MIMO-LTI Feedback Controller study

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FLASH seminar

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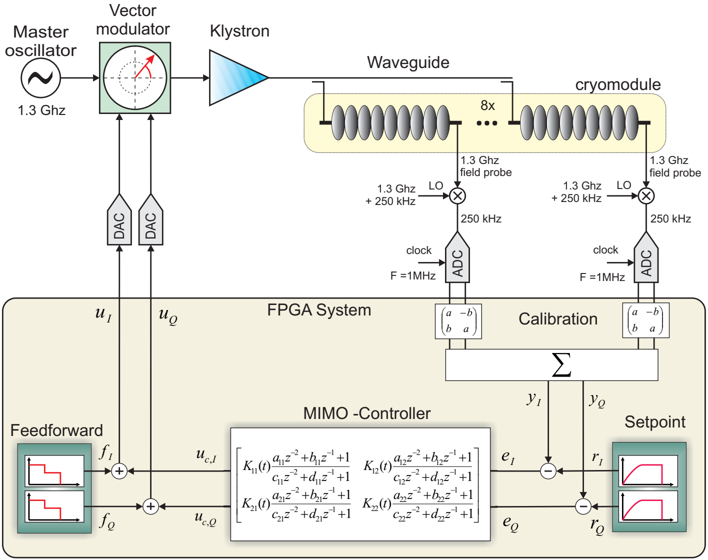
Outline

- System description and modeling
- Controller parameter estimation
  - General design procedure
  - Measurement results
- Learning feedforward
  - Algorithm properties
  - Measurement results
- Conclusion and Outlook

MIMO-Feedback Control System



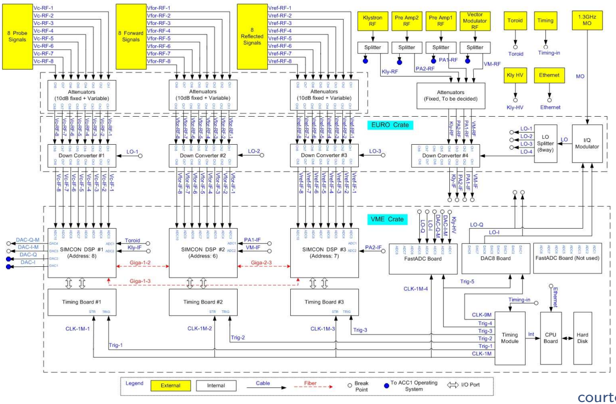
Design procedure during studies

1. Setup system for different controller structure (Software/Hardware)
2. System identification due to model changes
3. Use H_∞ algorithm to estimate controller parameters
4. Test estimated controllers offline/on the machine for field stability
5. Verify with beam to measure beam energy stability

Main improvements can be done after study period using measurement data.
Possibility now to use the Development system for verification and algorithm tests.

Development system on ACC1

SIMCON DSP Development System at ACC1

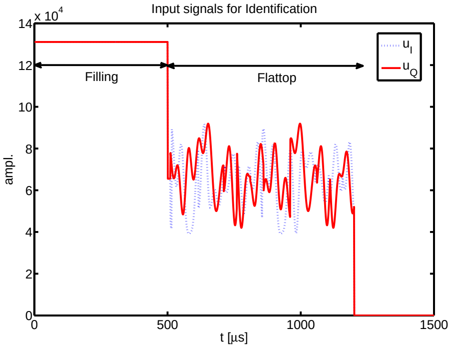


courtesy of Z. Geng

- 3 Simcon DSP boards connected to Probe/Forward/Reflected signals of real system
- Parallel measurements, Software development, Shift setup

System modeling

- Appropriate model is needed for higher order controller design
- Excitation of the system to model dynamic behavior
- Estimating black box model for current operation point
- Using several pulses for averaging or excitation channel

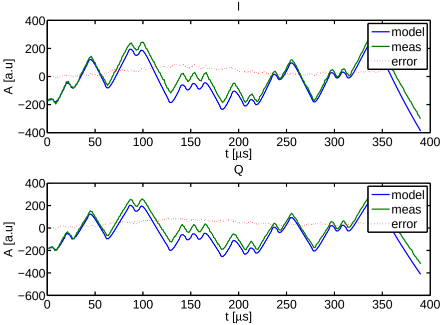


- state space system (LTI)

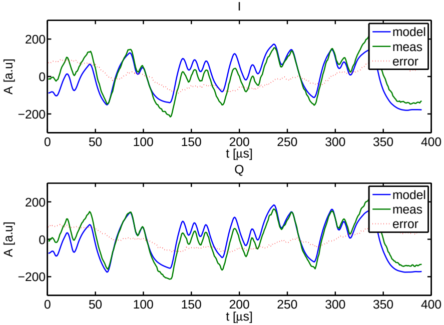
$$\begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) + Du(t) \end{aligned}$$

