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MAIN-RING CORRECTING MAGNETS

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The criteria for the specification of the main-ring correcting magnets have been reviewed in the light of the data from magnet models and consideration of the scope of the present construction project. In general, we have decided that correcting magnets which might be needed later for increases in energy above 200 BeV, and especially for increases beyond 400 BeV, should have space left for them, but their specification and design, as well as production and installation, can be left to the future. In most cases, this implies that the correcting magnets serve to correct injection fields for remanent effects. Another function, requiring the same magnitude of correction, is the compensation of survey errors during the first attempts to circulate beam.

Dipole Steering Magnets

These correct remanent fields and provide initial compensation for survey errors. If one assumes a 10% variation in remanent field (a large figure, when one remembers that this is an average over eight 20-foot magnets, so that it <u>includes</u> the needed factor of safety) the horizontally deflecting magnets must have a field of about 150 G peak for one foot of length, with one located near each horizontally-focussing quadrupole. Similarly, if the eight magnets have a field tilt of 1 mrad, the vertically steering dipoles would need a field of 60 G for one foot of length, with one magnet located near each vertically-focussing quadrupole.

Referring to quadrupole misalignments, to correct for 15 mils, one needs only 15 G peak. If there are field errors at high fields, much more likely at 400 BeV than 200 BeV, the magnet positions can be adjusted to keep the orbit distortions at full energy within allowable limits at the cost of errors at low fields which can be compensated, at least partially, by the correcting magnets. The needed, or useable strengths are the same as those given above.

The power supplies for the dipole steering magnets must be individually controlled, but since low-field effects only are being corrected, dc supplies, as constrasted with programmed supplies, are all that are needed.

Trim Quadrupoles

The principal trim quadrupole system, consisting of one correcting magnet near each main quadrupole, all connected in series with the same sign of focussing, adjusts the difference between ν_x and ν_z. The defining requirement is a separation of 0.05 at full energy to prevent difficulties with the resonant extraction system. If each magnet is a foot long, the required gradient is 15 G/cm = 1.5 kG/m. This system must also compensate for spill modulation by ripple in the main-quadrupole current and will probably be used in the spill control servo. The power supply must be bipolar with current control up into the audio-frequency range.

In order to correct for azimuthal variation in the focussing strength which opens up stopbands at $\nu = 20$ and $\nu = 20.5$, 16 of these trim quadrupoles must have separate control to control separately the sin and cos of the 40th and 41st azimuthal harmonics for x and z motion. Constant current power supplies connected in parallel with the magnets to be controlled will allow superposition of the two functions. Only low-field compensation is needed, as the important effect being eliminated is caused by space-charged coupling of phase and betatron oscillations, resulting in FM sidebands which could hit one of the stopbands. If one assumes that the rms variation in focussing strength is 10^{-3}, the required peak gradient is the same as that calculated for ν splitting at full energy.

Sextupoles

At the time the Design Report was written, a possible need for high-powered sext poles to correct for bending-magnet field errors was seen. However, model magnet measurements have shown that there is no significant sextupole component up to fields of 18 kG except for a small remanent effect. Accordingly, dc sextupoles with enough capability for correcting the injection field are all that are necessary. The second bending-magnet model (the first large gap, or B-2 model), using steel with a coercive force of about 1.0 Oe, had a measured remanent sextupole component of 0.4 kG/m^2. Allowing for twice this to include a factor of safety, a sextupole at each station, one foot long, with a strength of 60 kG/m^2 would be adequate.

One technique for preventing coherent instabilities is to introduce a tune spread. The inherent sextupole component in the bending magnets would provide a spread in ν of 0.12 for $-4\ \Delta p/p = 10^{-3}$ which would be more than sufficient. A slight under or overcompensation of the bending-magnet errors by these low-powered sextupoles can thus provide control at low-beam energies, especially for the period of coasting beam during injection.

The power for the tune spread control can be a simple dc supply (or a number of dc supplies connected in series to distribute the emf). Random fluctuations in the remanent field of the magnets will have a component at the 61st azimuthal harmonic which can drive the 20-1/3 nonlinear resonance used for beam extraction, or the equivalent vertical resonance. To eliminate this, eight of the sextupoles must have individual control, similar to that provided for the trim quadrupoles, only chosen to generate the 61st instead of the 40th and 41st azimuthal harmonics. Unlike the trim quads, however, these eight sextupoles must be stronger--a peak capability of 250 kG/m^2 being needed.

Skew Quadrupoles

Errors in the determination of the field directions in the quadrupoles can couple the vertical and horizontal betatron oscillations at the sum and difference resonances. The coupling at the difference resonance can be eliminated by six skew quadrupoles (or a multiple of six) placed uniformly around the ring. Assuming an error in the determination of the quadrupole axes of 1 mrad, and 6 correcting skew quadrupoles each 1-ft long, a field gradient of about 100 G/cm is needed. The power supplies for these magnets must be programmed.

The sum resonance should only cause trouble when space charge effects cause a spread in tune and coupling between betatron and synchrotron oscillations. Four skew quadrupoles each a foot long, placed so that they generate azimuthal harmonics proportional to sin 41θ and cos 41θ with peak field strength equal to 15 G/cm would adequately correct the injection field.

Magnet Design

There would be advantages in air-core magnets, where the power is low enough to make this practicable. Such do not have remanent fields or hysteresis which can plague adjustment procedures. On the other hand, there would be some influence from the adjacent structural iron, unless the air-cored magnets were shielded, and the power required for air-cored magnet could be significantly larger than that for iron-cored correcting magnets. It is also possible that the magnets could be designed shorter, with higher field with an iron core, saving space, and reducing remanent and hysteresis effects. In any case, they should be laminated to allow programmed currents to be used.