Optimum design of ‘kicking magnets’ for the successor of the LHC

The Future Circular Collider (FCC) is a conceptual study to develop the program for the successor of the LHC. A new particle accelerator will work at higher energies or with higher precision. New magnets that inject or extract particle beams – so-called ‘kicking magnets’ – need to be used due to the unprecedented collider energy. Researcher Alejandro Sanz Ull investigated three different types of those magnets and found the optimum injection and extraction design.

The discovery of the Higgs boson at the Large Hadron Collider (LHC) in 2012 marked an important milestone in particle physics and it provided confirmation of one of the cornerstones of the Standard Model of physics. However, it did not answer all the open issues in the Standard Model and it also opened many new questions. A deeper understanding of the open questions in physics, such as the details of the Higgs mechanism and discoveries on supersymmetry, dark matter, the matter-antimatter asymmetry and the origin of the neutrino masses may be found at higher energies or with a higher precision machine.

A collider of this magnitude will most likely take at least two decades, so it is necessary to start designing the machine now in order to start operating at the end of the LHC life. The Future Circular Collider study is meant to develop a long term program for a new accelerator project. The most promising approach is to first build a technology ready, high-intensity lepton collider (FCC-ee), followed by a high energy collider (FCC-hh).

To either inject a beam into or to extract it from a storage ring, kicker magnets are usually employed. They are able to generate extremely strong pulsed "kicking" fields to impart a sufficiently large deflection angle to be able to merge a particle bunch into or take it out of the storage ring orbit in a controlled way over a reasonable length.

In fact the required pulsed field strengths cannot be realized in practice. For this reason so-called (electrostatic or magnetic) septum modules (septa for short) are employed. A septum in a storage ring is a sharp division between a low-field region (ideally zero) and a high-field region (ideally uniform).

During normal operation the beam in the storage ring travels though the low-field region, ideally unperturbed. If, for instance, the beam has to be dumped, a kicker magnet will deflect the orbiting beam by a small angle, pushing it into the high-field region of the septum magnet downstream. In the high field region the deflection angle will be amplified significantly, allowing the beam to be extracted over a relatively short length. The septum module thus acts as a static amplifier of the pulsed kicker magnet.

The importance of the design and development of reliable septum modules can therefore hardly be overstated. The fundamental design challenges are immediately clear: the field in the high-field region should be as high and uniform as possible, the field in the low-field region should perturb the orbiting beam in the storage ring minimally, and the separation between the two, the septum (blade), should be as thin as possible, and also robust against activation and damage by the high-
energy particle beam sweeping through during injection of extraction.

Researcher Alejandro Sanz Ull performed finite element magnetic simulations to analyse in detail the maximum achievable magnetic field. He investigated three different superconducting septa types, which were ranked systematically using a new figure of merit developed during his research. He then used this to choose the best performing septa to propose a layout shorter than the baseline, both for injection and extraction. A shorter system means producing a lower number of magnets, which will reduce the overall cost. He developed an analytical method to find the optimum number of septa stages and to optimize the number of septa within each stage.

He also explored the novel idea of using a massless septum, which has no physical septum blade, in combination with a transverse deflecting radiofrequency cavity. The function of the RF cavity is to compensate the unwanted deflection produced by the leak fields. Alejandro estimated an energy range where this idea could be applied.

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