MAGNETIC FIELD MEASUREMENTS AND DATA ACQUISITION OF A MODEL MAGNET FOR THE B-FACTORY

Zhou Wenming* and Kuninori Endo
National Laboratory for High Energy Physics
1-1 Oho,Tsukuba-shi,Ibaraki-ken 305, Japan

ABSTRACT

In this paper we describe magnetic field measurements and the field data-acquisition system used to measure the model magnet for the B-factory booster.

The results of the measurements indicate that the method adopted here is good for acquiring field data . This type of measurement is highly accurate and involves almost no temperature coefficient. The instrument is used not only for ac, but also dc field measurements. It is especially good for field measurements in the case of simultaneous ac and dc field excitation .

DESCRIPTION OF THE DATA ACQUISITION SYSTEM

The proposed B-factory booster will be a rapid cycle-type accelerator. Its repetition rate is to be 50 Hz. A modified existing dipole magnet for the TRISTAN-AR is being used in the simulation research concerning the resonant magnet network and the power supply. The present work is part of a study on the rapid-cycle synchrotron magnet and power-supply system.

A measurement probe is attached to a table and has a small flip coil with 2065 turns and is movable over a region of 700 mm x 1500 mm on the measurement table. The positional error of the probe is about ± 10 µm at each step and less than ± 65 µm which is the error accumulated when traveling the entire table.

The computer controls dynaserv 1 through fineserv 1 in order to change the probe position.[1] An integrator controls dynaserv 2 through fineserv 2 in order to flip and flip back the probe coil. After the induced voltage of the flip coil is converted to digital data in the integrator , data is acquired by the computer.

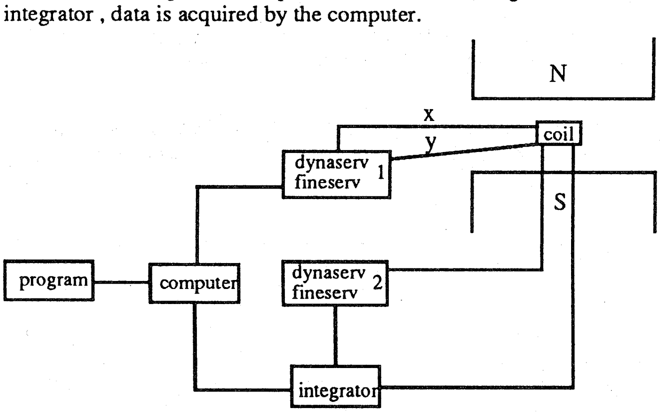

Figure 1 Data-acquisition system

The area of the magnet pole face is 200 mm x 1240 mm. Measurements are automatically performed point by point at an interval of one centimeter on the medium plane of the magnet. Data acquisition and the movement of the flip coil are alternatively performed during the measurement. The data-acquisition systems are shown in figure1.

The acquired data are plotted and displayed on a screen, stored in the hard disk of the computer and printed by a printer. If some acquired data is incorrect, it can be found immediately.

* On leave of absence from the Institute of Modern Physics, Lanzhou, The People's Republic of China.

MAGNETIC FIELD DERIVATION

The synchrotron magnetic-field wave form is shown in figure 2. Its wave form is expressed as

$$B(t) = B_{dc} + B_{ac} \sin \omega t, \tag{1}$$

where B(t) is the magnetic field ,

B_{dc} the dc magnetic field,

B_{ac} the ac magnetic field (amplitude) and

ω the angular frequency of the ac field.

