A (Not) Complete (Whish-)List of Procedures for the LLRF FSM

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1) Offset Calibration

Objective:

Get rid of constant (although slowly drifting) offsets induces by the vector modulator.

Prerequisites:

o No beam operation.
o Klystron is operating at secure HV-level (e.g. 80%).
o No feedback operation.

Procedure:

Set zero output at the DSP-DAC. Observe probe of some cavities. Scan through I- and Q-offset until the probe response is minimized.

2) Loop Phase Determination

Objective:

Set the phase advance of the whole control loop to an integer multiple of 2π.

Prerequisites:

o Klystron is operating.
o No feedback operation.
o Offsets are correct.

Procedure:

Scan through loop phase. Observe Vectorsum phase until it matches the setpoint phase. Or: apply small bump on feedforward table and evaluate output.

3) System Gain Determination

Objective:

Determine system gain. (Necessary for gain estimation or for feedforward adaption.)

Prerequisites:

o Klystron is operating.
o No beam operation.

Procedure:

Apply small bump on feedforward table and evaluate output. The system gain needs to be determined for different gradients individually!

4) Predetuning of Vectorsum Estimation

Objective:

Determining the detuning in the beginning and in the end of a pulse and approximating linearly in between is the simplest and often sufficient way to dertermine the detuning.

Prerequisites:

o Klystron is operating.
o Offsets are correct.
o The DSP matrices have been adjusted correctly.
o Apply constant phase in the beginning of a pulse.

Procedure:

Look at the phase derivative in the beginning of the pulse.

5) Tuning of the Cavities

Objective:

It is desirable to have the zero-crossing of the detuning of the cavities in the center of the flattop. Since the Lorentz-Force depends on the gradient, the optimal frequency where this

condition is fulfilled depends also on the gradient (in case of active lorentz force compensation, this objective is not longer valid). In addition, when modules are re-commissioned, the frequency is unknown and therefore needs to be adjusted.
Prerequisites:
o Klystron is operating approximately at the desired gradient.
o Setpoint is approximately at the desired gradient.
o Feedforward curve is rather well adjusted.
o Tuners are working. The frequency needs to be already within a few bandwidths.
o Feedback if off.
Procedure:
Scan through different tuner settings until the reflection coefficient is minimized in the center of the flattop.

6) Adapt Feedforward
Objective:
Optimize the feedforward tables such that the feedback has not much work left during the flattop.
Prerequisites:
o Klystron is working.
o Offsets, loopphase and system gain are adjusted.
o Feedback is on or off.
o Beam is on or off.
Procedure:
Adapt feedforward in an iterative fashion.

7) Synchronize ADCs of one RF Station
Objective:
Let all ADCs trigger at the same time with respect to the LO generation.
Prerequisites:
o If system is uncalibrated: let system run at secure lecel.
o If system is well adjusted: let system just run in feedforward mode.
Procedure:
Apply single nose on the LO-tables. Then scan through ADC-timing until they see this single nose.

8) Calibrate DSP Matrices
Objective:
In order to calculate the Vectorsum correctly, the individual probe signals of the cavities needs to be calibrated in amplitude and phase.
Prerequisites:
o The power-distribution (amplitude and phase, 3-stub-tuner) has been adjusted.
o System ist running with beam and feedforward only.
o It might be an advantage to run with a standard FF table (constant on flattop)
Procedure:
Evaluate beem transients and derive settings for DSP matrices.

9) Monitor Data Quality
Objective:
Have a direct measure of the quality of the RF pulse in terms of phase- and amplitude stability, eventually take into account pyro- or other detectors to calculate beam phase readback.

Prerequisites:
o System is making RF-pulses.
Procedure:
Record data and evaluate it.

10) Consistency Check
Objective:
Make a number of checks before system startup (cables connected correctly? hardware available?)
Prerequisites:
o None.
Procedure:
To be developed.

11) Interlock Reset
Objective:
In case of an interlock, the state machine should reset interlocks for a certain amount of times.
Prerequisites:
o An interlock occured.
Procedure:
Check severity of interlock, eventually reset it and count the number of resets.

12) Calculate Detuning and Bandwidth
Objective:
Provide a display of the detuning for certain cavities for manual inspection.
Prerequisites:
o RF is going in the cavity that is to be observed.
Procedure:
Evaluate data and provide display.

