PAUL SCHERRER INSTITUT

PSI

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Experience with high power RF sources and RF conditioning

8th Hard X-ray FEL Collaboration Meeting
24 - 26 October 2016, Pohang, Korea

Outline

- Types of RF systems in SwissFEL
  - S-band
  - C-band
  - X-band

- Some first experiences

- Discussion topics:
  1. Humidity of transformer oil
  2. ’Strange’ pulses from klystrons
  3. Experience with evacuation of transformer tank
  4. …

Types of RF systems in SwissFEL

	S-band	C-band	X-band
LLRF	Fully digital LLRF systems (presented at 2014 meeting)		
Drive amplifiers	Solid-state: Microwave Amplifiers	Solid-state: Advantech	Currently TWT amplifier, plan to upgrade to solid-state eventually
Klystrons	Thales TH2100L	Toshiba E37212	SLAC XL5
Modulators	*Solid-state* ScandiNova K2 from test facility	*Solid-state* *Linacs 1&2:* Ampegon Type-μ *Linac 3:* ScandiNova M1071	*Solid-state* ScandiNova K2 from test facility
Waveguides	SF_6 Mixture: MEGA, PSI, …	*Vacuum* MHI-MS Loads: CML	*Vacuum* CERN, PSI, Nihon Koshuha
Structures	PSI RF gun 1-2 x RI 4m S-band	PSI BOC + 4 x PSI C-band	CERN-PSI-Elettra X-band (2x)
	bake-out	no bake-out	bake-out

C-band drive amplifiers

S-band

- Re-use of Microwave Amps. amplifiers from injector test facility
- Initial stability: ~ 150 ppm
- Modified by PSI (group of C. Gough) in order to reach ~50 ppm

C-band

- Advantech won the tender
- Collaboration with PSI in order to achieve stability requirements
- Stability results of prototype: < 50 ppm, < 1 fs add. timing jitter

Sophisticated measurement system developed by C. Gough group to characterize amplifiers with ~10 ppm precision.

Solid-state modulators for C-band linac

Two prototypes were tested at PSI for evaluation of the series.

50 MW / 3µs RF, 370kV / 344A / <20 ppm voltage stability pulse to pulse @ 100 Hz

AMPEGON

Type-µ modulator prot. for PSI C-band

- 13 modulators (Linac 1, Linac 2)
- Installation planned from Nov. 2016 – June 2017