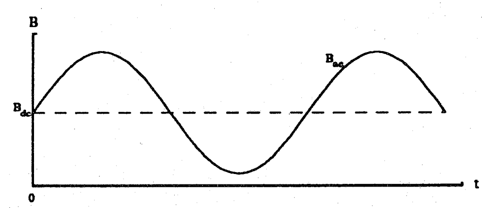

Figure 2 Magnetic field wave form

The inductive voltage of the flip coil in a magnetic field is calculated using the following formula:

$$e(t) = \frac{d\Phi(t)}{dt} = \frac{dNA(B_{dc} + B_{ac}\sin \omega t)\cos \omega_f t}{dt}, \tag{2}$$

where

$$\begin{aligned} e(t) &= NA[-\omega_f B_{dc} \sin \omega_f t + \\ &+B_{ac}(\omega \cos \omega t \cos \omega_f t - \omega_f \sin \omega t \sin \omega_f t)]. \end{aligned} \tag{3}$$

Here N is the number of the turns of the probe coil,

A the average area of each turn of the probe coil,

ω_f the angular frequency of the flip and

ω the angular frequency of the ac field.

$$T = \frac{2\pi}{\omega} \quad \text{and} \quad T_f = \frac{2\pi}{\omega_f} \tag{4}$$

when

$$T_f = kT \qquad (k=1,2,3,\dots). \tag{5}$$

Also

$$\begin{aligned} E &= \int_0^{T_f/2} e(t)dt \\ &= NA[\int_0^{T_f/2} - \omega_f B_{dc} \sin \omega_f t dt + \\ &+B_{ac}(\int_0^{T_f/2} k\omega_f \cos k\omega_f t \cos \omega_f t dt - \\ &-\int_0^{T_f/2} \omega_f \sin k\omega_f t \sin \omega_f t dt)]. \end{aligned} \tag{6}$$

Integrating last two terms from 0 to $T_f/2$ are zero respectively in Equation (6),we obtain

$$E = \int_0^{T_f/2} e(t)dt = -2NAB_{dc}\cdot \tag{7}$$

When the probe coil is stationary ($\omega_f = 0$) the induced voltage is

$$e_s(t) = \frac{dNAB_{ac}\sin\omega t}{dt} = NAB_{ac}\omega\cos\omega t \tag{8}$$

and $$E_s = \int_{-T/4}^{T/4} e_s(t)dt = 2NAB_{ac}\cdot \tag{9}$$

When $B_{ac}= 0$, the induced voltage of the flip coil is

$$e_f(t) = \frac{dNAB_{dc}\cos\omega_f t}{dt} = -NAB_{dc}\omega_f\sin\omega_f t \tag{10}$$

and $$E_f = \int_0^{T_f/2} e_f(t)dt = -2NAB_{dc}\cdot \tag{11}$$

Every E is converted to digital data corresponding to the magnetic field, and is then stored.

CONTROL AND DATA-ACQUISITION PROGRAM

All operations are controlled by programs stored in the computer. The probe coil is returned to the coordinate origin of the measurement table before carrying out any measurement. Data acquisition and control programs are written in assembly and BASIC languages, respectively.

The probe coil is flipped by 180 degrees, and then flipped back to origin while waiting for the next flip. Analog-to-digital conversion is carried out during the period of the coil flip. The data are acquired on-line by the computer. The probe is moved by Δx=10 mm with dynaserv 1 . This procedure is repeated until the measurement along the x-axis has been completed. The probe coil is then returned to the origin of the x-coordinate and moved by Δy=10 mm in the y-direction, and measurements along the x-axis are repeated.

The measurements are completed for a total of 1911 points over an area of 120 mm x 1460 mm. Field mapping all over such an area takes about 2.0 hours.

Acquired data are stored in the main memory during the measurements. After all data have been acquired, they are immediately stored on a hard disk as a data file. The control and data-acquisition program as well as its block diagram are given in the appendix.

MEASUREMENT

Two kinds of integrators ("a" and "b") are used for the measurements. When no ac field exists, we use integrator "a" for dc field measurements. Data acquisition follows the procedure described below:

A trigger pulse from the computer is transmitted to integrator "a". Both gates of the ADC (analog to digital converter) and the accumulator are opened. The integration timing circuit begins to work, and within 20 milliseconds the flip coil starts to flip. As soon as the integral time, which is selected to be within the 0.5 to 0.9 second range, reaches pre-setted one, the integration timing circuit and ADC are closed. After 10 microseconds the output register transfers data. Another 100 microseconds later the accumulator is cleared. Then, within 20 milliseconds the flip coil starts to flip back to the original position. The probe coil is moved and the next new measurement cycle starts.

