Heat resistant probe combining optic and acoustic sensors for advanced combustion monitoring including detection of flame instabilities

GT2017-63626

Lukas Andracher
Institute of Aviation, FH Joanneum - University of Applied Sciences Graz, Austria

ASME Turbo Expo 2017
Chapter Controls, Diagnostics & Instrumentation
Session 5-7 Advances in Instrumentation 1
Co-authors and background

Gerhard Kraft, Fabrice Giuliani, Lukas Pfefferkorn, Nina Paulitsch
Combustion Bay One e.U., advanced combustion management
Graz, Austria

The project ”emotion” is supported by the FFG (Austrian Research Promotion Agency) and by the BMVIT (Austrian Federal Ministry for Transport, Innovation and Technology) in the frame of the ”TAKE-OFF” programme (Contract 850470).
Contents

1 Introduction & Incentive
2 Technical details about the probe
3 Experimental setups for basic and advanced testing
4 Results
5 Conclusions and perspectives
Contents

1 Introduction & Incentive

2 Technical details about the probe

3 Experimental setups for basic and advanced testing

4 Results

5 Conclusions and perspectives
Introduction

Feasibility study on optical-based instrumentation for a better combustion monitoring

"Better" means that all the following features are covered at once by the same instrumentation:

- Is there a flame or not?
- Is the ignition sequence fully completed?
- What are the current operating conditions?
- Is a combustion instability taking place?

Better combustion monitoring $\rightarrow$ Smarter management of the safety margin
The project "emotion" I

emotion
Engine health MONitoring and refined combustion control based on optical diagnostic techniques embedded in the combustor

Objective: each turbofan combustor is equipped with 4 to 8 of such miniature optical sensors
The project "emotion" II

**An exploratory project** (Combustion Bay One e.U. + Institute of Aviation at FH Joanneum)

- Feasibility of embedding a miniature optical probes in an aeroengine (towards a refined combustion monitoring in gas turbines)
- **Aim =** delivery a robust, miniaturised optical sensor concept with a portable autonomous measurement & processing unit
- Both variants CCD chip or photosensors are considered (this communication = photosensors)
The project "emotion" III

Strategies

1. the optics are embedded in the injector
   - observe the flame throughout the injection
   - fuel used as a coolant

2. the optics are mounted on the pressure casing
   - observe the flame through the cooling holes or perforated plate
   - active cooling
The project "emotion" IV

Casing: Delta P...30 bar
Delta T... 600K

Optical interface

HEAT TRANSFER

Liner = screen, multi-scattering, reflexions...

Dilatation
Vibrations

OPTICAL SENSOR

HARDWARE
(OPTICS + Sensor + Cable + Connexion)

Aggressive flow conditions (erosive, dirt deposit)
Contents

1 Introduction & Incentive

2 Technical details about the probe
   - Optical sensor’s sensitivity and dynamic response
   - Probe circuits
   - The Rayleigh Criterion Probe

3 Experimental setups for basic and advanced testing

4 Results

5 Conclusions and perspectives
Optical sensor’s sensitivity and dynamic response

Tested sensors

- photoresistors and photodiodes
- all cut-off frequencies above 500 Hz
- best sensitivity observed with photodiodes, up to 2 kHz
- sensor Osram Opto SFH 229 downselected for this study

Selection = best trade-off between sensitivity and dynamic response

Dynamic response using a strobe
Probe circuits

Were tested:

a. condenser microphone
b. Wheastone bridge with two photosensors
c. reverse-circuit with one single photosensor
d. Wheastone bridge with one single photosensor

Only the non-amplified signals are reported in this study.
The Rayleigh Criterion Probe (RCP) I

- Idea = add an acoustic sensor to the optical probe, for a combined optical - acoustic flame monitoring
- Artefact noise (e.g. other machine noises than the flame) can be filtered out
- “Point measurement”: both sensors are arranged as near as possible to each other
- Combustion instability: the study on the time-lag between the periodic signals at the resonant frequency leads to the determination of Rayleigh Criterion
- Therefore the device was called the Rayleigh-Criterion Probe
The Rayleigh Criterion Probe (RCP) II

Rayleigh Criterion Probe concept: circuit board with photodiode and microphone mounted in a probe tube and cooling strategy
Contents

1 Introduction & Incentive

2 Technical details about the probe

3 Experimental setups for basic and advanced testing
   - Rijke Tube
   - Flame propagation tube
   - Combustion test rig specifications
   - Forced combustion instability using a siren

