CLIC module

Thermal and mechanical test results of T0#1

Team

Daskalaki Elena
Duquenne Mathieu
Rude Vivien
Vamvakas Alex
Xydou Anastasia
Zelios Athanasios

Contents

CLIC two-beam module

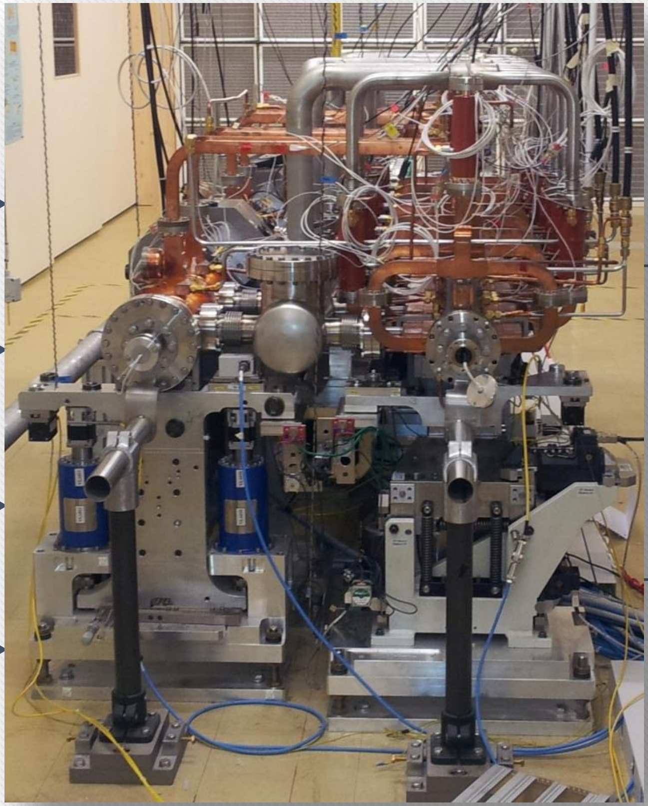
Mock-up of a real module where power dissipation is simulated by electrical heaters

Ambient temperature

Air velocity

Thermal power

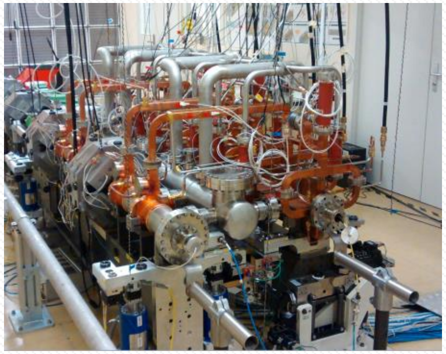
Water flow



Temperature

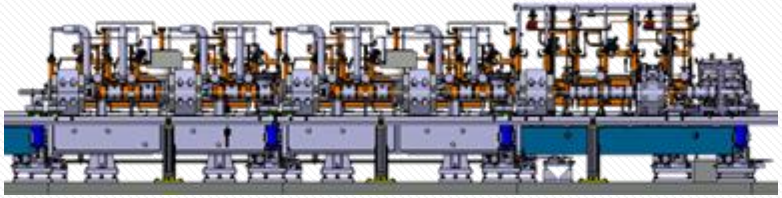
Displacement

CLIC two-beam module



2011 - 2015

- One module T0-1
- First attempt to study the thermo-mechanical behaviour of CLIC **(Phase-I)**



2016 - …

- Module array: Three modules T0-1, T0-2, T1
- Extension of experimental program **(Phase-II)**