DC field measurements are carried out after waiting for a warm-up time of 40 minutes. Both the accuracy and the reproducibility of the measurements are better than $\pm 1\mathrm{x}10^{-4}$.

When the probe coil is stationary, the induced voltage appears across the coil due to the time-dependent magnetic field. If the voltage is integrated from the bottom to the top of the ac field, B_{ac} is obtained. If the probe coil is flipped by 180 degrees, only B_{dc} is obtained under both ac and dc excitations of the magnet.

Both B_{ac} and B_{dc} are obtained using integrator "b", in which the induced voltages are converted to frequency by two VFC's (voltage to frequency converter).

The frequency of the induced voltage is about 50 Hz in a B_{ac} measurement. The timing circuit, which is based on the same frequency, generates two timing signals. Their periods correspond to 24.5 and 49.5 times the B_{ac} cycle, respectively. The first signal determines the integration time, and the second determines the measurement cycle. The initial time of every measurement cycle is deferred by ten milliseconds. The measurement cycle is just one second.

A total of 24.5 cycle's pulses converted from the induced voltage of the probe coil are counted by a counter . If the induced voltages are symmetric in both half cycles, the pulses of the positive and negative half cycles of the induced voltages cancel each other every cycle. The counter gives no output during the first 24 cycles. Only the last half cycle's pulses of the induced voltage are counted by the counter during the integration time.

After waiting for the integration time and an additional 101 microseconds, the output register transfers data. After another 101 microseconds delay, data are acquired. The probe coil is moved and the next measurement cycle starts.

When the probe coil is flipped during a magnet field measurement, from equation (3) the induced voltage has two parts caused by Bac and B_{dc}. The pulses caused by B_{ac} are canceled in the counter. No contribution is made to B_{dc}. The measurement procedure is similar to that of B_{ac}.

The relations between the magnetic field, inductive voltage, flip and integration time in the integrator "b" are shown in figure 3.

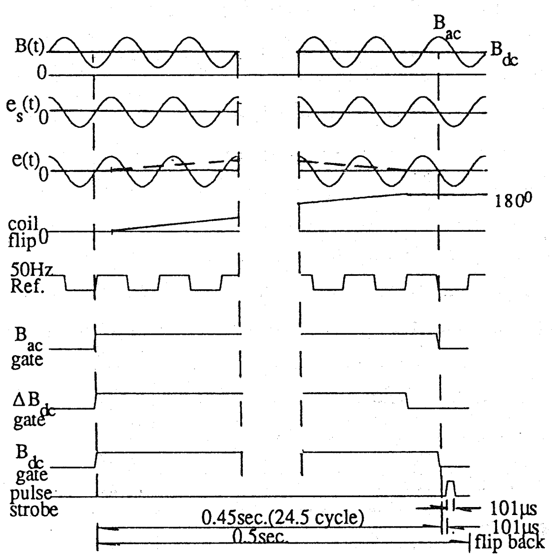

Figure 3, Time chart of the fild,voltage,flip and integration time

B_{dc} was measured with integrators "a" and "b". The difference between the two kinds of azimuthal magnetic-field distributions at y=0 is plotted in Figure 4. The maximum difference is 2.5 x 10^{-2} at the fringing region. The magnet center is located at 66 cm on the abscissa.

