In addition, the flow velocity field inside the flame is calculated by means of signal correlation between different pixel data. Finally, the FTF is calculated by fusing both measurement data.

References:

[1] J.W.S. Rayleigh, "The Explanation of Certain Acoustical Phenomena", Nature, 18(4): 319-321, 1878.

[2] S. Candel, D. Durox, T. Schuller, J.F. Bourgouin, J.P. Moeck, "Dynamics of swirling flames", Annu. Rev. Fluid Mech., 46:147-173, 2014.

[3] C.O. Paschereit, B. Schuermans, W. Polifke, O. Mattson (2002) "Measurement of Transfer Matrices and Source Terms of Premixed Flames", J. Eng. Gas Turbines Power, 124(2):239.

[4] M. Lauer, T. Sattelmayer, "On the adequacy of chemiluminescence as a measure for heat release in turbulent flames with mixture gradients." J. Eng. Gas Turbines and Power, 132(6):061502, 2010.

[5] R. Schlüßler, M. Bermuske, J. Czarske, A. Fischer, "Simultaneous three-component velocity measurements in a swirl-stabilized flame", Exp. Fluids, 56:183 (13pp), 2015.

[6] S. Köberl, F. Fontaneto, F. Giuliani, J. Woisetschläger, "Frequency resolved interferometric measurement of local density fluctuations for turbulent combustion analysis", Meas. Sci. Technol., 21:035302 (10pp), 2010.

10329-67, Session 15

Optical rotor-blade deformation measurements using a rotating camera system

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The knowledge of the movements and the deformation of rotor blades is of great importance for the performance and the safe operation of a rotor system, especially for blades with a high aspect ratio like on helicopter main rotors or wind turbines. To measure these parameters in the rotating system is not easy, because the number of sensors is limited due to their impact on the aerodynamics and the modification of the structure.

Measurements with strain gauges can furthermore directly be affected by the choice of the sensor location, temperature effects, etc. [1]. To avoid those problems and in addition enable direct shape measurements contactless optical methods have still been applied to rotor and propeller deformation measurements in the past [2][3][4]. These attempts have been done with measurement devices out of the rotating frame observing either only small rotors or the blade passing within the field of view. Former recordings with rotating camera devices have been performed just to visualize the flow over the blades [5] or the general blade movement.

Based on their experience from the in-flight application of a rotating camera on an aircraft propeller [6], DLR and Hardsoft developed a rotating 3D image acquisition system for helicopter rotors [7] and performed first tests on the whirltower of Airbus Helicopters in Donauwörth, Germany. The system is mounted on the hub and co-rotates with the rotor. It includes four CMOS camera sensors and a complete data acquisition system and is able to record images of the whole blade at each azimuth angle. Later, those images are processed with an IPCT software tool and deliver the continuous 3D surface shape and location of the observed blade. From the comparison of the 3D surfaces for different recordings, the bending and torsion of the blade can be obtained.

The paper will briefly describe the rotating camera system itself, the non-intrusive deformation measurement method IPCT and the measuring setup. The presentation of the recorded images, the obtained data and a discussion of the measurement results will conclude the paper.

The lessons learned from the presented campaign will be helpful for manufacturers in the design and measurement of their future rotor systems.

[1] Papadopoulos, K., Morfiadakis, E., Philippidis, T. P., Lekou, D. J. "Assessment of the strain gauge technique for measurement of wind turbine blade loads." Wind Energy, John Wiley & Sons, Ltd., 2000, 3, 35-65

[2] Sicard, J., Sirohi, J. "Measurement of the deformation of an extremely flexible rotor blade using digital image correlation." Meas. Sci. Technol 24(6):065203, 2013.

[3] Fleming, G. A., Gorton S. A. "Measurement of Rotorcraft Blade Deformation Using Projection Moiré Interferometry." Shock and Vibration, vol. 7, no. 3, pp. 149-165, 2000. doi:10.1155/2000/342875.

[4] Boden F., Torres A., Maucher C. "Advanced optical rotor blade deformation measurements on a flying helicopter." 35th European Rotorcraft Forum, Sept. 22nd – 25th 2009, Hamburg, Germany. ISBN 978-3-932182-65-0. ISSN 0178-6326.

[5] Gustafson, F. B., and Myers, G. C., Jr. "Stalling of Helicopter Blades." NACA TN No. 1083, 1946.

[6] Boden, F., Stasicki, B., Szypu?a, M., Ru?i?ka, P., Tvrdik, Z., Ludwikowski, K. "In-flight measurements of propeller blade deformation on a VUT100

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