FROM RESEARCH TO INDUSTRY

EXPERIMENTAL STUDY OF STABILITY AND TRANSIENTS IN A HORIZONTALLY HEATED BOILING HELIUM THERMOSYPHON

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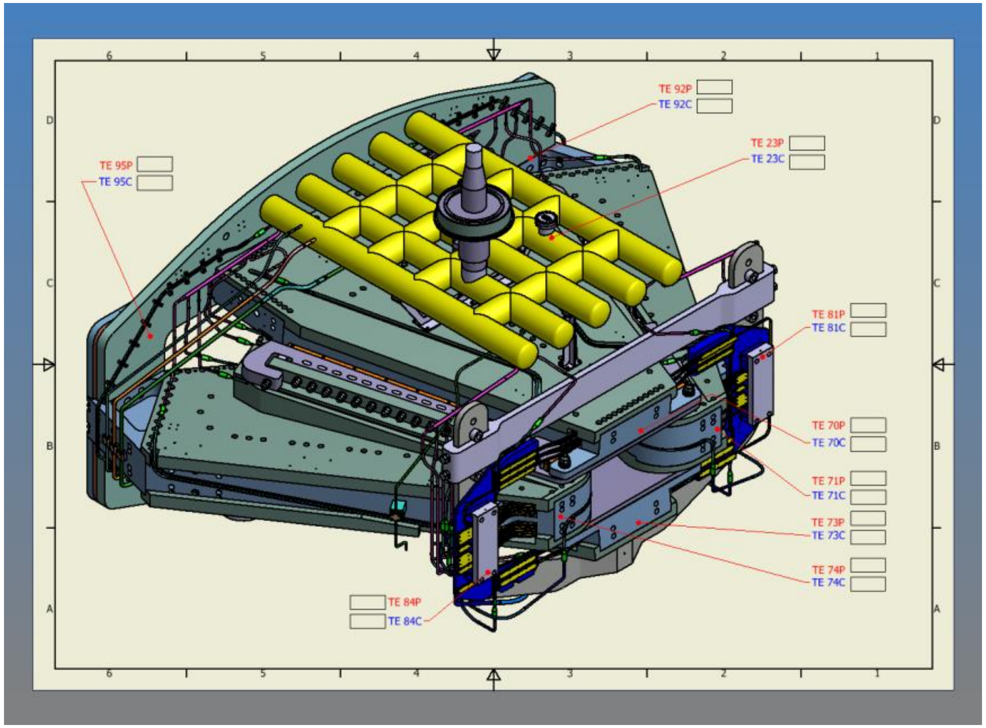
MOTIVATION

Helium natural circulation loops are used for **cooling large superconducting magnets**.

Within the R&D program for the R3B-GLAD spectrometer, horizontally heated loops started beeing studied at low power. Interesting dynamic behavior was observed.

