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IN THE LOS ALAMOS PROTON STORAGE RING

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A NOVEL CURRENT MONITOR FOR DC AND MODULATED MAGNETS IN THE PROTON STORAGE RING*

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The zero flux dc current transformer has been described before in literature.¹⁻² This paper endeavors to present a more analytical approach. The method of demodulating the dc channel is novel, using a time-domain scheme rather than the usual second-harmonic method. The current monitor measures bipolar currents up to 2 000 A without physical contact of the single-turn primary. Choosing the secondary current as 1 A sets the turns ratio at 1:2000. The magnetic material used is of the molybdenum Permalloy variety with its high (30 000) initial permeability and almost square-hysteresis loop. Its saturation flux density is about 0.74 T. The toroidal geometry of the tap-wound transformer insures almost unity coupling of the windings.

As depicted in Fig. 1, the ac channel consists of one toroidal transformer with bifilar wound secondaries, R_1 and the input impedance of the differential input amplifier must be very large; otherwise they would rob amperes-turns from $N_1 I_p$, and a serious error would appear in the output voltage across R_2 . As seen in the figure, the ac channel has a J-dB bandwidth from a low-frequency pole to infinity. The amplifier extends the transformer output response to lower frequencies by a factor of almost A_1 ; and the mutual inductance of the windings takes over at higher frequencies above the bandwidth of the amplifier.

At frequencies above 500 kHz the resonances in the transformer's secondary windings become a nuisance and a simple low-pass filter could be used to eliminate them. The output voltage across R_2 is not within the feedback network. Therefore R_2 must be a very high-quality resistor in terms of temperature stability and accuracy.

Figure 2 shows a dc channel. Two toroidal transformers are used that are identical to the one employed in the ac channel. This circuit is obviously a sampled data or discrete system. The state of the

net error current, $I_E = (N_1/R_1)I_1 - I_f$, is determined every period, T_S , of the square wave switching voltage V_{DR} . If the net error current I_E is not zero, a correction is made by I_f to bring it toward zero. I_f also flows through R_0 producing an output voltage, V_0 , proportional to the input current I_1 .

The best way to understand this dc channel is to study the actual waveforms in Fig. 2 that are shown for two conditions: with $I_E = 0$ and with $I_E > 0$. I_1 is greater than zero in both cases and steady. The toroids, flux biased by I_E , are both switched by V_{DR} from one saturated state to the other in such a way that, except for a very short interval proportional to I_E , no net voltage is induced in the primary or the secondary windings in series with R_1 . Thus the secondaries in series present only R_1 as a load to the power amplifier V_{DR} . The toroids must be selected and matched by their switching time under a constant voltage low-impedance source. The signal derived from R_{D1} in series with the switching windings is squared up by an adjustable dead-zone and limiter circuit.³ The purpose of this adjustment is to zero the output voltage with $I_1 = 0$, due to the finite slope of the signal across R_{D1} as the toroids go into saturation.

The voltage switching signal V_{DR} and the modulation signal V_{DM} must be in synchronism and are derived from a two-stage debouncer circuit. The bipolar logic level signals are level shifted by complementary emitter-follower input amplifiers to provide the 11.5-V bipolar signals that feed the dead-zone and limiter circuits. The actual demodulator is a sample-and-hold amplifier circuit that adds and inverts the demodulating signal and the squared signal across R_{D1} followed by another dead-zone and limiter circuit. Thus the demodulator provides a bipolar, impulse-like signal of strength $V_{DR}I_E$ when $I_E \neq 0$. I_E is made short by adjusting the frequency $1/2T_S$ of the clock that drives the Johnson counter so that the toroids saturate, with $I_1 = 0$, about 60 ns before $t_1/2$.

*Work performed under the auspices of U.S. Department of Energy.

Fig. 1.

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