

AN ANALYSIS TOOL FOR RF CONTROL FOR SUPERCONDUCTING CAVITIES

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Abstract

The rf control analysis tool consists of a set of library blocks to be used with SIMULINK. The tool allows to study the performance of a given rf control design. The library blocks include models for the superconducting cavities, the rf power source, the beam, and the rf feedback system.

The rf control relevant electrical and mechanical characteristics of the cavity are described in form of time-varying state space models. Included are perturbations from Lorentz force detuning and microphonics with the appropriate parameters for several mechanical resonances. The power source is calibrated in terms of actual power and includes saturation characteristics and noise. An arbitrary time structure can be imposed on the beam current to reflect a macro-pulse structure and bunch charge fluctuations. For rf feedback several schemes can be selected: Generator driven system or self-excited loop, traditional amplitude and phase control or I/Q control. The choices for the feedback controller include analog or digital approaches and various choices of filters for the gain stages. Feed forward can be added to further suppress repetitive errors. The results of a performance analysis of the TTF Linac rf system using these tools are presented.

1 INTRODUCTION

Superconducting cavity technology has developed very rapidly over the past 15 years. While the first large scale applications are now in operation for many years, they have been limited to medium gradient, CW operation and relativistic electron beams. Meanwhile significant progress has been made on the issues of pulsed operation of superconducting cavities at high gradients with respect to Lorentz force detuning and the associated resonant excitation of mechanical resonances, microphonics, the transients induced by the pulsed beam, and the control of the vector-sum of many cavities driven by one klystron.

This development necessitates the need for computer modelling of the associated rf control systems to assess the expected performance in field control, and rf power requirements in presence of perturbations. Several rf control model have been developed in the past years [1,2,3,4,5] but they are mostly specifically adapted to a particular accelerator. The authors of this paper have continued the project [6] of developing a generic rf simulation code with emphasis on superconducting rf systems. This tool is to be used for the design and

performance assessment of new or existing rf systems. The ultimate goal is a tool which supports on-line diagnostics during the commissioning phase and during routine operation of the rf system. The tools make use of the high level programming language MATLAB and SIMULINK which are available at most accelerator facilities. MATLAB provides a natural environment for analysis, algorithm prototyping, and application development which is complemented with SIMULINK's graphical user interface for construction of block diagram models using "drag-and-drop" operations. A major new feature since the first attempt in 1998 [6] is the library function in SIMULINK which simplifies the development and maintenance of new sub-systems blocks.

The rf system design and performance analysis tool is freely available via world wide web at "http://tesla.desy.de/acc_simulations/rf_model.html". The authors appreciate feedback from potential users of this software on their specific needs so that the tool can be made more universal. Presently models have been developed for high and low loaded Q cavities, heavy and light beam loading and CW and pulsed operation thereby covering the range of current projects under study.

2 CONCEPTUAL DESIGN

The concept of the analysis tool for rf control systems is based on library of sub-system blocks used in SIMULINK. The rf systems is usually modelled as a combination of such sub-system blocks as shown in figure 1. The key properties of the rf system analysis tool are:

- main blocks for major rf sub-subsystems.
- well defined interface for inputs and outputs for the sub-systems with possibility to add ports and new parameters.
- initialization files for sub-systems parameters and simulation parameters.
- variable interconnection structure between sub-systems.
- possibility of adding various new sub-subsystems.

Once the library is established the user can simply select the desired sub-systems from the rf component library to develop a new model as shown in figure 2. The user has the possibility to use also other SIMULINK library blocks.

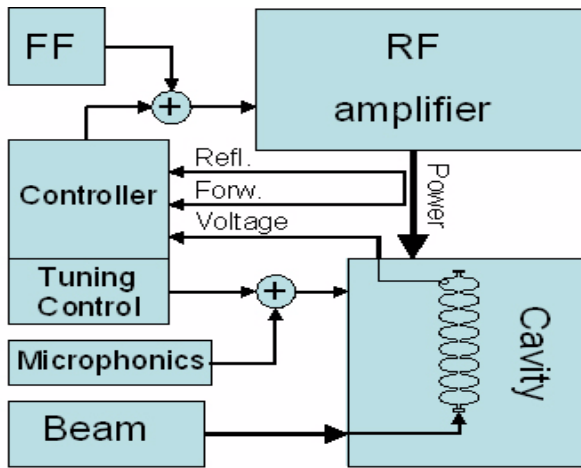


Figure 1: RF Sub-systems and Interconnections

3 RF SUB-SYSTEM BLOCKS

The rf sub-systems contain user-defined blocks with accompanying initialization files. These rf system specific blocks are added to a library which can be exchanged between various users since the interface between the sub-systems is well defined.