ScandiNova

K2-3 proto. for PSI C-band

- 13 modulators (Linac 3)
- Installation planned from March 2016 – Sep. 2017

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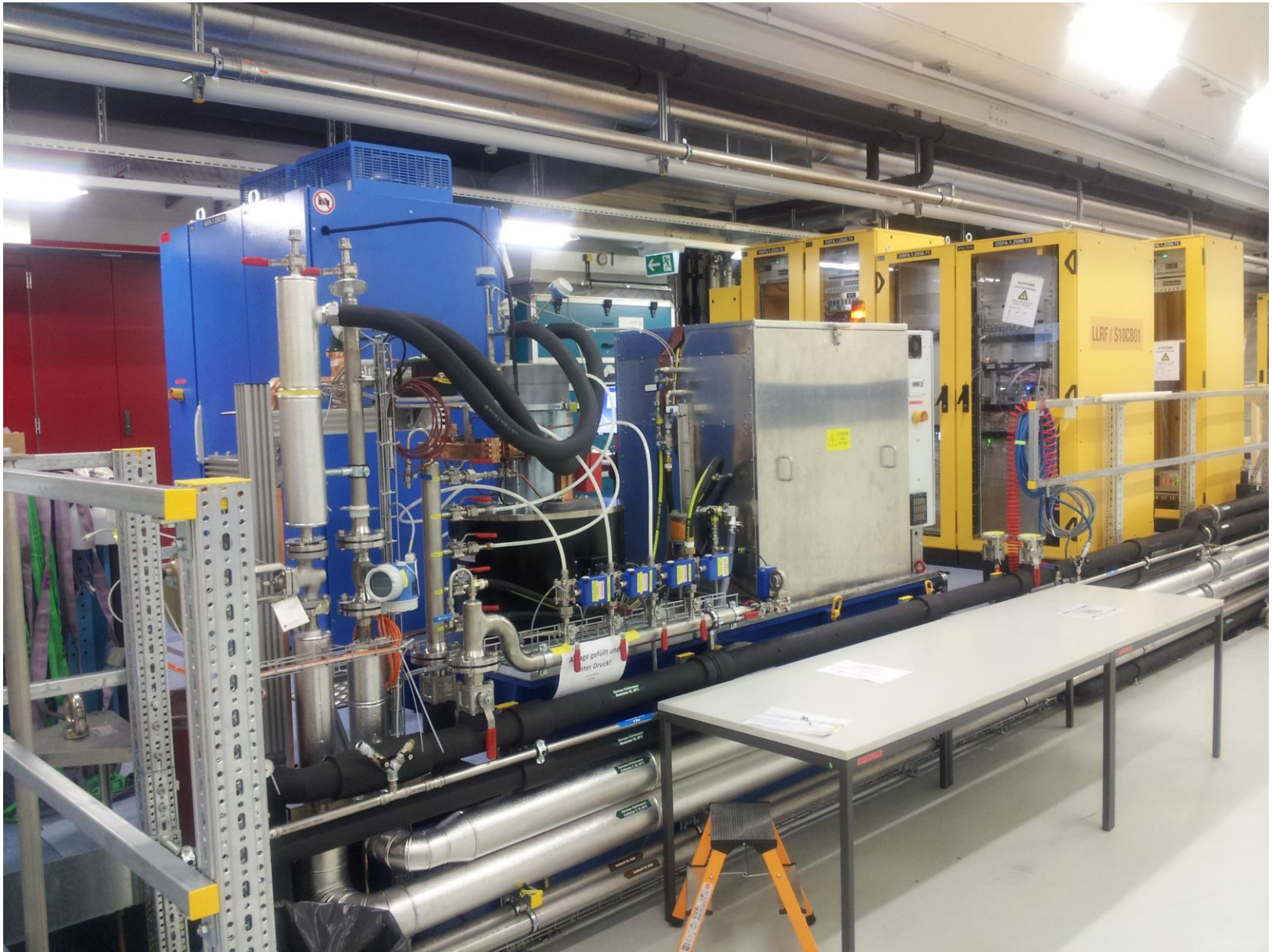
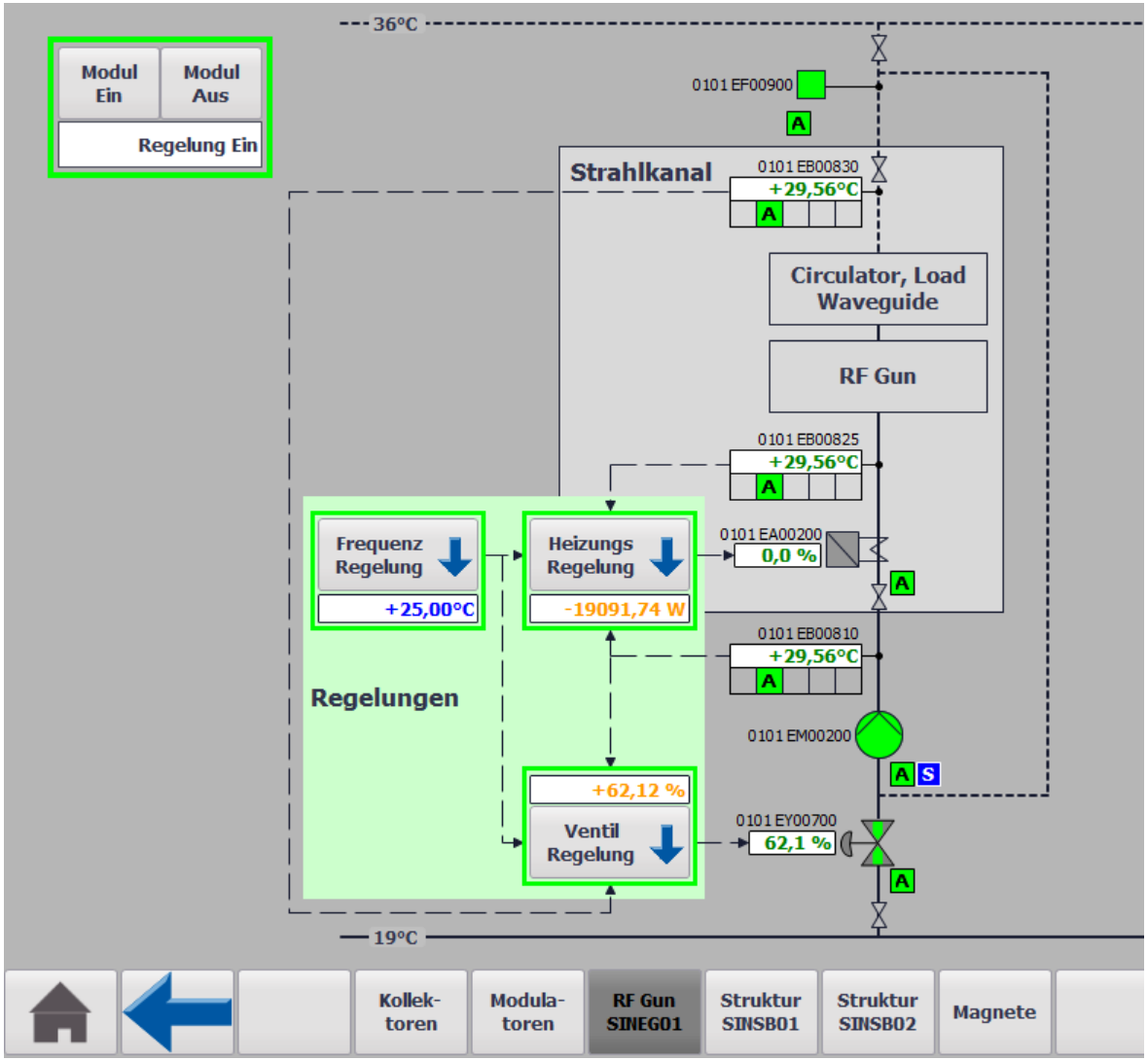
Power source of first C-band station (Ampegon prototype modulator)