- estimating system parameters A,B,C,D with subspace algorithm n4sid

Model verification



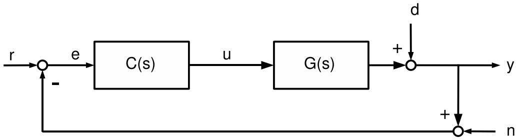
open loop model



closed loop model

- Representing system dynamics in given frequency range
- Verification using different system models / excitations
- Model depending on application and machine setup

Controller design objectives

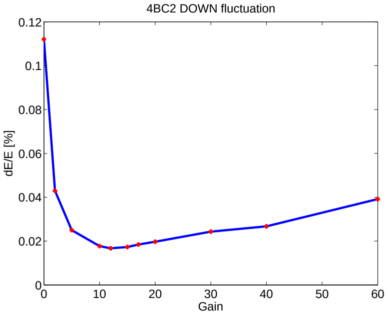


$$y = \underbrace{(I + G\,C)^{-1}\,G\,C}_{T(s)}(r - n) + \underbrace{(I + G\,C)^{-1}}_{S(s)}\,d \quad , \quad S + T = I$$

$$\begin{aligned} y &= T\,(r - n) + S\,d \\ e &= S\,(r - n - d) \end{aligned}$$

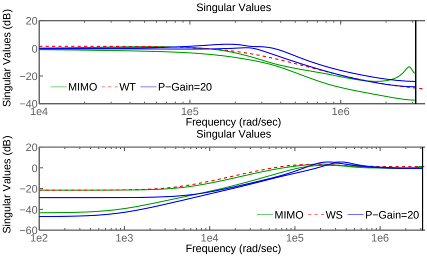
- Perfect tracking $T = 1\,,\ S = 0$
- Noise rejection $T = 0\,,\ S = 1$

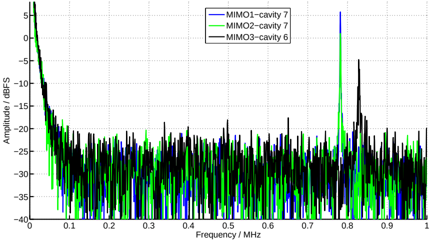
↷ conflicting design objectives



Frequency loop shaping

1. Definition of closed loop bandwidth by filter functions
2. Solving H_∞ algorithm to estimate controller parameters
3. Test controller parameters in closed loop

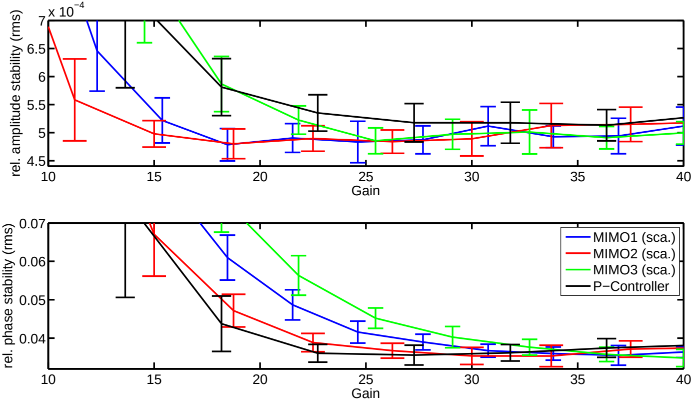




Closed loop Shaping filters and spectrum of probe signals with MIMO-Control (Non-IQ-sampling)

RF field stability measurements

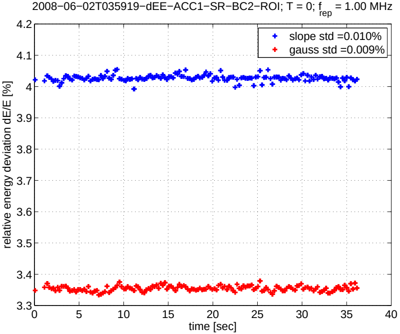
- RF field stability of MIMO-Controller compared to P-Control
- Gain values are scaled for comparison of different controllers
- MIMO-Controllers mainly for different closed loop bandwidths

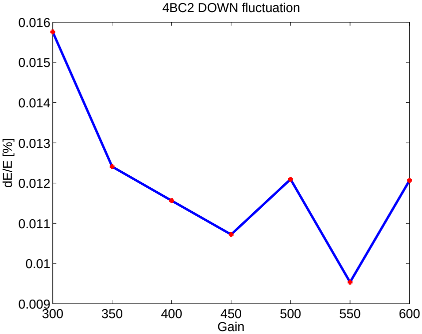


Field stability during flattop of different controllers (09/28/08)

Measurement results

- Beam energy stability measurements done with synchrotron radiation camera (4BC2-Down)
- Gain values are scaled proportional gains
- Best achieved beam stability with MIMO-Controller so far





Modeling and design procedure under investigation to achieve better performance.