3.1 Beam

The beam can be modelled with arbitrary time-varying amplitude and phase as specified in a table. It is also possible to use pulse generators for a repetitive pulse structure and add a noise source to simulate bunch charge fluctuations. The beam library contains blocks for the cw beam at ERL/RIA and the pulsed beam for TESLA Test Facility and SNS.

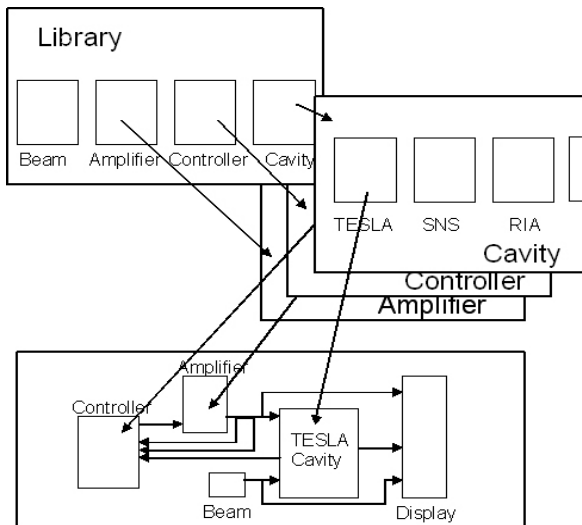


Figure 2: RF component Library and RF System Model

3.2 Amplifier

It is possible to use the measured non-linear characteristics of a klystron to create an input-output mapping table. The present klystron library contains a linear amplifier with table of real klystron saturation curve which can be normalized for maximum output and drive power.

3.3 Cavity

The use of superconducting cavities implies that Lorentz Force detuning and microphonics are included in the model. The state space representation of a cavity including Lorentz Force detuning.

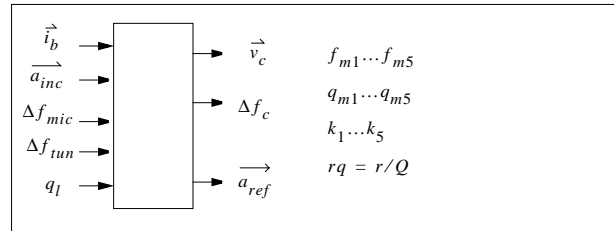


Figure 3: Cavity Interface Definitions and Parameters

The cavity library supplies a model for the cavities at ERL, RIA/SNS and the TESLA Test Facility. For the TTF rf system a model of 16?? cavities with different parameters.

3.4 Controller

The Controller is generic for different type of controls (self excited loop (SEL), generator driven resonator (GDR) amplitude and phase detectors and controllers, and IQ detectors and controller) composed of the sub-systems feedback, feed forward, and tuner control. It is possible to mix different type of controls during simulation and/or simultaneously.

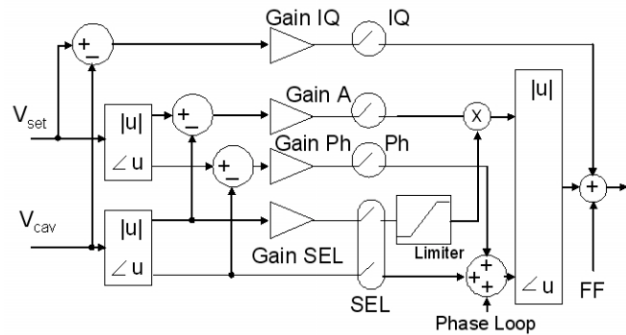


Figure 4: Controller Scheme

4 SELECTED SIMULATION RESULTS

Simulations have been performed for different type of cavities with high, medium and low loaded Q values, high and low beam currents, and CW and pulsed operation

4.1 TESLA Test Facility

The TESLA rf system is an example for medium loaded Q values of 3e6 and medium beam current of 8 mA operated

in pulsed mode. In the case shown in Figure 11 is the pulsed operation of a TESLA cavity with an IQ controller. During the cavity filling time of 500 μ s, the gradient is regulated on a time varying filling curve computed from the time constant of the cavity. The additional klystron power required during filling and flat-top as result of the dynamic Lorentz force detuning.