Objectives

1. Study the effect of:

- Power
- Water flow
- Air speed
- Ambient temperature

on temperature and displacement

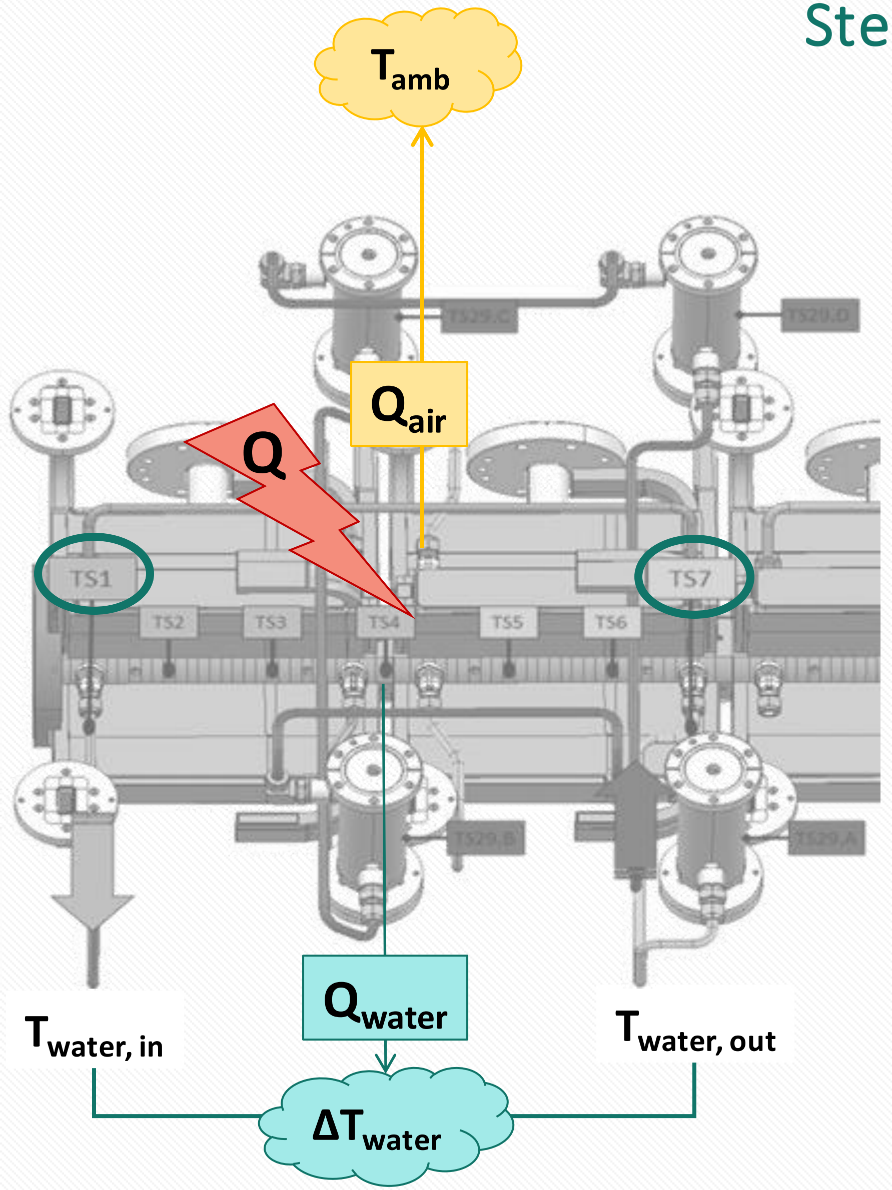
2. Simulate CLIC duty cycles

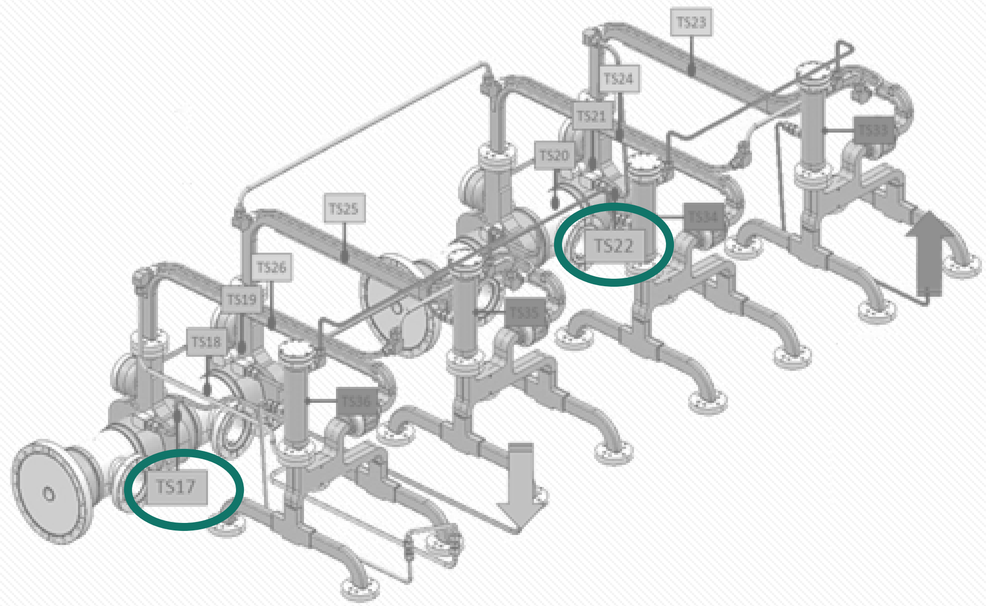
3. Study the dynamic response of CLIC components

4. Develop FEA simulator for module T0 in steady-state

Theoretical analysis

Steady state





$$\dot{Q}_{water} = \dot{m} c_p (T_{water,out} - T_{water,in})$$

$$\dot{Q}_{air} = h(T_{comp} - T_{amb})A$$

Theoretical analysis

Transient

$$Q = Q_{cu} + Q_{water} + Q_{air}$$

To copper → $Q_{cu}(t) = m_{cu} c_{p,cu} \frac{dT_{cu}}{dt}$

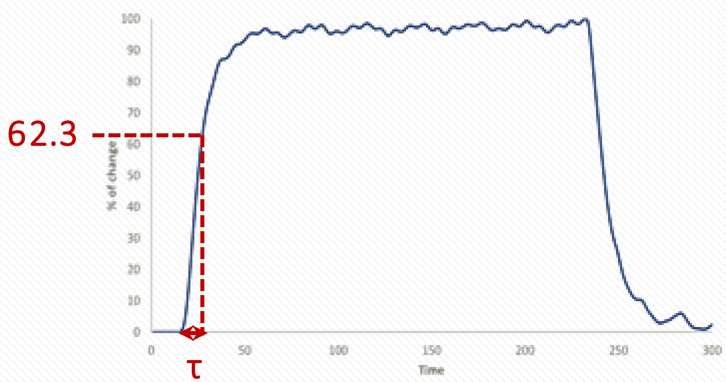
To water → $Q_{water}(t) = \dot{m}_w c_{p,w} [T_w(t) - T_w(0)]$

To air → $Q_{air}(t) = hA_{cu} [T_{cu}(t) - T_\infty]$

$$T_{cu}(t) = \mathrm{T}_{\substack{steady \\ state}} - c e^{-t/\tau}$$

Time constant

- Speed of system response excited by a step input
- Time to reach 62.3% of final state

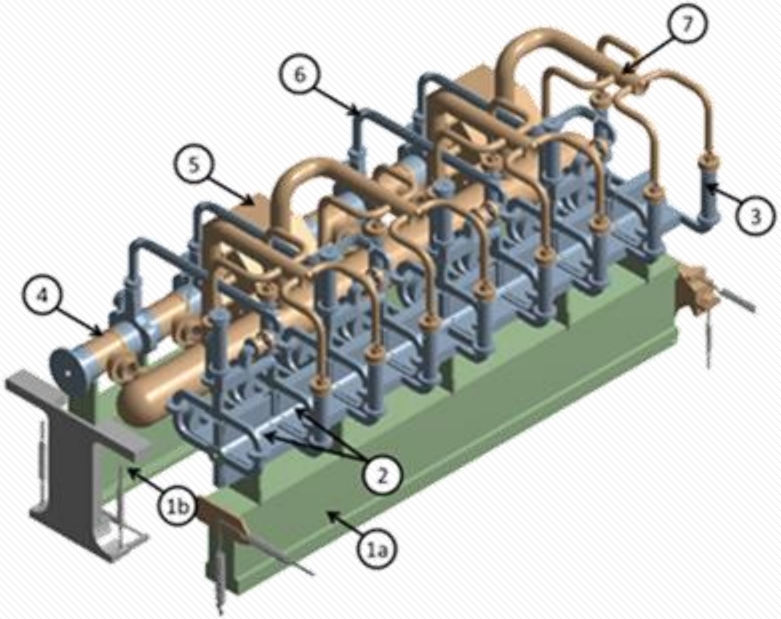


geometry

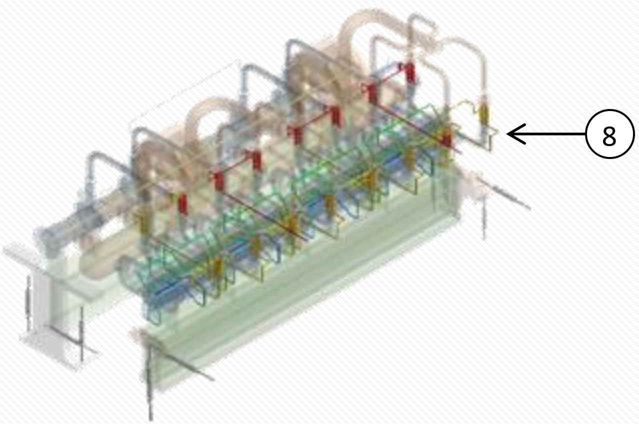
$$\tau = \frac{m_{cu} c_{p,cu}}{\dot{m}_w c_{p,w} + hA_{cu}}$$

