Fast retuning of superconducting radiofrequency accelerating cavities in the European Spallation Source linear accelerator.

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ESS stands for "European Spallation Source" and will be the worlds most powerful neutron source. A neutron source is used much like a microscope, to investigate all kinds of materials in order to gain an understanding about them. In a microscope, light is used for investigation of materials whereas ESS will use neutrons. Neutrons interact with matter in a different way than light. This means that other characteristics of materials can be identified and understood using a neutron source compared to what characteristics can be investigated using a microscope.

Small particles are accelerated towards a metal target which causes the neutrons in the metal nuclei to be knocked out from the nucleuses. This process is called *spallation*. The small particles used at ESS are protons. Protons are used because they are heavy enough to be able to knock out neutrons and because they are charged particles. Charged particles are convenient since they can be accelerated using electromagnetic fields. The protons at ESS are accelerated using a linear accelerator. The linear accelerator at ESS will be 600 m long and the protons will gain most of their energy using 146 superconducting radio frequency cavities, which are called RF cavities. A simplified model of a cavity is an empty metal can in which standing electromagnetic waves can be maintained. A fast particle passing though a cavity will experience the field at one phase of the standing wave. What this means is that the particle will experience different field strengths depending on what point in the standing wave cycle the particle enters the cavity. This point in time is called *input phase* and is one of the two settings that can be tuned on a cavity. The second setting is the power, i.e. the amplitude of the standing wave. The power of a cavity has a max value due to limitations in the powering system. The RF cavities require a lot of energy to run and are powered by a sophisticated power system. Each cavity is powered by an independent power system. Because of the complexity of these power systems, a cavity is sometimes offline because of power supply failure. The researchers using the neutrons want the beam to be on at all times which means that ESS should be able to handle an offline cavity.

In essence, each of the cavities give the protons a little kick. The tricky part is that the kick needs to be at the correct time and strength to give the protons as much energy as possible. Imagine a relay-race where the protons are the sticks being passed between the cavities which can be thought of as the runners. Each runner have to know the speed of the runner before and after to be able to pass the stick as effectively as possible. If one runner is standing still the stick does not reach the end of the track. But perhaps if the runners around the still one adjusts their speed and timing, the stick will reach the end of the track? So if the cavities surrounding the offline cavity have their settings retuned, the stick might still reach the end of the accelerator. The final speed of the protons might be a little less but as long as the beam is stable this is not a huge issue.

In order to find the correct cavity settings, the accelerator was represented by a mathematical model. In this model two virtual accelerators could be created, one where all the cavities are functioning and one where one of them is offline. Most cavity settings were left unchanged, only the settings of the four closest cavities to the offline one were changed. How good the settings of the faulty accelerator are can be determined by comparing one or two different characteristics of the two virtual accelerators. The best settings were found by letting the computer try hundreds of different settings and choosing the settings that resulted in the faulty accelerator having the most similar characteristics to the fully functioning accelerator. The computer did not just guess, it used a genetic algorithm that uses the principles of evolution to generate better and better solutions.

Using just one characteristic of the accelerator while choosing the best settings resulted in a beam that was fairly stable, but with slightly lower final speed compared to the fully functioning accelerator. A lower final speed is expected. In order to improve the stability further, another characteristic of the accelerator was included in the choosing of the best solution. Sadly this attempt was not very successful since the beam stability barely improved but the calculation of choosing the solution took a really long time. The retuning should be quick to ensure access to the neutron beam. There is still room for improvement of the retuning routine. One of the major things that were not include in the mathematical model of the accelerator was that the beam in the accelerator is not just one proton but many protons together. The protons are all positively charged and will be affected by the electromagnetic fields generated by the other protons in the beam which alters the trajectory of the particles in the beam. Including this affect in the mathematical model might enable the computer to choose an even better solution to the accelerator settings.