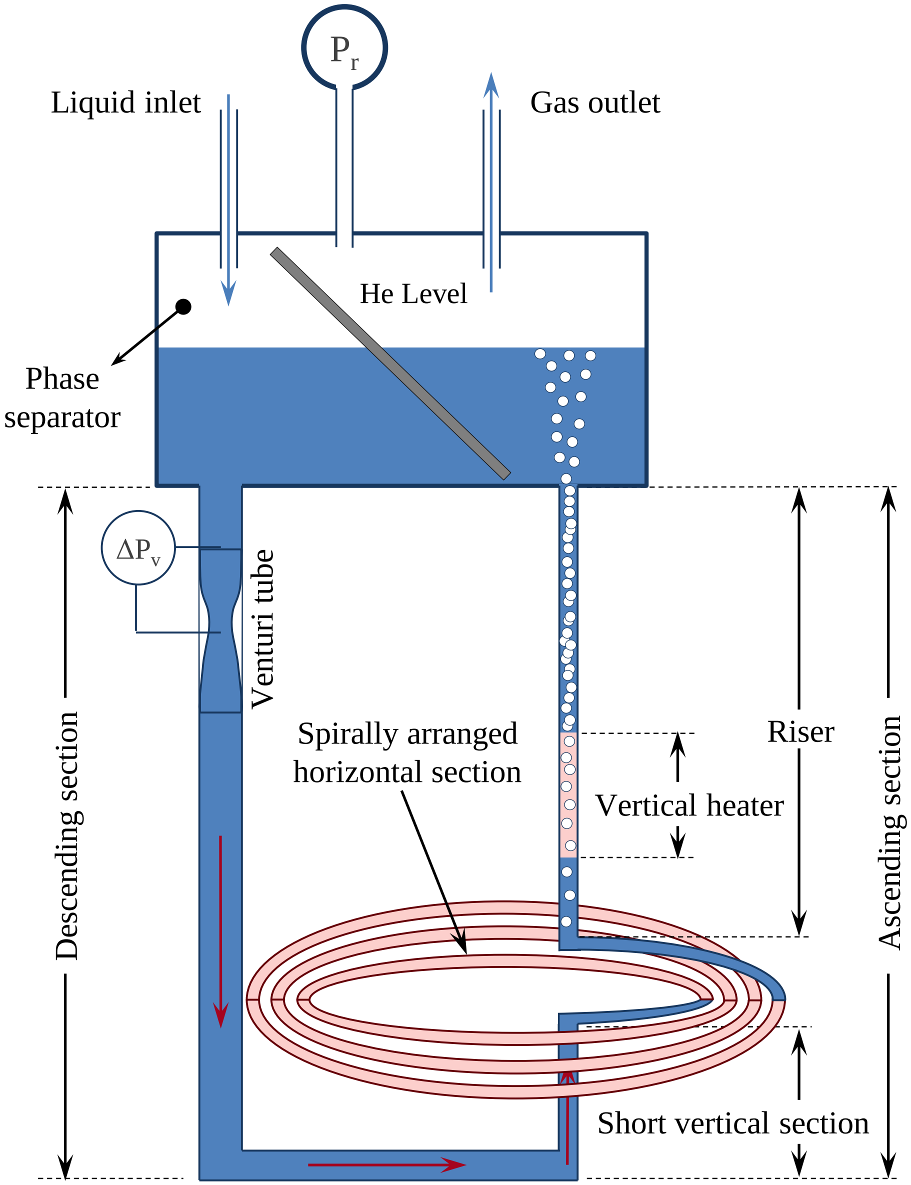


R3B-GLAD cooling system

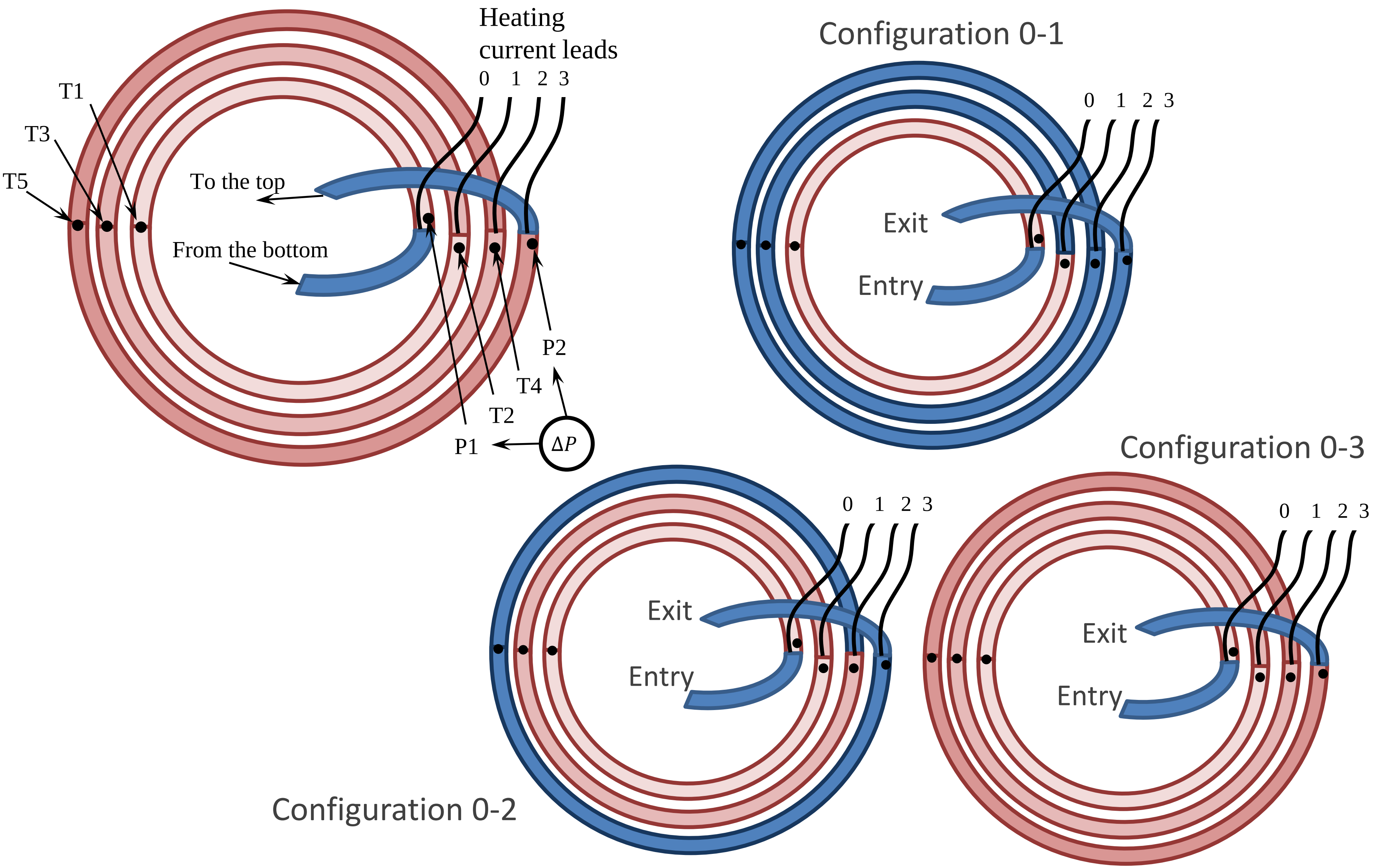
We now perform **experiments** on a big size helium natural circulation facility

