CALIBRATION OF THE RING MODEL FOR THE NSLS RINGS*

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Abstract

The mathematical model of an accelerator can be used to control its operation and also to simulate its behavior. Part of the model is the conversion between the computer controlled digital setpoints of the magnets and the actual field acting on the average particle in the magnet. We are using tune, dispersion and chromaticity measurements to calculate this conversion, thus calibrating the model rather than the magnets themselves. This is one way to include effects, not taken directly into account in the model. The model has to be calibrated at different beam momenta, and possibly at different beam intensities.

Model calibration

The mathematical model of an accelerator can be used to control its operation and also to simulate its behavior. Through the use of such modeling programs it is possible to control a few important machine parameters rather then the many individual magnets. Such programs have been developed for the current generation of accelerators, and the RING[1] program at the NSLS falls into that category.

The control and predictions are as good as the models themselves. All models represent a simplification, thus introducing deviation of the real machine from its mathematical model. The accuracy of the model is limited by the approximations made in describing the structure and components of the accelerator and the behavior of the beam, by the omission of some effects from the model and also by the errors and uncertainties of magnet calibrations which are incorporated into the model (see Fig. 1.).

An alternative or complimentary method to the magnet calibrations, a method which empirically eliminates the effect of all inaccuracies is the calibration of the model itself through calibration of "physics" quantities (e.g. tune, dispersion, chromaticity, etc.) from measurements on the operating machine (see Fig. 2).

Magnet calibration

A procedural step in the RING program operation is the conversion between the computer controlled digital setpoint of the magnets and the effective magnetic field acting on the average particle traversing the magnets. The conversion is made in two steps:

1) D, digital setpoint ⟷ I, current in Amp
2) I, current in Amp ⟷ F, effective magnet strength (B [KG], B'[KG/m], B''[KG/m^2])

The first conversion, the Amp/Digit ratio is characteristic to the power supply feeding a group of magnets and not the magnets themselves, and it was measured with ~.3% accuracy.

The second conversion requires time consuming measurements on individual magnets or samples of each magnet type. These measurements should include the magnet strength/current ratio as a function of the excitation current, the degree of uniformity of the magnetic field along the magnet, the presence of multipole fields and the "edge" effect in dipoles. Pressure of construction schedules often precludes complete field mapping of all magnets at many excitation levels.

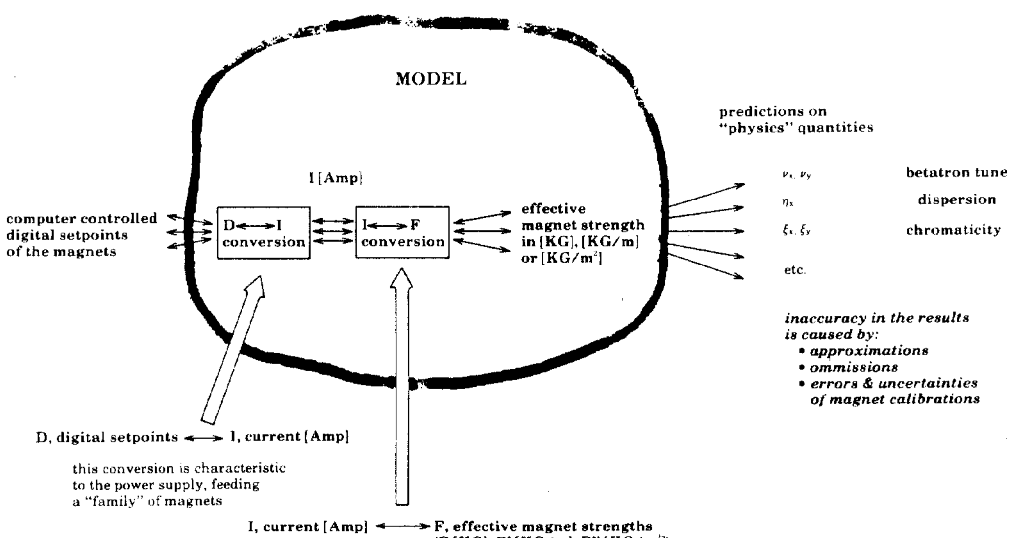

Fig. 1.

