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B-CLOCK SYSTEM FOR THE KEK MAIN RING

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Summary

For the monitor of magnetic field of the dipole magnets of the KEK main ring, the "B-clock" system was constructed. This system is useful to control the R.F. acceleration system. As the sensors of magnetic field, we use a Hall probe and a stationary search coil. The measurement is done in the power house for the main magnets, and data are transmitted to the central control room and the auxiliary equipment houses. At present the accuracy of this system is about 10^{-3}. We plan more accurate system of 10^{-4} accuracy with the aid of N.M.R. magnetometer.

Magnetic Field Measurement

The sequence of magnetic field measurement is shown in Fig.1. Measurement is done by the successive two processes. First, the average of dc field at injection porch during the gate time of 20.0 m sec is measured by a Hall probe. As soon as this measurement is completed, a search coil follows change of pulsed magnetic field. The sum of the dc field and the pulsed field measured by the search coil shows the instantaneous value of magnetic field at any timing. As the measured dc field is not a instantaneous value but an average value, the sum of dc and pulsed field contains the error which originates from the difference between average and instantaneous value. The maximum error is the peak value of current ripple of the main power supply at the injection porch. The resultant error of 0.05 % is not avoidable.

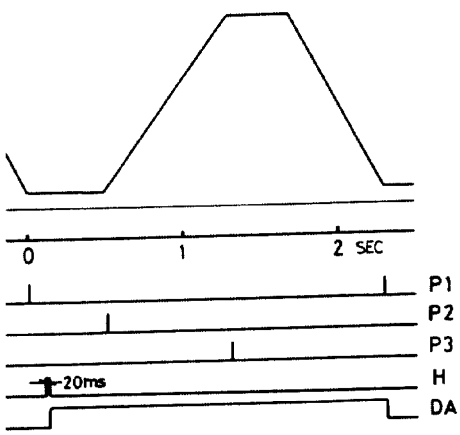

Fig.1

Hall Probe

Many methods of measuring magnetic field have been employed, including nuclear magnetic resonance (N.M.R.), flip coil, rotating coil, Hall generator, magneto-resistance, etc.. All of those have their advantages and disadvantaes. For example, the most accurate method is nuclear magnetic resonance, but this method is not adequate in a magnetic field which contains ripple or in a high gradient field. Flip coil and rotating coil are conventional methods of measuring dc field, but their complicated mechanisms for flipping or rotating coils, are less reliable than the static systems such as Hall probe. Though Hall probes have drawbacks of nonlinearity and temperature sensitivity, it is a advantageous that they have small electrical systems and have no moving parts. For this reason, we decided to use the Hall probe (SBV-595, manufactured by Siemens) as a sensor of dc field at the injection porch. The SBV-595 is a Hall probe with an epitaxial semiconductor layer of GaAs. This probe has a very small electrical system (1 mm × 1 mm), low resistive zero component of the Hall voltage and relatively high sensitivity. As the rated control current and power dissipation is low and it has small temperature coefficient, the design of the temperature control system is easy. Table shows the characteristics of the SBV 595 and the usual FC 33. Though the Hall probe is mounted in the temperature controlled housing for the search coil, it is difficult to obtain 0.01 per cent precision over temperature variation of 1°C in the housing. So, the temperature control of the Hall probe must be adopted. To avoid the effect of induced eddy current, we can not use not only magnetic but also metalic materials. The Hall probe is mounted on the end of the bar of sintered beryllia, and the bifilar-wound heater is on the other end of the bar. As the sensor of temperature, a small glass moulded thermistor is glued on the back of the bar. This thermistor is in one leg of a bridge which provides an error signal of temperature. The error signal is amplified and controls the amount of dc heater current to keep the probe at a temperature of about 45°C. The simple temperature control system holds the temperature of the probe constant within plus or minus 0.2°C for a temperature variation of plus or minus 1°C in the housing for the search coil system. Although the temperature stability of the system is not so good, the output voltage variation of the Hall probe due to

