PAUL SCHERRER INSTITUT

Low Level RF Workshop 2022 -Poster #15

Startup Sequencer for Tuning and Starting up High Power RF into 50 MHz accelerator cavity

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Abstract

The two cyclotrons at the High Intensity Proton Accelerator (HIPA) at PSI are equipped with eight high-power CW RF cavities at 50 MHz and one flat-top cavity at 150 MHz with input power levels up to 500 kW.
The purpose of the startup sequencer is to establish continuous (CW) high power RF operation as safe, fast and reliable as possible from both cold and warm cavity initial states. Precise impedance matching and resonance frequency tuning are mandatory pre-conditions before continuous high power is allowed. Due to multipactoring, the cavity is forbidden to operate in certain levels between zero and nominal power. For this reason, slow RF ramping is not possible and a pulsed startup scheme is used. Pulses with fast transitions through the forbidden regions help suppress the multipactoring effects and guarantee smooth measurements of RF phase and amplitude during the startup.
The new type digital LLRF startup sequencer has integrated diagnostics and exception handling for debugging purpose. Two fast RF feedback controllers for the startup and nominal operation are implemented with smooth transition.
Real RF-experience and testing has been done on the test stand with the cavity

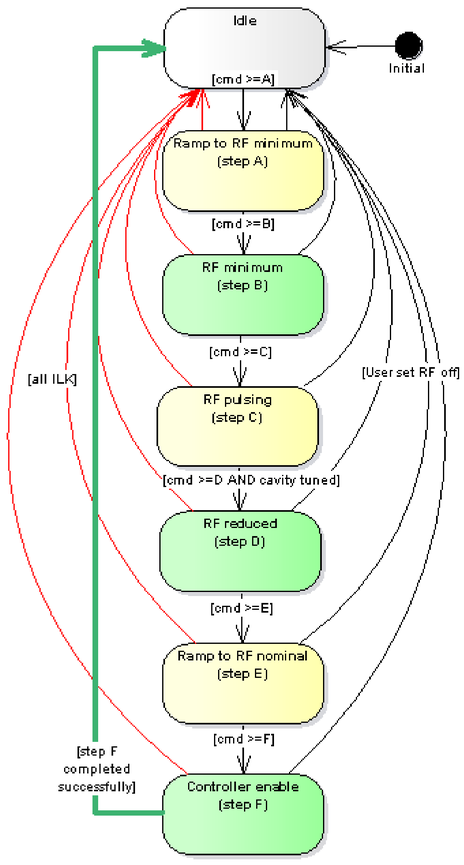

Figure 1: Start-up Sequencer FSM

Pulsing and Tuning

RF-startup into a detuned cavity is achieved with a start up sequencer to control the output power setting and to measure the matching of the tuning position. With a minimum power level the RF-High Power Amplifier can safely operate into detuned load without damaging the in coupling device and the RF-High Power Amplifier. This minimum power setting allows the tuning system to start the tuning. With adjustable pulsed power the cavity is filled. The LLRF system measure the reflected power and the startup sequencer decide, if in the pulsed window the reflected power is below a threshold level and cw power can be applied to the system.

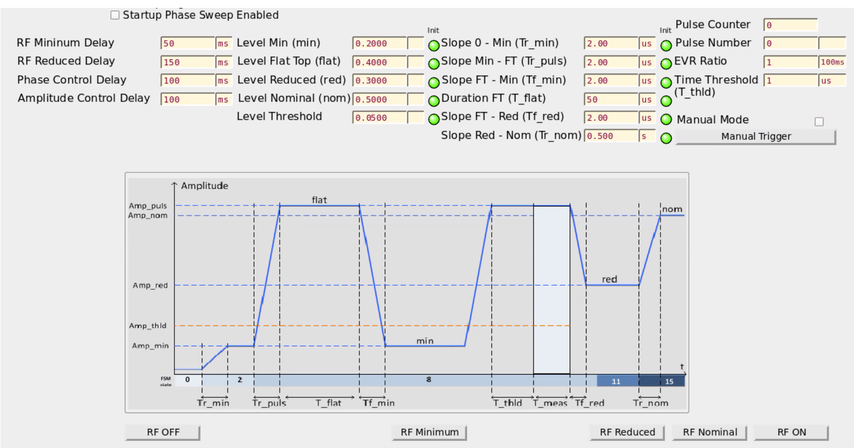

Figure 2: Start-up Sequencer control panel

After approximately 28 pulses at a 10Hz rate
(2.8 sec.) the cavity is tuned to reach the threshold level criteria. During this minimum level, pulsing period, reduced level period and ramping up to nominal power, the forward power into the cavity is regulated. During these phases the tuning system proceed working to improve the matching, to reach a minimum reflected power measurement.