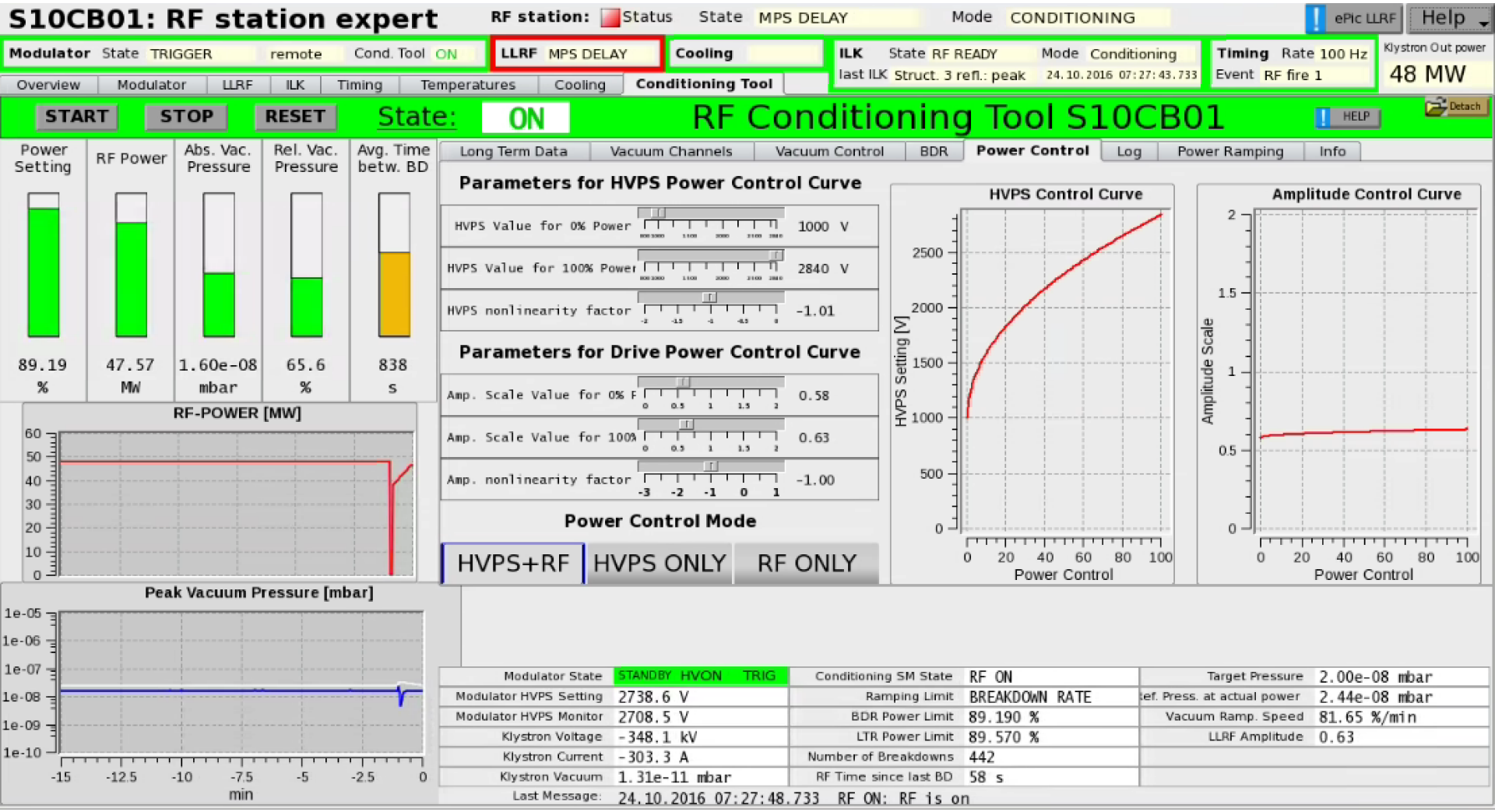


Precision temperature control



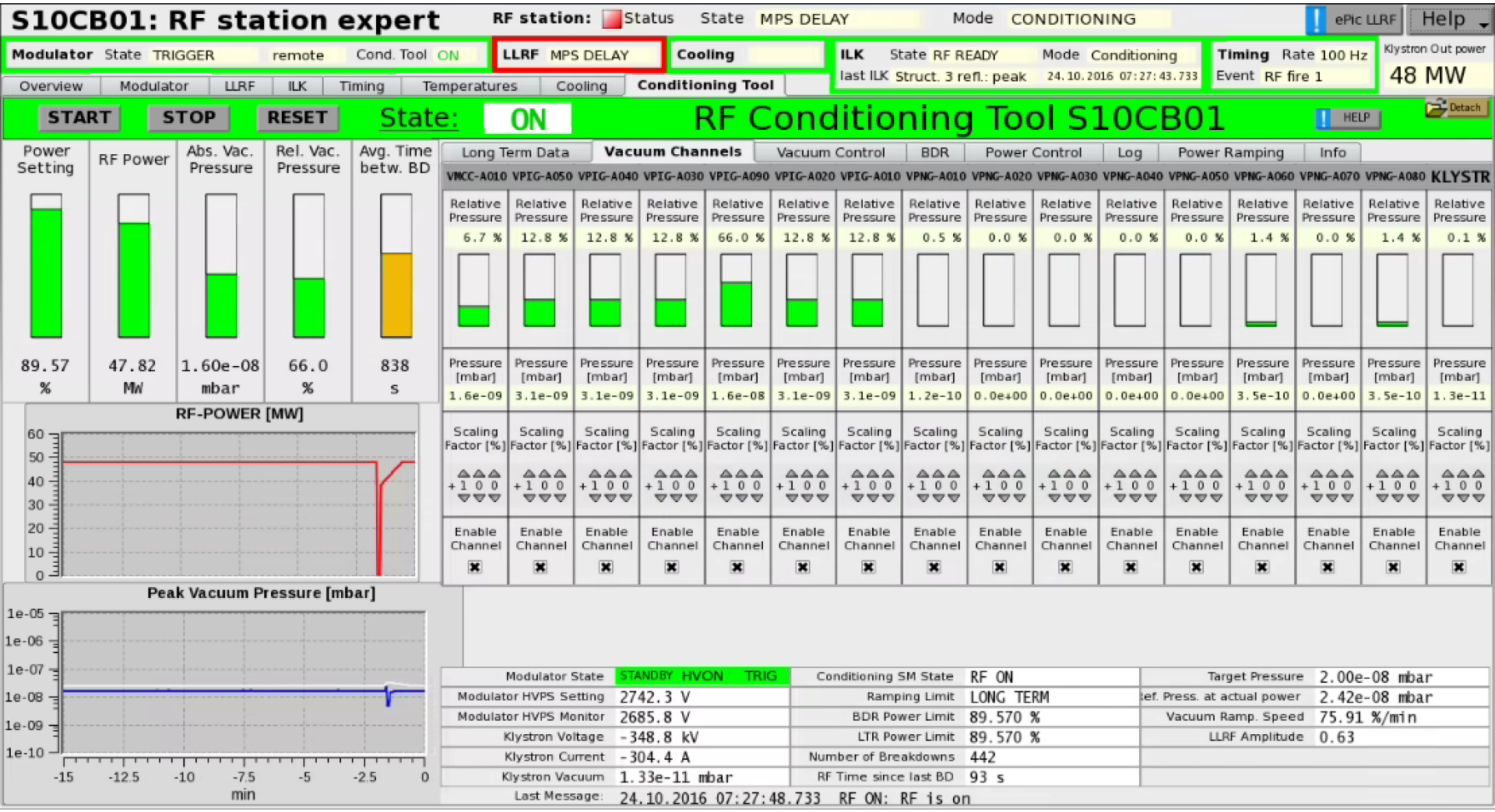
Few mK stability by combination of 3 coupled feedback-loops, including an RF-based measurement

