HARDWARE AND SOFTWARE FOR MAGNETIC MEASUREMENTS WITH MOVABLE COILS

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Abstract

The method of magnetic measurement using moving coils is the most important measurement method for particle accelerator magnets. Although this oldest of the currently used method have remained unchanged for a very long time, the electronic equipment and software have been subjects to continual development and improvement. Report describes a new set of specialized electronic modules intended for measurement with moving coil. This set includes Integrator with Digital Output (Digital Flux meter) and Low-noise zero-drift preamplifier. The principles of operation and main characteristics of these devices are discussed. A few systems, based on described equipment, are built up during last two years. These systems used different coil configuration: rotating coils, flip-flop coils, stretched wire. Parameters of systems and description of software, developed for moving coil measuring systems are reported.

PREFACE

Change of magnetic flux through coil causes EMF $\varepsilon(t)$ appearance on the coil's terminals $\varepsilon(t) = = -d\Phi/dt = -\int BdS/dt$. Integral of EMF on time equals to the total change of magnetic flux through coil during integration time $\Delta\Phi = -\int_0^T \varepsilon(t)dt$. It is possible to calculate different spatial characteristics of magnetic field, using coils' geometry, parameters of its moving, and the value of magnetic flux.

Integrals of signals from coils are about several millivolt·second. For measuring such small signals with good accuracy specialized electronic modules were developed. Signal from coil is amplified using low-noise zero-drift amplifier. Amplified signal is integrated and digitized using digital flux meter (Volt·second-to-Digital Converter VsDC).

INTEGRATOR WITH DIGITAL OUTPUT

Integrator with digital output (Volt second to Digital Converter - VsDC) is specialized VME module, destined to arrange magnetic measurement with movable coils. The integrating time from 0.02 second up to 10 seconds, 16-bit resolution, four input ranges ($\pm 10mV\cdot s$, $\pm 20mV\cdot s$, $\pm 50mV\cdot s$, $\pm 100mV\cdot s$) and flexible start-stop logic allows use this device in different kinds of magnetic field measuring systems. For measuring of microvolt signals an external amplifier, installed close to coil may be used as option.

The VsDC is well known two-step integrating ADC with variable time of integration. The principle of operation is shown on fig. 1. On the first step the input signal is integrated during time, determined by interval between "Start" and "Stop" commands (figure 2). On the second step the integrator input is connected to Eref, which has opposite to input polarity, and then capacitor is discharged down to initial value (zero). Counter measures discharging time T. If initial and final charges of capacitor are equal, the next equation may be written:

$$\int_{t_{start}}^{t_{stop}} \frac{U_{in}}{R} dt = \frac{E_{ref}}{R} \cdot T \Rightarrow \int_{t_{start}}^{t_{stop}} U_{in} dt = E_{ref} \cdot T$$

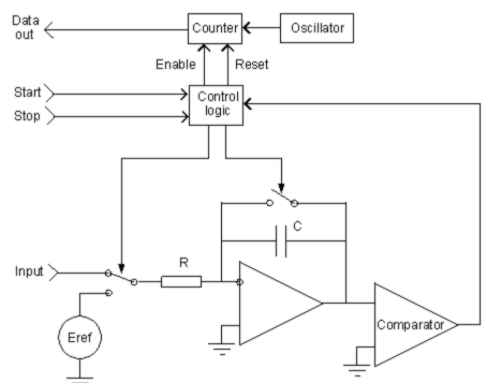

Figure 1: Simplified structure of VsDC.

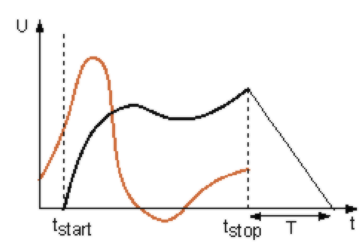

Figure 2: Input signal and integrator output.

Table1:Main VsDC parameters

Resolution	16bits (15+sign)
Integrating time	0.02 – 10 seconds
Conversion time	$100ms$
Input ranges (software selectable)	$\pm 10mV\cdot s$, $\pm 20mV\cdot s$, $\pm 50mV\cdot s$, $\pm 100mV\cdot s$
Noise	< 1 LSB (300nV)
Nonlinearity	$2 \cdot 10^{-5}$ FS