- To **explore other existing thermalhydraulic regimes** during steady and transient power solicitation;
- To identify eventual **heat transfer deterioration** phenomena;
- To determine ways of **mitigating harmful effects**.

EXPERIMENTAL SET-UP

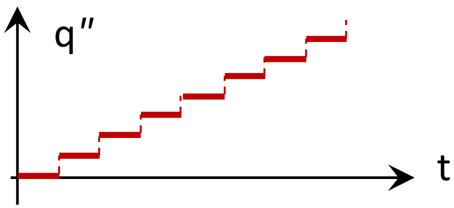


EXPERIMENTAL SET-UP



STEADY-STATE POWER SOLICITATION

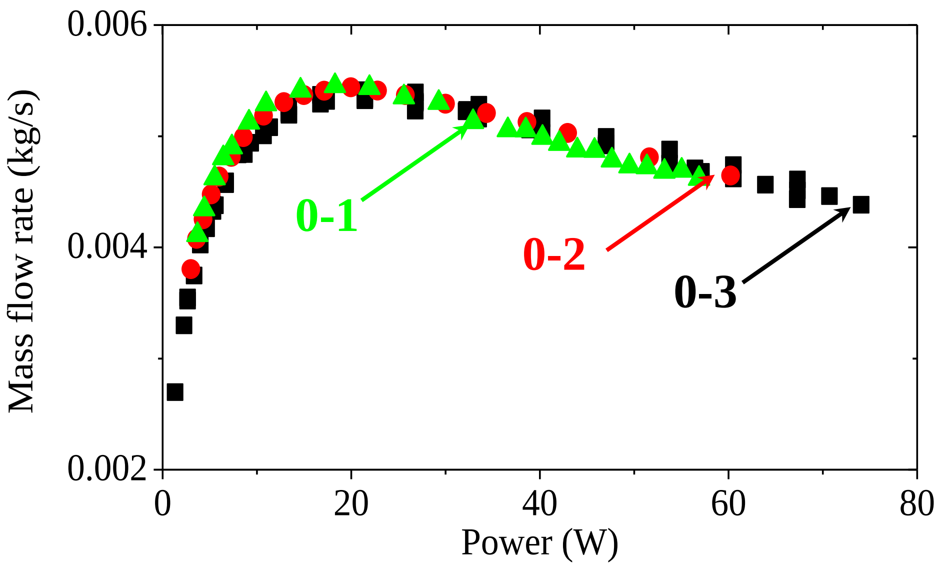
Power is increased gradually, at steps (quasi-steady evolution)

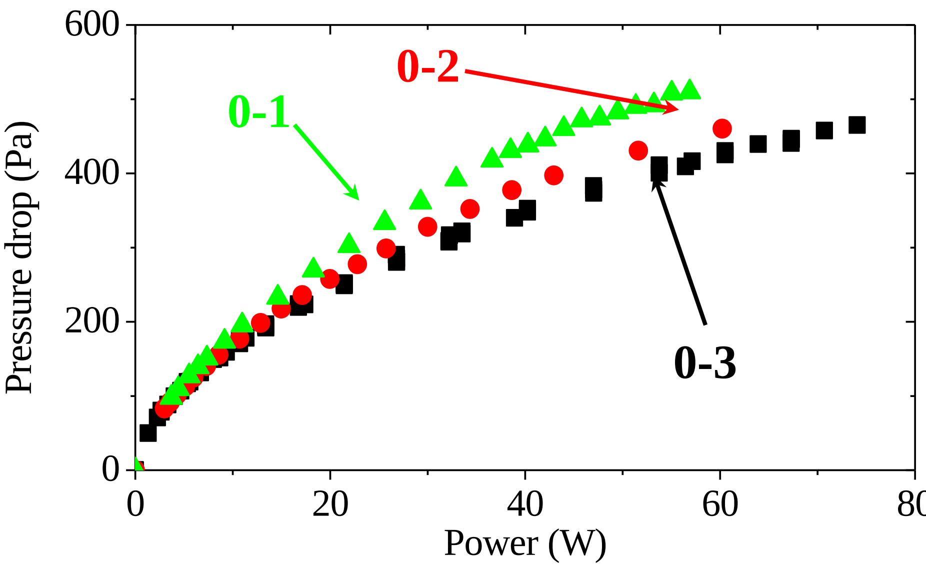


Stability limits

Configuration	NHHL (m)	Lower limit (W)	Upper limit (W)
0-3	0.360(10)	1.2(4)	78(3)
0-2	1.895(10)	2.8(4)	71(2)
0-1	3.315(10)	3.7(2)	60(1)

Stable behavior is only observed between lower and upper stability limits. The stability limits are affected by the heating geometry.