RF conditioning automation



J. Alex

RF conditioning automation



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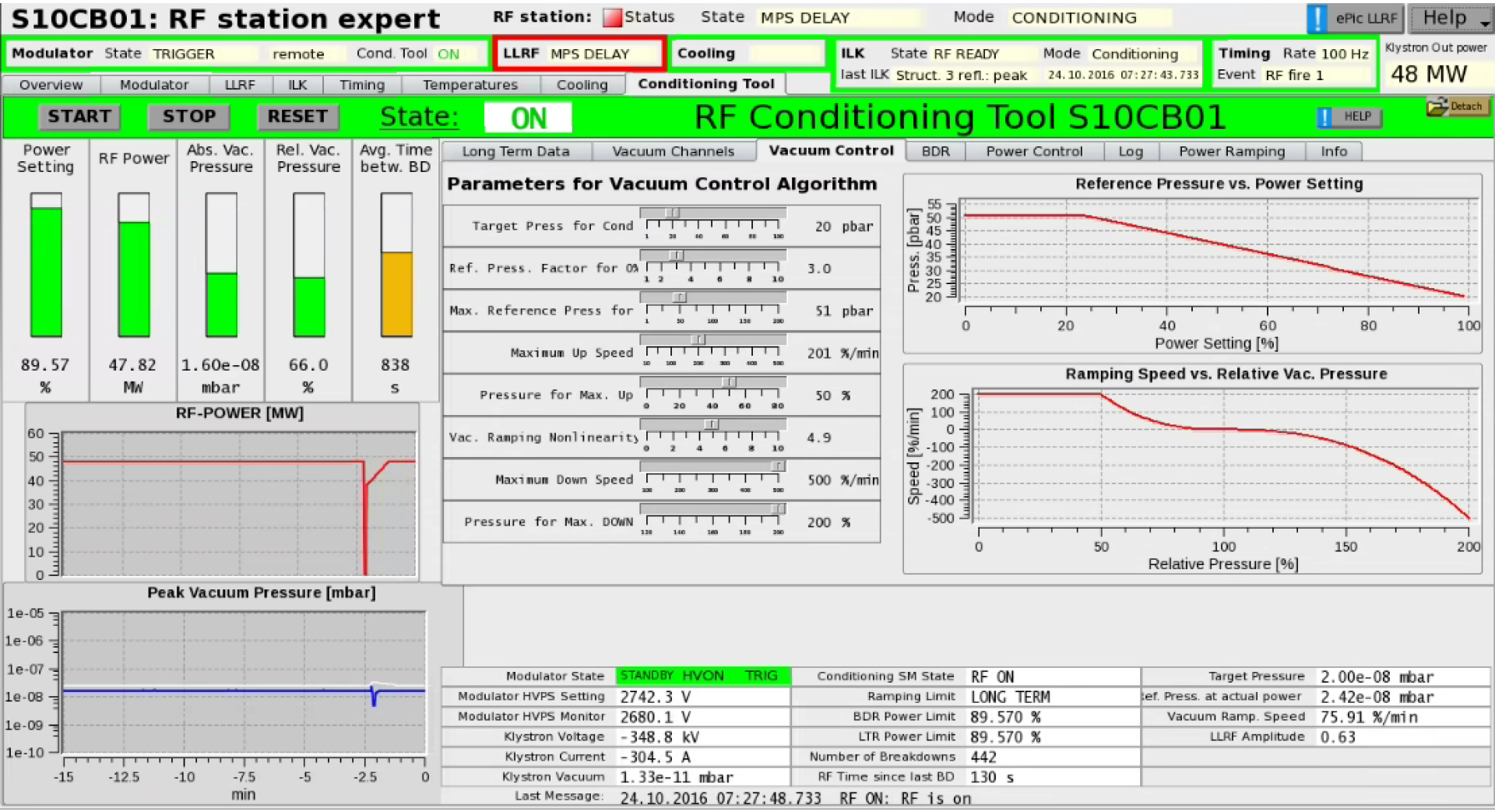

