PAUL SCHERRER INSTITUT PSI

Automation of RF Cavity Conditioning

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Abstract

To facilitate and speedup the conditioning process of RF systems consisting of high-voltage modulators, klystrons, waveguides or RF structures or cavities, a set of automation tools was created and is currently in operation at SwissFEL. The two main components are the state sequence controller for the various subsystems of the RF plant and the cond-itioning algorithm controller. Additional logic is required which allows deciding whether a safe automatic restart after breakdowns or errors is possible.
The tools and algorithms implemented in different strategies are presented and the experiences from the already conditioned RF stations is shown.

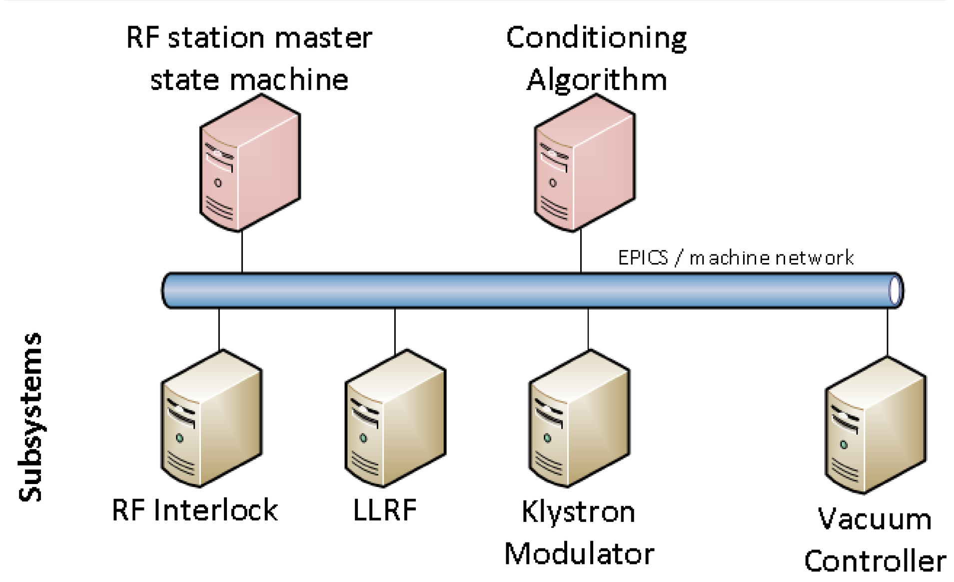


Figure 1: Subsystem setup, control system perspective

Framework Overview

The current framework used for the automation of the conditioning evolved during the last years: It started from stand alone client applications in Tcl/Tk running on a control room console, going to SoftIOC servers and from single to multiple RF stations which are similar but not equal. This path was driven by better maintainability for handling the different RF stations and for making upgrades in the conditioning algorithm independent of the other infrastructure-type subsystems.