Table Characteristics of SBV595 and FC33

Characteristics (T_{amb} = 25°C)		SBV595	FC33	
Semiconductor material		GaAs	InAsP	
Size of electrical system		1mm 1mm	3mm 6mm	
Rated value of control current (free in air)	I_{1n}	10	100	mA
Open-circuit Hall voltage (at I_{1n} and B=1T)	V_{20}	>300	>145	mV
Control-side internal resistance	R_{10}	∿200	5	Ω
Hall-side internal resistance	R_{20}	∿200	3	Ω
Linearization error in open circuit (field range 0 to 1T)	F_{LL}	<0.2	<0.2	%
Open-circuit sensitivity	K_{B0}	>30	>1.45	V/AT
Resistive zero component	R_0	$<5\times10^{3}$	$<1.0\times10^{3}$	V/A
Mean temperature coefficient of V_{20} between 0 and 100°C	β	∿-0.025	∿-0.04	%/°C
Mean temperature coefficient of R_{10} and R_{20} between 0 and 100°C	α	∿0.3	∿0.2	%/°C

*Linearization error for termination into R_{LL} = 1.5Ω (referred to 1T) the temperature coefficient is within plus or minus 0.005 per cent.

The control current of 10 mA is supplied by the constant current source which provides a current constant within 0.01 per cent. The output voltage of the Hall probe is amplified by the dc preamplifier. The error of the measurement by the Hall probe is mainly due to input noise and drift of the preamplifier. As the preamplifier, the Analoge Devices Model 184 L is employed. Input noise and drift of a few microvolt of 184 L, corresponds to an error of about 0.1 Gauss.

The Hall probe, the preamplifier and the current source were calibrated at 1.0 k Gauss and at 1.5 k Gauss using a N.M.R. fluxmeter. Over the range of 1.0 ∿ 1.5 k Gauss, the accuracy is better than 0.3 Gauss. On subsequent equipment test the accuracy has proved to be better than 0.3 Gauss over three months.

Search Coil

The stationary search coil and the digital integrator system follow changing magnetic field. The search coil is wound on a bobbin of fiberglass reinforced epoxy resin. The diameter and the height of the bobbin are 40 mm and 35 mm respectively, and the turn area of the coil is 0.382 m^2. The other coil parameters are 297 turns of 0.23 mm polyurethan wire, 23 Ω resistance and 3 mH inductance. The impedance of the coil is quite small compared to the input impedance of the preamplifier of 10 MΩ. Resonance of the search coil and the cable is also negligible.

Coefficient of linear expansion of epoxy resin is $2 \sim 6 \times 10^{-5}$ 1/°C. To obtain 0.01 per cent accuracy, temperature control of the search control must be used. Two search coils (one of them is the spare coil) are mounted in the housing made of fiberglass reinforced epoxy resin. Temperature of air in the housing is stabilized as follows. Air is circulated through the housing and the heater by the blower. Temperature at the housing is sensed by the platinum resistance thermometer and an error signal from the thermometer controls a duty cycle of ac heater current with the zero-volt switch of SCR. The temperature at the housing is 40°C and its stability is plus or minus 1°C for the room temperature change of plus or minus 10°C.

The output voltage of the search coils is amplified by the variable gain preamplifier. It is not easy to calibrate the turn area of a stationary search coil. The value of the turn area which we adopt is caliculated value by the dimensions of the bobbin and the wire. The estimated accuracy is about 0.1 per cent and its stability is about 0.01 per cent. These values were verified by some tests with such as the field marker which consists of calibrated Hall generator and the voltage comparator.

Electronic Apparatus

The signals from the Hall probe and the search coil are digitized as follows. The sequence of the measurement, the blockdiagram of the system and the typical pattern of output signals are shown in Fig.1 and Fig.2. P1, P2 and P3 are the timing pulses from the power supply for the main magnets and they denote "start of injection porch", "start of acceleration" and "start of flat top" respectivley. H and DA shown in Fig.2 show the periods of measurement by the Hall probe and by the search coil respectively. To avoid the undershoot of the magnetic field, for the period of about 0.3 sec from P1 to H, the system is in pause.