General FF-Correction

Idea: Use information from previous trails to improved the FF signal for upcoming pulses.
Issue: Just repetitive signals can be covered!

General form of input update equation:

$$u_{k+1} = Q(u_k + L\, e_k) \quad k \Rightarrow \text{number of trial}$$

Different approaches are available

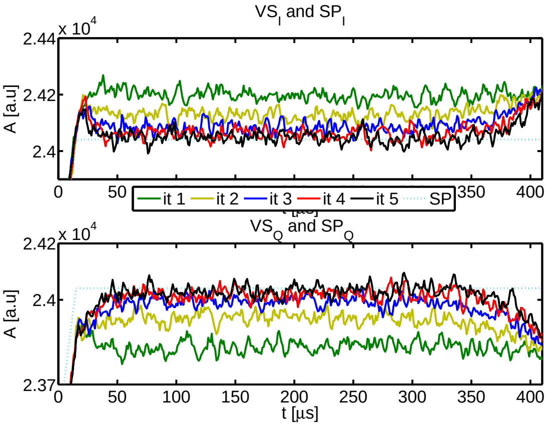
- Backward lowpass filter
- Backward system model
- Norm-Optimal Iterative learning Control[3]
- $\vdots$

Combination of Iterative Learning Control and Feedback Control

[3] N. Amann, D.H. Owens and E. Rogers, *Iterative learning control for discrete-time systems with exponential rate of convergence*, IEEE Proceedings - Control Theory and Applications, 217-223, 143, 1996

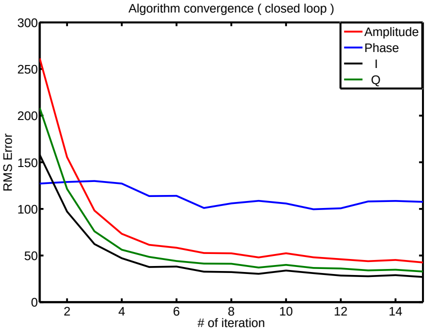
Adaptation of VS deviation

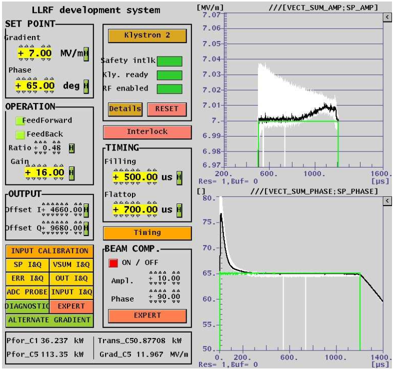
Using error signal to find optimal input signal minimizing deviations (FB steady state error) from setpoint.



- Tests with beam loading compensations couldn't be done

Convergence of the algorithm





- Tested for different setpoints with model adaption
- Stable to phase and fb gain changes
- Convergence speed can be adjusted depending on application

Implementation of Learning FF

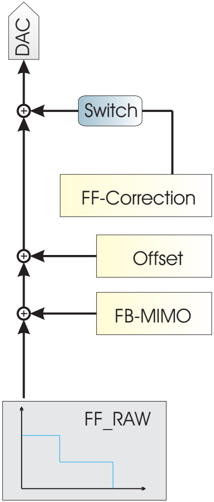
Deterministic signals to be covered

- Beam loading !
- Lorentz force detuning
- Overshoot of the system on transition from filling to flattop
- Optimal filling

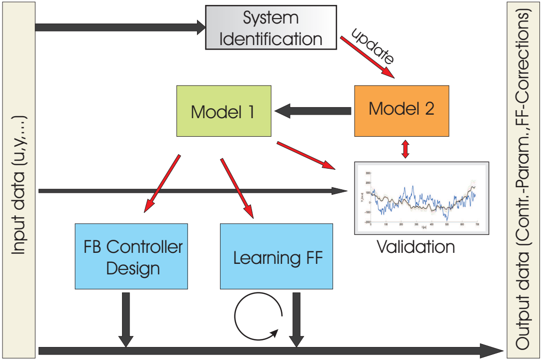
Exception handling is very important

- protection of trips and quenches in absence of beam
- Software issues
- Fast recoverable / convergence

⇒ Fast switch off correction tables



Basic concept of implementation



- Frequently or by change of operation point update the model
- Offline controller parameter estimation and verification
- User decision of updating parameters

Summary

- Development system can be used for parallel tests
- Identification procedure works sufficient
- Controller parameter estimation works reliable
- Stability measurements with beam show improvements
- Model based iterative learning controller was tested
- Combination tested $\Rightarrow$ runs successfully
- Automation !

Next shift period: tests of L-FF/MIMO performance with beam

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