Synchronous capture of GT combustor operating conditions and main combustion dynamics parameters combining quasi-static and fast-response measurements in a well-documented and compact manner

Lukas Pfefferkorn, Christoph Wieland, Fabrice Giuliani
COMBUSTION BAY ONE e.U.
Austria

Hans Reiss,
MEGGITT
SENSING SYSTEMS
Switzerland

Presentation Ref serial no: 0026

Joint conference EVI-GTI and PIWG on Gas Turbine Instrumentation
GTI 2016, Berlin, Germany, 26-29 September 2016
Motivation

- The FFG-sponsored project rePorT is about real-time monitoring of the injection in gas turbine combustors. It combines dynamic and quasi-static data acquisition.

- This feature was used within a co-operation between MSS and CBOne on combustion monitoring for power gas turbines. Attention was paid to:
  - a detailed description of the operating conditions
  - an effort on the synchronization of data logging using several instruments
  - a compact database containing all important information for causal analysis
Contents

• Experimental set-up and instrumentation

• Methodology for a data set combining machine states and detailed dynamics

• Case study
  – Characterisation of combustion stability using precisely controlled forced flow conditions
  – Detailed description of a flashback
Contents

- Experimental set-up and instrumentation
- Methodology for a data set combining machine states and detailed dynamics
- Case study
  - Characterisation of combustion stability using precisely controlled forced flow conditions
  - Detailed description of a flashback
Experimental set-up

Exhaust with measurement ports

Reduction

Liner

Casing with optical accesses

Plenum

Siren pulsating the air of the pilot flame

Front plate & burners

Siren
Premixed, swirl-stabilised pilot flame
Siren-3G from CBOne
Forced pulse combustion

Conventional (Steady-state flows)

Pulsed pilot stage (Exciter=pilot flame, excited by the pulsator)
Measurement chain summary
assembled out of standard commercial products

Dynamic Pressure
CP232  750pC/bar  520°C  2-10.000Hz

Acceleration
CA134  10pC/g  500°C  2-6.000Hz

Data Acquisition/ Processing
XMC16/XIO16T
16CH, synchronous, continuous
fs = DC to 98kHz, SNR = 18dB

Analysis / Storage
VibroSight Software

Post Processing / Replay
VibroSight Vision, Matlab, Labview,
Regenerate the original signals from saved files for replay
### Denomination

#### Accelerometers
- **ACC01**: -2PL, 12h
- **ACC02**: +1CC, 6h

#### Pressure transducers
- **CP01**: -1PL, 12h
- **CP02**: +1CC, 1h
- **CP03**: +1CC, 12h
- **CP04**: +1CC, 9h
- **CP05**: +2CC, 12h
- **CP06**: +3CC, 12h

### Other signals
- **Siren**
- **Frequency**: Excitation Frequency Tacho (TTL)
- **Angle**: Angle of rotation
  
  \[(1 \text{ revolution} = [0 \ldots 4V])\]

### Ext. Microphones
- **Micro01**: 2.5m away

---

**Probe Positions & Nomenclature**

- **Exhaust**
- **Combustion Chamber**
- **Plenum**
- **Siren**
- **Top view**

---

**Position**

- **Level**: -2PL, +1CC, -1PL, +2CC, +1CC, +2CC, +3CC
- **Angle**: 12h, 6h, 12h, 12h, 12h, 12h, 12h
Contents

• Experimental set-up and instrumentation

• Methodology for a data set combining machine states and detailed dynamics

• Case study
  – Characterisation of combustion stability using precisely controlled forced flow conditions
  – Detailed description of a flashback
Smart monitoring: adapt the acquisition/documentation to the situation
1) Custom history database

- Chunks of dynamic signals coming from the fast sensors
- Machine states via protocols such as OPC, Profibus or Ethernet
- The custom history mixes both informations and the database allows to navigate quickly through the dataset
2) Highly resolved and seamless datafiles per dynamic channel

- VibroSight can activate the recording of highly resolved and seamless datafiles

- A multiplexer is used to compile all machine states on one single input

- This allows a detailed post processing e.g. using a replay option
Detail: the multiplexer

- Hardware = CD4051BE 8-Channel switch
- Clock = Raspberry Pi, programmed with a scanning frequency from 1Hz
- Two first channels = GROUND then Uref for recognising when a sequence starts
Multiplexing

The Multiplexer:

- Hardware = CD4051BE 8-Channel switch
- Clock = Raspberry Pi, programmed with a scanning frequency from 1Hz
- Two first channels = GROUND then Uref for recognising when a sequence starts

![Multiplexer diagram]

CH1 (GND)  
CH2 (Uref)  
CH3  
CH4  
CH5  
CH6  
CH7  
CH8
Pattern recognition on the MUX signal (3 channels connected):

1. Seeks for transitions greater than 4.5V
2. Checks that before the transition it is GND, after it is Uref
3. Checks that the distance from one front (noted *) to the next is approximately one second
De-Multiplexing

Reorder each consecutive sequence and average per band (overshoots due to switching are sorted out)

e.g. Fuel mass flow changing with time
Contents

• Experimental set-up and instrumentation

• Methodology for a data set combining machine states and detailed dynamics

• Case study
  – Characterisation of combustion stability using precisely controlled forced flow conditions
  – Detailed description of a flashback
MusicPaper experiment

The machine states recorded are the siren parameters: flame Excitation Tachometer and Siren Angle.
MusicPaper experiment

CP02 pressure response
MusicPaper experiment

CP02 pressure response

208 Hz
With variable amplitude
MusicPaper experiment

CP02 pressure response

368 Hz

With variable amplitude
MusicPaper experiment
CP02 pressure response

CP02

515 Hz
With variable amplitude

515 Hz
Flame transfer function using order tracked measurements
Flame transfer function using order tracked measurements

Machine | From 04.08.2016 11:25:01, to 11:57:07, (32,1 mins)
Analysis of a flash-back

- The set-up can reproduce controlled flash-backs
- One event is visible using the historical database
Analysis of a flash-back

- The event is analysed using the most responsive signal (fast pressure sensor in the plenum)
- The event happens shortly before 9h37
The machine states on the flow conditions are extracted from the time-resolved MUX datafile ...

1. Progressive augmentation of main gas
2. Flashback and reduction of main gas
... and translated into physical value. A rise in main gas did provoke the flash-back.

1. Progressive augmentation of main gas
2. Flashback and reduction of main gas
Discussion

- Methods combining quasi-static and fast-response measurements in a well-documented and compact manner were presented.

- Combining machine states and dynamic measurements eases the understanding of a given situation.

- For detailed analysis using highly-resolved data, multiplexing helps to gather the information from a large number of sensors using only one dynamic channel.

- The post-processing effort and the risk of losing data or of poor synchronicity are reduced in a remarkable way.

- Parallel to this study, another work on amplitude-to-frequency encoding is ongoing.
Conclusion

• Detailed combustion monitoring can be made with smart combined methods of acquisition and active data selection with a large number of sensors, for a reasonable computational power and disk space.

• This approach helps the operator to get a better understanding of the machine, make selective decisions, and operate the gas turbine in a smoother way.

• The presented technologies allow to chart into details the characterization of a burner on a test bench.

• Next logical step: deployment for industry field application.