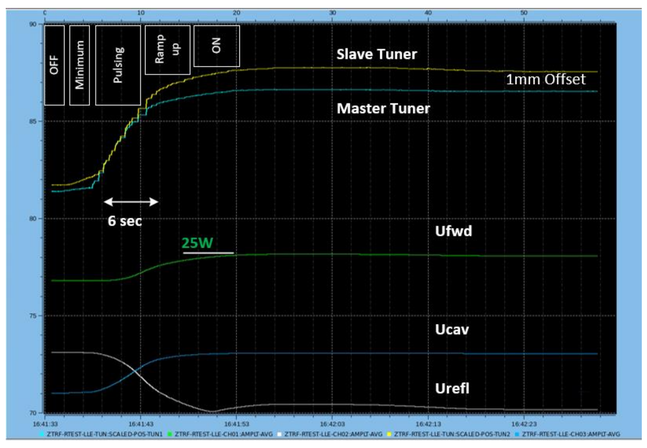

Figure 4: Tuning average measurement

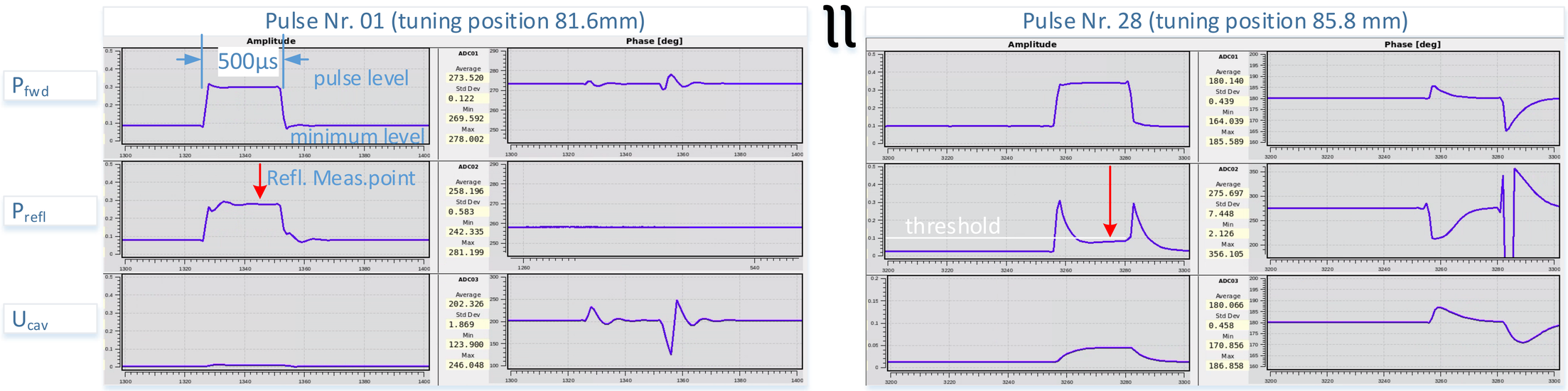

Figure 3: Single RF pulse during the startup sequence

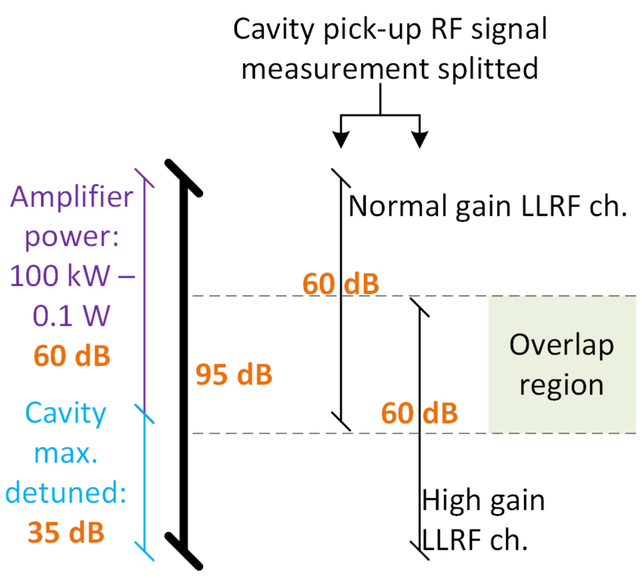

Figure 5: Dynamic range requirement

Dynamic range requirement

A normal gain and additional a high gain LLRF signal path of the cavity pick up signal is used, to increase the overall dynamic measurement range covering the cases of minimum power level from the amplifier and the case where the cavity is detuned maximum.

Conclusion / Outlook

This startup sequencer support a reliable and quick startup and tuning of the system to nominal power. The system increase the overall availability in the HIPA machine environment due to the shorter startup time to nominal operation. Remote access and faster cavity filling compared to the analog system are already visible. The system is tested with a 25W solid state amplifier and is now ready for operation with the high power amplifier chain. Testing with up to 100kW RF Power will start in November 2022.

Revision 2, Matthias Stoll matthias.stoll@psi.ch 05.10.2022, presented at LLRF Workshop 2022 (LLRF2022)