DEPARTMENT OF PHYSICS
Institute for Beam Physics and Technology

Stability Improvements at FLUTE
(Verbesserung der Stabilität von FLUTE)

Master thesis
of

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at the Institute for Beam Physics and Technology

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Abstract

The **F**erninfrarot **L**inac- **U**nd **T**est-**E**xperiment (FLUTE), a compact linear accelerator, is currently designed and under commission at the Karlsruhe Institute of Technology (KIT). Its main purposes are to serve as a technology platform for accelerator research, the generation of strong and ultra short THz pulses and in the future as an injection device for **c**ompact **St**orage ring for **A**ccelerator **R**esearch and **T**echnology (cSTART).

At the current commissioning state, the klystron which powers the electron gun/RF cavity and in later stages the linear accelerator is fed by a pulse forming network, which is driven by a high voltage source connected to mains power. For high and a stable output power of the cavity resonator, several parameters have to be tuned to the correct values and kept inside of sometimes small tolerance bands.
In the past, the coolant temperature of the cavities water cooling system and the dependency of the pulse forming network output of the mains voltage phase were predominant sources of instability. After dealing with these issues, the cavity output power stability was improved significantly but further improvements to the stability were still desired.

In this work instead of passively optimizing the stability of system parameters, an active approach is evaluated. By controlling the amplitude of the RF input signal of klystron, which is easily possible since it is low power, the effects of noise and/or drifts are mitigated. Here it is evaluated if a simple of the shelf voltage controllable attenuator is a feasible choice to control the RF input signal, which input data should be used and which algorithm and/or control system is suitable to determine the needed attenuator setting to stabilize RF output (of the cavity).
Furthermore since the next stage in the system depends on a stable electron bunch charge rather than cavity power, it is determined whether the charge measurements of a Faraday cup can be used to directly control electron bunch charge.

Kurzfassung

–TODO–

1. Theoretical Framework

1.1. Accelerator Physics

1.1.1. Some Beam Diagnostic Devices

1.2. Signal Analysis

1.2.1. Estimating the Spectrum of a Stochastic Process

For a deterministic signal $x(t) \in \mathcal{L}_1$, the Fourier transform exists[1] and is defined as

$$\hat{x}(f) = \int_{-\infty}^{+\infty} x(t)\, \mathrm{e}^{-j2\pi f t}\, \mathrm{d}t. \tag{1.1}$$

As $\hat{x}(f)$ is in general complex valued, it is often convenient to split it into $|\hat{x}(f)|$, called the magnitude and $\angle\{\hat{x}(f)\}$, called the phase.

It is also common to refer to

$$10 \cdot \log\left(|\hat{x}(f)|^2\right) \tag{1.2}$$

as the energy density spectrum, expressed in the pseudo unit "decibel'' (dB).

If the signal originates from a stochastic process

1.3. Feedback Control Systems

Appendix

A. Lab Test and Measurement Equipment

A.1. Benchtop multimeters

A.1.1. Agilent 34411A

Table A.1.: Agilent 34411A specifications

Specification	Value
	DC volt
Digits	6 1/2
Measurement method	cont integrating multi-slope IV A/D converter
Accuracy (10 V range, 24 hours)	0.0015 %+0.0004 % (% of reading + % of range)
Bandwidth	15 kHz (typ.)

Table A.2.: Agilent 34411A some SCPI commands

Description	Example command	Example return
Read current measurement	`READ?`	`+2.84829881E+00` (2.848 V)

A.1.2. Keysight 34470A

Table A.3.: Keysight 34470A specifications

Specification	Value
	DC volt
Digits	7 1/2
Measurement method	cont integrating multi-slope IV A/D converter
Accuracy (10 V range, 24 hours)	0.0008 %+0.0002 % (% of reading + % of range)
Bandwidth (10 V range)	15 kHz (typ.)

Table A.4.: Keysight 34470A some SCPI commands

Description	Example command	Example return
Read current measurement	`READ?`	`+9.99710196E+00` (9.997 V)

A.2. Data Acquisition/Switch Unit

A.2.1. Keysight 34972A

Table A.5.: Keysight 34972A specifications

Specification	Value
34907A (Multifunction module)	
DAC range	±12 V
DAC resolution	16 bit ($24\,\mathrm{V}/2^{16}$ = 366.21 µV per bit)
DAC maximum current	10 mA
34901A (20 channel multiplexer)	

Table A.6.: Keysight 34972A some SCPI commands

Description	Example command	Example return
Read current measurement	`READ?`	`+2.00200000E+01` (20.02 °C)
Set DAC voltage of ch 204 to 3.1 V	`SOUR:VOLT 3.1,(@204)`	

A.3. Oscilloscopes

A.3.1. Tektronix MSO64

Table A.7.: Tektronix MSO64 specifications

Specification	Value
Bandwidth	6 GHz
Sample rate	25 GS/s
ADC resolution	12 bit
DC gain accuracy (@ 50 Ω, >2 mV/div)	±2 %

Table A.8.: Tektronix MSO64 some SCPI commands

Description	Example command	Example return
Read mean of measurement 1 (current acq.)	`MEASUrement:MEAS1:RESUlts:CURR:MEAN?`	`3.0685821787408`

A.4. RF signal generator

A.4.1. Rohde and Schwarz SMC100A

Table A.9.: Rohde and Schwarz SMC100A specifications

Specification	Value
Frequency range	9 kHz to 3.2 GHz
Maximum power level	17 dBm
SSB phase noise (@ 1 GHz, $f_o = 20\,\mathrm{kHz}$, $BW = 1\,\mathrm{Hz}$)	−111 dBc
Level error	<0.9 dB

Table A.10.: Rohde and Schwarz SMC100A some SCPI commands

Description	Example command	Example return
Set RF power level to 10.5 dBm	`SOUR:POW 10.5`	
Set RF frequency to 3.1 GHz	`SOUR:FREQ:FIX 3.1e9`	
Enable the RF output	`OUTP on`	

A.5. RF power meter

A.5.1. HP E4419B

Table A.11.: HP E4419B specifications

Specification	Value
Digits	4
Accuracy (abs. without power sensor)	±0.02 dB
Power probe: E4412A	
Frequency range	10 MHz to 18 GHz
Power range	−70 dBm to 20 dBm

Table A.12.: HP E4419B some SCPI commands

Description	Example command	Example return
Measure power on input 1	`MEAS1?`	`+2.89435802E+000` (2.894 dBm)

A.6. Vector Network Analyzer

A.6.1. Agilent E5071C

Table A.13.: Agilent E5071C specifications

Specification	Value
Frequency range	9 kHz to 8.5 GHz

A.7. Phase noise analyzer

A.7.1. Holzworth HA7062C

Table A.14.: Holzworth HA7062C specifications

Specification	Value
DUT input frequency	10 MHz to 6 GHz
Measurement bandwidth	0.1 Hz to 40 MHz offsets

Bibliography

[1] A. Lapidoth, *A Foundation in Digital Communication.* Cambridge University Press, Mar. 26, 2019, 920 pp., ISBN: 1107177324.