

**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 max. of all channels
2. Weight + convert channels from abs. to relative max of all ch.
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 reason, the conditioning algorithm keeps track of two power settings ramps:
1. Power Setting (actual)
2. LTR (long-term) Power Limit

**Feedforward Power Setting Laws and Modes**

When conditioning is started the final calibrations of voltages and powers is sometimes not available. 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
3. Used e.g. for klystron diode mode conditioning

**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:**
- Reduced klystron output power (here 50 MW)
- Reached breakdown rate @ nominal power over last 80% better than 1x10^-5.

**RF peak trips**

<table>
<thead>
<tr>
<th>Part</th>
<th>RF peak trips</th>
<th>Other trips</th>
<th>Trip rate avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station</td>
<td>~ 8k</td>
<td>216</td>
<td>~ 6 trips/h</td>
</tr>
<tr>
<td>Modulator</td>
<td>391</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Waveguides</td>
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</table>

**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 region 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.

**Limitation for Rate of Breakdowns**

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 fireresor 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.