Control Theory for RF Feedback and Longitudinal Beam Stability

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Introduction

Progress in digital hardware solutions such as field programmable gate arrays (FPGA) has raised the question of how to design the algorithms of RF feedback. This especially applies to the feedback of the RF cavities and the longitudinal beam feedback for SIS100. For example, FPGAs currently allow FIR (finite impulse response) filter lengths of several tens of taps. This number of degrees of freedom requires the appropriate modeling of the RF feedback loops and a subsequent analysis and design. The status of current control theory projects for RF feedback loops is described.

Progress in RF Feedback Analysis

Several aspects of the modeling of longitudinal single-bunch oscillations and their RF feedback have been studied [1]. In particular, the dynamics of the quadrupole mode damping loop were modeled and a stability analysis of the feedback parameter space was performed. Measured and simulated amplitude signals for three different experiments agree well as shown in Figure 1. In addition, it has been shown that the feedback of the sextupole mode behaves distinctly different in linear vs. nonlinear simulations. This result implies that the consideration of nonlinearities is necessary for a proper analysis of the bunch feedback. Therefore, the approach of [1] has been extended to include arbitrary nonlinear RF potentials [2]. The extended models rely on a moment approach and can be applied for small and long bunches in the stationary and acceleration case and for single and dual-harmonic operation. In the latter case, a linearization of the RF voltage is not feasible even for small bunch oscillations. To obtain models suitable for controller design, a simplification is made that neglects Landau damping. This makes the stability analysis of the feedback more conservative. However, this may be improved by including additional damping terms that approximate the Landau damping rate. Comparison with simulations shows a good agreement between the models and the full nonlinear beam dynamics. Collective effects are not covered explicitly, but may be incorporated in principle within a robust feedback design.

In a design study, a so-called Fuzzy Controller was developed and simulated to examine a different feedback approach [3]. This feedback uses linguistic rules to calculate the necessary phase shift for damping dipole oscillations. Simulations show good results in keeping the rms emittance at a very low level compared to Landau damping. In a further work, RF models have been derived which include Fourier coefficients [4]. This enables the analysis of beam loading.

Practical Implications

The analysis of RF loops has the following practical implications: Due to dynamical coupling between modes, a strong feedback that may damp a specific mode may therefore excite another. Thus, higher order modes should be taken into account during the feedback design process. The models reflect also the well-known fact that the RF phase modulation acts on odd modes, whereas the RF amplitude modulation acts on even modes. This is however only true for the stationary case. During acceleration, the phase modulation has a significant additional impact on the odd modes. However, a simple transformation may decouple this effect.

References