13) Adjustment of Waveguide Tuner
Objective:
It is necessary to have the power distribution system of a set of cavities that belong to one module calbrated in such a way, that the rf power approaches at the cavity input coupler in the same phase and at the desired level of attenuation.
Prerequisites:
o Offsets are adjusted etc.
o Medium to high beam current operation w/o feedback.
Procedure:
The algorithm will evaluate beam transients and give suggestions on how to adjust the waveguide tuner. At present, this will be done manually. The procedure already foresees an automativ adjustment of this part.

14) Momentum Management
Objective:
Certain cavities might run on lower gradient, e.g. due to quenches. This needs to be compensated by the other cavities in a vectorsum.
Prerequisites:
o There is a need for momentum management.
Procedure:
To be developed.

15) Exeption Handling
Objective:
An exception occured.
Prerequisites:
An exception occured.
Procedure:
Detect exception. Decide what to do.

16) Save and Restore Settings
Objective:
Save and restore all or a subset of the settings (mainly DSP parameters).
Prerequisites:
o No RF should be applied at least during “restore”
Procedure:
Save and restore settings.

17) History
Objective:
Provide a history for important values.
Prerequisites:
o None.
Procedure:
Automatically record data.

18) Calibration of Forward and Reflected Power
Objective:
The forward, probe and reflected power signals are in arbitrary phase / amplitude relationship with respect to each other. Additionally, one has to deal with offsets. This needs to be corrected.
Prerequisites:
o Data available from individual cavities or the klystron.
Procedure:
Calculate calibration parameters.

19) Beam Phase Measurement
Objective:
Have a reliable read-back value for the beam phase.
Prerequisites:
o Run with beam and feedforward only (Maybe feedback, too? I don’t know.)
Procedure:
Look at data and calculate beam phase.

20) LO-Generator-Optimization
Objective:
A wrongly adjusted LO induces noise in the system. The purpose of this procedure is to reduce this noise.
Prerequisites:
o Unknown so far.
Procedure:
To be developed.

21) Track Frequency of RF Gun during Warm-Up

Objective:

Reduce the time it takes to have the RF gun at the correct temperature and therefore correct frequency.

Prerequisites:

o RF gun is warming up.

Procedure:

To be developed.

22) Klystron Linearization

Objective:

Linearize the klystron in order to have reliable amplitude and phase translation from DAC output to the cavities.

Prerequisites:

o To be developed.

Procedure:

To be developed.

23) Kryo Heatload Calculation

Objective:

Calculate the cryo heatload.

Prerequisites:

o To be developed.

Procedure:

To be developed.

27) Hardware Diagnostics

Objective:

Keep track of hardware status.

Prerequisites:

o To be developed.

Procedure:

To be developed.

28) Database with Calibrations

Objective:

Save and restore calibrations.

Prerequisites:

o To be developed.

Procedure:

To be developed.

29) Database with Operational Limits

Objective:

Deliver a basis for decisions like “is this dark current too much”?

Prerequisites:

o To be developed.

Procedure:

To be developed.

30) Adjustment of Amplitude and Phase

Objective:

On user request, the state machine should set amplitude and phase of the rf to the desired setpoint value. Together with this might go a set of optimizations.

Prerequisites:

o Klystron is operating.
o Machine is able to provide a read-back value for amplitude and phase.
o

Procedure:

To be developed.

31) Close the Loop and increase Feedback Gain

Objective:

Close the feedback loop.

Prerequisites:

o Klystron is operating.
o Offsets, loop phase, system gain are estimated
o Consistency check has been performed

Procedure:

To be developed.

Some comments on Stefans "Functionality required for the FSM for LLRF"

01 "start-up of individual rf system without beam": The individual system startup will be covered by a sequence of procedures listed above. It will be part of the FSM logic to invoke the correct sequence.

02 "preparation of rf system for beam operation": Same as above (01), but the sequence might be different.

08 "turn on – off klystron": This task is left to the klystron state machine.

09 "fault recovery": Recovering from a fault is done by the exception handling procedure.

10 "performance optimization": for different performance-parameters there are different procedures. For example, the feedforward tables are optimized by the adaptive feedforward. Or: the loop phase is determined by another algorithm.

21 "quench detection": I think, this is covered by the bandwidth measurement.