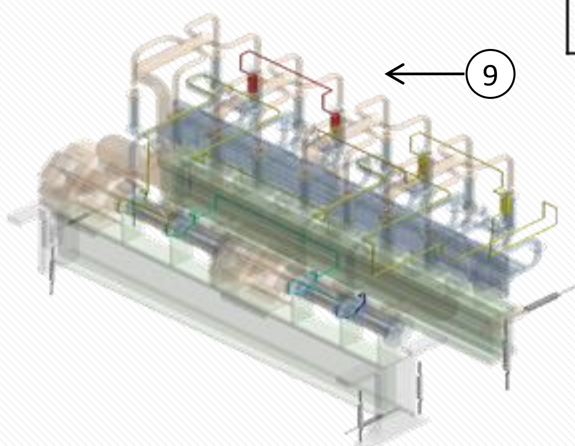
water flow

FEA Simulator



1a	Main Beam Girder
1b	Drive Beam Girder
2	SAS
3	Compact Load
4	PETS Unit
5	DBQ
6	RF network
7	Vacuum Network
8	Cooling system SAS
9	Cooling system PETS



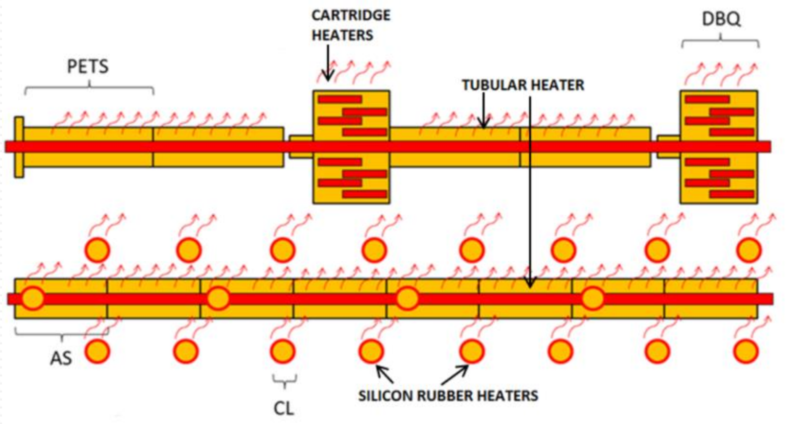


A. Xydou, A. Vamvakas. G. Riddone, E. Daskalaki, "Themo-mechanical tests for the CLIC two-beam module study"

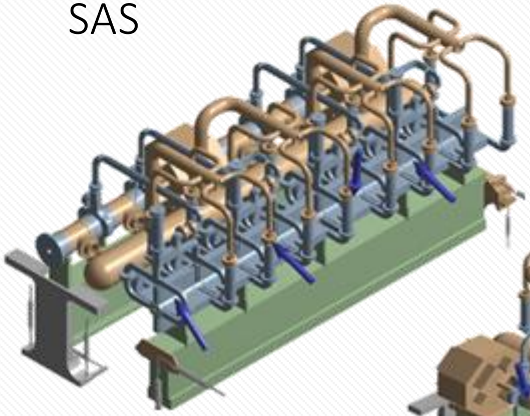
FEA Simulator

- Heaters used in the thermal tests have been modelled in the simulation

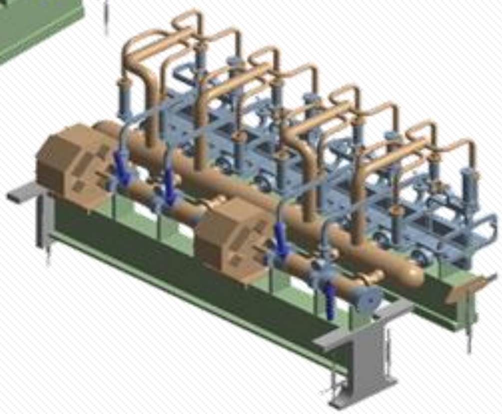
COMPONENTS	NOMINAL POWER (W)
SAS	820
PETS	110
CL	150
DBQ	150



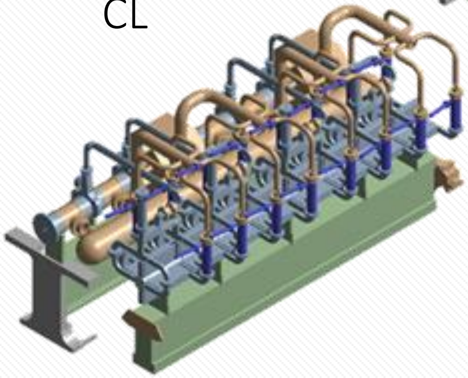
SAS



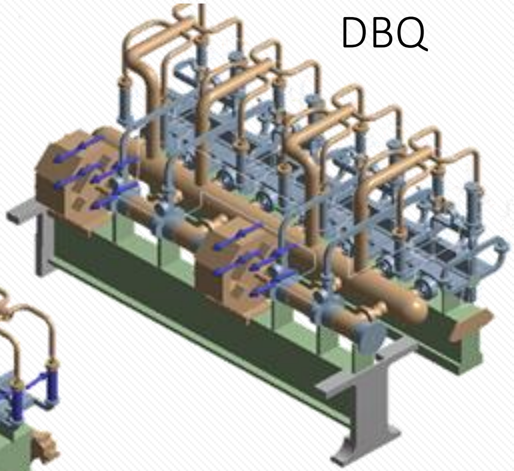
PETS



CL



DBQ



Preliminary tests

STEP	T_{amb} (°C)	v_{air} (m/s)	Q (%)					
			SAS	*AS Load*	*PETS*	*RFN Load*	*DBQ*	$T_{i,water}$ (°C)
0	20	0.3	0	0	0	0	0	25
	20	0.4	0	0	0	0	0	25
	20	0.5	0	0	0	0	0	25
	20	0.6	0	0	0	0	0	25
	20	0.7	0	0	0	0	0	25
	20	0.8	0	0	0	0	0	25
1	20	0.3	0	0	0	0	0	25
	30	0.3	0	0	0	0	0	25
	40	0.3	0	0	0	0	0	25
2	20/40	0.4	50	50	0	0	0	25
	20/40	0.4	100	100	0	0	0	25
	20/40	0.8	50	50	0	0	0	25
	20/40	0.8	100	100	0	0	0	25
3	20/40	0.4	0	0	50	50	5	25
	20/40	0.4	0	0	100	100	10	25
	20/40	0.8	0	0	50	50	5	25
	20/40	0.8	0	0	100	100	10	25
4	20/40	0.4	50	50	50	50	5	25
	20/40	0.4	100	100	100	100	10	25
	20/40	0.8	50	50	50	50	5	25
	20/40	0.8	100	100	100	100	10	25