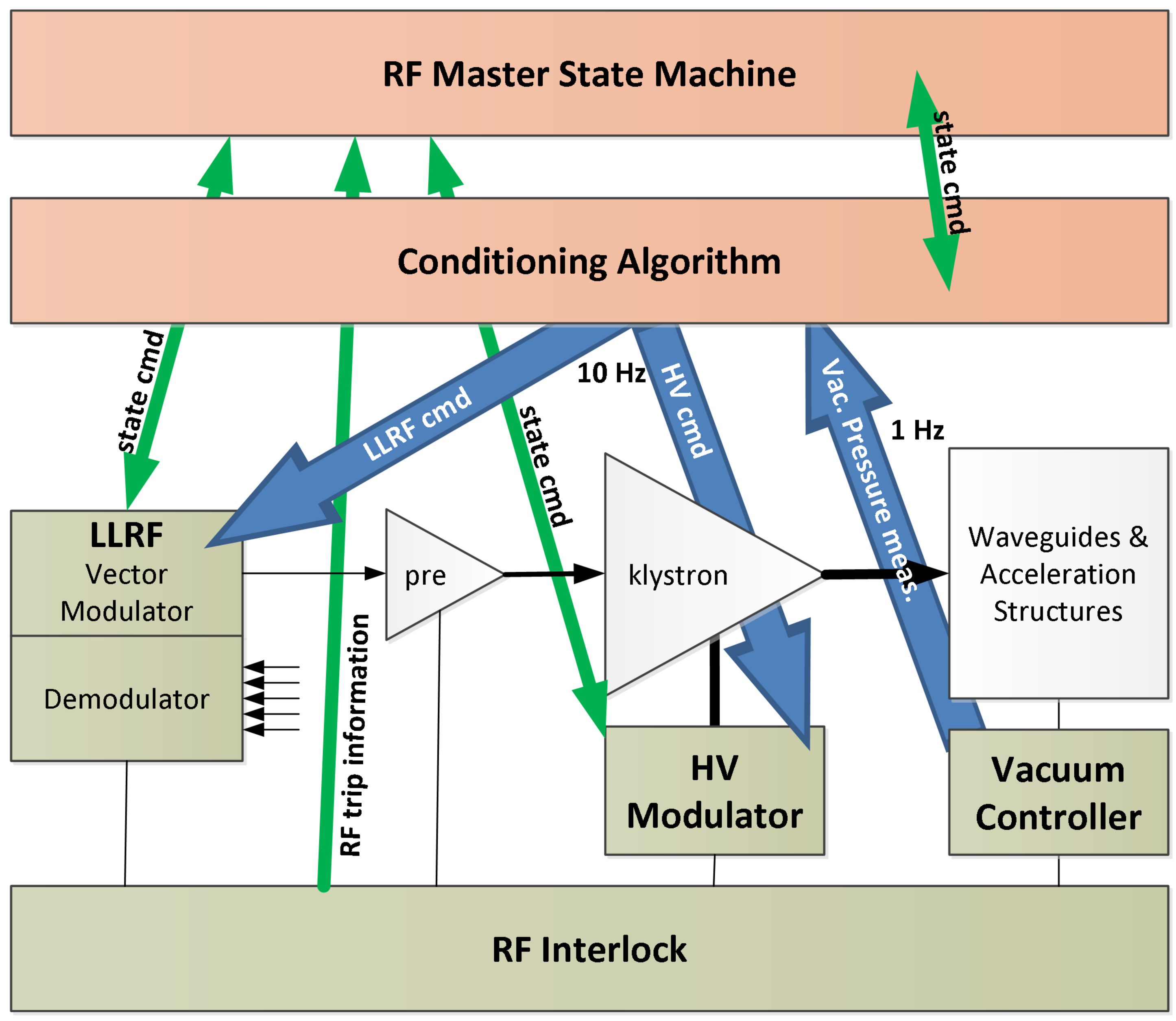


Figure 2: Single RF station subsystem setup, hierarchy and interactions

Limitation for Rate of Breakdowns

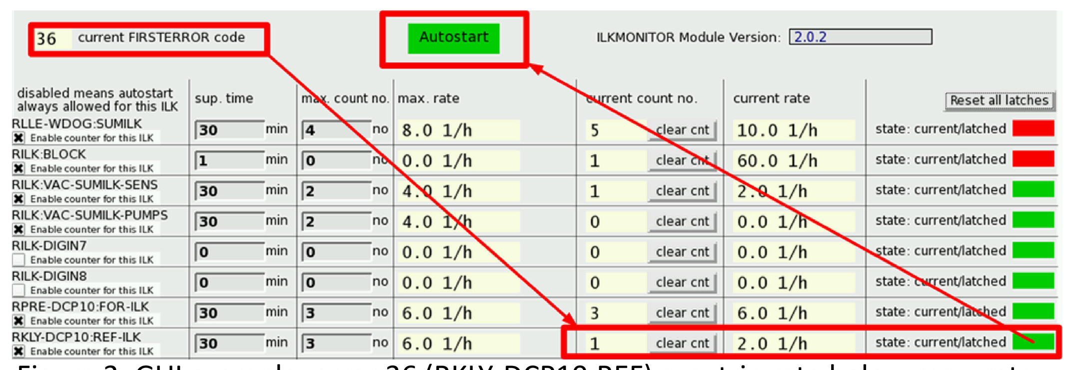


Figure 3: GUI example, error 36 (RKLY-DCP10:REF) avg. trip rate below max. rate

The typical **RF-operation-stop** faults detected by the RF interlock system which fall into the category which allow automatic restart of the system are **vacuum peaks**, **RF detector reflected peaks** or **arc detections**.

A control system module which is running directly on the RF interlock IOC detects and remembers the detected