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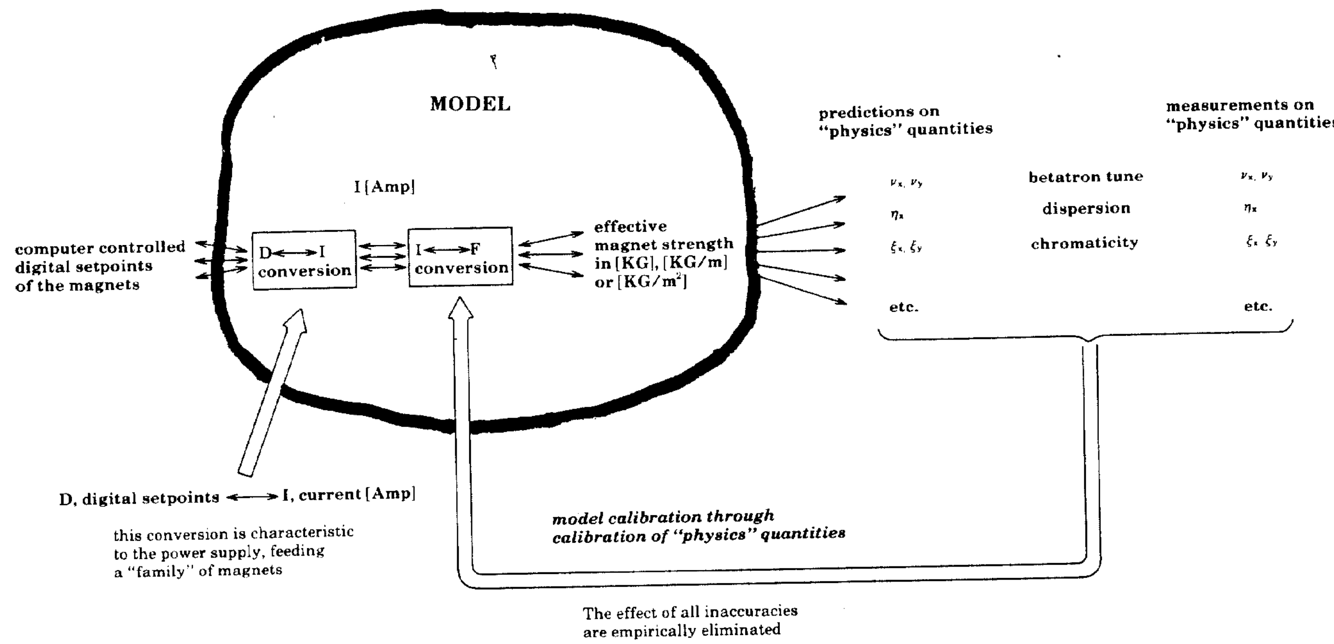

Fig. 2.

For those NSLS magnets which are operated in the region of significant saturation, a polynomial

$$F = \sum_{i=o}^{n} a_i \, I^{i-1}$$

was fitted to the available measured data. Otherwise $F = C*I$ linear behavior was assumed, where the C constant conversion factor was measured at one excitation current only.

