Design and Preliminary Results of a Feedback Circuit for Plasma Displacement Control in IR-T1 Tokamak

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Abstract. Since displacement is very important for plasma position control, in IR-T1 tokamak a combination of two cosine coils and two saddle sine coils is used for horizontal displacement measurement. According to the multiple moment theory, the output of these coils linearly depends to radial displacement of plasma column. A new circuit for adding these signals to feedback system designed and unwanted effects of other fields in final output compensated. After compensation and calibration of the system, the output of horizontal displacement circuits applied to feedback control system. By considers the required auxiliary vertical field, a proportional amplifier and driver circuit are constructed to drive power transistors these power transistors switch the feedback bank capacitors. In the experiment, a good linear proportionality between displacement and output observed by applying an appropriate feedback field, the linger confinement time in IR-T1 tokamak obtained, applying this system to discharge increased the plasma duration and realizes repetitive discharges.

Keywords: tokamak, displacement
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INTRODUCTION

Control of plasma displacement has the most important role in magnetic confinement of plasma in tokamak system. To achieve longer time the plasma should be in the center of the torus. In this feedback system, plasma position signal that is identified by Horizontal Displacement (HD) circuit from cosine coils and saddle sine coils, is applied to control system circuit. Then two arrays of transistors, switch the charged capacitors to auxiliary vertical coil in two directions. This field acts on plasma column and push it back to the set position.

PLASMA DISPLACEMENT MEASUREMENT

Measuring magnetic field due to plasma current would give information regarding to the position of the plasma. According to the multiple moment theory [1], a combination of cosine Rogowski foil, with winding density as $\cos n\theta$, and saddle coils would determine plasma horizontal displacement [2]. In IR-T1 tokamak, two continuous coils wound according to the multiple moment concepts [3]. These coils placed around minor radius of tokamak chamber, as illustrated in Figure 1. The main parameters of IR-T1 tokamak are presented in Table 1.

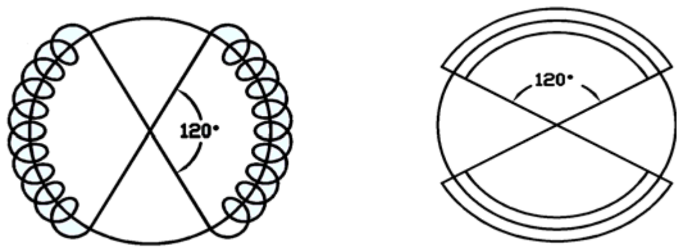

FIGURE 1. Schematic diagram of cosine and saddle coil of IR-T1 tokamak

TABLE 1. Main parameters of IR-T1 tokamak

Parameters	Value
Major Radius	45.0 cm
Minor Radius	12.5 cm
Toroidal Field	<1.0 T
Plasma Current	<40 kA
Discharge time	<35 ms
Electron Density	$(0.7\text{-}1.5)\times10^{13}$ cm^{-3}

EXPERIMENTAL SET-UP AND RESULTS

After fabrication of cosine and saddle sine coil, we used a 20-turn toroidal wound wire. For calibration, we observed that these coils posses an output that is directly proportional to the displacement of the current as it is moved radial outwards from the center of the coils, as shown in Figure 2. In the distance of 5cm from the center a non linear behavior of the output is observed which is due to overlapping of cosine and saddle coils on each other. Since the plasma radius in IR-T1 tokamak is about 12.5cm the threshold value for displacement is less than 5cm for plasma column, because after that the plasma will hit the circular limiter. Thus from the slope of the curve, the constant of proportionality is determined with a good approximation. Also with this system, we are able to identify the polarity of each signal.