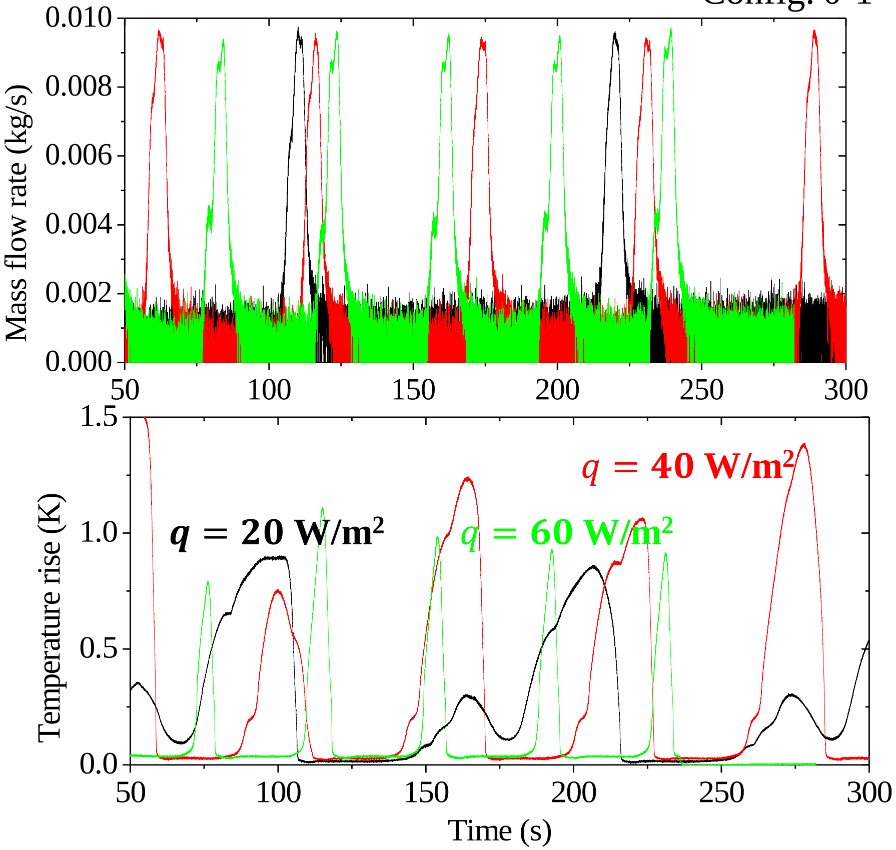


STEADY-STATE POWER SOLICITATION

The unstable behavior at low power

- Exit quality strongly influential on density.
- Low mass flow rate → long transit time.
- Important transport lag on riser density.