firsterror codes. Then based on the allowed maximum threshold for the **average error rate** a sum flag for "Autostart" is generated. In the example screenshot (Fig. 3) it is shown that only the most recent fault is used to generate the sum flag for next automatic restart decision.
This allows operators to override the system by manual restart.

Conditioning Algorithm

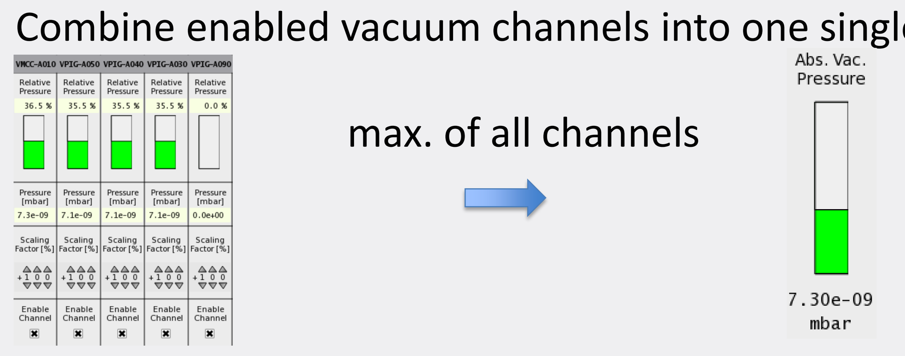
Vacuum based Power Ramping Controller

Configuration:

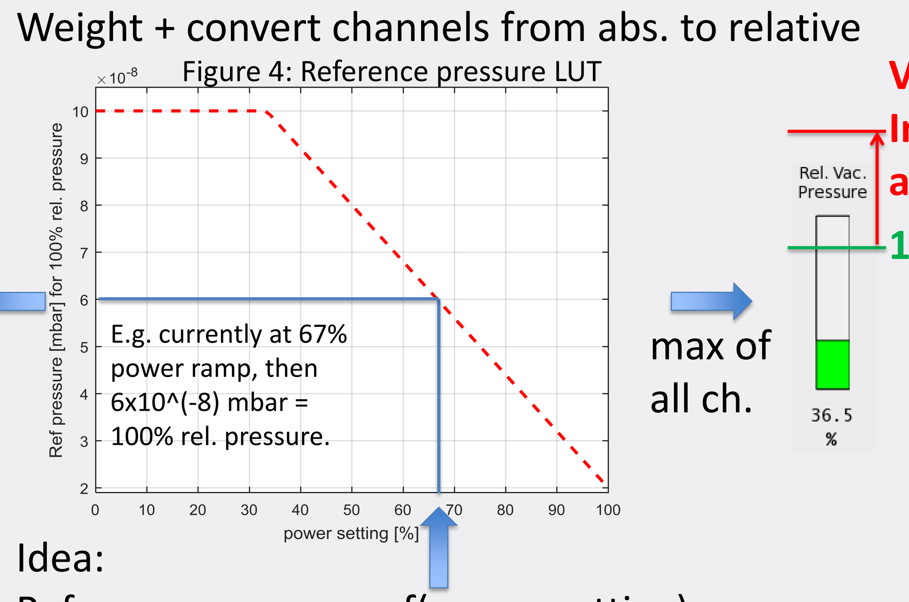
1. Enable + weight the available vacuum channel
2. Define parameters for reference pressure + ramping law