The output voltage of the preamplifier for the Hall probe is converted to pulse train by the VFC-I

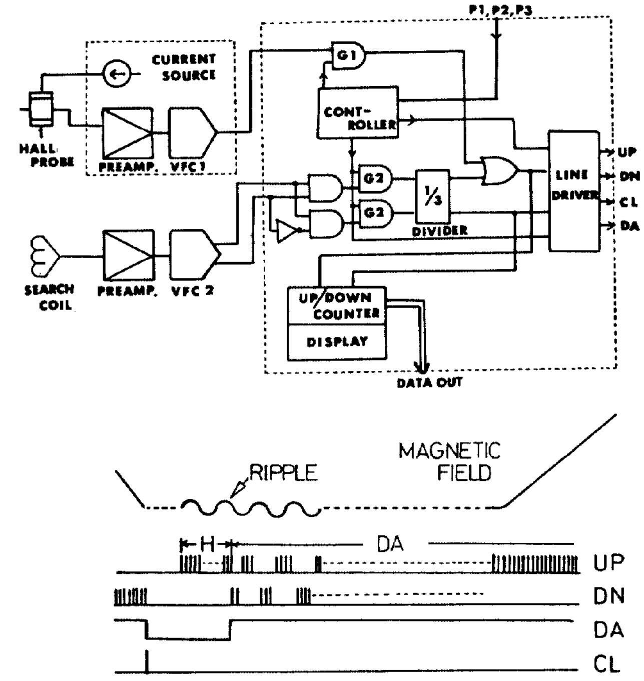

Fig.2

(Teledyne Philbrick, Model 4707-02). The preamplifier and the VFC is adjusted so that the output frequency of the VFC is 500 Hz/ Gauss. As the gate time of G1 (i.e. the period of H) is 20.0 msec, the total number of pulses which pass through G1 is 10 pulses per 1 Gauss. The gate time of 20 ms is corresponds to one period of fundamental frequency of ripple of power supply. (The main power supply is the type of 12 phase rectifiers. But, an unbalance between phases yields ripple of 50 Hz.) Thus, the average value of the injection field is obtained. At the end of H, G1 is closed and G2 is opened and the follow of magnetic field by the search coil is started. The output voltage is amplified and applied to the bipolar VFC-II (Vidar, model 251). As the output frequency of the VFC-II is proportional to the induced voltage in the search coil subjected to the change in magnetic field, the total number of pulses emitted from the VFC-II during a certain time interval is proportional to change of flux (ΔB) during the same time interval. Gain of the preamplifier is adjusted so that the output of VFC-II is normalized frequency of 30 Hz per unit change of field i.e. 1G/sec. For the output frequency of the VFC-II is divided by three, the final frequency is 10 Hz per 1 G/sec. The output pulses and polarity signal of the VFC-II are converterd to the pair of outputs of "Up" and "Down" correspond to positive input (ΔB is positive, i.e. B is increasing) and to negative input (ΔB is negative, i.e. B is decreasing) respectively. These two outputs are connected to the UP/DOWN counter and to the line drivers. First the whole system is cleared by the P1 pulse, and in the period of H, the UP/DOWN counter counts the pulses from the VFC-I and next in the period of DA, it counts the pulses from the VFC-II. At any timing during the period of H, as it is in the middle of averaging, a datum of the UP/DOWN counter is nonsense. In the period of DA, a dantum becomes available, for the search coil integrator system shows the instantaneous value of field. Outputs of the UP/DOWN counter are displayed on the five digit, seven segment LED.

The preamplifiers for the Hall probe and search coil, and two VFC are operated in the incubator to avoid a influence of ambient temperatue change.

Data Transmission and Display

Data transmission

There is the system for the magnetic field measurement in the power house of the main magnets, and the data are treated in the central control room and in the auxiliary equipment rooms for the main ring such as the room for the R.F. acceleration system. So, the data must be transmitted to those rooms. The whole system of the data transmission are shown in Fig.3. Distance of the central control room from the power house is about 300 meters and distance of the auxiliary rooms from the control room are about 200 meters. And there are many noise source such as pulse magnets and the feeder lines for the main magnets on the course of the transmission. The data must be transmitted freely from noises for these distances. The data are transmitted on four lines, i.e. the line for the "Up" pulse (UP), for the "Down" pulses (DN), for the clear pulses (CL) and for the data available signal (DA). These transmission lines consist of four coaxial cables (8D2W). The line drivers are single ended type. To obtain high common mode noise rejection, their common levels are isolated from the ground of the field measuring system with optically coupled isolators, and to be insensitive to normal mode noise they drive relatively high voltage signals on the 50 Ω lines.