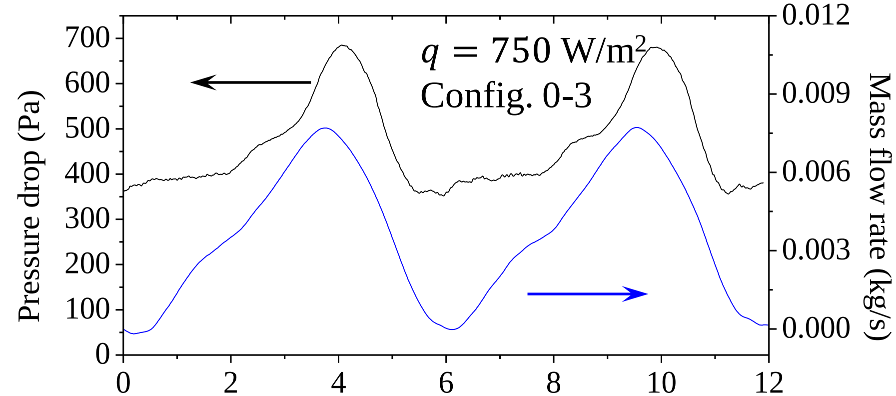
Config. 0-1

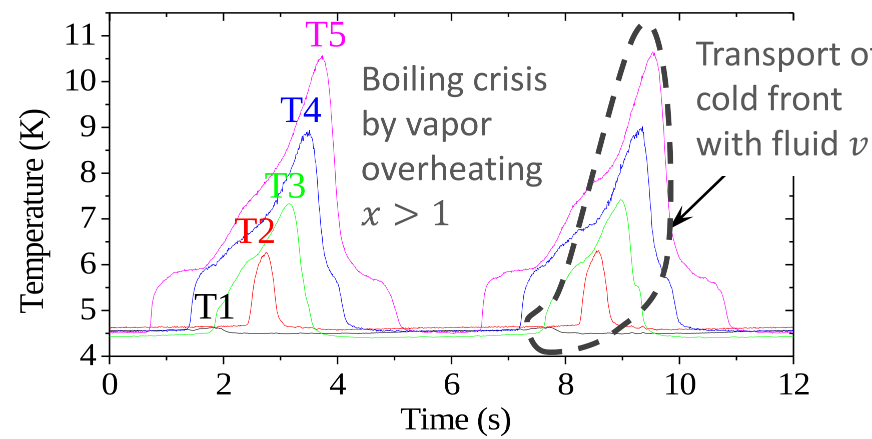


The unstable behavior at high power

- Equilibrium $\dot{m}$ diminishes with q.
- *Friction* } → immediate response
- *Acceleration* }
- *Gravity (density)* → transport lag