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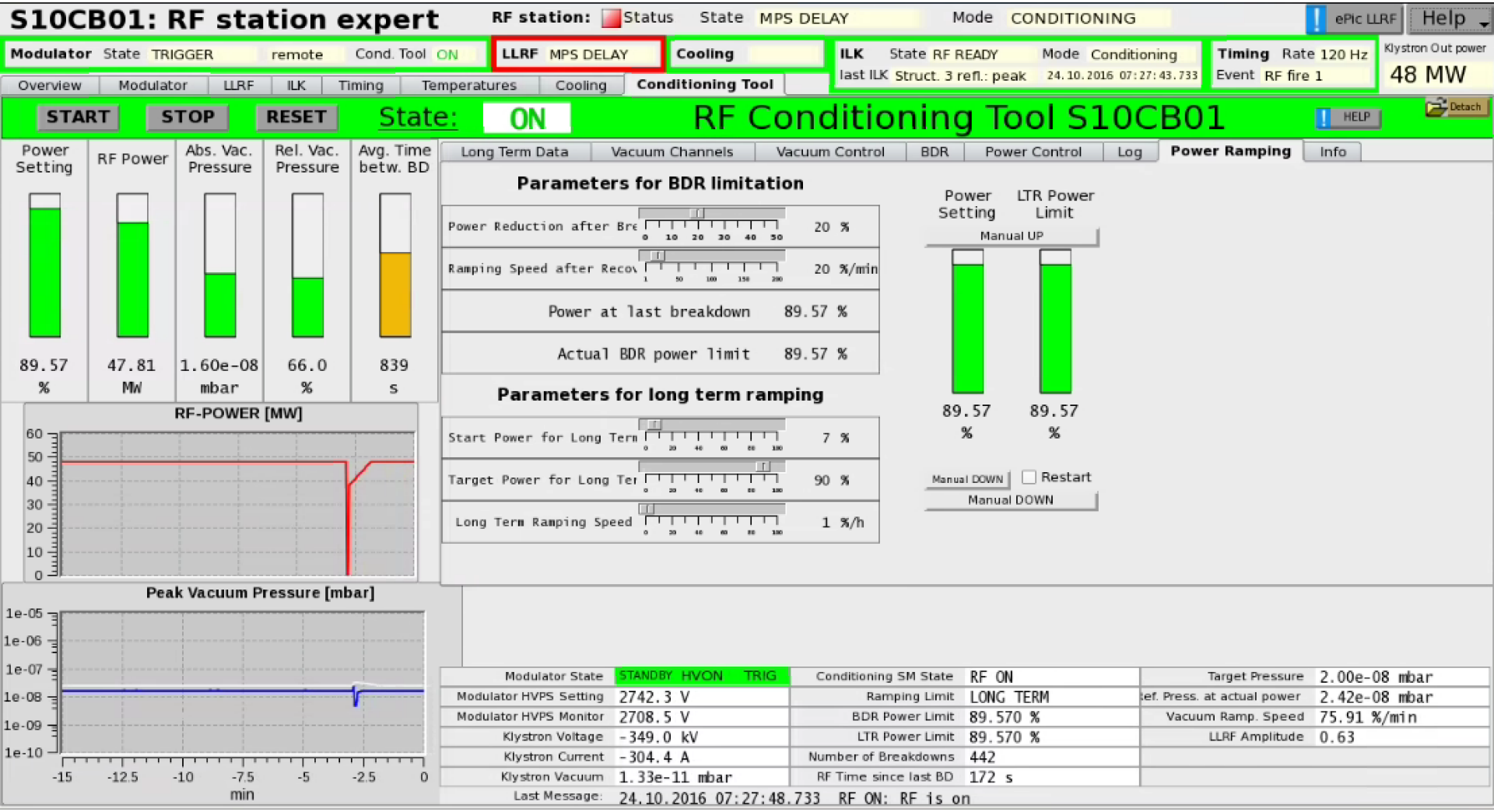
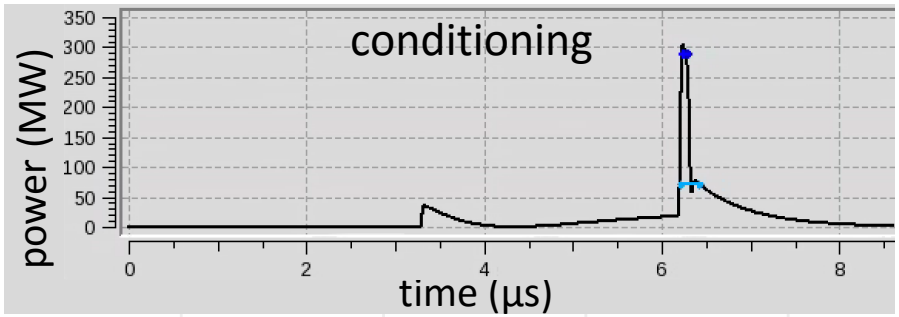
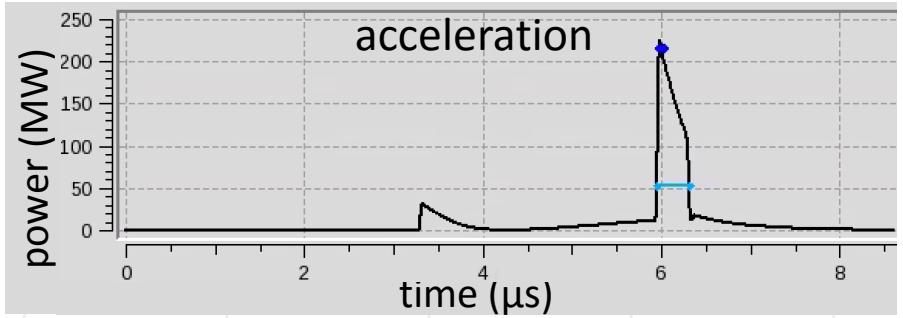
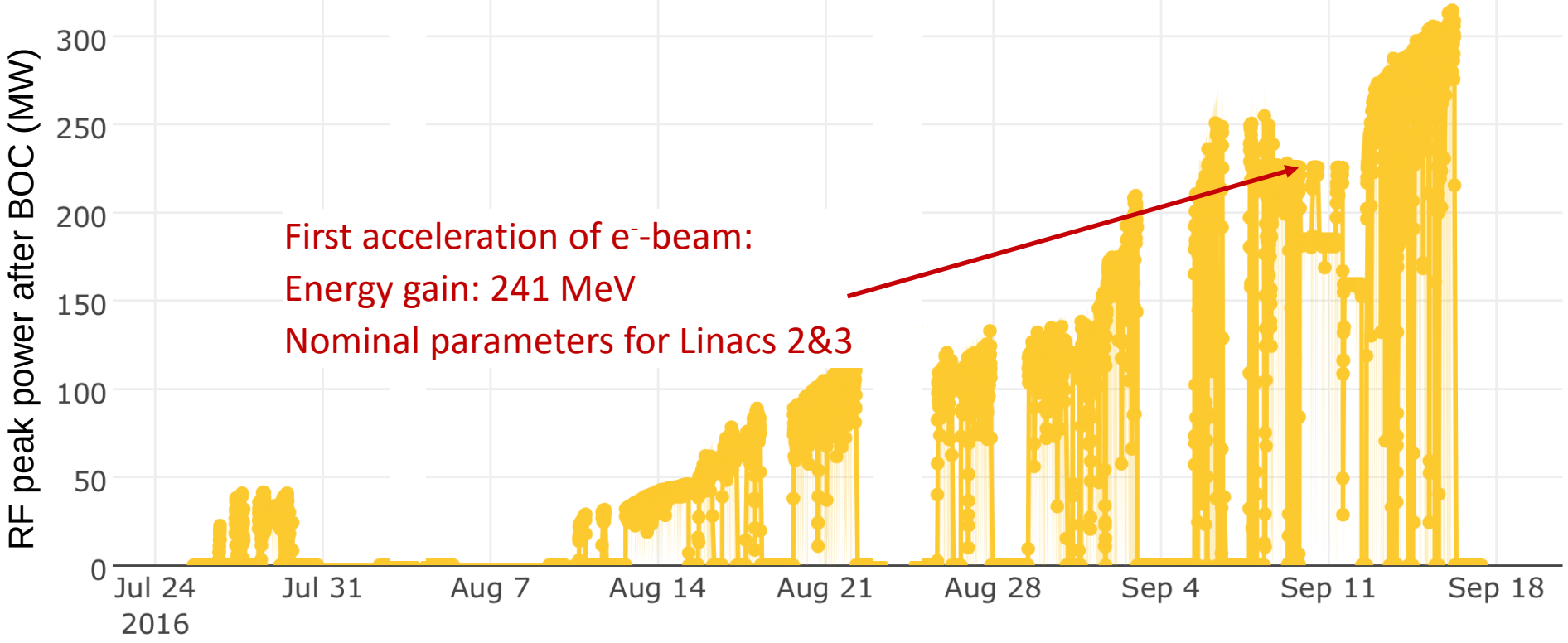