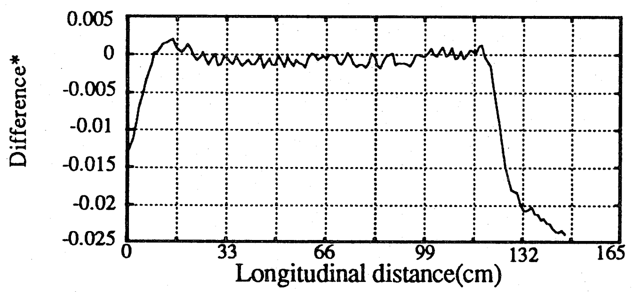

Figure 4 Difference in the B_{dc} field whether B_{ac} is applied or not

*) difference(normalized) = B_{dc} (B_{ac} not exist)-B_{dc}(B_{ac} exist).

The effective magnetic field length is calculated by the following formulae :

$$B_a = (B_{-5} + B_{-4} + \cdots + B_0 + \cdots + B_4 + B_5)/11 \,, \tag{12}$$

and

$$Bl = \int_{-\infty}^{\infty} B(x)dx \tag{13}$$

$$\approx (B_{-x} + B_{-x+1} + \ldots + B_0 + \ldots + B_{x-1} + B_x)\Delta x$$

$$L = \frac{Bl}{B_a} \,. \tag{14}$$

where B_a is the average field at the central region .

-x to x is the range of the measurement (x is far from the magnet fringe), and

Δx is the measurement step .

The effective magnetic field lengths under I_{ac} and I_{dc} excitation are about one centimeter longer than those under only I_{dc} excitation in the useful radial region. They are listed in the table below:

Table Effective magnetic field length in cm

y	I_{dc}=1000A,I_{ac}=566 A	I_{dc}=1000A, I_{ac}=0A
-6	126.81	126.01
-5	126.93	126.27
-4	127.15	126.44
-3	127.29	126.54
-2	127.37	126.62
-1	127.67	126.66
0	127.72	126.67
1	127.61	126.66
2	127.57	126.63
3	127.53	126.56
4	127.47	126.46
5	127.57	126.33
6	127.29	126.10

ACKNOWLEDGMENTS

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REFERENCE

(1) The words "dynaserv" and "fineserv" are the brand names of the servo motor and its controller, respectively. Products of Yokogawa Precision Co.

APPENDIX

1, Control and data-acquisition program block diagram.

2, Program list:

Program BDC. BAS is for control and data acquisition.

Program READBDC. BAS is for reading data from the disk file.

Program PLOT. BAS is for plotting both the radial and azimuthal field distributions.

Program LENGTH . BAS is for calculating of the effective magnetic length between y=6cm and y=-6cm .

Program PLODIF. BAS is for plotting the difference in B_{dc} when B_{ac} is applied or not .

All of the above program are stored on the hard disk of the computer (PC-9801 ns/t).

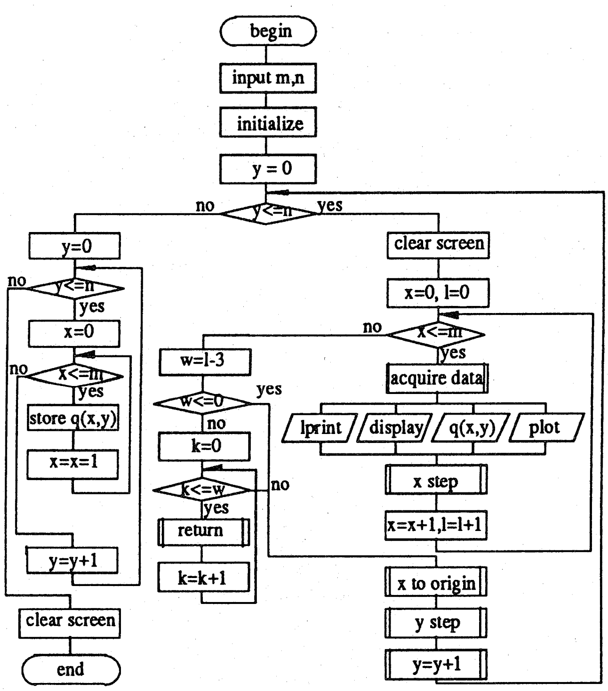

Figure 5 Program BDC.BAS block diagram