Config. 0-3





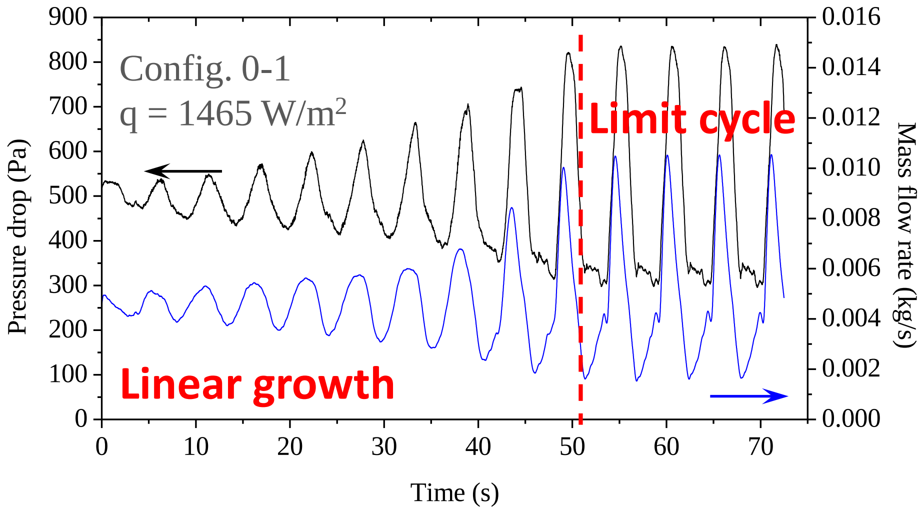
STEADY-STATE POWER SOLICITATION

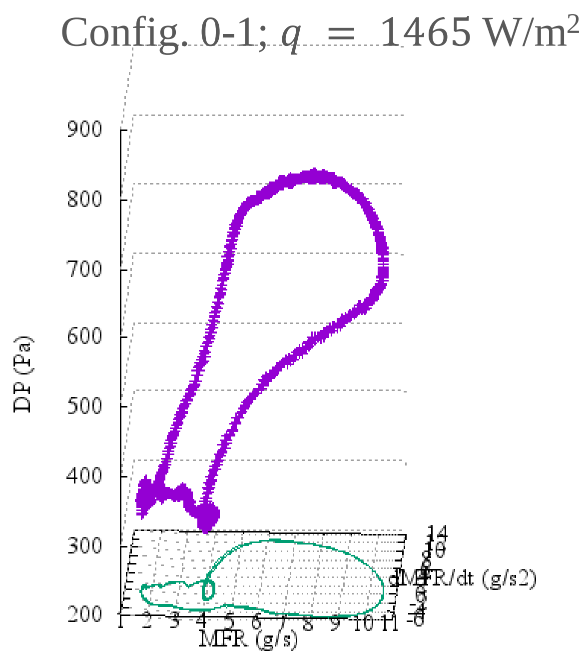
During the high power instability

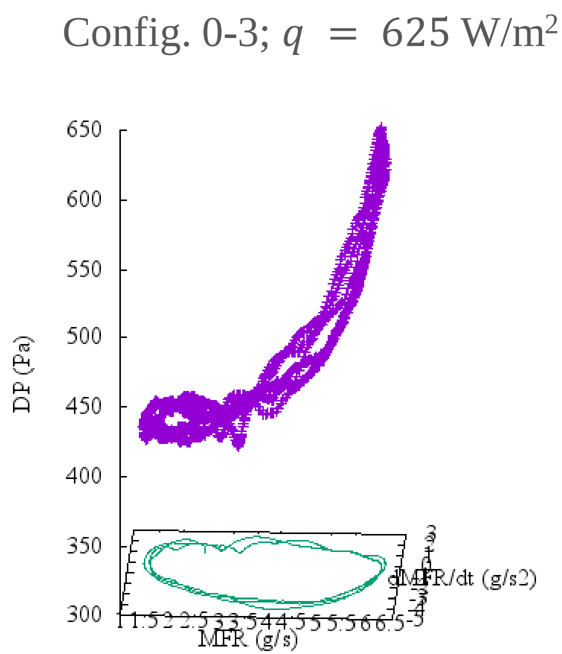
- initially linear (exp-sin)
- saturates to a periodic oscillation

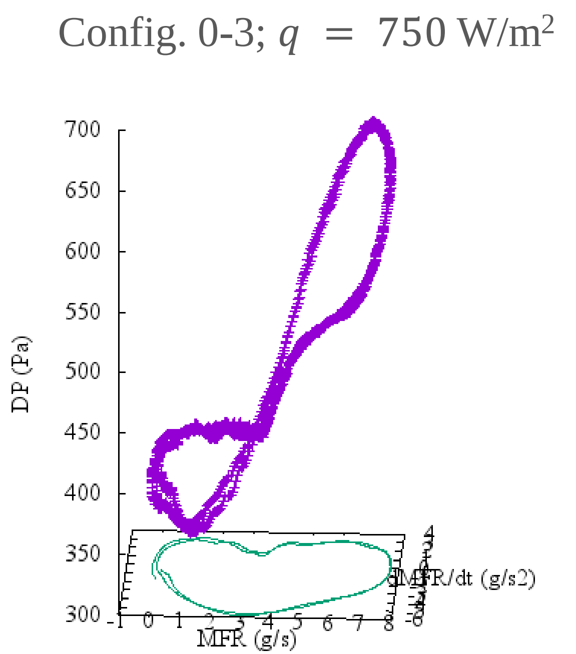
The attractor is a **Limit Cycle**.

No quasi-periodicity, no chaos.









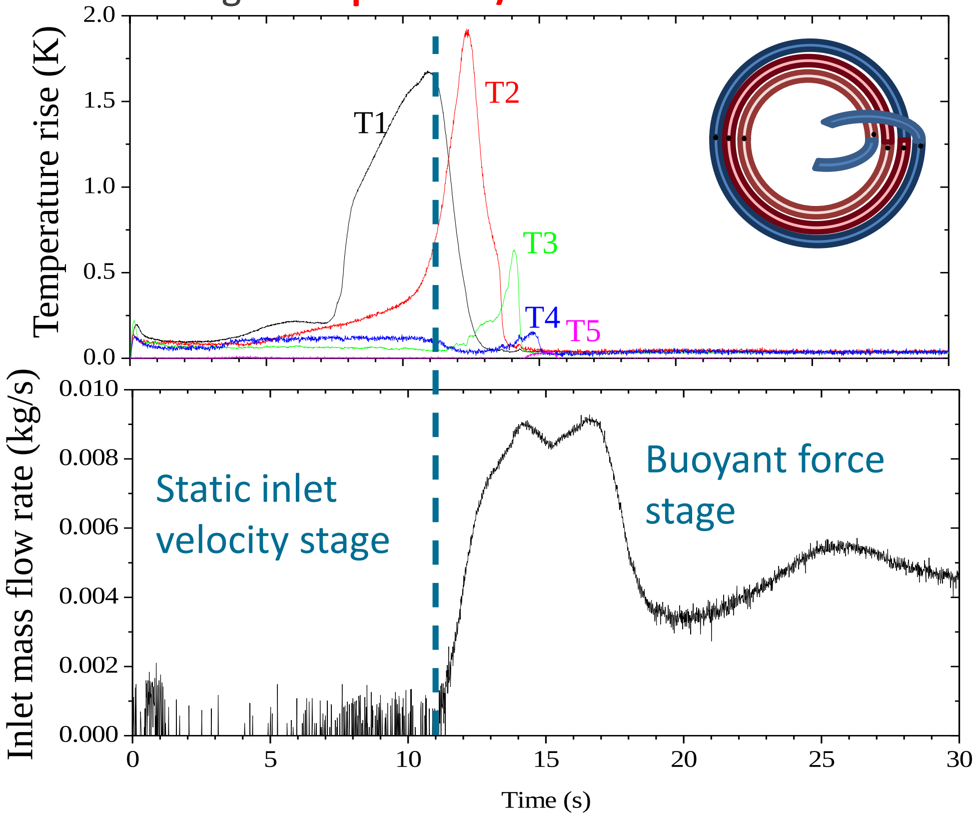
STEP-PULSED POWER SOLICITATION

The system response to step heat load pulses was measured. In general, **2 stages** are observed:

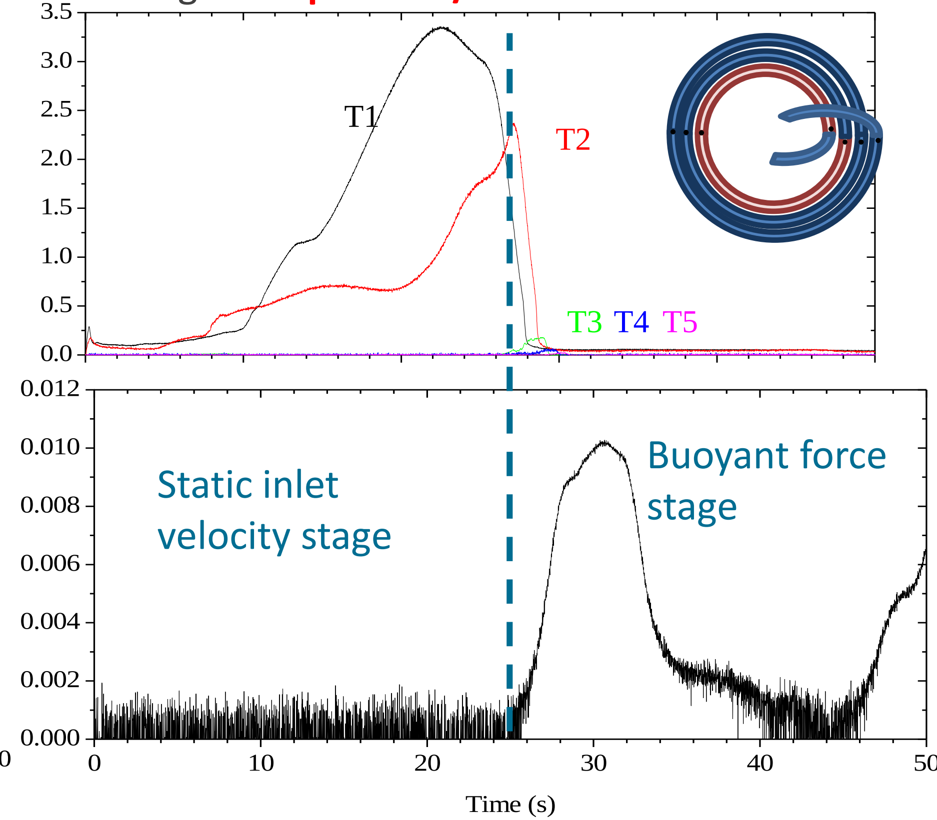
- **Static inlet velocity stage:** no buoyant force, two-phase expansion in the horizontal section, stratification.
- **Buoyant force stage:** vapor reaches the riser, positive inlet velocity, homogenization of flow.

At **low power** (boiling crisis is not expected at all) **high temperature** excursions can happen.

