Integrator for the KSTAR magnetic diagnostics

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Classical inductive sensors were used as magnetic diagnostics (MDs) in the most of tokamak machine. The integrator was required in order to obtain the value of magnetic field from induced voltage in the sensors. Thus, the research and the development of the integrator have been carried out for the accurate measurements of the magnetic field in several tokamaks [1-3]. Especially, for the long pulse operation of longer than 1000 s required in the future device, the development of the integrator for the improvement of its drift characteristics has been progressed.

An analogue integrator has been developed for the field measurement by using inductive MD sensors during a plasma discharge with a pulse length of up to 300 s in the KSTAR machine [4,5]. The details of the KSTAR MDs were described in Ref. [6,7]. The value of magnetic flux Φ picked up by each MD sensor during a plasma discharge was estimated from a calculation by using some parameters proposed for the KSTAR operation. The values of the parameters were following; $B_T = 1.0$ T and $I_p = 100$ kA, and $B_P = 0.02$ T at a sensor position. Also, both values of the vessel and the halo current were assumed as 10 % of I_p, and the value of an error field related to the locked mode was assumed as 3 % of B_P. The estimated values of Φ are given in Table 1, together with an effective area S or a sensitivity k_R of each sensor. The design requirement of the integrator was determined by considering the estimated values; the integrator has an RC time of 1ms, and the full operational range of the integrator is 10^{-2} Wb, and the drift is less than 10^{-5} Wb during the integration time of 60 s.

Table 1. Estimated value of the magnetic flux obtained from the KSTAR MD sensors.

Sensor	S [m^2]	Φ [mWb]	Sensor	k_R [$A^{-1}\mu Vs$]	Φ [mWb]
Flux loop*	1.079	22	Rowgoski coil	0.10	10
Magnetic field probe(B_z)	0.059	1.2	Halo current monitor*	0.04	0.4
Magnetic field probe(B_r)	0.093	1.9	Vessel current monitor	0.025	0.25
Saddle loop*	0.128	2.6			
Locked mode coil	0.46	0.28			
Diamagnetic loop**	0.161	0.81			

* : The smallest value is presented. ** : The differential flux between an inner and outer loops is presented.

The integrator, which automatically compensates a drift, can be controlled by a PC through the RS-232 interface. The drift is compensated by the ADC-register-DAC in the integrator (see Fig. 1), which is improved from the technical data in the drift measurement by using a previous integrator. In addition, the digital integrated data can be obtained from the integrator, which will be used for a real-time monitoring of the integrated signal. Details of the integrator were described in Ref. [4, 5]. The prototype integrator was fabricated as a modular type contained four independent channels and a calibration of the ADC-register-DAC component in the integrator was carried out in order to minimise the drift. The calibration was done according to the procedure as follows; at first, the adjustment of the baseline level and the gain in the ADC part, and then the adjustment of the offset and amplitude in the ADC-DAC part, and finally, the offset adjustment of the integrator.
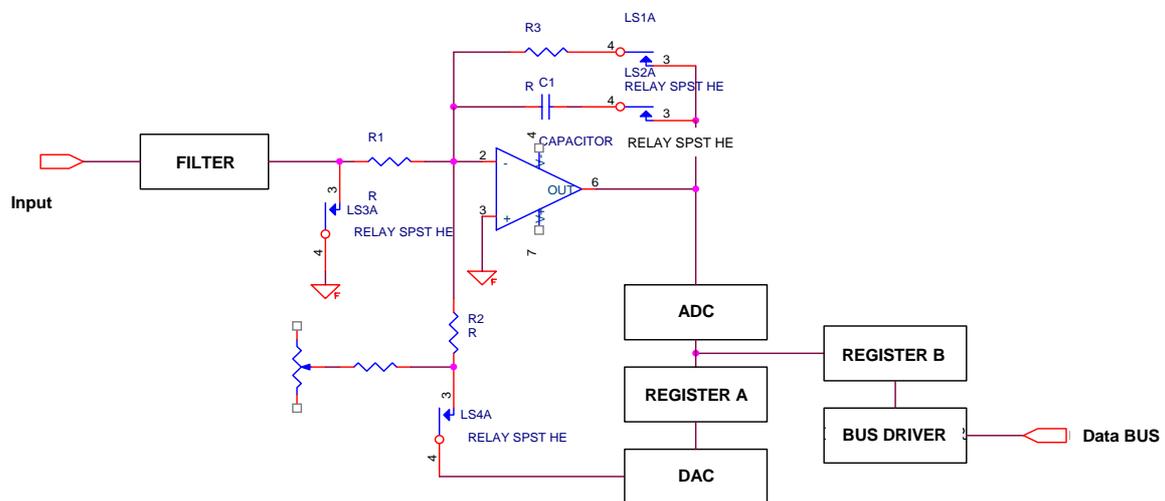

