Control of the electron beam in the 1.5 GeV and 3 GeV storage rings at MAX IV using Model Predictive Control

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At MAX IV, electrons are accelerated to nearly the speed of light and then circulated in one of two storage rings at MAX IV. It is important that this electron beam is stable and controlled to a certain position. The aim of this thesis has been to develop a program that uses a model of the dynamics of the electron beam to predict how the beam will move in the rings, and by using that information, activate magnets placed around the rings that "push" the electrons to their correct position.

MAX IV is a synchrotron facility in Lund, Sweden that produces X-ray radiation for a wide variety of applications, from life sciences and biology, to material sciences and physics. There are two so called storage rings at MAX IV where electrons are circulated. One is the small ring of 1.5 GeV and the other is the large ring of 3 GeV.

We have developed a program to control the electron beam in both storage rings in the horizontal plane and the vertical plane using a method called Model Predictive Control, often shortened to MPC. The advantage of an MPC is that it can, as the name suggests, predict how the beam will move in the rings given where the beam is currently, and then apply the optimal control signal to the corrector magnets to push the electron beam in the right direction. Another big advantage of an MPC is its ability to respect constraints, in this case that there is a maximum magnitude of current which can be sent through the corrector magnets. If the magnets saturate, then the current program can not control the beam correctly and the program will have to be restarted. This slows down research and every minute of downtime costs a lot at MAX IV.

Our MPC has shown in tests that it can handle constraints on the control signal, that is find a solution that controls the electron beam while simultaneously working within the boundaries in both of the rings. This greatly improves the reliability of the control system. Another task of the MPC is to help offload a second controller that reduces the amount of noise in the beam. Our MPC has in tests not been able to offload the second controller properly. A third task of the MPC has also been to control the energy shift caused by changing the magnet currents. Every time the corrector magnets receives a new control signal, the total energy of the beam is shifted due to the circumference of the beam's orbit being changed and this needs to be corrected. Unfortunately time to test was limited and this was not confirmed to work, but some of the results were hopeful. The program was implemented using the programming language Python and a system called Tango which facilitated communication between the MPC and the ring.