Config. 0-2. **q=100 W/m²**



Config. 0-1. **q=100 W/m²**



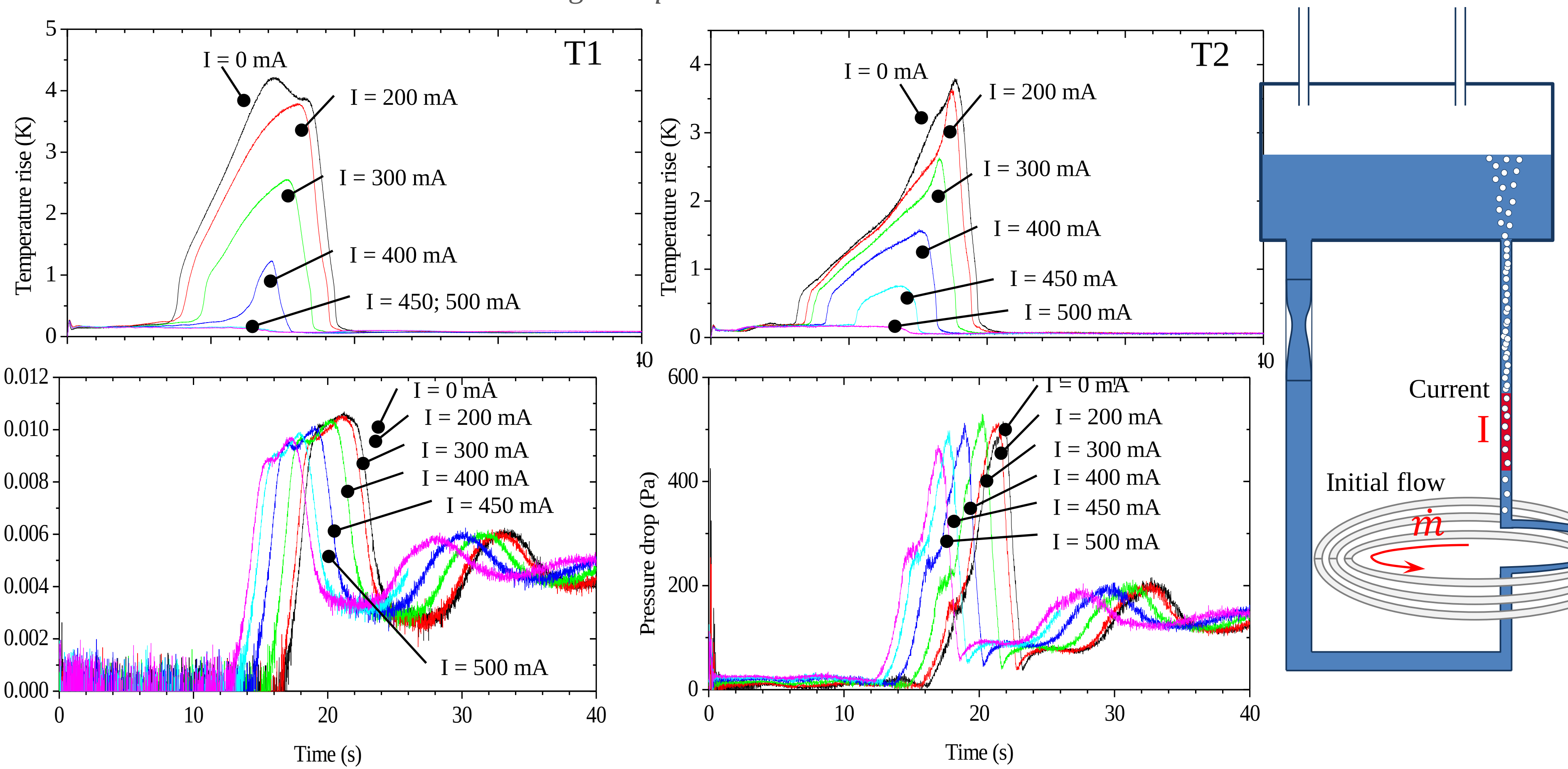
STEP-PULSED POWER SOLICITATION

Applying of **power on the riser**.

Low power-high temperature **excursions are very sensitive to small mass flow rates** imposed externally.

$v_i \neq 0$ → delays heat transfer deterioration
→ advances the initiation of the buoyant force
} → Mitigation of the excursion

Config. 0-1 $q = 150$ W/m^2



CONCLUSION

Steady heat load

- **Horizontally heated helium natural circulation loops can be unstable** at sufficently low or high driving power.
- The **stability power range** decrease as the **NHHL** downstream the heated section increases (transport lag destabilizes).
- The **unstable dynamics is attracted by limit cycles**.

Step-pulsed heat load

- **Transients** after a step-pulsed heat load **have two stages**:
  - static inlet MFR stage
  - buoyant stage
- **High temperature excursions** (a few K) **at very low heat flux** (even <100 W/m^2) can take place during the first stage if initially the system is at rest, especially for long NHHL.
- **Initially established flow and short NHHL can inhibit** this transient feature, which gives us hints of how to protect devices from this undesired effect.

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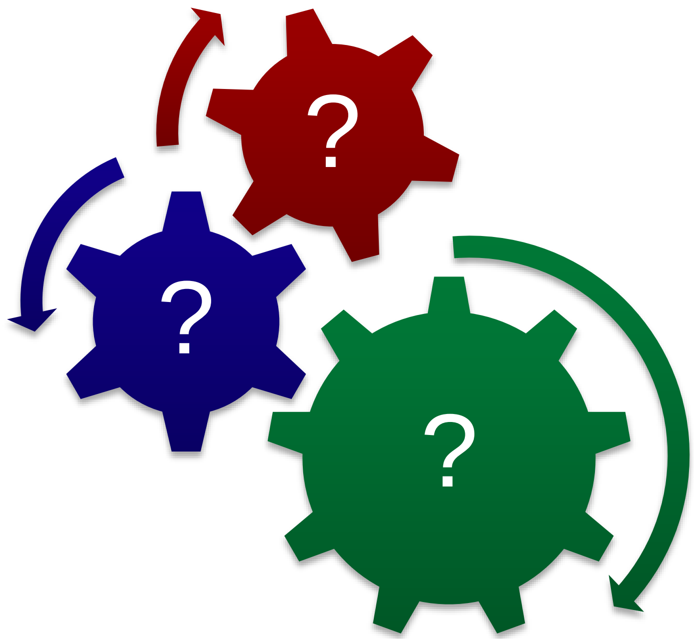
Thank you for your attention!



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