J. Alex

Conditioning of first C-band module







Module conditioning: Reached almost maximum available RF power (50 MW, 3 µs, full compression)

Break-down statistics during conditioning: First C-band module

Discussion topics

S-band klystrons (Thales TH2100L):

Long-term experience only from test facility (SITF)

Many gun arcs in 10 Hz operation at SITF, little experience at 100 Hz

Two klystrons with high body losses, 100 Hz operation critical with these klystrons

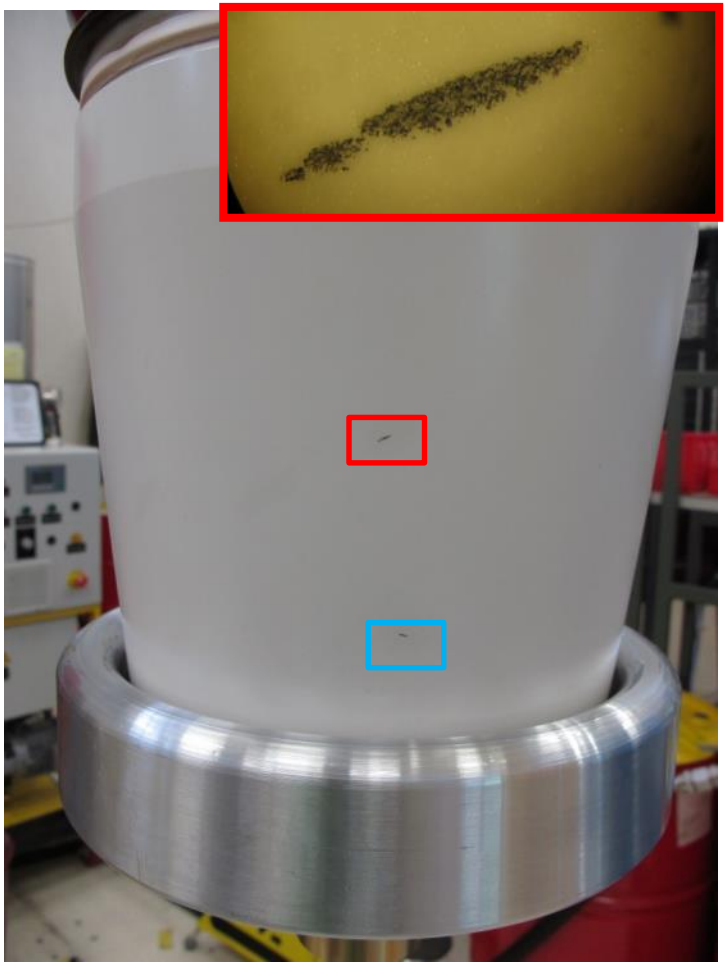
Poor lifetime record in SITF -> potential risk for operation of SwissFEL

