The on-line nonliearities measurements of the VUV-FEL accelerator RF- stations high power chain.

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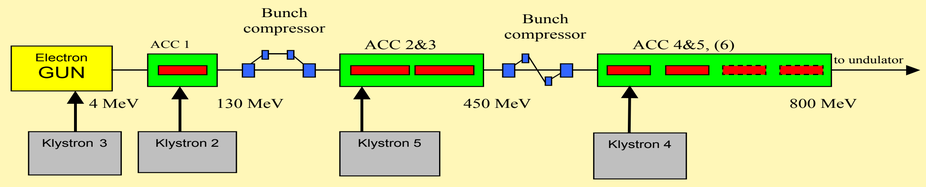
ABSTRACT

As every high power amplifier also the pulse microwave 10 MW klystrons (in the VUV-FEL accelerator) have nonlinear output power vs. input power characteristic near to the device saturation point. This undesirable behavior of the tube amplifier may cause lower efficiency of the close loop RF field regulation in LLRF control system.
In order to provide a solution for existing distortion compensation it is necessary to examine each of the RF-power station. The main goal is then designing and establishing an on-line measurement system and appropriate procedures that would give comprehensive knowledge about distortions introduced by the klystron and power preamplifiers and will be transparent for regular accelerator operation.
In this poster the problems concerning appropriate amplifiers characterization as well as propositions for on-line nonlinearities monitoring will be discussed. Also the currently used solutions for the high power amplifiers linearisation will be presented and a proposition for VUV-FEL RF-station high power chains distortion compensation will be described.

LINEAR ACCELERATOR - PART OF VUV-FEL

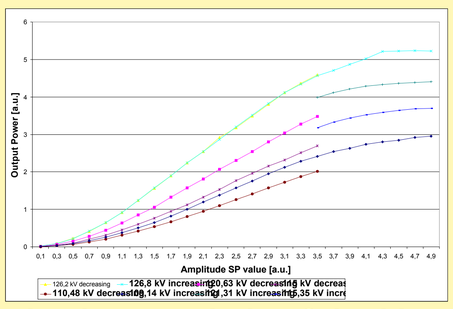
New facility VUV-Free Electro Laser have been established in the DESY Hamburg [8]. The part of the laser which is dedicated to accelerating the electrons (feature source of the laser) consists of five accelerating modules and two bunch compressors and many steering magnets and dipoles (used for electron bunch direction correction). Each of accelerating modules consists of eight superconducting cavities. Inside this components the electron beam energy is being increased by the electromagnetic field.



The overview of the accelerator part of the VUV-FEL

NONLINEARITIES AND SATURATION IN AMPLIFIERS

The klystron tube is supplied with high voltage pulse. For a specific value of the HV pulse that is powering the klystron and for some level of driving (input) signal that is produced in LLRF controller, klystron may reach saturation. Then change of the input signal level will not cause change in the measured output power of the device. Even in the vicinity of the saturation point the nonlinear amplification characteristic may cause a problems in the controlling of the electromagnetic field in the accelerating cavities.

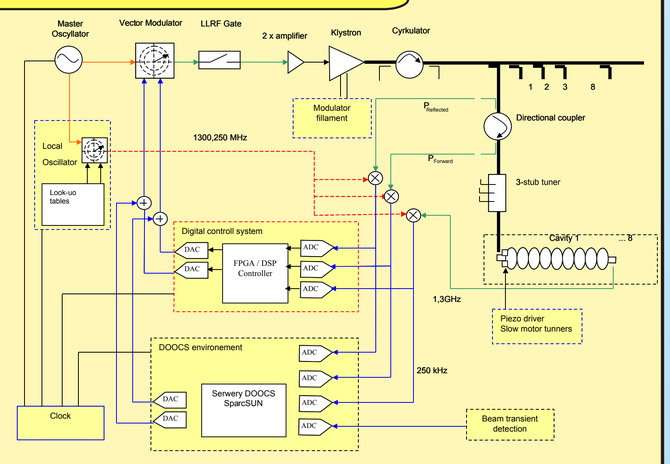


Static characteristic of the klystron

The saturation of the device depends on various parameters like HV pulse level and duration.
In order to improve klystron work efficiency especially near to the saturation the method for comprehensive device characterization have to be proposed and implemented.
The easiest way is to attach power meters at the input and output of the klystron. Than measurement process can be as follows: sweep driving signal input within possible range and observe the power at the output of the klystron. The main disadvantage of this solution is the lack of the information about the klystron phase nonlinearities.
What is more one has to be sure that observed saturation and nonlinearities are introduced by the klystron not by the preceding components.