Control law update steps:

1. Combine enabled vacuum channels into one single

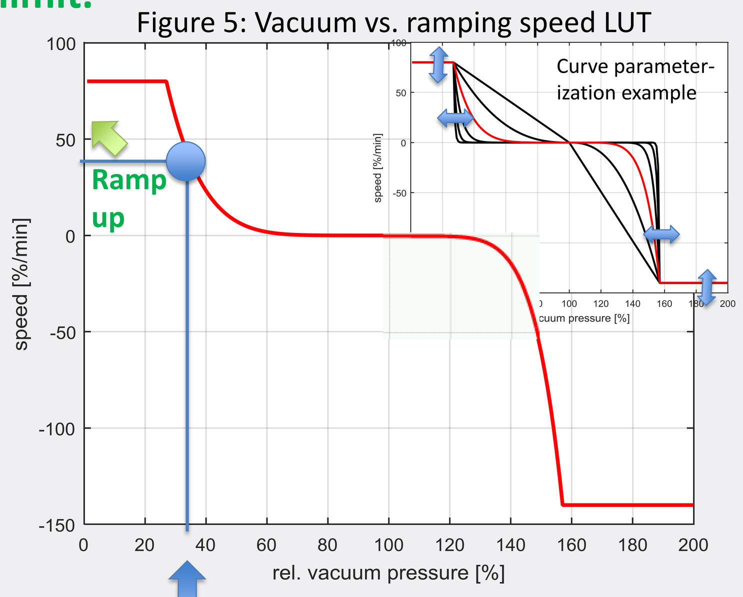


2. Weight + convert channels from abs. to relative



Idea:
Reference pressure = f(power setting)
Higher power ➔ better vacuum required

3. Look-up the ramping speed up or down based on the current relative pressure reading. Around 100 % rel. pressure the differential gain is 0 to get a stable operation point at the critical region.
Goal of the ramping speed control law is NOT to reach the vacuum interlock limit.



Ramping Speed Limitations

The determined ramp-up speed (Fig. 5) is limited dependent on the conditioning state. For that reasons the conditioning algorithm keeps track of two power settings ramps:

1. Power Setting (actual)
2. LTR (long-term) Power Limit

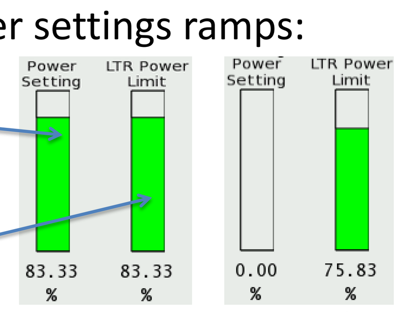


Figure 6: conditioned up to 83.33 / 75.83% (here system currently OFF)

Ramp Up-Limit	Used for	Example value
Long term ramp	**Slow** ramp up for initial conditioning	5 %/h
Breakdown recovery ramp	After breakdown detected: Do a **fast ramp-up to a slightly reduced** point where breakdown happened	Other BD: 20 %/min Kly BD: 30kV/h (slow ramp)
Vacuum controller	Dependent on rel. vacuum automatically ramp up/dn	Vacuum LUT -200..+200 %/min

Table 1: Ramp up speed is limited by the **min.** of above limits.

Feedforward Power Setting Laws and Modes

When conditioing is started the final calibrations of voltages and powers is sometimes not avail-able. Therefore the power setting between 0 and 100% is done with feedforward LUT for the klystron modulator high voltage command and for the LLRF RF drive amplitude command.

