Tutorial 1 :
Control Theory and Application to Accelerators and Fusion Reactors
Stefan Simrock

Feedback control plays an important role in the design and operation of modern accelerators and fusion devices. Feedback is required to stabilize inherently unstable system dynamics and processes and to improve machine performance. To better understand the theory of feedback control and be able to design feedback controllers this tutorial will consists of 3 parts:

1. Introduction to control theory (60 min)
2. Examples for control applications in accelerators and fusion devices (30 min)
3. Demonstration of control system analysis and design tools in the MATLAB / Simulink environment. (30 min)

Control theory deals with the behaviour of dynamical systems. The desired output of a system is called the reference. When one or more output variables of a system need to follow a certain reference over time, a controller manipulates the inputs to a system to obtain the desired effect on the output of the system.

Rapid advances in digital system technology have radically altered the control design options. It has become routinely practicable to design very complicated digital controllers and to carry out the extensive calculations required for their design. These advances in implementation and design capability can be obtained at low cost because of the widespread availability of inexpensive and powerful digital processing platforms and high speed analog IO devices.

The emphasis of the tutorial is on designing digital controls to achieve good dynamic response and small errors while using signals that are sampled in time and quantized in amplitude. Both transform (classical control) and state-space (modern control) methods are described and applied to illustrative examples. The transform methods emphasized are the root-locus method of Evans and frequency response. The state-space methods developed are the technique of pole assignment augmented by an estimator (observer) and optimal quadratic-loss control. The optimal control problems use the steady-state constant–gain solution. Other topics mentioned are system identification and non-linear control.

The example applications for accelerators will focus on beam energy, bunch shape, and orbit control, the examples for fusion devices include vertical position and shape control.

The demonstration of MATLAB / SIMULINK tools will cover the following topics:

1. Transfer function model of open and closed loop system (1st and 2nd order) for SISO and MIMO system.
2. Stability analysis using bode plots and root locus tool for SISO system
3. Controller design using pole placement, LQR design
4. Comparison of analogue versus digital designs for the PID controller

Stefan Simrock, Phd

Stefan Simrock received his Master's degree in Physics in 1983 from the Technical University of Darmstadt (TUD). His Ph.D. in engineering he received in 1988 for his pioneering work on "Radio Frequency Control for Superconducting Cavities" at the S-DALINAC pilot project at the Institute of Nuclear physics at TUD. In 1988 he went to the United States to join Jefferson Lab (former CEBAF), a worldwide leading facility for Nuclear Physics as deputy group leader of the Radio Frequency Systems group. As project leader of the RF control system he was responsible for the construction and commissioning of the rf control systems for the world's largest installation of 338 superconducting cavities. In 1993 he was appointed leader of the accelerator commissioning team with the goal of establishing recirculating beams with unprecedented CW performance.

During all times he was involved in international collaborations on rf control and in 1995 he was granted a sabbatical year at DESY to develop the first fully digital LLRF control system for the TESLA Test Facility. In the following he joined DESY as deputy group leader of the RF systems group. In 2003 he was appointed group leader of the beam controls group which is responsible for the timing and synchronization systems, the beam feedback system and the RF control systems at DESY. From 2005-2009 he concentrated on the development of a large collaborative effort with several universities and the introduction of modern system engineering methodologies for the design and construction of complex electronics systems.

Beginning of 2010 Stefan Simrock joined the CODAC group at international fusion project ITER located in southern France. He is now working on real time control issues related to the more than 50 diagnostics systems at ITER and their integration with the plasma control system.