Fig. 1. Electronic circuit diagram of the analog integrator for the KSTAR MDs.

Figure 2 shows the integrating drift of each channel in the integrator. The drift is less than 1×10^{-6} Wb during an integration time of 100 s. The input of each channel was shorted to the signal ground in the measurement to investigate the drift characteristics of the integrator itself.
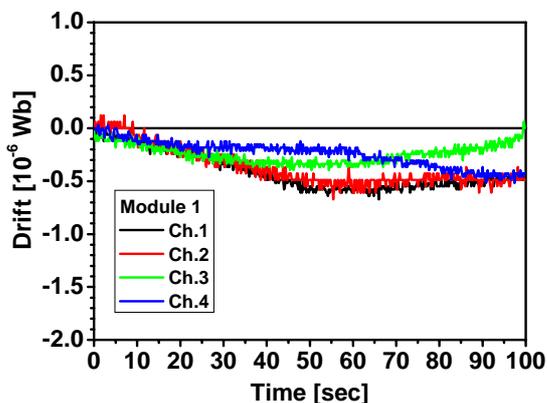

Fig. 2. Integrating drift of the integrator itself. An input of each channel is not connected to the magnetic sensor and is shorted to the signal ground of the circuit ("F" in Fig. 1).

Two different Rogowski coils were connected to the integrator by using a 100 m long paired signal line (Belden, model 9841) that will be used for the signal line of the KSTAR MDs. Its nominal conductor DC resistance is about 8 Ohm for the length of 100 m. At first, the drifts from integrator were investigated in the case of zero input signals from the coils (see Fig.3). The effective area of each coil was 9.8×10^{-3} m^2 and 0.118 m^2. The integrating drift is less than 3×10^{-5} Wb during the integration time of about 104 s. The drift was larger than 10 times that of the integrator itself.
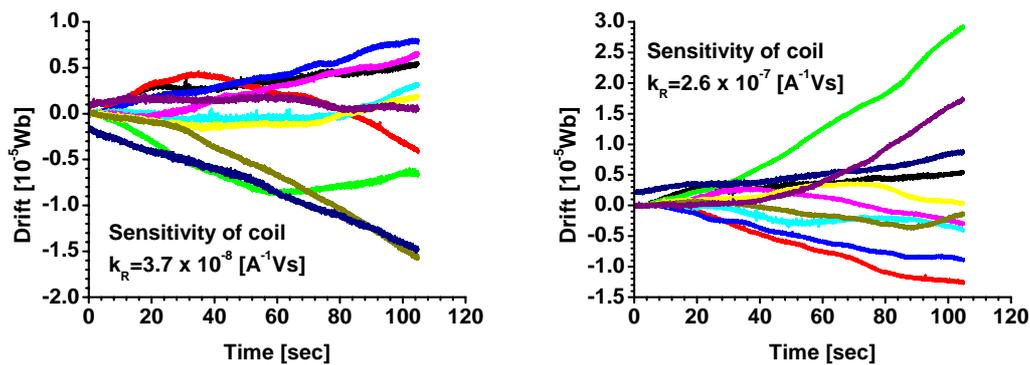
Fig. 3. Integrating drift of the integrator connecting with two different coils.