- Final state depends on power, ambient temperature and water flow.
- No dependence on air speed
- The temperature rise is linear to the applied power

F. Rossi, "Thermo-mechanical tests", Review of CLIC Two-Beam Module lab program, 6 November 2013

Duty cycles

Mode	#	INPUT								
		T_{amb} (°C)	v_{air} (m/s)	Q (W)					$T_{i,water}$ (°C)	F_{water} (m^3/h)
				SAS	*AS Load*	*PETS*	*RFN Load*	*DBQ*		
Nominal operation mode	DBQ only	20/40	0.7	0	0	0	0	150	25	0.311
	Unloaded	20/40	0.7	820	178	220	178	150	25	0.311
	Loaded	20/40	0.7	683	137	220	178	150	25	0.311
Failure mode *SAS breakdown*	Loaded	20/40	0.7	683	137	220	178	150	25	0.311
	SAS breakdown	20/40	0.7	0	27.4	220	178	150	25	0.311
	PETS off	20/40	0.7	0	27.4	55	0	150	25	0.311
	Loaded	20/40	0.7	683	137	220	178	150	25	0.311
Failure mode *PETS breakdown*	Loaded	20/40	0.7	683	137	220	178	150	25	0.311
	PETS breakdown	20/40	0.7	683	137	55	0	150	25	0.311
	SAS off	20/40	0.7	0	27.4	55	0	150	25	0.311
	Loaded	20/40	0.7	683	137	220	178	150	25	0.311

Temperature and position of all components were measured in steady-states

E. Daskalaki, A. Vamvakas, A. Xydou, "Nominal operation mode: Temperature results"

M. Duquenne, V. Rude, A. Xydou, "Nominal operation mode: Displacement results"

Results: Temperature

Steady-state temperature in nominal operation mode: Comparison between experiment and simulator

	DBQ only			Unloaded			Loaded		
	Experiment	Simulation	Diff.	Experiment	Simulation	Diff.	Experiment	Simulation	Diff.
SAS#1	23.7	24.7	1.0	29.5	31.1	1.6	29.0	30.0	1.0
SAS#2	24.3	24.7	0.4	32.2	32.4	0.2	31.5	31.1	-0.4
SAS#3	24.4	24.7	0.3	32.2	32.2	0.0	31.5	30.9	-0.6
SAS#4	24.2	24.7	0.5	32.2	32.5	0.3	31.5	31.2	-0.3
PETSu#1	22.7	24.0	1.3	25.9	28.0	2.1	26.4	28.0	1.6
PETSu#2	23.2	23.9	0.7	29.4	29.9	0.5	30.1	29.9	-0.2
DBQ#1	37.6	39.3	1.7	34.4	32.2	2.2	33.2	31.8	1.4
DBQ#2	36.1	38.4	2.3	33.6	33.9	-0.3	31.8	33.6	-1.8

- The FEA simulator predicts effectively the experimental temperature response

Results: Temperature

Nominal operation mode: Comparison between experiment and theoretical expectation

	$T_{water,in}$ (°C)	$T_{water,out}$ (°C)	Flow (m^3/h)	T_{amb} (°C)	T_{comp} (°C)	Q_{water} (W)	Q_{air} (W)	$Q_{tot,theory}$ (W)	$Q_{tot,exper}$ (W)
SAS#1	24.6	32.3	0.07	20	31.5	628	92	720	817
SAS#2	24.6	33.7	0.07	20	33.6	733	109	841	817
SAS#3	25.0	34.8	0.06	20	34.4	724	115	839	817
SAS#4	25.0	34.3	0.07	20	33.8	718	110	829	817
SAS total								**3228**	**3280**
PETS	24.7	30.1	0.04	20	28.6	255	69	**324**	**420**

$$\dot{Q}_{water} = \dot{m} c_p (T_{water,out} - T_{water,in})$$

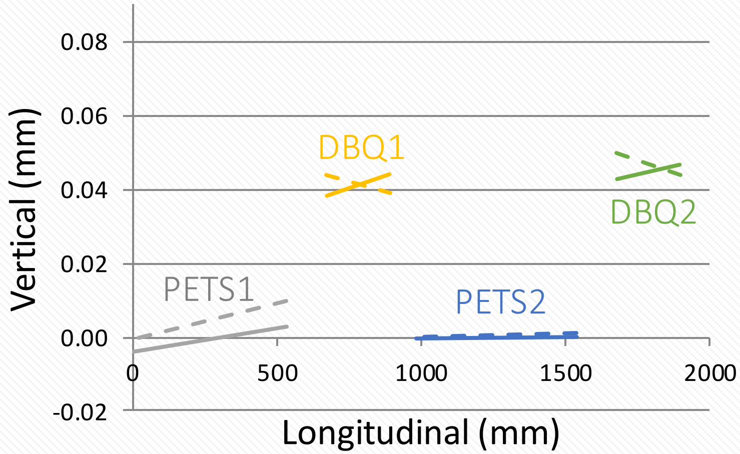
$$\dot{Q}_{air} = h(T_{comp} - T_{amb})A$$

- Theoretical analysis matches well with experimental results
- Better match in the case of SAS

