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ABSTRACT

This report outlines the system of computational codes used to obtain values for the trim-coil currents to effect an optimal adjustment of the magnetic field in the 88" cyclotron at Berkeley according to the method described by one of the authors.

The machine computation is traced through steps of analysis of measured field data, determination of restraints for a linear model of the problem, construction of the linear-program matrix, solution for values of trim-coil currents, iteration to improve on this solution, and prediction of orbit properties in corrected field.

COMPUTATIONAL PROCEDURES IN THE ADJUSTMENT OF A CYCLOTRON MAGNETIC FIELD BY TRIM COILS†

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1. Introduction

This report outlines the computer system used to calculate trim-coil currents which will minimize phase-shift and gradient fluctuation in the magnetic field of a fixed-frequency spiral-ridge cyclotron. The theoretical exposition for this task and its reduction to a linear programming problem have been given by one of the authors (see ref. [1])).

The numerical calculations of the optimal currents may be readily separated into four blocks, consisting of data preparation, analysis of the measured field, construction and computation of the linear programming problem, and adjusted field prediction and iteration. Calculations may be made at any excitation level for which field and trim-coil effects data are available. A schematic diagram of the calculations is shown in fig. 1. Greater detail on this system is given in (ref. [2])).

2. Data Preparation

For a particular level of excitation the following information is required:

(1) Uncorrected field measurements, in gauss, on a polar grid with coordinates (R,θ) with uniform steps in R, and for each R with uniform steps in θ.

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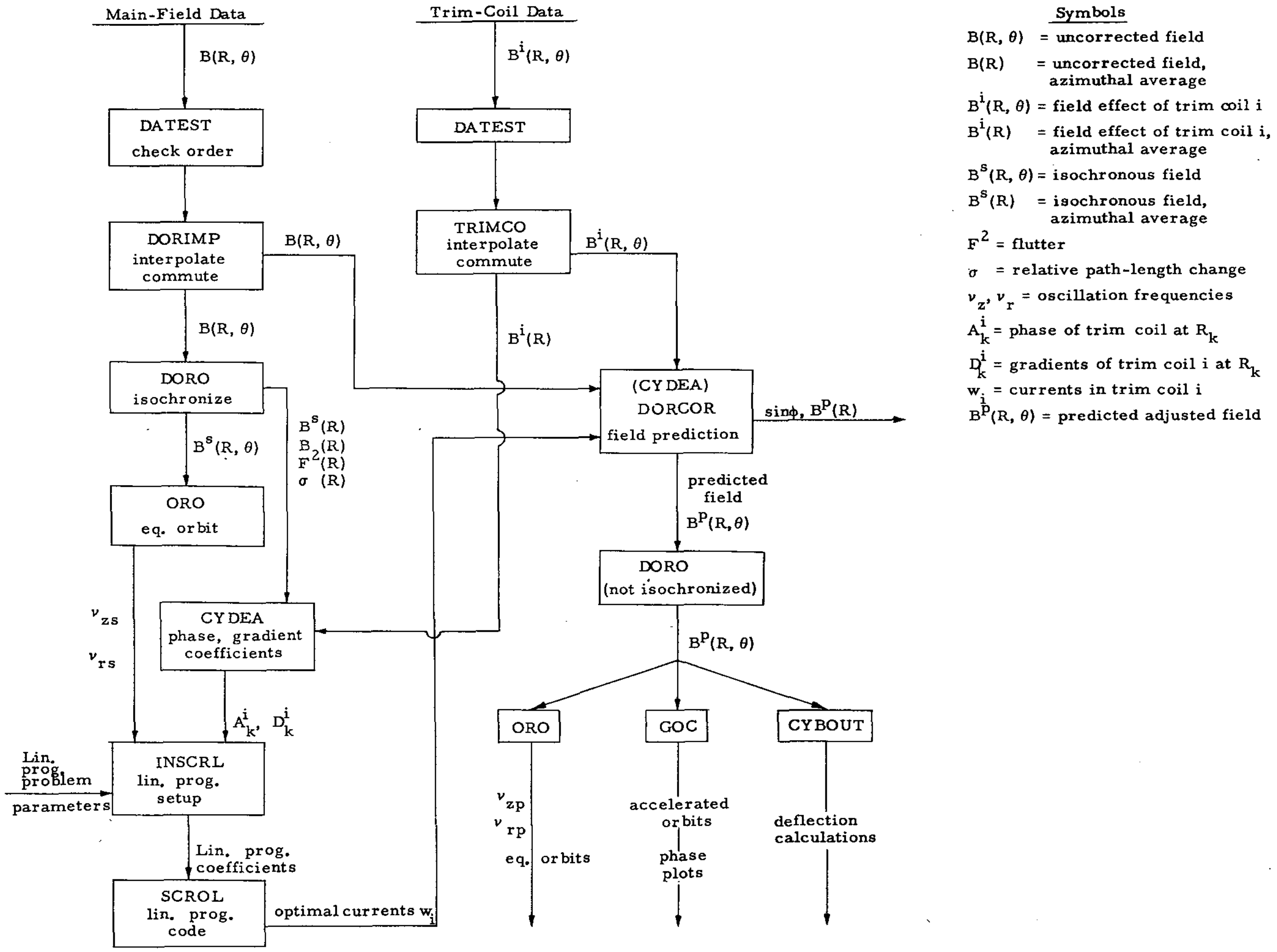

Fig. 1. Schematic diagram of trim-coil adjustment computation. (Boxes indicate calculation by codes in capitals; output is indicated along exit lines.)