ACCELERATING MODULE WITH LLRF SYSTEM

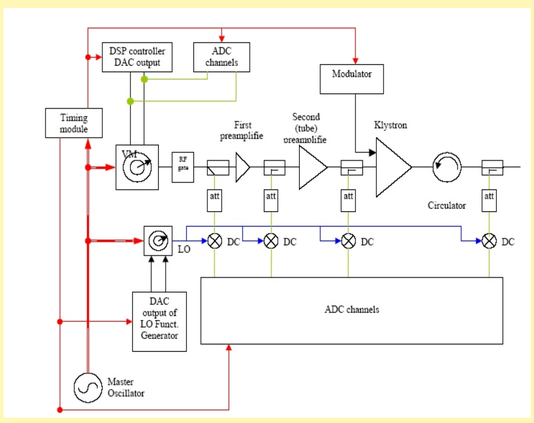
The module is powered by the 5MW (or 10 MW) microwave amplifier - klystron. The 1,3 GHz klystron produces energy with 1,7 ms rectangular pulses with the repetition rate of 1, 2 or 5 Hz. The output signal from is delivered to the superconducting cavities through waveguide system.
In order to achieve the best efficiency of the bunch accelerating process there should be appropriate level of parameters as accelerating field amplitude and field phase relating to the beam provided.
Dedicated field controller has been developed working in a feedback loop the low level Radio Frequency Control System (LLRF). In the digital controller data achieved from the cavity response measurement is processed and corrected. Afterwards signal for driving the klystron is calculated. As klystron supplies whole module (or even two modules) with eight cavities the controller output signal is prepared using the module cavities field vector sum.



LLRF system and accelerating module

DIAGNOSTIC SETUP AND MEASUREMENT TOOL

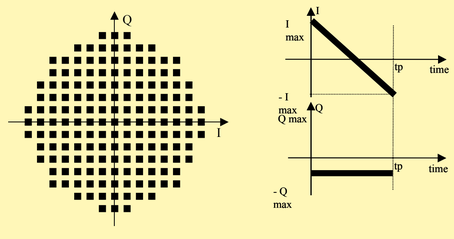
There are four measurement points installed in the high power chain. First is placed just after the vector modulator in order to observe nonlinearities introduced by this device in up-conversion process. Than after each of the preamplifiers and at last after the klystron output.
The signal is taken for the measurement using power splitter or directional coupler (for higher power signals). Then signal is attenuated. In the down-converter the 250kHz analog signal is achieved. Afterwards it is converted to the digital form (sample frequency 1 Mhz).



Diagnostic points configuration

Then is stored in the Distributed Object Oriented Control System servers that can be described as a virtual drivers of the hardware in the global control system environment. The DOOCS provides access to the data using the Matlab software.
In the digital controller I & Q vector form is used in the driving signal correction calculation. Also this representation is used in preparation test signal used for klystron nonlinearities examination.

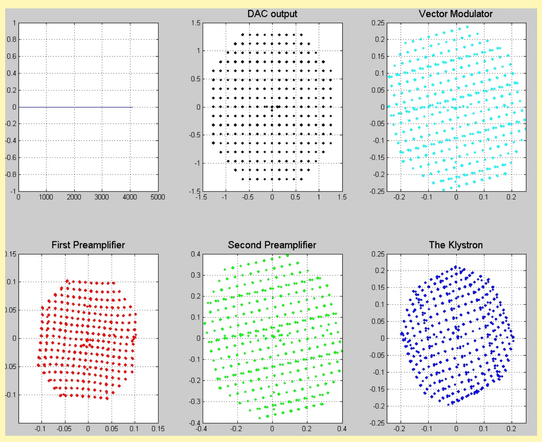
The test signal used for klystron and amplifiers driving is generated in the digital controller from prepared look-up tables. Within couple RF pulses the I and Q driving signals are swept in given range.