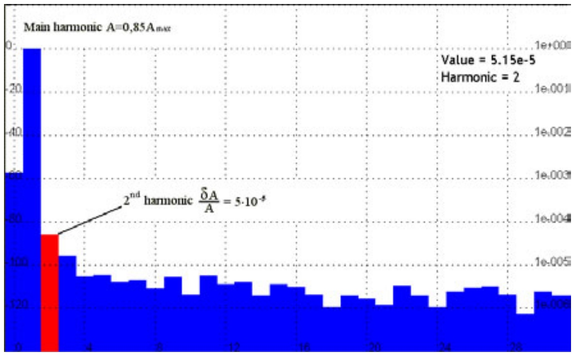

Figure 3: 2nd harmonic $\delta A/A = 5 \cdot 10^{-5}$

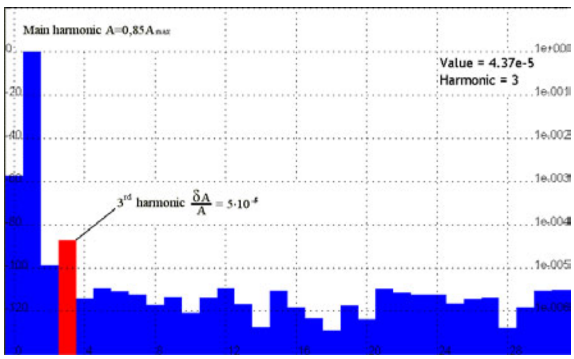

Figure 4: 3rd harmonic $\delta A/A = 5 \cdot 10^{-5}$

The linearity of measuring device is one of the main parameter of system for rotating coil measurements. Special test stand is elaborated in order to determine nonlinearity of VsDC. This stand includes high precision 24-bit DAC and VsDC under testing. DAC, controlled by program, generates the sequence of voltage steps on sinusoidal law, where value U_i changes in accordance with equation:

$$U_i = A \cdot \sin(\frac{2\pi}{k} \cdot i) + \delta A \cdot \sin(\frac{2\pi}{k} N \cdot i)$$

$i = 0 \div k$	step number
k = 120	quantity of steps
N	harmonic number
A = 0.8·(input range)	amplitude of main harmonic
$\delta A = 5 \cdot 10^{-5} \cdot A$	amplitude of N-th harmonic

On figures 3,4 spectra of signal with 2^{nd} and 3^{rd} harmonics with relative amplitude $\delta A/A = 5 \cdot 10^{-5}$ is shown. It is seen that the value of higher parasitic harmonics caused by VsDC noise is less than $1.5 \cdot 10^{-5}$.

LOW-NOISE ZERO-DRIFT AMPLIFIERS

Coil amplifier use double channel scheme, combing low-noise amplifier, which actually amplifies signal and zero-drift amplifier, which amplifies and compensates offset (and thus its temperature drift) of low-noise amplifier. Because of ultra-low bandwidth of zero-drift amplifier (~0.01 Hz) its noise doesn't affect the resulting signal. Amplifier's schematics is shown of figure 5.

Amplifiers' noise is presented on figure 6.

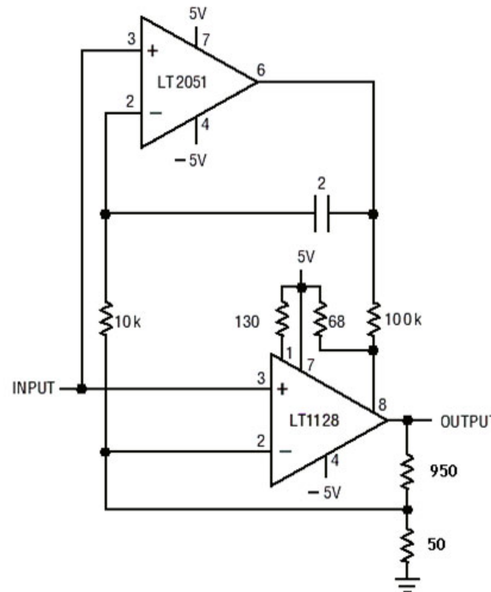

Figure 5: Amplifier schematics.

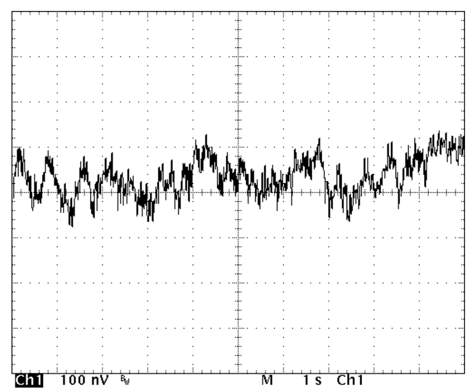

Figure 6: Amplifier noise (scale 100nV/div, 1sec/div).