Discussion topics

C-band klystrons (Toshiba E37212):

Overall very good experience, but…

- Lost one tube in test stand
  - Crater on gun ceramics
- Exact cause unclear, candidates are:
  - Air bubbles in oil
  - Oil humidity too high?
  - ‘Strange pulses’

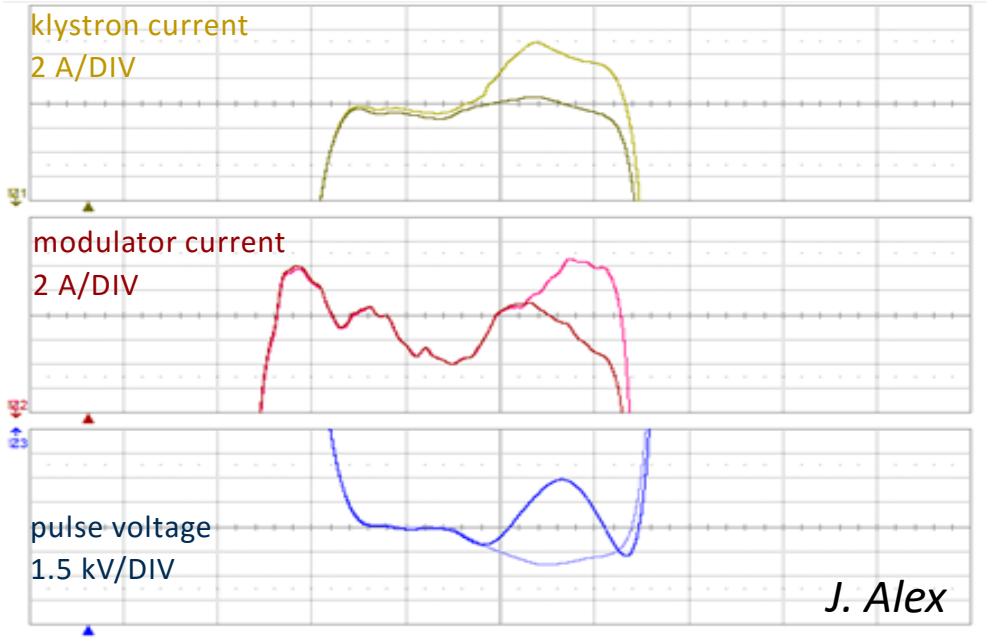


Discussion topics

C-band klystrons (Toshiba E37212): ‘Strange pulses’

From time to time (rate can vary a lot), we observe ‘strange pulses’

- During the pulse the klystron current increases up to 1%

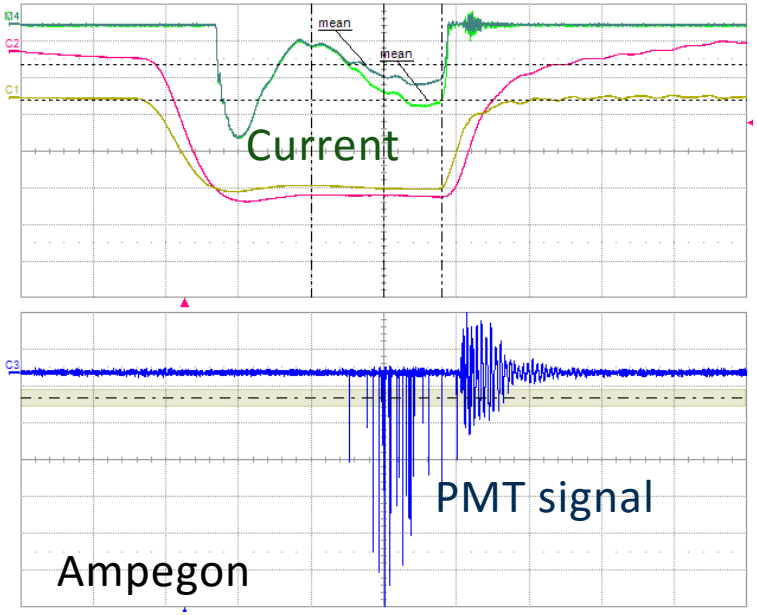


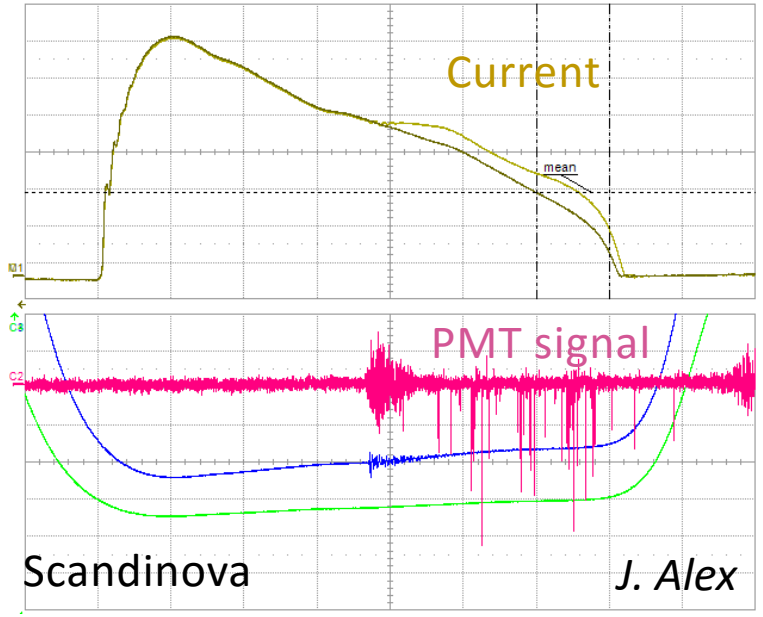
‚Strange‘ pulse waveform
(zoom into flat-top)