Results: Displacement

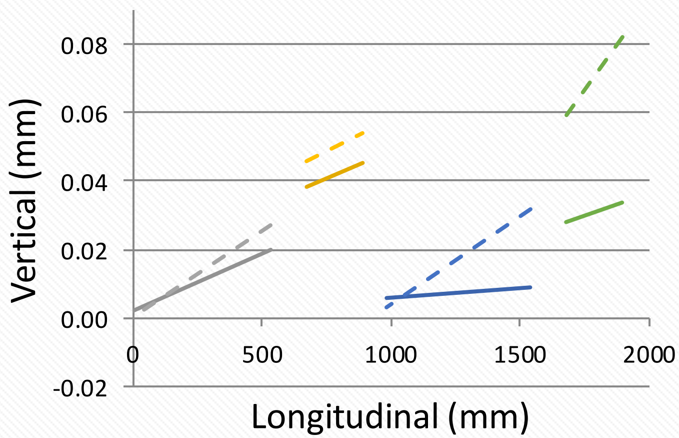
Drive beam

DBQ only

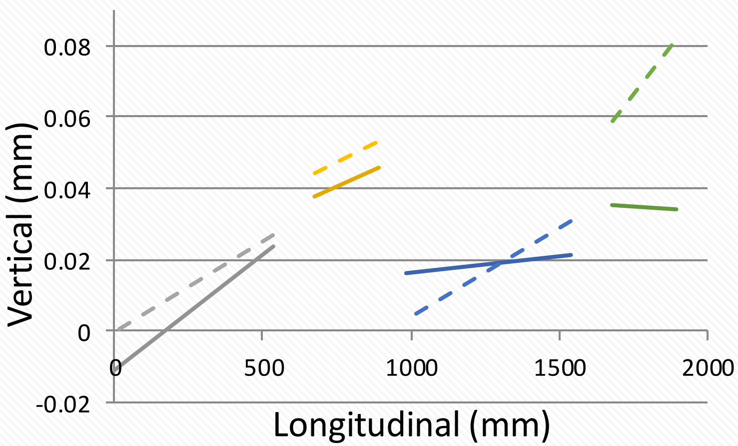


Absolute displacement of components: Experimental (—) and simulation (----)

Unloaded



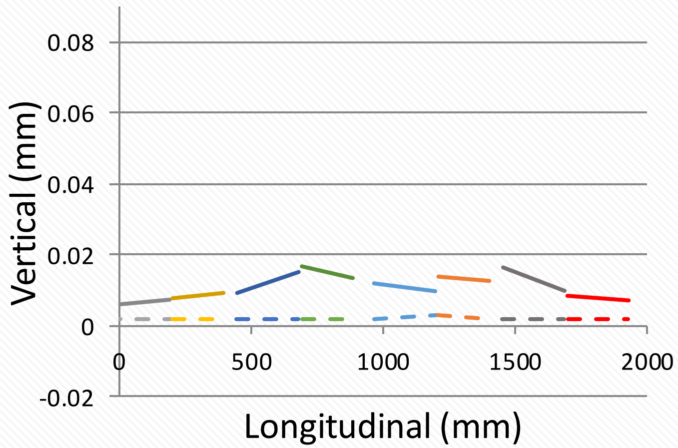
Loaded



Results: Displacement

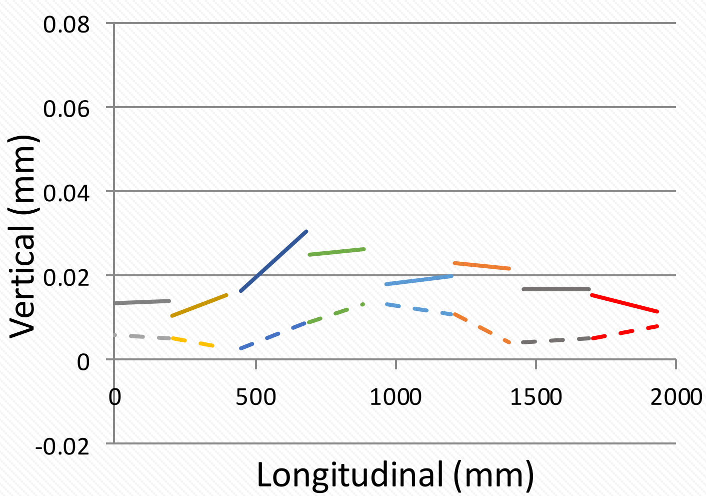
Main beam

DBQ only

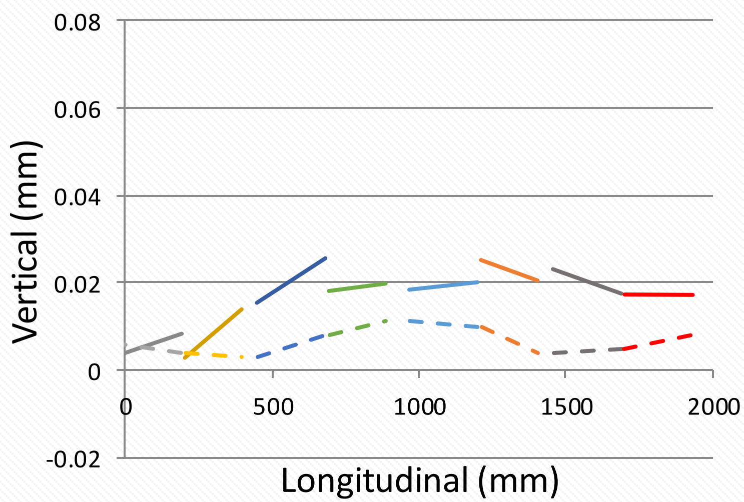


Absolute displacement of components: Experimental (—) and simulation (----)

Unloaded



Loaded



Transients

Phase 1: Temperature

Dynamic **thermal** response as a function of:

- Power applied
- Water flow
- Ambient conditions

Phase 2: Displacement

Dynamic **mechanical** response and its correspondence to the thermal dynamics

E. Daskalaki, M. Duquenne, V. Rude, A. Vamvakas, A. Zelios, "CLIC module: Analysis of dynamic response"

Procedure

Phase 1: Temperature

- Three cases of applied **power**, **water flow** and **ambient temperature** in all possible combinations

Power (W)	Water flow (m^3/h)	Ambient temperature (^oC)
290	0.040	20
820	0.068	30
910	0.090	40