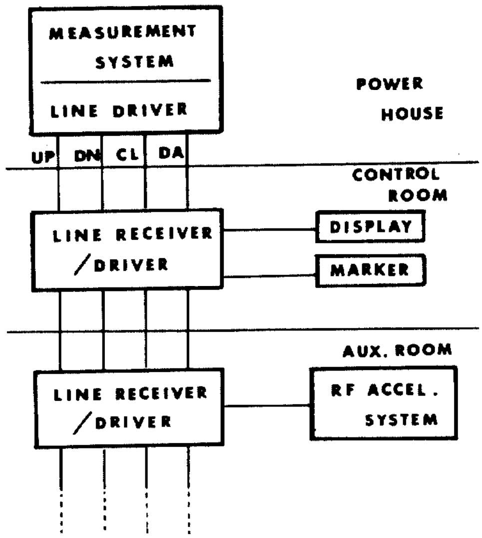

Fig.3

These signals are received at the central control room by the line receivers with optically coupled isolators and the levels of the data are shifted to TTL level. These level shifted data are distributed to the devices of display and the field markers. Moreover these signals are transmitted from the control room to auxiliary rooms for the main ring the same transmission systems.

Display

Received data at the central control room and the auxiliary rooms are used as follows (See Fig.3).

1. Digital display (in the control room)
2. Analogue display (in the control room)
3. Field marker (in the control room and auxiliary rooms)
4. Control of the R.F. acceleration system (in the auxiliary room for the R.F. system)

Magnetic field at the injection porch and at the flat top are displayed on the five digit, seven segment LED display by means of UP/DOWN counters (1 Gauss unit). And the latter is read by the computer for the accelerator control system, and the final energy of protons is calculated and displayed.

If necessary we can display the value of magnetic field at any timing in the period of DA. The data of UP/DOWN counter are converted to analogue data with a D.A.C. and are convenient to display the wave form of the magnetic field on the oscilloscope. The typical wave form are shown in Fig. 4.

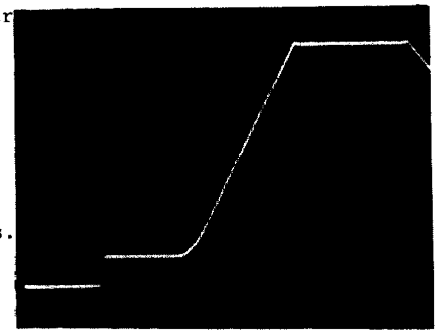

Fig.4

The field marker which consists of a UP/DOWN counter and a digital comparator, provides one pulse when the magnetic field reaches a certain value determined by the digital switches.

Frequency of the acceleration R.F. system is controlled by the data of the B-clock to hold a certain relation between magnetic field and frequency. And phase jump at the transition is directed by the field marker.

Monitoring of the Q-magnets

To monitor field gradient of quadrupole magnets of main ring, the "Q-monitor" system was also constructed. The method of field sensing is similar to the "B-Clock", but the pair of Hall probes and the pair of search coils are used to sense field gradient. Field gradients of the focusing quadrupoles (F) and the defocussing quadrupoles (D) are measured independently at the same time. These data are also transmitted to the central control room and displayed. To check the tracking of field gradient of quadrupole magnets and field of dipole magnets, ratios of dB/dx of F and D to B of dipoles measured by B-Clock are calculated and may be displayed.

Tests for Future

As stated above, the error which originates from the difference between average and instantaneous value of the dc field is not avoidable. Moreover, aging effect in Hall probe and reproducibility of gain and input offset voltage of the preamplifier are annoying problems. To solve them, we are now testing a new fluxmeter with N.M.R. for dc field which contains ripple field. The scheme is as follows. First, the average value of magnetic field (B_{av}) is measured by a Hall probe. Next, the Larmor frequency ($f_r = \frac{\gamma}{2\pi} B_{av}$) corresponding to B_{av} is calculated by the digital multiplier and f_r is generated by the frequency synthesizer. The frequency of the marginal oscillator of N.M.R. detector is locked on the input frequency of f_r by means of the technique of phase lock loop. The head of N.M.R. is in the biasing coil. The current wave form of this coil is ramp wave, on which ripple bucking current and modulation current are superimposed, so that the magnetic field in the coil increases linearly. When the magnetic field in the coil reaches B_{av}, the N.M.R. system provides a signal (N), and the biasing field (B_b) is detected by means of ADC which reads the current of the coil. The instantaneous value of the magnetic field at $t = N$ is given by $B(t = N) = B_{av} + B_b$. Each device was tested, and we are now designing the whole system.

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