Table 2: Main amplifier parameters

Gain	20
Gain bandwidth	40Hz
RMS Noise (bandwidth 40Hz)	40nV
Offset	2μV
Offset temperature drift	40nV/°C

SOFTWARE

The software of the magnet measuring system is built on client-server architecture. Server is embedded software for VME bus controller. It runs under control of operation system μCLinux. Functions of server are to provide remote access to hardware of measuring system. The set of commands were implemented for this goal. They can be used for configuration of integrators and stepping motor, reading data from angle encoder and integrators. Figure 7 demonstrates how command is executed by server. Library functions use special device drivers to operate with hardware (integrators, asynchronous serial controller VMIVME 6015) connected to VME bus.

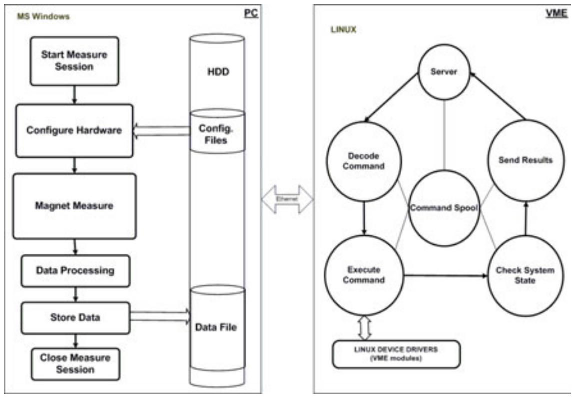

Figure 7: Software structure.

ROTATING COIL MEASURING SYSTEM

Rotating coils are used in measurements of parameters of multipole magnetic lenses. Using it, spatial harmonics of magnetic field, effective magnetic length, displacements and tilts of magnetic axis of lens could be measured. This method also is indispensable tool for correct alignment of lens on girder[1].

Usually special construction of coil is used. There are two (or more) coils of different sizes. Signals from this coils are subtracted from each other with its own coefficients to compensate main harmonic and improve accuracy of measuring higher harmonics.

Because VsDC has very low noise and high linearity it is possible to use simple coil construction without compensation coils. This simplifies measurement system and also allows to measure absolute value of main harmonic.

Using this measurement system different multipole lenses produced in BINP were measured[2, 3].

FLIP-FLOP COIL MEASURING SYSTEM PROTOTYPE

For measurements of high intensity magnetic field maps flip-flop coils are used. Flip-flop coil usually is a small coil which makes half-turn relative transversal axis in magnetic filed, so change of magnetic flux through coil equals to double initial flux. This method comparing to Hall-probe has several advantages. Inductive methods have absolutely linear dependence on intensity of magnetic filed. So the calibration process, especially for high intensity fields is much easier. This method also has much smaller temperature influence on measurement accuracy. And comparing to NMR method, flip-flop coils could be used for measure of non-uniform fields. Structure of system for measuring filed map in shown on figure 8. Test measurement of uniform field area in calibration magnet is presented on figure 9.

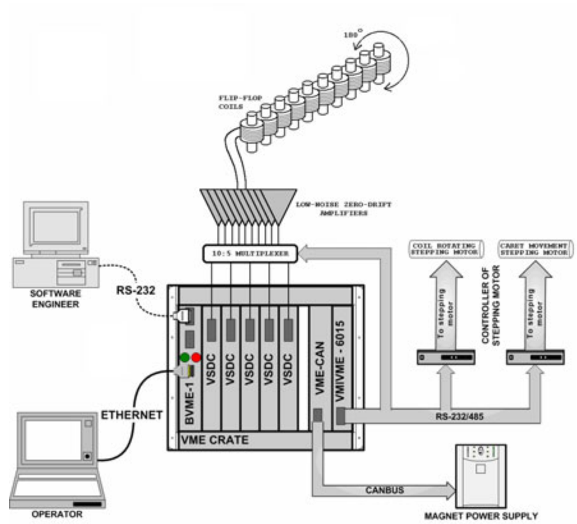

Figure 8: flip-flop coil measuring system structure.

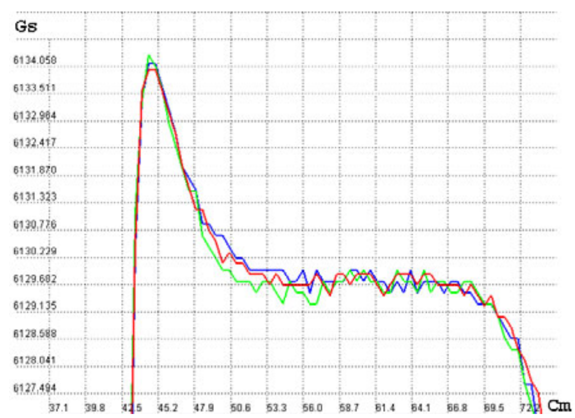

Figure 9: B(x) (Gs vs. cm) test measurement.

CONCLUSION

Electronics for magnetic measurements using different configuration of movable coils were developed. A few measuring systems using this modules were built. This systems demonstrated high performance.

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