MAP Acceleration Meeting, April 2011: Hybrid Fast-Ramping Synchrotron

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Abstract

For the initial design configuration for a muon collider, the Muon Accelerator Program (MAP) has chosen a hybrid fast-ramping synchrotron as the final acceleration stage. By "hybrid," we mean that the bending is accomplished with a combination of fixed-field superconducting and ramped room-temperature dipoles. At the meeting, we specified the basic structure of the lattice. The dipoles will use grain-oriented silicon steel, quadrupoles and sextupoles will use non-oriented silicon steel. We specify the maximum magnet pole tip fields based on these material choices. We describe a program of magnet studies for the ramped magnets, focused on the dipoles constructed from grain-oriented silicon steel.

1. Lattice Design

The machine will use 1.3 GHz superconducting RF cavities with a gradient of 25 MV/m phased 30° off-crest. It will accelerate from 375 GeV to 750 GeV in 24 turns. This number of turns is approximately the transition between the when the RF efficiency is rapidly increasing with number of turns and when its increase with number of turns slows.

The lattice will consist entirely of FODO cells, arranged into 8 superperiods, each superperiod having an arc and a straight section. 8 superperiods is chosen to ensure a sufficiently large number of RF sections to allow a high synchrotron tune, while not unnecessarily increasing the number of straight sections and the consequent loss of average bending field due to unused straight sections (see below) and matching sections. Chromaticity will be corrected globally in the ring using sextupoles in the arcs. Each arc cell has two sextupoles, one near each quadrupole. To maintain symmetry and maximize the effectiveness of the sextupoles, each quadrupole in the arc cells will be split in two with the sextupole placed between the two, leading to a structure of QF-SF-QF-O-QD-SD-QD-O. All arc cells will be identical. Their phase advance will be a rational number times 2π which will give cancellation of resonance driving terms from the sextupoles.

Each straight section (of which there are 8) will consist of three cells. The two outer cells will contain RF cavities, and the central cell will be left available for injection, extraction, or other diagnostic hardware. This choice (rather than having special straights for injection and extraction) gives the lattice symmetry which should improve the lattice's dynamic aperture. The three straight cells will be identical. Their phase advances will be different from that of the arc cells so as to prevent the tune from being a rational number. There will be two-cell matching sections between each arc and straight, which will zero the dispersion in the straight and make the energy-dependent closed orbit go down the center of the straight, as well as matching the Courant-Snyder lattice functions.

The arc cells will contain a combination of fixed-field superconducting dipoles and ramped room-temperature dipoles. The room-temperature dipoles and the quadrupoles will be ramped as the beam momentum increases so as to

- Keep the phase advance constant through each individual cell.
- Keep the global time-of-flight constant in the ring.

The fixed-field and ramped dipoles will be arranged so as to minimize the beam excursion in the magnets while maintaining these constraints. If there are multiple ramped dipoles in a drift, they may have different fields at a given time so as to help achieve this goal.

We envision having preliminary designs available by the end of September 2011.

2. Magnets

To insure that the ramped magnet stored energy is dominated by the field in vacuum, fields in ramped magnets should be kept below where the iron saturates. Thus, maximum fields will be as follows:

- 8 T fixed-field superconducting dipoles
- 1.8 T in ramped dipoles, based on the use of grain-oriented silicon steel.
- 1.3 T in ramped quadrupoles in sextupoles, based on using non-oriented silicon steel.

We discussed the use of a cobalt-iron alloy which could achieve 2.1 T, but

- Eddy and hysteresis losses would be doubled
- The cost of the steel would be around 10 times higher
- The cobalt could be activated

This alloy will not be used unless design studies show that the benefit of the higher fields justifies the disadvantages of using the material.

2.1. Hardware Studies

The dipole magnets are the main hardware challenge for the fast ramping synchrotron. While the quadrupoles have challenges which are in some sense similar, the use of grain-oriented silicon steel in the dipoles is a significant innovation in accelerator magnets.

A first dipole has been built and tested. It was only able to achieve 1.5 T, and the losses were about twice what was expected. A second dipole will be built and tested in the summer of 2011. Compared to the first dipole, it uses a different geometry for the connection between the flux return and the pole piece on one side, in that the pole piece penetrates into the flux return, and there is a diagonal boundary at the turned corner. A new gaussmeter is being purchased to obtain better field measurements.

We also identified a need to have code that would properly simulate the grain-oriented steel. This will allow us to understand more precisely why the performance of the tested magnet was less than expected. We did not know of any code that was capable of this, though one company that produces a 2-D code suggested that they could insert that capability into their code. However, a 3-D simulation was considered essential since the magnet ends have a significant effect on losses. We will consult with magnet experts to determine if there are any codes with these capabilities.

To be able to verify that the model in the code was correct, we also identified a need to have a device that measures the directional B-H curve of a sheet of material. Such a device would cost around $20K. It would be most useful in conjunction with the simulation studies, to verify that the B-H curves use in the simulation are accurate.