For the performance test of the integrator in the magnetic flux measurement, a pulse current of 200 A was applied to a cable during a time of up to 85 s. The two coils fully encircled the current carrying cable in order to measure the flux. The applied current was monitored by a current sensor (Sypris, model RS - 1000 A). Figure 4 shows typical fluxes measured by the two coils connecting to the integrator.
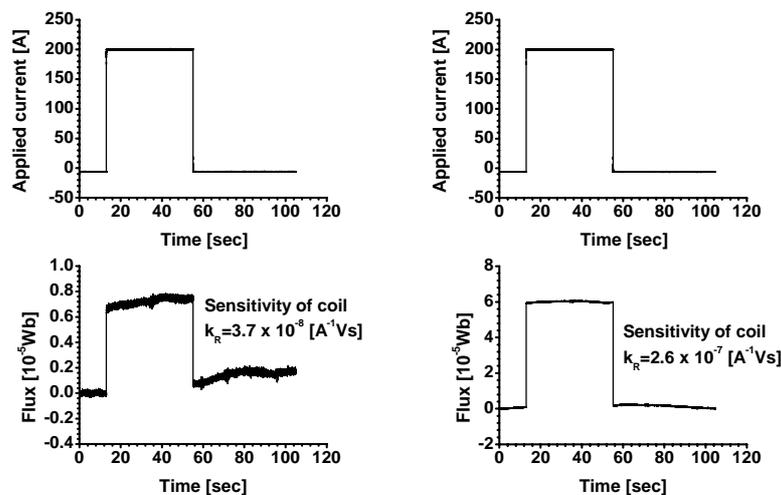
Fig. 4. Typical fluxes obtained from the two coils in the current measurements, together with the applied current measured by a commercial sensor.

The fluxes measured by two coils are 0.67×10^{-5} and 5.8×10^{-5} Wb, and the ratios of the integrating drift as a baseline level to the magnetic flux in each flux measurement are 27 % and 4 %, respectively. Figure 5 shows a typical flux obtained from a coil during the integration time of 524 s. The drift is 0.29×10^{-5} Wb, which is 44 % of the magnetic flux (0.66×10^{-5} Wb) within a 120 s. But the baseline level increases up to 0.56×10^{-5} Wb within a full time.
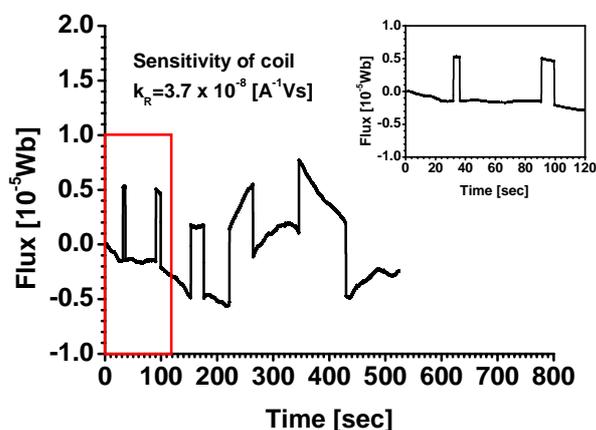

Fig. 5. Typical flux obtained from a coil in the current measurements during an integrating time of 524 s. A figure at the upper right side shows the measured curve within 120s.

In the performance test of the integrator using the ADC-register-DAC component for the compensation of an integrating drift, it was found that the drift was less than the value required in the design of the integrator, and it was expected that the ratio of the drift to the magnetic flux became less than few % by using a coil with a larger effective area from the comparison between the measurements by two different coils. In addition, it was observed that the drift was less than 5×10^{-5} Wb during an integration time of up to 524s. Thus, it is estimated that the integrator can be used in the long pulse operation of the KSTAR in the future. In order to achieve the purpose, there are some technical issues as future works such as minimizing the noise picked up in the measured signal, reducing the effect of the environmental conditions on the drift, and reducing the effect of the resistance of the sensor on the integrated value.

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