Discussion topics

C-band klystrons (Toshiba E37212): ‘Strange pulses’

- We see these pulses with both modulator types
- We see light with a photo-multiplier tube when these pulses appear
- Unclear, if strange pulses are dangerous to the klystron
- We experienced very high rate (1/4000) of strange pulses prior to klystron failure

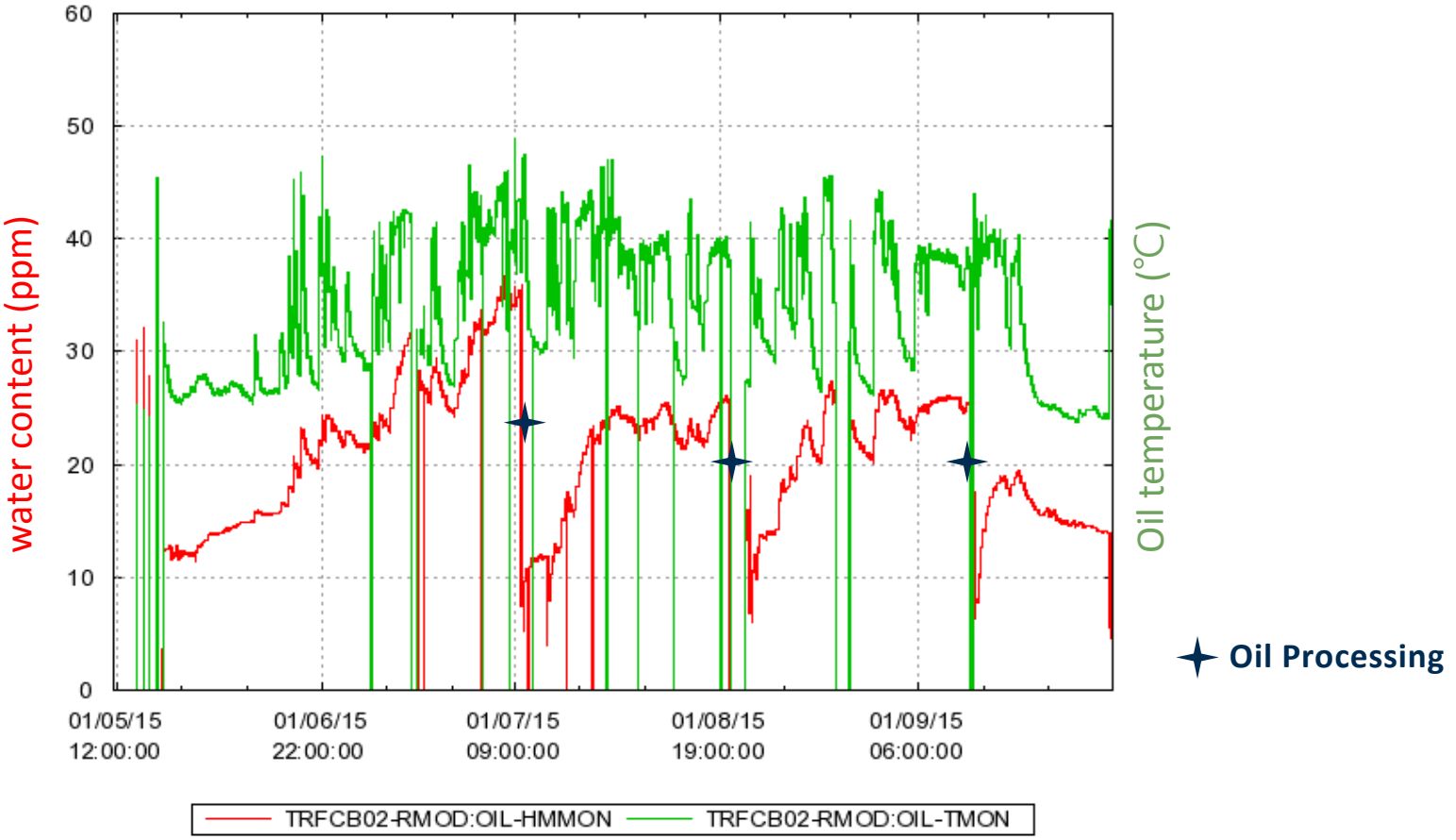




Discussion topics

Humidity of transformer oil in modulators

- In one of the modulator types, we saw a quick increase of the oil humidity during operation
- Rate of increase correlates with oil temperature



Discussion topics

Humidity of transformer oil in modulators

- In one of the modulator types, we saw a quick increase of the oil humidity during operation
- Rate of increase correlates with oil temperature
- Around 2-3 g of water are added into the system per day during operation

PSI evaluated possible sources. Water seems to come out of isolation paper and other plastic material in the transformer.

→ Around 500 g of water can be stored in the transformer when assembled at 50% relative humidity

→ Tested: oil could be dried using a N_2 flow over the oil surface

→ Tested: oil could be dried using a room air flow over the oil surface

Chemical equilibrium between humidity in air cover layer, oil, and plastic material in transformer

→ Need a way to dry the transformers / oil during operation

Discussion topics

Actions by PSI

- Oil tanks of C-band modulators (both from Ampegon and ScandiNova) allow for an evacuation
  - → Air bubbles in the oil can be removed
  - → Can help drying the transformers?
- Oil drying system is added to modulator(s)
  - → Allows operation when transformer is not yet dry

Experience at your facilities?