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High accuracy measurement of magnetic field in pulse magnetic elements

V.Kargaltsev, E.Kuper
Institute for Nuclear Physics,
Novosibirsk, 630090, USSR

Abstract

CAMAC module intended for measurements of instant magnetic field using coil sensor is described. It is four channel integrating ADC with current input in which signal integration time is controlled externally and may be optimized for a given signal. Original technical solution allowing to eliminate influence of the integrator capacity and switches instability on overall accuracy is described.

The large accelerator facilities include a great number of magnetic elements interacting with a beam for a short period ranging from 0.01 ms to 10 ms. For example, this class of elements includes all the magnetic components of channels for particle transportation. In addition, most of these elements are operating rarely - once in 1 - 10000 s. For these elements the most optimal is the use of a pulse power supply that reduces the electric power consumption and which is most important, it solves the problem of heat removal. Though, the pulse power supply poses some problems in providing the accuracy of magnetic field and its measurements.

In practice, the measurement problem can be reduced to the measurement problem of instantaneous value of the magnetic field. In fact, the time of the beam-field interaction is usually so short then the field can be taken quasistatic and acting equally on all the portions of a bunch of particles.

There are some elements interacting with a beam for a long time during which the field can be changed substantially. For example, the cyclic accelerators operate in the similar way. But the pulse shape in these elements is determined by the properties of the feeding generator and it is very conservative. The shape relevance can be checked by the point by point measurements while development of such an element and during the operation it is sufficient to control one or two characteristic points (instantaneous value) of a pulse. Usually, the values are measured which correspond to the beginning and the end of the field interaction with a beam.

The inductance sensor proved to be very convenient for the pulse measurements. It can easily allow the shielding and galvanic de-coupling from the facility construction that facilitates substantially the problem of producing the measuring devices.

The experience of operation of the facilities at the Novosibirsk Institute for Nuclear Physics (INP) has shown that at the requirements to the accuracy of magnetic field lower than 0.05% the tuning of magnetooptic channel was determined by the measurements of fields with these sensors. At higher accuracies one should take into account the deviations between the field (flux) value measured with the help of this probe and the properties of magnetic element as a whole, which are caused by the magnetic temperature variations and some other reasons.

While measuring the instantaneous value the following approach seems to be natural: the field signal is traced with the analog memory device, stored in the memory at the moment of interest and then it is transformed into the code.

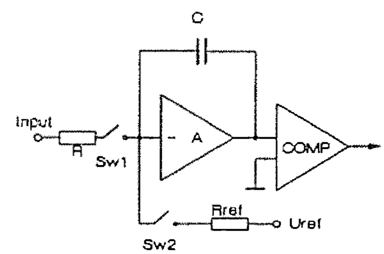

Fig.1. The analog section of module.

The use of the inductance probes enables one quite simple to realize this process with the help of the analog integrator. In fact, the signal voltage from the inductance probe is proportional to the speed variation of the passing magnetic flux:

$$E = W \frac{d\Phi}{dt}$$

Here W is the number of turns of a probe.

If this signal is integrated by the analog integrator, the charge stored in the capacity can be described as follows:

$$q=\int_{t_0}^{t_x}\frac{dE}{R}dt=\frac{W}{R}\int_{t_0}^{t_x}\frac{d\Phi}{dt}dt=\frac{W}{R}(\Phi(t_x)-\Phi(t_0))$$

In this case, the integration limits are given by the moments of connection (t_0) and disconnection (t_x) of the switch Sw1. If the integration is started before the field pulse, the stored charge is equal to:

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$$q(t_x) = \frac{WS}{R} B(t_x)$$

B is the magnetic inductance
S is the sensor cross-section

The product W * S characterizes the sensor sensitivity.

For converting the charge into the code the capacity C is discharged by the calibrated current on the circuit Uref, Rref and Sw2 and the discharge time indicated by the comparator is then measured. As a result, the value

$$N = \frac{q(t_x)}{Iref} = \frac{W\ S\ Rref}{R\ Uref} B(t_x)$$

is uniquely related to the magnetic field value at the moment when the integration is stopped. From it is seen that the accuracy of measurements is determined by the stability of the sensor parameters (W * S) and three elements of the measurer: R, Rref, and Uref. In order to provide the high accuracy the wire and the metal-film resistors of highest stability are used as R and Rref. The voltage reference diodes have passed the preliminary test, certified of the thermostable point. This mode enables one to avoid the use of the oven for the diode at the accuracy of the reference voltage of up to 0.002%. As to the capacity C, its nominal is not important. The only thing required is its short-term stability. The leakage currents of modern capacitors are negligible small and the only error, which could be introduced by the capacitor is the variation of the effective charge caused by the adsorption (the polarization of the dielectric of capacitor). In order to achieve the accuracy about 0.01% it is sufficient to use the capacitors with the low polarization dielectrics (polystirol, teflon). In order to reach the higher accuracies one has to use the special analog circuit of the compensation for polarization. The parameters of the circuit are selected for each certain capacitor.

As a rule, the problem of precise measuring the time interval does not make any difficulties.

Some difficulties occur with the switch Sw1. To provide the time for commutation (about 10 ns) requires the use of semiconductor switches which have the noticeable switch-on-resistance. The switch resistance is added to the integrating resistance R and its instability introduces the error. This problem is solved by the "triangle" of switches Sw1 (Fig.2) assembled with the field transistors.

In this scheme, the on-state of the switch S1a, S1c and off-state of S1b correspond to the on-state of Sw1. While the integration of a signal the current passes through the switch S1a but the amplifier watches the point G via the switch S1c and namely at this point provides the zero potential. Thus, the voltage drop on the switch (in this case, on S1a) does not make any influence on the charge stored in the integrator capacity. During the storage and conversion the switch Sw1 is disconnected (S1a and S1c are off, S1b is in the conducting state providing the connection of the feed back circuit).

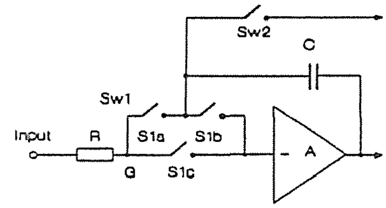

Fig.2. The integrator with "triangle" of switches.

The typical current of a signal is of 0.1-10 mA. Therefore, the operational amplifier with the field transistors with the input current lower than 0.1 nA with an extra circuit of dynamical correction of the input bias voltage fits quite well as the integrator amplifier.

For carrying out the practical measurements, requiring, as a rule, the simultaneous measurements of a few tens of signals the four-channel CAMAC-module is designed that is operated according the principal described.

The field sensors are located just in the magnets and they are connected to the measuring devices with a coaxial cable. The connecting cable can be up to 100 m long with substantial capacitance. To avoid the distortion of the signal by the capacity of the cable and thereby to avoid errors, the integrating resistor is removed to the sensor. In this case, the measurer has the zero input resistance, which cancels the influence of the track capacity.

The moments of the integration start and stop are given from outside and usually by the pulses of synchronization system of the facility under service. In this case, the input "integration start" is common for four channels and the control for the integration stop is individual for each channel.

Technical parameters of the module:

Number of channels	4
LSB weight	5 pQ
Dynamic range	16 bit
Accuracy	0.01 %
Conversion time	50 ms

The given accuracy is realized at the integration time of a signal of longer than 500 µs, at lowest times the accuracy decreases.

At present, the apparatus is modified in order to improve the measurement accuracy (an accuracy nearly 0.002%, scale 18 bit).