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Pulse to Pulse Stability of an Ampegon Short Pulse Modulator

Andreas Epp[1], Marcel Frei[1], Guido Blokesch[2], Dominic Gerber[3]

[1] Ampegon AG, Spinnereistrasse 5, 5300 Turgi, Switzerland
[2] Ampegon PPT GmbH, Feldstrasse 56, 44141 Dortmund, Germany
[3] Laboratory for High Power Electronic Systems, ETH Zürich, Physikstrasse 3, 8092 Zürich, Switzerland

Abstract

Ampegon, in collaboration with the Laboratory for High Power Electronic Systems HPE/ETH Zürich, has developed a novel short pulse modulator for high power microwave klystrons. A full scale industrialized modulator based on the C-band RF station specification for the SwissFEL project (PSI, Paul Scherrer Institute, CH), has been built and fully load tested with a Toshiba E37212 klystron at PSI. Since the pulse to pulse stability is critical for the whole SwissFEL machine performance, special emphasis has been given to the voltage measurement and regulation of the capacitor charging power supply of the modulator system. Values well below 10ppm pulse to pulse stability have been measured during tests at PSI. The verification measurement of the stability has been done with a measurement setup developed by PSI. This poster will review the conceptual design of the charging unit and its measured stability. In addition we will explain why the pulse to pulse stability is a critical value for the SwissFEL, and explore how the verification measurements were done with PSI equipment, the PSI measurement setup and the remaining uncertainty in the measurement results.

Calculation of Pulse to Pulse Stability

The pulse to pulse stability is determined by measuring the klystron voltage inside the flat top of the high voltage pulse. The pulse voltage is measured over a time window of 2 us on the flat top. The average value is recorded over a time period of at least 10 minutes. During this period, the RMS stability measured over a moving window of 100 pulses is calculated. The test was repeated between 80% and 100% of the nominal klystron voltage of 360 kV in 5% steps.

The measurement and calculation procedure is done with the oscilloscope. Figure 1 shows a print screen of the measurement and calculation during the site acceptance test of the system at PSI with 350 kV output voltage and 100 Hz repetition rate. The measured mean pulse to pulse stability of the Ampegon Short Pulse Modulator is 8.7 ppm. This value still contains the measurement noise (<4 ppm) of the measurement equipment, which means the real pulse to pulse stability is even lower.