Procedure

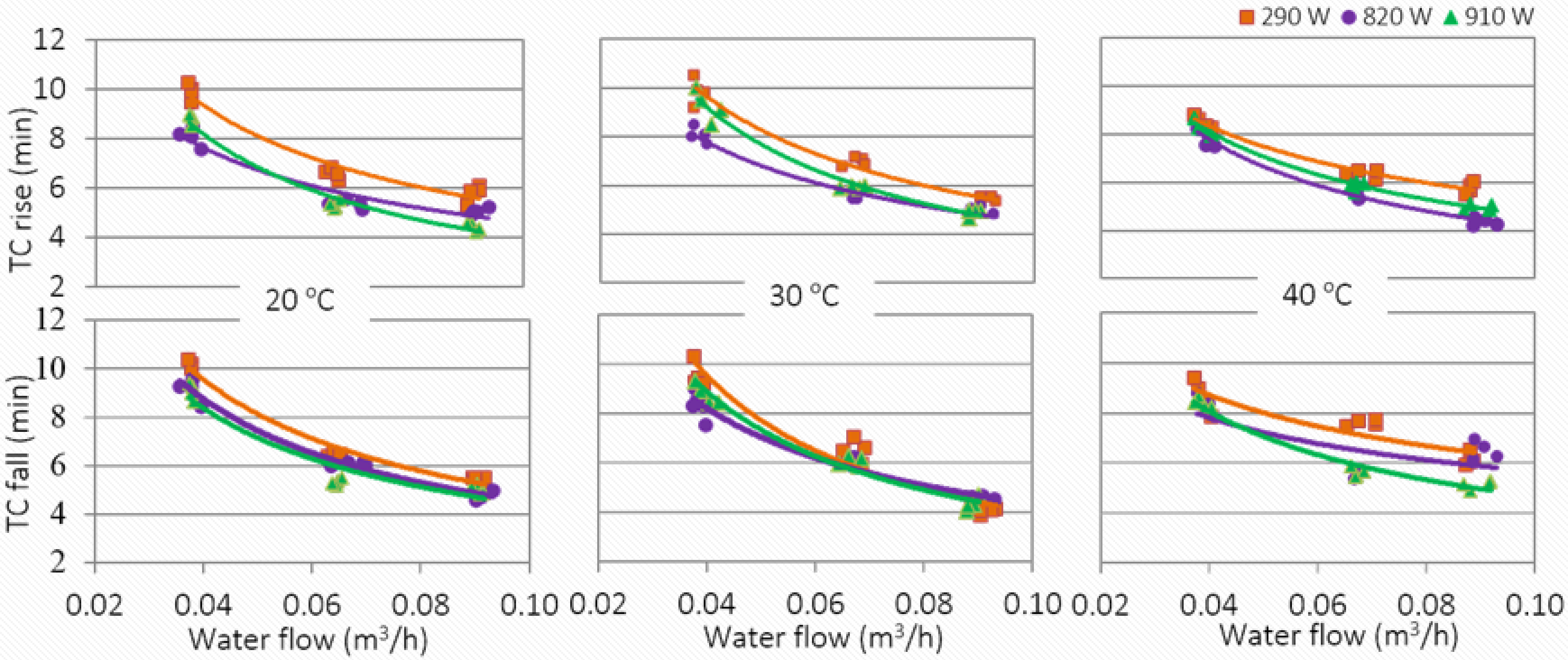
Phase 2: Displacement

- **Case 1:** Follow one point of an AS
  - More frequent measurement of point's position
  - Investigate the dynamics of a single point accurately
  - Not adequate for the determination of AS axis movement
- **Case 2:** Follow one AS (4 points)
  - Determine the AS axis movement
  - Investigate axis dynamics based on point-to-point dynamics

Experiment conditions

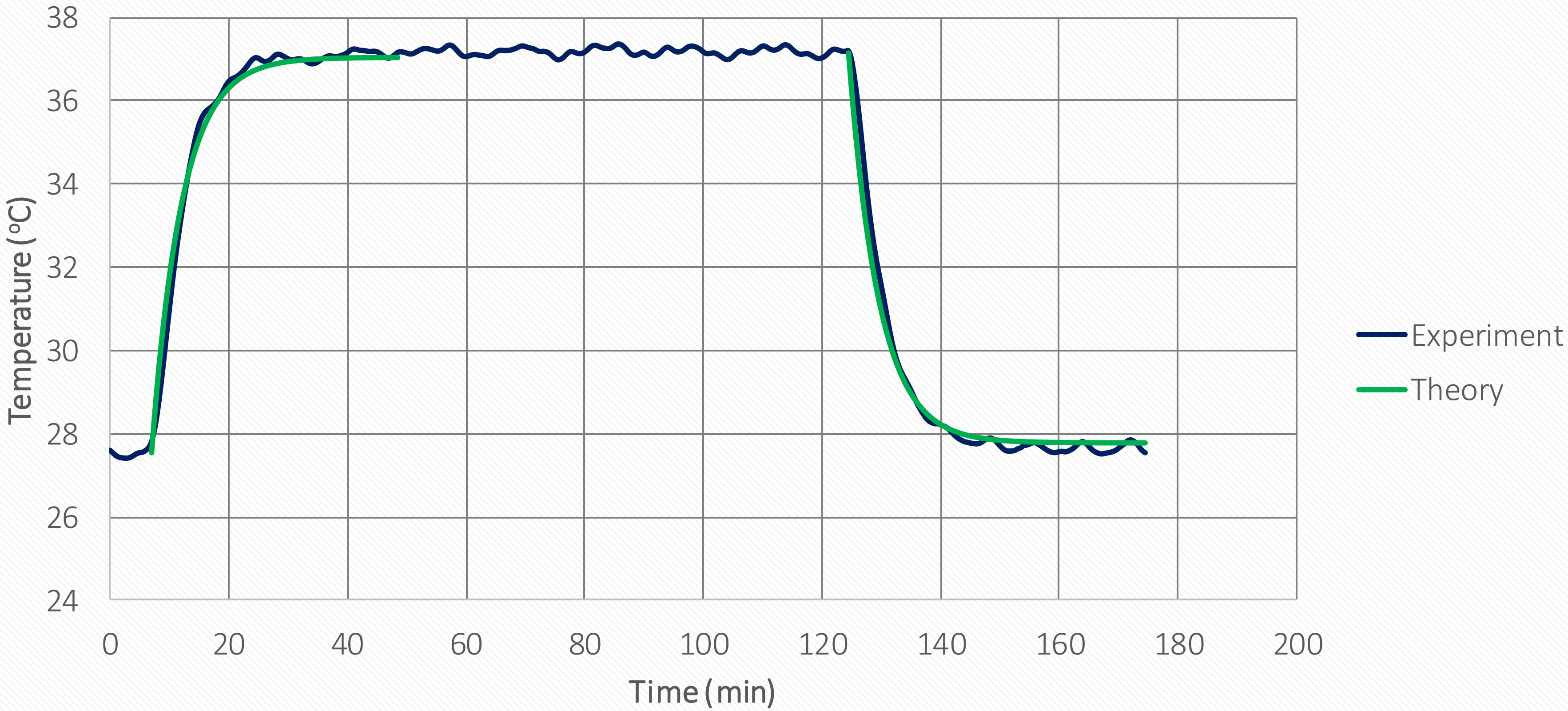
- Power: 820 W
- Water flow: 0.04 m^3/h
- Ambient temperature: 20 °C