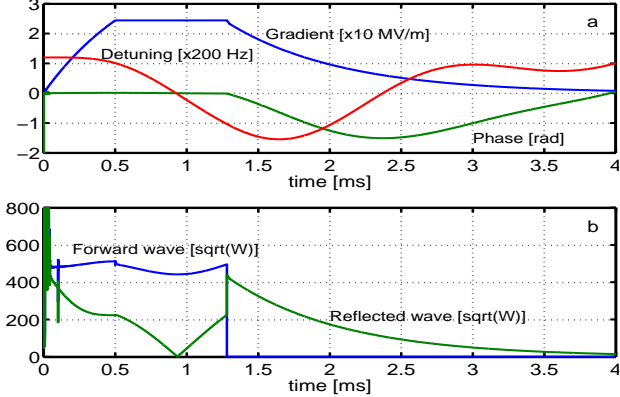


Figure 5: TESLA Cavity Control. a) gradient, phase, detuning, b) forward and reflected wave.

4.2 SNS Cavity Control

The SNS rf system is an example for low loaded Q values of $7e5$ and large beam current of 27mA in a $\beta = 0.81$ cavity operated in pulsed mode. In the case shown in Figure 12 is the pulsed operation of a SNS cavity with an amplitude and phase controller. During the cavity filling time of 150 μ s, the gradient is regulated on a time varying filling curve computed from the time constant of the cavity. The additional klystron power required during filling and flat-top as result of the dynamic Lorentz force detuning is relatively smaller than for the TESLA cavity.

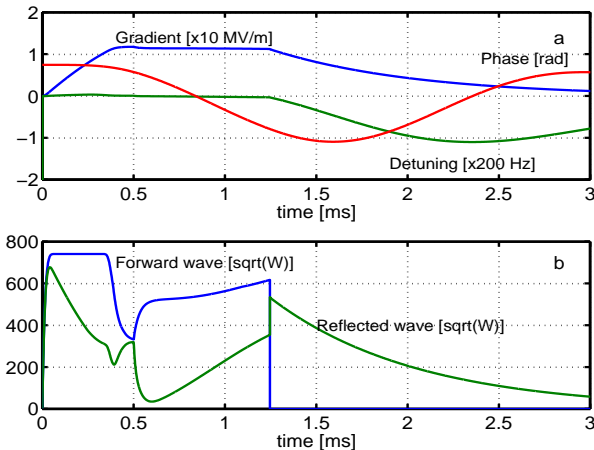


Figure 6: SNS Cavity Control. a) gradient, phase, detuning, b) forward and reflected wave.

4.3 RIA Cavity Control

The RIA rf system is an example for high loaded Q values

of $2.3e7$ and a small beam current of 0.38 mA of the $\beta=0.81$ cavity operated in long pulse mode to demonstrate the conditions for CW operation including the turn-on process. In the case shown in Figure 12 is turn-on and CW operation of a RIA cavity with a self excited loop during turn-on and phase lock before the beam is turned on. During the cavity filling time of 5 ms, the gradient is regulated on a time varying filling curve computed from the time constant of the cavity. At 7.5 ms the phase loop is closed resulting in a large forward power spike due to the large instant deviation from the phase setpoint. The power during filling is quite low since the self excited loop tracks the cavity frequency. Additional klystron power required during the flat-top as result of the dynamic Lorentz force detuning and microphonics is relatively large compared to TESLA cavity.

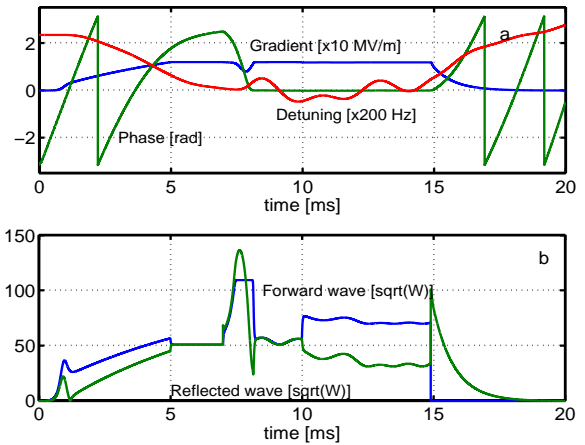


Figure 7: RIA Cavity Control. a) gradient, phase, detuning, b) forward and reflected wave.

5 CONCLUSION

A SIMULINK library blockset with rf control blocks for control of superconducting cavities been developed and tested for various rf systems. It allows the user to develop a model of his own control system and predict the expected performance. A well defined interface will allow the exchange of user defined sub-system blocks with the according initialization files among different users.

6 REFERENCES

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