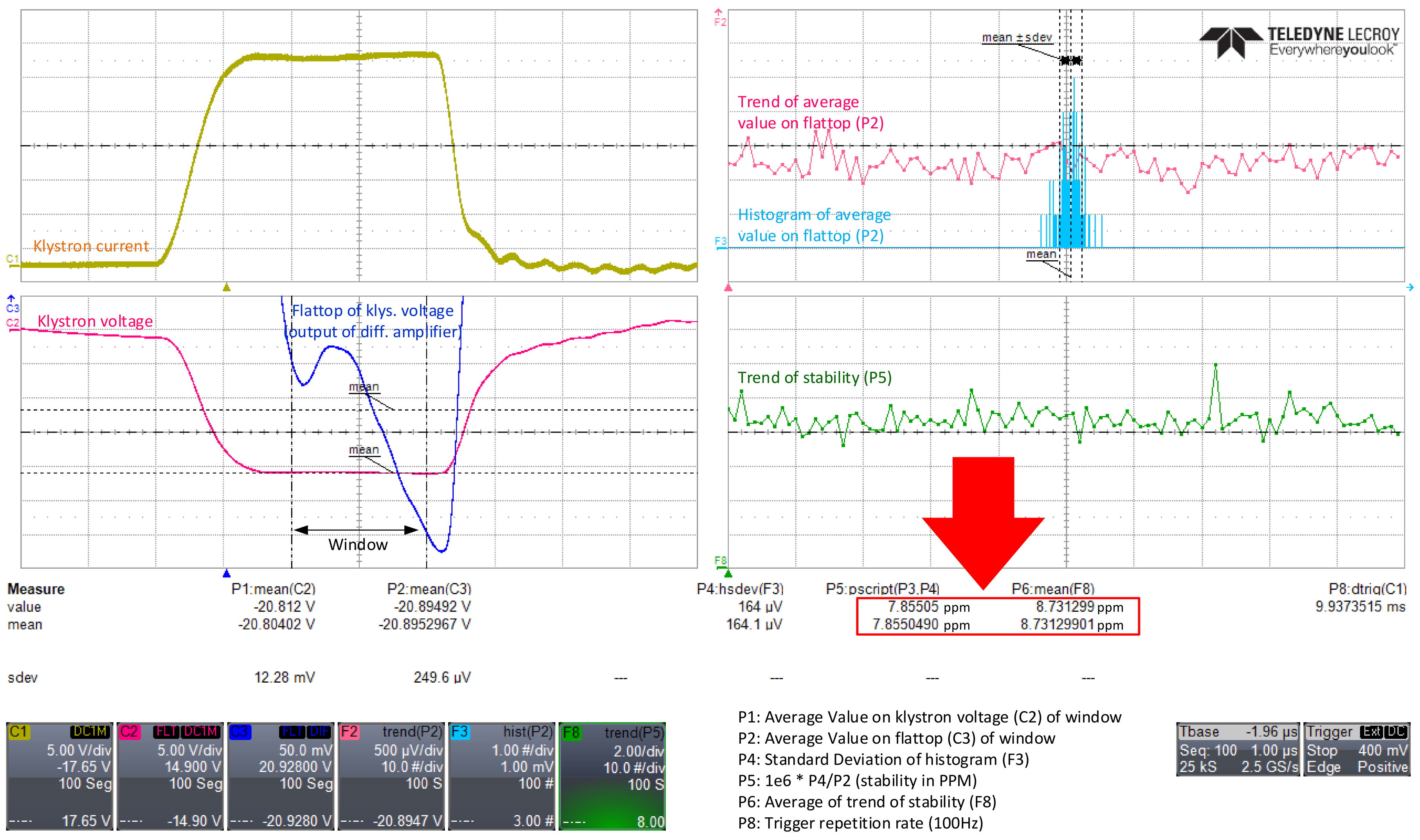

Figure 1: Pulse to Pulse Stability Calculation with the Oscilloscope

Measurement Circuit

The most difficult task during measurement of the pulse to pulse stability is to determine the stability without the noise. 10 ppm of 10 V means that the noise has to be less then ≈ 8 ppm, this means 80 µV. Great efforts were made to set up such a measurement circuit. Different approaches were also made to have as low noise circuitry as possible.

Figure 2 shows the measurement circuit with the lowest possible noise characteristic. The klystron voltage is measured with a high voltage divider from Ross Engineering. The klystron current is measured with a Pearson Coil. A Lecroy DA 1855A was used as a differential amplifier, while a Lecroy Waverunner 610Zi is used as oscilloscope. The advantage of this equipment is that the generated offset from the differential amplifier is directly used in the calculations done by the scope. Several common mode chokes, made with nanocristalline cores, were used to damp the noise.

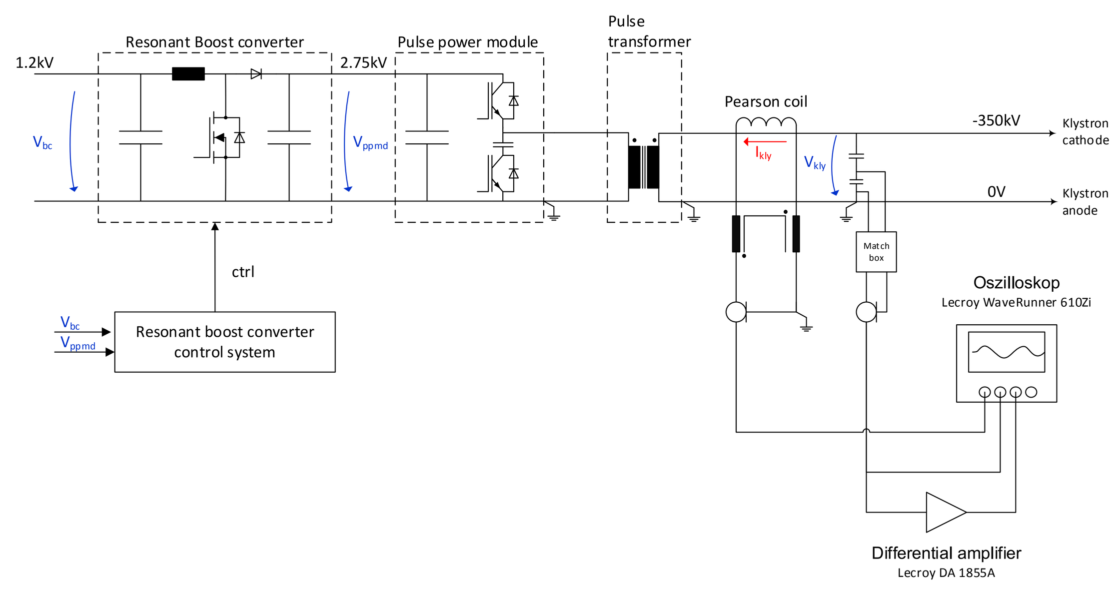

Figure 2: Measurement Circuit

Achieving High Stability

The pulse to pulse stability depends upon the accurate loading of the pulse power module capacitor charged by the resonant boost converter controller between the pulses. There are several points which were considered during the design phase to reach this high stability:

- Development of a resonant boost converter:
  - High frequency of the resonant boost converter (> 80 kHz) leads to accurate loading charges
  - Resonant topology leads to low switching noises and more accurate measurements
- Grounding concept to avoid ground loops
- Regulation of the boost converter
- Hardware and software filter design of the regulation
- High voltage of 3 kV at the pulse power module

Modulator Specifications

Description	Result
Output Voltage	370 kV
Output Current	335 A
Voltage Rise Time 10 – 90%	0.86 µs
Voltage Fall Time 90 – 10%	1.2 µs
Voltage Flat Top (Puls within ± 1%)	≥ 4.6 µs
Flat Top Ripple or Droop (3 µs flat top)	± 0.98%
Voltage Pulse to Pulse stability 355 kV / 320 A	8.7 ppm (PSI requirement: <10 ppm)
Jitter (Trigger to modulator output)	< 1 ns
Repetition Rate	100 Hz
Pulse Energy	496 J

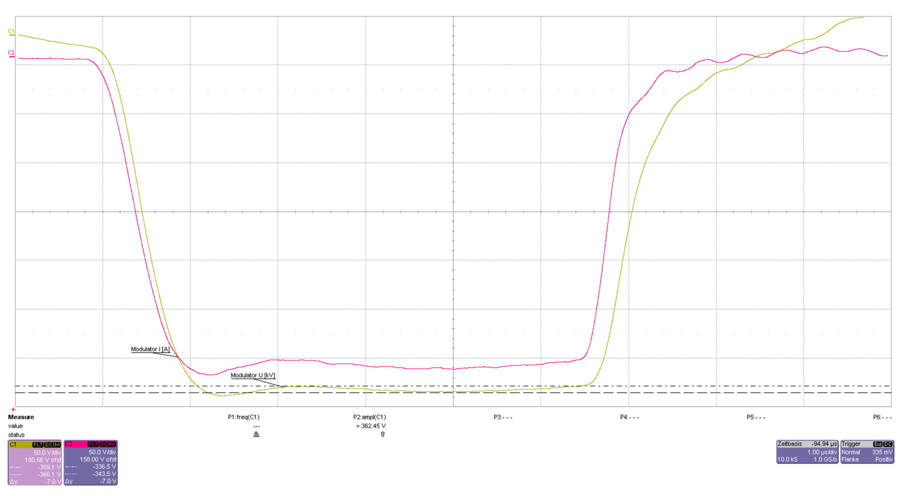

Figure 3: High Voltage Pulse

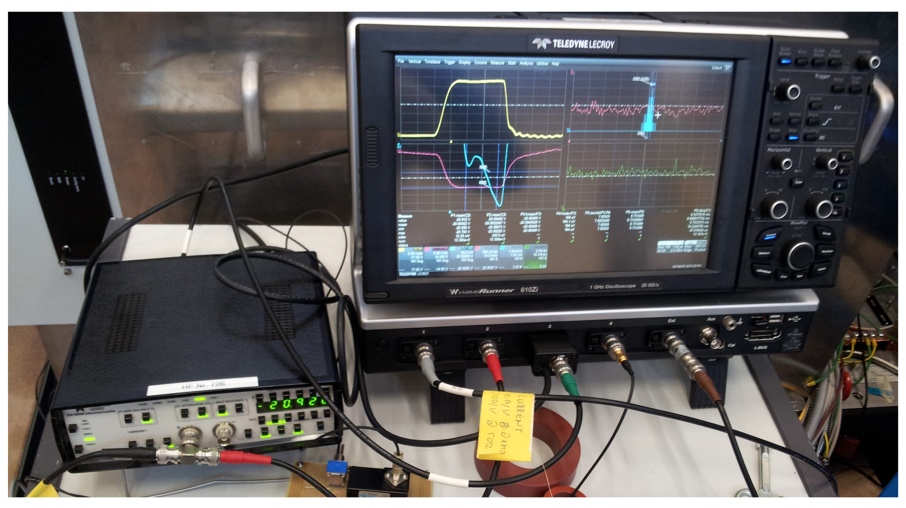

Figure 4: Measurement Setup

Importance of Power Stability for FELs

One useful property of FELs is their ability to achieve microbunching of the electrons in the beam. This is best achieved if the electrons have identical energies leaving the LINAC. Therefore, the greater the LINAC RF stability, a greater degree of microbunching can be achieved. Thus, the RF output from the klystron amplifiers is of critical importance.

The klystrons are powered by modulators that have to deliver ultra-stable accelerating voltages to the tube amplifiers. Fluctuations of the modulator voltages lead to phase variations of the amplified RF signals, and these variations can disturb the bunch compression process, and leads to arrival-time and energy variations of the electron bunches. The charging circuit in our modulator is capable of reaching pulse to pulse stability of < 10 ppm and is therefore important in achieving maximum performance with a FEL.

Figure 5: C-Band Short Pulse Modulator for SwissFEL