Results: Temperature



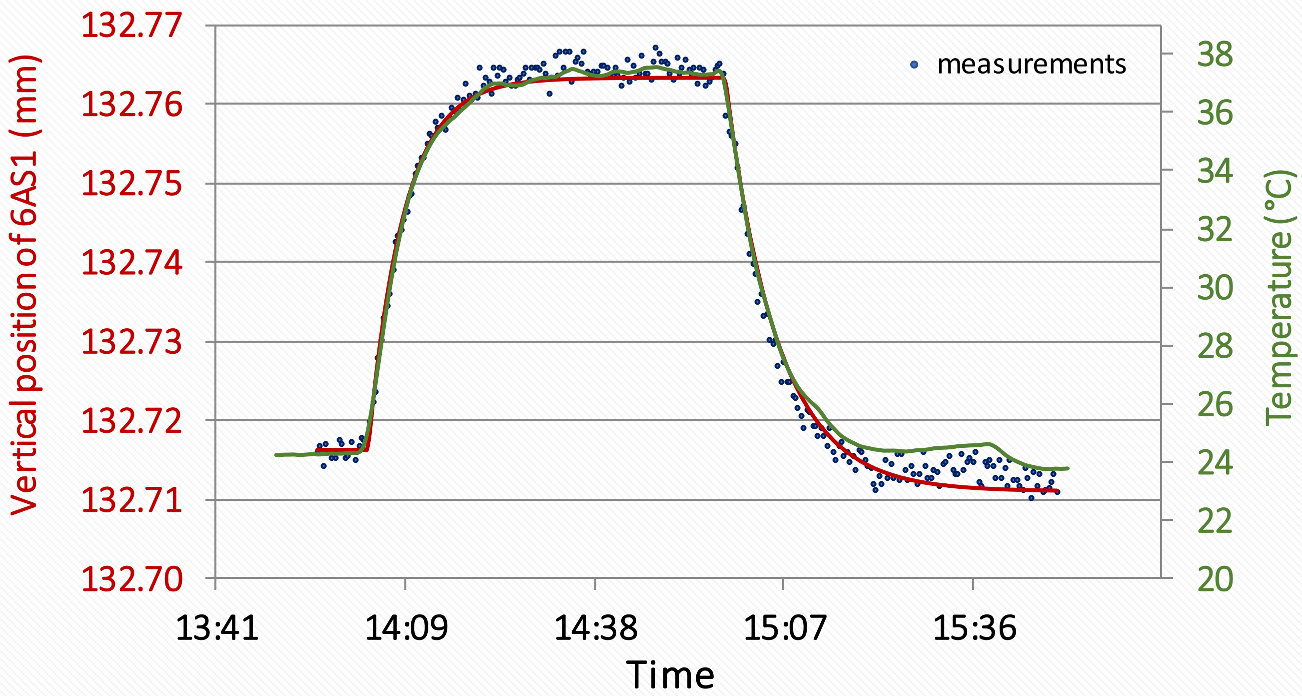
TC of SAS versus water flow for each power and ambient temperature case during temperature rise (upper graph) and fall (lower graph)