(2) Measurements, in gauss, of the effect on)or change in) the above field for a specified change in main-coil current on a similar grid.

(3) Measurements of the effect on the field (1) for specified currents in each of the trim-coils on similar, but not necessarily identical, grids.

Each set of measured data must be ordered into subsets corresponding to increasing radii, and within each such subset the data must be in order of increasing azimuth. The data may be checked for proper ordering by the IBM 709 code DATEST (ref. [2])).

Since the various data (1), (2), (3) need not be measured on the same grid, it is necessary to select a basic sector grid on which all later computation is based. Averaging sector-wise (if more than one sector has been measured), interpolation in azimuth (if some grids are more coarse than others) and commutation in azimuth (if the first θ of the measurement grid is not the initial θ of the basic sector) may all be necessary.)

The IBM 709 code DORIMP (ref. [2])) processes the main-field data (1) and produces a basic sector map of main-field data in suitable format for later use.

The IBM 709 code TRIMCO (ref. [2])) performs a similar function on the effects data (2) and (3) with any specified normalization. This code also computes, for each effect, the azimuthal average at each radius.

3. Analaysis of Measured Field

In order to calculate the isochronous-field profile corresponding to the flutter produced by the uncorrected field, we run a sequence of calculations with the isochronization code DORO (ref. [3])) and the Oak Ridge Orbit code 1482 (ref. [4])). The first run with DORO reads the measured "iron" field from DORIMP and outputs parameters and binary tapes containing a field with the same azimuthal variations, but with the radial profile approximately corrected for isochronism. The orbit code ORO is then run with these parameters and tapes from DORO, and the revolution times of the equilibrium orbits calculated at the measurement radii. These times are used in a second DORO run to further correct the isochronous profile. From this DORO run we obtain the (azimuthally) average uncorrected field, the average synchronous field, the flutter-squared, and fractional change in path length at each radius. The new binary tapes produced are used for a second ORO run which provides us with the synchronous radial and vertical oscillation frequencies.

4. Construction and Computation of the Linear Programming Problem

The IBM 709 code CYDEA uses various parameters pertaining to the field, to the particle being accelerated, and to the operation of the cyclotron. It also uses the average uncorrected field values, average synchronous field values, flutter-squared values and fractional path-length change values (all of which are functions of radius that were computed in the second DORO run). With this information CYDEA computes the phase shift and radial gradient of the uncorrected field at each radius. In addition, using the average-effects values (functions of R computed by TRIMCO), this code computes the changes produced in the phase shift and gradient at each radius by unit (normalized) change of current in the main coil, and by unit (normalized) current in each of the trim coils. The change in phase shift at each radius for change in frequency is also computed. All computations performed by this code are in accordance with formulas given in (ref. [1])).

The IBM 709 code INSCRL, run subsequent to and in conjunction with CYDEA, reads in bounds for main-coil current change, for trim-coil currents, for the variable δ (corresponding to the fractional frequency shift), for the variable λ (corresponding to the maximum-in-R sine of the phase shift, and for the variable μ (corresponding the maximum-in-R gradient fluctuation). It also reads in necessary coefficients for the last two variables. INSCRL uses these quantities, together with those produced by CYDEA, to construct the linear program matrix and right-hand side in format suitable for the linear programming code SCROL. (For code description of CYDEA and INSCRL see ref. 2)).

The IBM 704 code SCROL (ref. 5)) computes the optimal solution to the linear programming problem as constructed. This solution is optimal in terms of minimizing λ and μ (see ref. 1)). The output provides (as values for the dual variables of the linear program) the optimal change in main-coil current, optimal trim-coil currents, optimal frequency shift, and corresponding absolute values of λ and μ for the minimization of some linear combination of the latter variables.

With fewer power supplies than trim coils, it is necessary that some trim coils must be combined in series, so that they operate at the same current level. The results from the SCROL run above can be used to select these combinations.

CYDEA-INSCRL may now be run with variables representing currents in power supplies rather than in individual trim coils. The subsequent SCROL run will then provide optimal currents for the trim coils when they are run in combination.

5. Adjusted Field Prediction

The IBM 709 code DORCOR (ref. 2)) may be used in conjunction with, and subsequent to, CYDEA to construct a predicted adjusted field on the basic sector grid from the uncorrected field map obtained from DORIMP, and from the effects maps obtained from TRIMCO. DORCOR also computes the main and trim coil currents in amperes and, for each radius, the average adjusted field, the phase shift, and gradient fluctuation.

The adjusted field, as predicted by DORCOR, should be analyzed by use of DORO and ORO. This analysis is necessary to determine if the adjusted field as predicted is satisfactory.

6. Iteration

The cyclotron magnet can now be operated with the computed currents in the main and trim coils, and the resulting field measured and compared with the predicted field. Some discrepancy is to be expected because of linearity assumptions implicit in the linear program approximation. If improvement seems desirable we may repeat the computing process, replacing the uncorrected field measurements by adjusted field measurements and using variables in the linear program to represent changes in coil currents from the first computed values. The results from the SCROL code will then provide optimal values for these changes, which can be added to our original currents.

Use of Results

The resulting currents should then be used for actual cyclotron operation. Orbit characteristics may be predicted by use of DORCOR, DORO, and ORO as previously described. Accelerated and deflected orbit studies may be made by using DORO-produced binary tapes with the codes GOC and CYBOUT (ref. [6])).

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