4 Results

5 Conclusions and perspectives
Rijke Tube

- Quarter-wave thermoresonator, with a bunsen burner as a heat source
- Dimensions: length 0.5 m, inner diameter 0.04 m

\[ \lambda_{Rijke} = 2L \text{ and } c = \lambda_{Rijke} f \]

▶ LINK TO MOVIE
Flame propagation tube

- Assembly = 1.5 m long quartz glass tube
- Fresh mixture injected in the tube at 0.1 m/s
- A flare is placed at the end of the tube
- The mixture ignites and the flame progresses against the flow within the tube
- Three sensors placed along the tube report on the flame front displacement

▶ LINK TO MOVIE
Combustion test rig specifications

- 20 kW compact atmospheric combustion facility
- plenum + staged burner (concentric) + combustor casing + exhaust
- premixed, lowly-swirled pilot flame placed in a strongly-swirled main flame
- fuel: propane

▶ MOVIE → Steady State
▶ MOVIE → Pulsed
Forced combustion instability using a siren

Siren specifications:
- 0 to 2000 Hz
- Adjustable amplitude from 0 to 100% of pulsation
- Precise, robust, programmable
Forced combustion instability using a siren II

More about the siren with variable amplitude, visit:

Improvement of impaired combustion conditions at some off-design operation by driving a precisely controlled modulation of the burner air feed.

GT2017-64429
Combustion, Fuels & Emissions 4-39
Combustion Dynamics: Damping & Controls II
Wednesday 28.06, 10:45
Probe mounts and cooling

- Probes are air-cooled
- An 0.1 g/s air flow keeps the sensors below 80°C
- The probe survives peak temperatures up to 125°C
- This study totalises 30 hours of runs without measurable alteration of the probe
Best trade-off with the reverse circuit

Experiment with the Rijke Tube:

- poorest dynamic response observed with the Wheatstone bridge with one → not further investigated.
- reverse circuit simpler than Wheatstone bridge with two PDs → all further tests are performed using the reverse circuit

Amplitude spectrum, using a stroboscope

Spectrograms, using the Rijke Tube
Flame propagation speed

Flame propagation set-up: detection of the flame front moving, and flame speed measurement

✓ Flame propagation at ignition (using several probes)
✓ Flame propagation speed (repeated 1.3 m/s $\phi=0.8$)
✓ Flame / no flame detection
Flame power and position, flame - no flame

Flash-back tests performed on the combustion test rig

- RCP3 positioned remotely, RCP4 near the flame
- Flashback pikes detected by the microphone while the flame retreats in the burner
- The nearer the probe from the flame, the better the optical signal

Results:

- ✓ Flame / no flame detection
- ✓ Operation load
- ✓ Flame behaviour
Combustion instability I

- 20 s sequence where the siren is turned on at 368 Hz, then off, then on again
- Microphone 4 detects the instability despite the noise due to air cooling
- All sensors also detect 515 Hz, a natural resonant frequency
Combustion instability II

- The phase shifts $\Delta \varphi$ at 368 Hz are computed
- Repeatability within $\pm 0.1$ rad range at 368 Hz
- Provided the time shifts are well understood, the type of combustion instability is revealed (axial mode, azimuthal mode, etc.)
- Relevant time lags can be computed for active control purpose

Phase shifts $\Delta \varphi$

✓ Combustion instability detection
✓ Understanding the physics of the combustion instability
Conclusions

- A proof of concept toward the optical monitoring in a combustor was presented.
- A fast pressure sensitive sensor was combined with the optical one in order to measure simultaneously the flame’s noise and its intensity of luminescence.
- The resulting RCP probe is a powerful tool that can interpret the flame’s dynamic behaviour, and detect for sure the presence of a combustion instability.

This monitoring strategy has a high potential and could become a standard for the future generations of aeroengines.
Perspectives

- Replace the microphone with a flush-mounted, high temperature resistant, miniature fast pressure sensor.
- Wavelength-specific optical measurements (e.g. flame front in the UV and soot generation in the IR).
- Optimisation of the cooling.
- Testing at realistic conditions
- Effort on the packaging.
Thank you for your attention!

Heat resistant probe combining optic and acoustic sensors for advanced combustion monitoring including detection of flame instabilities

Gerhard Kraft, Fabrice Giuliani, Lukas Pfefferkorn, Nina Paulitsch, Lukas Andracher

Paper GT2017-6326

Combustion Bay One e.U.
advanced combustion management
Schuetzenhofgasse 22
8010 Graz, Austria

Download this presentation under www.CBOne.at