Results: Temperature



Comparison of SAS temperature profile: Experimental vs theoretical data

Results: Displacement

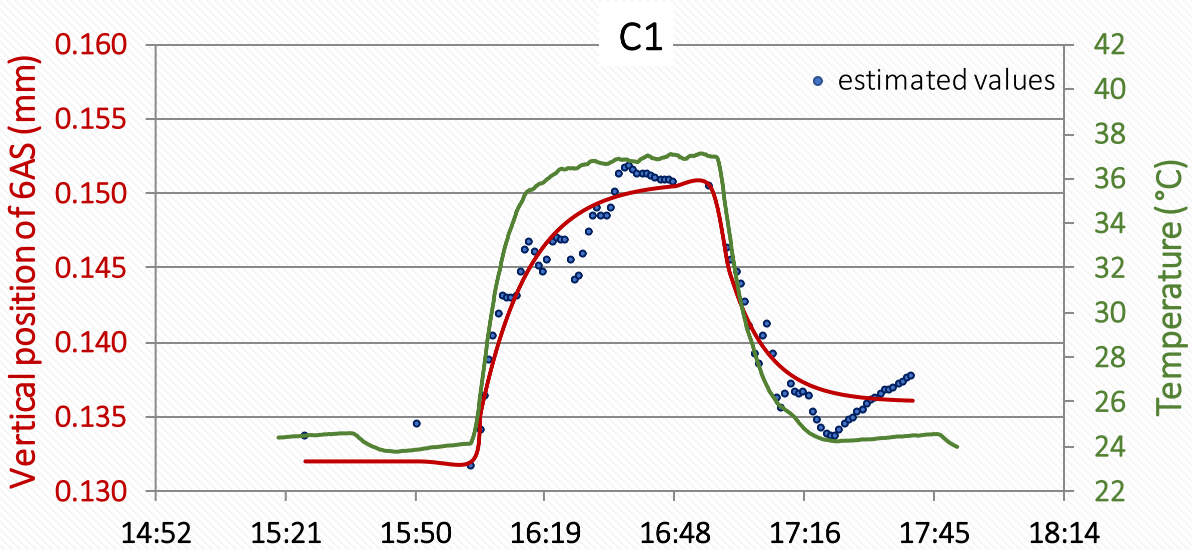


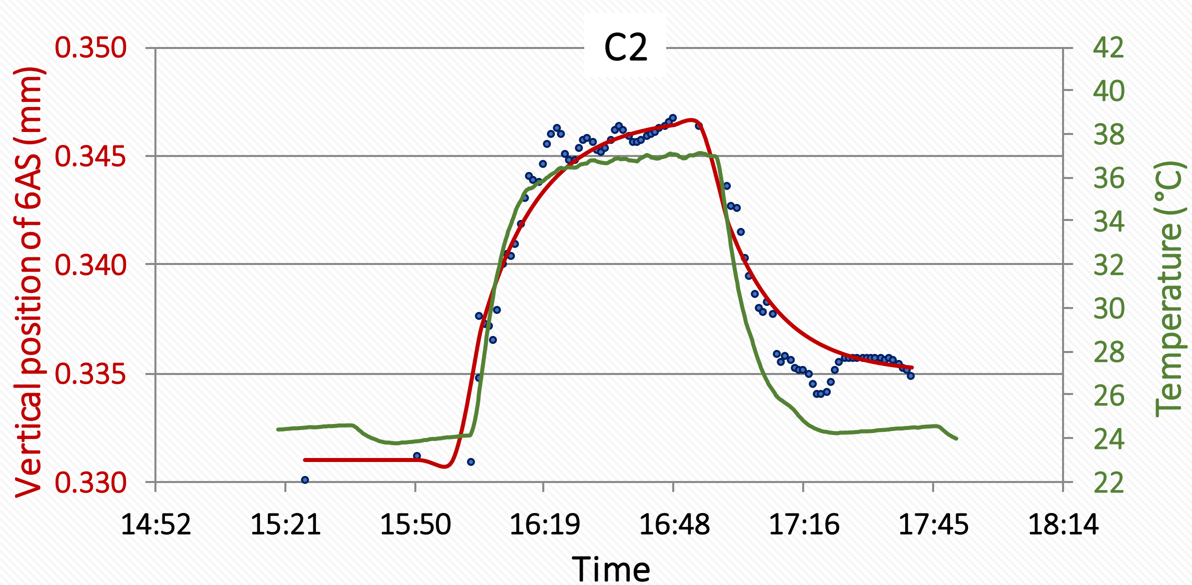
Time constants (min)

	Δx	ΔT
Rise	7.28	7.52
Fall	7.87	7.33

- Movement and temperature dynamics are the same
- Time constants can be calculated as in the case of temperature

Results: Displacement





Time constants (min)

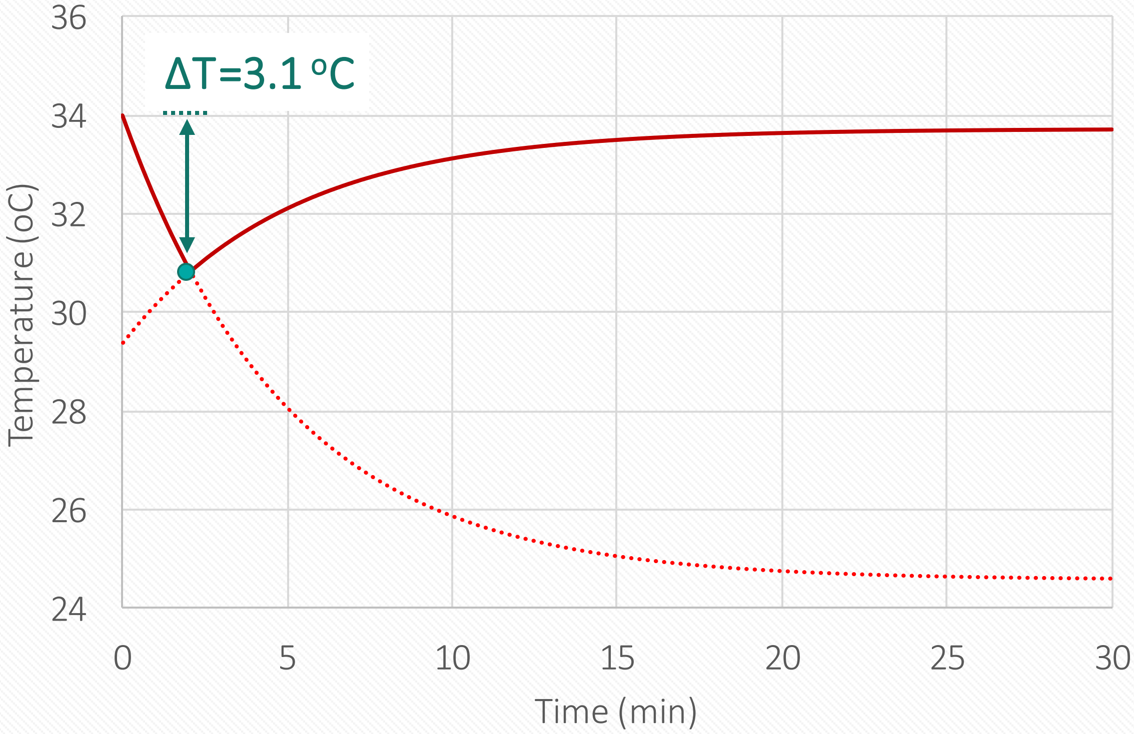
	ΔT	Δx C1	Δx C2
Rise	7.35	11.00	13.28
Fall	7.47	8.65	12.38

- *Vertical displacement of AS axis*
- *No radial displacement was detected*

Results: SAS breakdown

Extrapolate results to the estimation of displacement during a SAS breakdown

Loaded conditions → SAS breakdown 2 minutes → Step-up to loaded conditions



SAS axis displacement

≈ 3 – 4 µm

Conclusions

Steady-state response

- Final state depends on power, ambient temperature and water flow.
- No dependence on air speed
- Temperature results match well with theoretical expectation especially in SAS.
- Displacement of ≈ 50 µm measured in DBQ
- Observed displacements of 10 µm, close to the uncertainty of the measurement
- Higher deviation of experimental and theoretical results observed in Drive Beam

FEA simulator

- The first version of the FEA simulator can predict well the temperature and displacements in steady-state especially for the Main Beam
- Deviation of the displacements on the Drive Beam:
    - Temperature deviation between the experiment and the simulator
    - Stiffness of springs representing actuators stiffness

Conclusions

Transient response

- Dynamic response depends highly on water flow.
- Thermal time constant of SAS ranges between 4-11 minutes.
- Thermal transient response can be modelled as a first order differential equation.
- Displacement dynamics match well with the thermal ones.

- Temperature measurement (easy and fast process) could be used as an indicator of AS displacement (complex and time consuming process).

- The time constant of the components could be controlled as desired through regulation of the water flow.

Open issues

- DBQ not cooled
- DBQ and PETS heated simultaneously by common heater
- PETS testing prone to inaccuracies due to
    - Their proximity with DBQ
    - The cooling channel which connects the two PETS units is heated by intermediate DBQ
- SAS cannot be heated independently

- Limited accuracy in DB thermo-mechanical testing
- Reduced heating flexibility

} To be addressed in the next experimental program

Thank you for your attention