Three different modes are available:

1. High-voltage + RF drive
   default choice, ramp-up at kly. saturation
2. High-voltage only
   Used e.g. for klystron diode mode conditioning
3. RF drive only

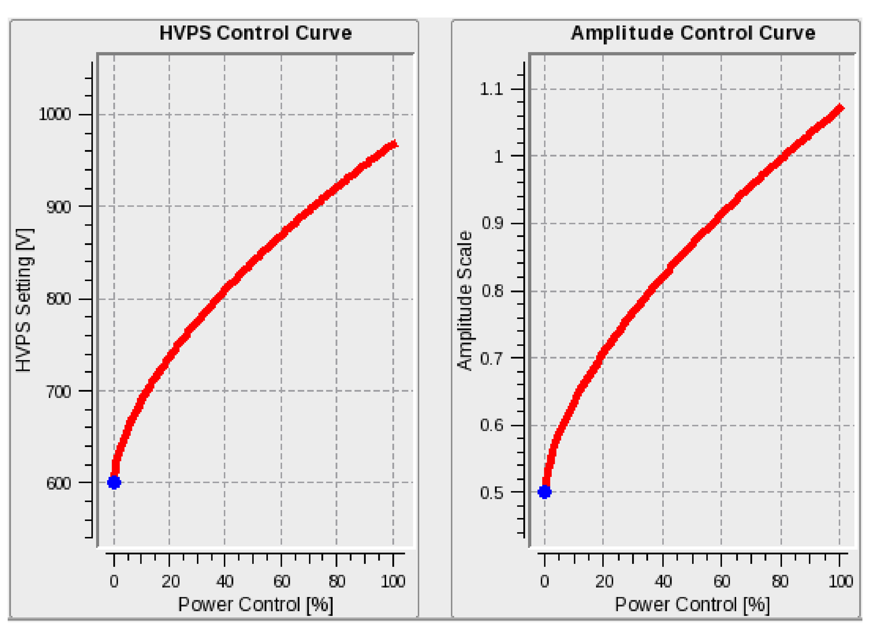


Figure 7: Feedforward control laws for klystron mod. and RF drive

RF Cavity Conditioning Experience SwissFEL C-band Modules

Fast RF conditioning progress during the outgassing phase can be reached by operating the system at a constant vacuum pressure which is below the vacuum interlock threshold but high enough to allow the vacuum outgassing.

Because trips typically happen in clusters, it is required to reduce settings such as RF pulse duration or allowed maximum power to avoid damage. The uniform distribution of the RF peak trips over the structures as shown in this example is a good indicator of success or conditioning problems.

Criteria to go to higher pulse width:

- ✓ Reached nominal klystron output power (here 50 MW)
- ✓ Reached breakdown rate @ nominal power over 10 last BD better than 1x10^(-5).

Typical pulse width steps:

1. Start: 50ns (or 30ns in case of problems)
2. Uncompressed: 80, 100ns
3. Compressed: 200/20ns, 500/50ns, 800/80ns, 1.2/0.1us, 1.8/0.1us, 2.4/0.1us, 3.0/0.1us (final conditioning), **3.0/0.35us (final for beam operation)**