Test signal generation

Matlab tool for the klystron and other amplifiers characterization had been prepared. The tool features:

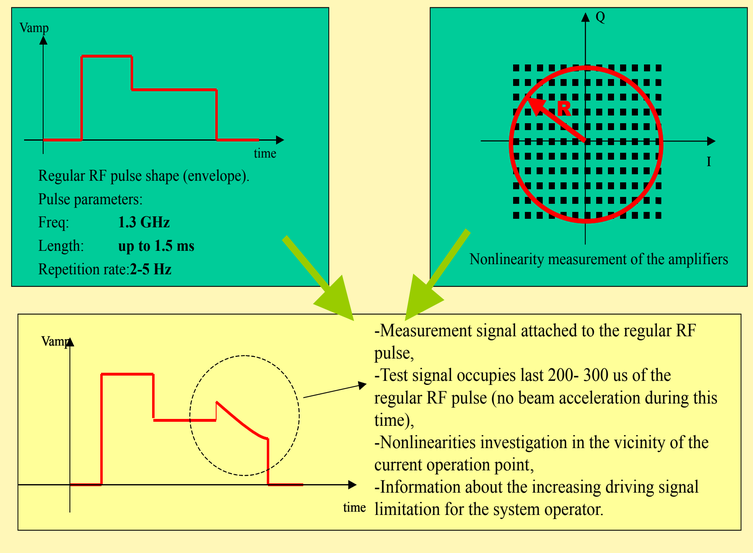
- User may define some parameters important for the analysis accuracy,
- Behavior of each high power chain components can be observed simultaneously,
- Measurement data are stored in the Matlab workspace type files – can be used for the further analysis and processing,
- Measurement is not transparent for the regular module operation.



Measurement result example

ONLINE MEASUREMENT

In order to investigate nonlinearities in the vicinity of the current klystron operating point a tool for on-line tube characterization is under development.
Information about high power chain components limitation maybe very important for the accelerator user. According to this knowledge one can estimate how big power margin he still have for the module operation.



On-line measurements principles

LINEARIZATION METHODS

At present there are three main different ways of high power amplifier linearizations known and used in the industry solutions. There are RF feedback loops around the high power amplifier, adaptive feedforward and predistorers (Allen Katz "Lineariztion reducing distortion in power amplifiers", may 2004; Frederick H Raab at all, "RF and Microwave Power Amplifier and Transmiters Technologies Part 4", November 2003 High Frequency Electronics Copyright 2003 Summit Technical Media, LLC).
According to the specific features of each of the solutions and existing system structure and possibilities there is a last method of using predistorers the most promising one. Unlikely to the solutions available on market, designed predistorer will react on not only klystron nonlinearities but also those introduced by the preamplifiers and the vector modulator.
The structure would be modeled and tested using Matlab environment and then implemented as a one of the control algorithms incorporated in the LLRF controller (DSP or FPGA).
First implementation of the predistorer bases on the result of the high power chain characterisation. Using achieved curves the look-up tables will be written to the field controller for driving signal correction

CONCLUSIONS

The present configuration of the VUV-FEL accelerator was presented. The problems encountered during the operation the klystrons near to the saturation was described. The method for klystron characterization for the different working parameters was presented. First results from one of the klystron (kly5) were discussed.
One can conclude that mentioned method give a possibility of nonlinearities and saturation point observation and comprehensive tube characterization. Implemented solution gives information about amplitude and phase deviation of the klystron tube and different devices. Thanks to this information it is possible to provide algorithms for klystron work linearization in the vicinity of the saturation point. This solution may also be used for the phase drift measurement in high power chain components as well as for this devices malfunction detection.
Short description of the currently used high power amplifiers linearization approaches was discussed and proposition for the solution that should meet existing accelerator setup requirements was given.
A proposition for on-line nonlinearities measurement around the operating point was described and the tool implementation is in the development stage.