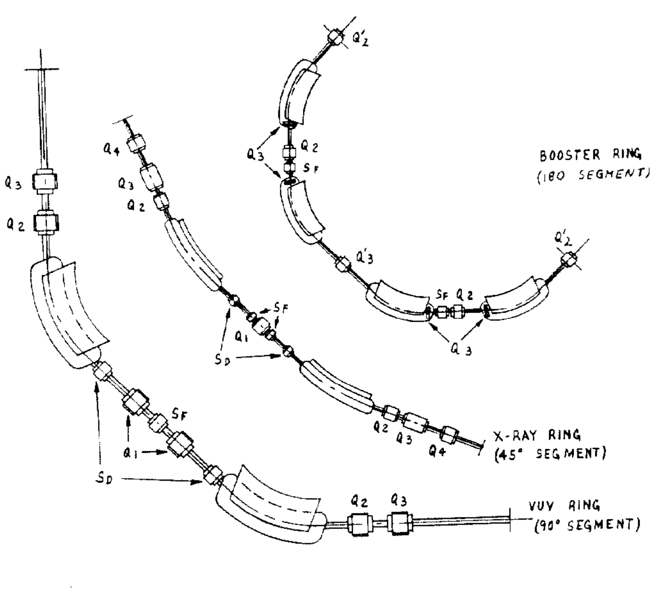

Fig. 3.

Calibration of the model from beam measurements

All NSLS rings (shown in Fig. 3) were designed to have modular control features; that is certain groups of magnets are used to control only specific "physics" quantitites.

There is only one family* of dipoles in each ring, and its strength, B relates only to the P_o beam momentum, as P_o [GeV/c] = B[KG]ρ[m]/33.356 where ρ is the bending radius of the magnet. One family of quadrupoles of strength B'_{Q1} is used to make the straight sections dispersion free: $\eta_x = 0$. The desired ν_x and ν_y betatron tunes are achieved by adjusting the strengths of two** families of quadrupoles, B'_{Q2} and B'_{Q3}. Finally, the ξ_x and ξ_y chromaticities are controlled by the B''_{SF} and B''_{SD} sextupole strengths. The orthogonality of these control functions enables convenient calibration of the model. In each case, an experimental calibration factor can be derived which is used for the conversion between magnet strength and current.

Measuring η_x in the straight section as a function of B'_{Q1} at different beam momenta on one hand, and modeling the ring to calculate B'_{Q1} which yields $\eta_x = 0$, the $C_{Q1} = B'_{Q1}/I$ calibration factor have been obtained.

* When a number of identical (within manufacturing tolerances) magnets are powered by the same power supply and thus controlled together, we will refer to them as one "family" of magnets.

** In the X-ray ring three quadrupole families are used to control ν_x, ν_y and one other measurable machine function. The Booster ring also poses a special problem since there is only one power supply feeding 2 different magnet types (they have different coil turns) Q_2 and Q'_2. In addition the Q_3 quadrupoles are much weaker, their max. strength is 15% of the max. strengths of Q^2.

Measuring the ν_x, ν_y tunes at different momenta and at B'_{Q1}, B''_{SF}, B''_{SD} such as to make $\eta_x = 0$, $\xi_x = \xi_y = 0$ and asking the model for B'_{Q2} and B'_{Q3} (and B'_{Q4} in case of the X-ray ring) which yield the measured tunes, the C_{Q2}, C_{Q3} (and C_{Q4}) calibration factors have been obtained.

Measuring the ξ_x, ξ_y chromaticities and using the model to simulate the corresponding sextupole strengths, the C_{SD} and C_{SF} factors have been obtained.

When the C calibration factor was found to be different at different P_0 (i.e. at different I excitation currents) the F = C(I)* I calculated fields were fitted with a polynomial whose coefficients then are stored for the given magnet group. The calibration factors can exhibit non-constant behavior not only when the magnet's "working point" falls into the saturation region, but also due to non-linear effects in the rings, which were not included into the model.

The advantage of this method is, that it compensates for any inaccuracy in the magnet measurements. Actually, there is no need for magnet measurements at all, which might be of great help for super large accelerators where accurate measurement of all magnets is very time consuming and costly.

Inaccuracies in the calibration

There are effects, not directly included into the model, whose significance are different under different operational conditions. This introduces some inaccuracy into the model calibration. For example, as the beam intensity is increased, different beam instabilities will be important and they effect the measured tune.

Acknowledgement

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