LLRF Feedback Controller Design for ACC 1

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1. LLRF Control Structure
2. Feedforward and Feedback Control
3. Standard Controller Design Methods
4. March 2006 Shifts
5. Summary / Work in Progress
VUV-FEL - Structure

ACC 1
Low Level RF-System

How to do it best??
Current LLRF Control Structure

Feedforward

Feedforward Tracking Controller Error

Reference
Feedforward and Feedback Control

- **Feedforward**
  - No possibility to react on disturbances
  - Applicable for well known systems behaviour

- **Feedback**
  - Can attenuate disturbances
  - Robustness w.r.t parameter changes

- **Design inner prior to outer loops**
  - First steps: inner feedback loops!
Controller Design – Standard Method

• Modelling / Parameter Identification
  – Linear/nonlinear, discrete/continuous time models, …
  – Validation

• Design Control Loop Structure
  – Decentralized, MIMO, Robust, adaptive, …

• Choose Controller Structure
  – E.g. linear, PID, 2nd order discrete time, …

• Find Parameter of Controller Components
  – Rules of thumb, Optimization, Tools based, …

• Test Closed Loop
  – Simulation
  – Experiments
Modelling & Validation

Validation with newly estimated \( p(t) \)

Validation with \( p(t) \) identified for original ID data

[Koch 2005]
Control Loop & Controller Structure

• Experiences show that 3 parts should be used together
  – Feedforward Tables: adapted to current detuning situation
  – Reference Tables: tuned to basic system and setpoint properties
  – Feedback Controller: for disturbance attenuation

• New SIMCON developments [Buchholc, Koch et al.]
  – Feedback controller can be dynamic, not only proportional
  – Feedback controller need not to be decentralized
  – Parameters have to be found (robust / adaptive)

• Open Problems
  – Calibration: belongs to the controller & is tuned manually
  – Vector sum: Only solution to the problem of underactuation?
  – Feedforward tables: Adaption based on measurements?
March 2006 Shifts

- 2 main and 4 parallel studies

- SIMCON Implementation of 2nd order MIMO controller
  - Thanks to S. Buchholc, W. Kopreck et al … !
  - Not installed permanently
  - At the beginning of each shift calibration necessary
March 2006 Shifts

Main Aims During March Shifts:

- Check performance of SIMCON software
  - Limitations of the board
  - Data acquisition for modeling
  - Saturation limits

- Check response of dynamic controllers
March 2006 Shifts

Structure:

\[ K(z) = \begin{bmatrix} K_{11}(z) & K_{12}(z) \\ K_{21}(z) & K_{22}(z) \end{bmatrix}, \]

\[ K_{ij}(z) = k_{ij} \frac{1 + a_{ij} z^{-1} + b_{ij} z^{-2}}{1 + c_{ij} z^{-1} + d_{ij} z^{-2}}, \forall i, j = 1, 2 \]
Controller Parametrization Panel
Figure 1: Saturation of states in implemented controller (red)
To avoid saturation of states slide buttons are introduced in controller input screen.
March 2006 Shifts

Controller Design Approach

1. Single P controller
2. Full P controller
3. Decentralized dynamic controller
4. Full MIMO dynamic controller
5. Robust or gain-scheduled controller
Figure 3: System response to full P controller. (single gain resulted in RMS value of ~1.24 deg)
Figure 4 System response with dynamic controller (with only K11 dynamic).
Summary

• Software for SIMCON board is tested.
  – Cannot apply test signal for modeling
  – State saturation problem is encountered and rectified.
  – Can measure actual data.
  – No 250 kHz noise

• Full P controller is tuned which shows improvement in system response.

• Dynamic controller is designed and tested in closed loop.
Work in Progress

- **6 / 2006**
  - Further tests with 2nd order feedback controller
- **7-12 / 2006**
  - Better models for disturbances
  - Adaption / Robustness of feedback controller / Antiwindup?
  - Include Piezo Actuators in Control Loop Structure?
- **1-6 / 2007**
  - Adaption of Feedforward / Reference Tables
  - Iterative learning control?
- **7-12 / 2007**
  - Other ACCs
  - Integration test in closed loop
- **2008**
  - Increasing setpoint gradient
Thank you for your attention!

- Discussion -