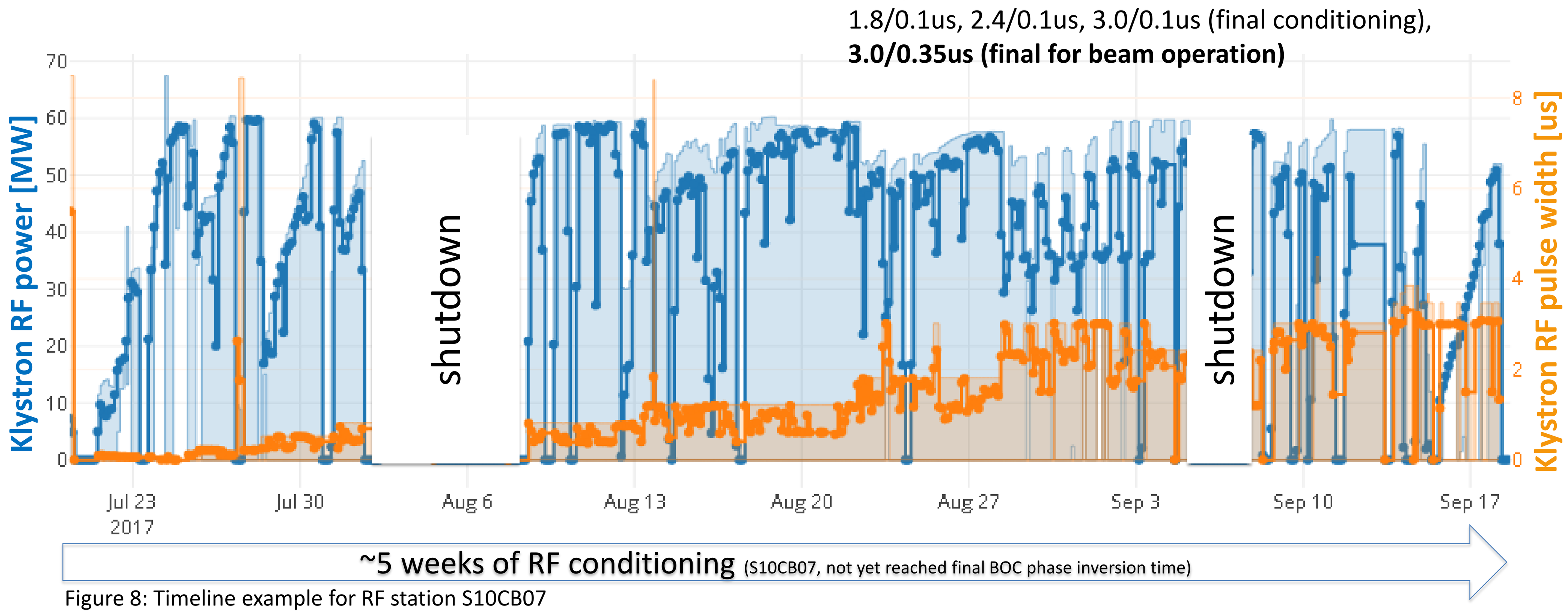


Figure 8: Timeline example for RF station S10CB07

Part	RF peak trips	Vac. peak trips	Other trips	Trip rate avg.
RF Station	**~ 5k**	216	-	**~ 6 trips/h**
Modulator	391	-	36	
Waveguides		159	-	
BOC	11	17	-	
ACC100	1239	40	-	~ 1 trip/h per structure
ACC200	863		-	
ACC300	1296		-	
ACC400	1110		-	

Table 2: S10CB07 C-band RF conditioning distribution of RF trips over 5 weeks conditioning

Conclusion / Outlook

RF cavity conditioning is a good candidate for automation because it typically runs a long time from days to weeks in 24/7 operation, needs slow but continuous adjustments of the power set points and needs only then human interaction when for example error rates are above a defined limit.
Algorithm: Further studies can be done in the algorithm / ramp speed limitation part. The goal is to have an algorithm which allows quick ramp-up to the point just before the next breakdown might happen and which passes through the critical regions with a slower speed. It can also be studied to automatically control the increase or decrease the RF pulse width based on conditioning quality criteria such as the break down rate.
Subsystems: The readout of the vacuum pressure measurements provided by the vacuum controller can be easily changed from 1 to 10 Hz processing, which then allows faster reaction to vacuum bursts. Other improvements are error analysis of the klystron modulator subsystem with automatic restart flag generation.

Revision 3, Roger Kalt roger.kalt@psi.ch , 11.10.2017, Paper Reference: P-34, LLRF17