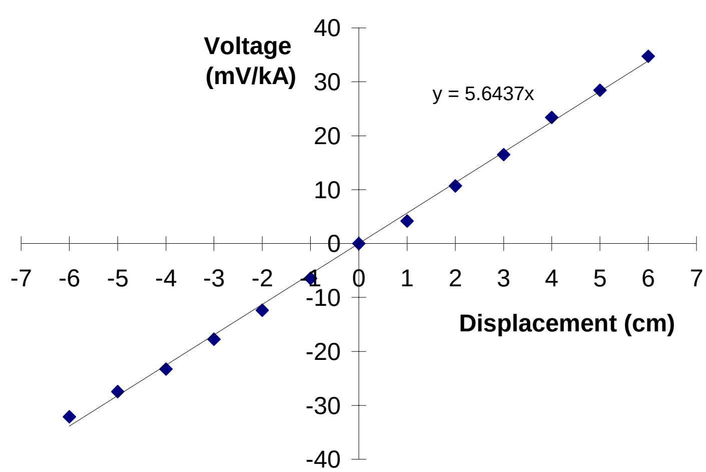

FIGURE 2. Cosine coil output as a function of horizontal displacement.

The output of H-Cosine and L-Cosine coils are added together with an appropriate ratio. They must be equal when the plasma column is in the center of the torus. Also Up-Saddle and Down-Saddle sine are added in the same way. Polarity and ratio of each signal has been identified by a plasma current simulation system.

By a Hitter switch, we can change polarity of cosine and saddle sine coils. Also their gain is adjusted by a potentiometer. Finally the sum of signals has been integrated by an active integrator, with gain as $1/RC = 10^4\ S^{-1}$. With a FET transistor, signals can be integrated in an appropriate time, which is identified by an IC timer 555. Then the coil is mounted on the shell of the machine. Also with this system we are able to identify the polarity of each signal.

In real experiment on tokamak, except for plasma current field, there are some other magnetic fields such as vertical, toroidal and ohmic fields, which their flux passes through the coils and affect on output signals [4]. To omit these unwanted signals, dI_V/dt, dI_T/dt, dI_H/dt etc. added to the circuit.

Then by discharge of each magnetic field separately, the potentiometer is adjusted to achieve the zero output. Therefore, the output signal depends only to plasma displacement. Plasma position would be obtained by dividing this signal to plasma current. In the last step this signal has to be applied to the feedback control system for improving the duration and quality of discharge.

Negative Feedback Control System

The negative feedback control system of horizontal displacement is designed to balance plasma and improve the quality of discharge and physics diagnoses. According to tokamak plasma equilibrium theory [2], the total vertical magnetic field used to equilibrate plasma can be calculated:

$$H = I_P/CR\ (Ln\ 8R/a + \beta_\theta + L_i/2 - 3/2) \qquad (1)$$

where, I_p is plasma current β_θ is poloidal β and R and a are major and minor radius of torus respectively, so that $H_\perp \approx 373.5G$. The control precision requirement for vertical magnetic field can be estimated by taking differential coefficient of equation (1) by R. considering the effect of R varying to a.

$$a = a_o - (R - R_o) \qquad (2)$$

For IR-T1 tokamak, when R approximately equals to R_o (45 cm) and others parameters are considered constant, the equation (2) can be written as;

$$\partial H_\perp/\partial R = -5.14\ G/cm \qquad (3)$$

The equation (3) shows that, if the vertical magnetic field H varies 5.14Gs (1.38% H), the plasma column displaces 1cm in the IR-T1 tokamak. Thus, plasma equilibrium requires high control precision of vertical magnetic field. According to the reports on negative feedback control system in other tokomaks, the programmable control field is about 15%- 20% and in the IR-T1 tokamak the feedback capacity is 16%. The relative parameters of IR-T1 tokamak are shown in Table 2.

TABLE 2. The relative feedback parameters of IR-T1 tokamak

The constant of time for vacuum room	T_s=0.7ms
FB coils distribution angle	±30º ±60º ±140º ±160º
FB field strength	B_f = ±30G
Sensitivity of FB field	H_{fo} = 0.06G/A
Ability of FB control	ΔH_f = 5.2G/cm
Response time of FB field current	15G/1ms
Current I_f of feedback electric field	$I_{fo} = B_f / H_{fo} = \pm$ 500A
The output voltage of feedback	U_f = 25 V

After preparation of feedback system, the H.D. signal should be amplifier and after compensation, apply to power switches. The signal will be amplified, by a Hitter switch and a potentiometer, which can be used for adjusting the gain and polarity. When plasma column moves outwards, feedback field must push it to equilibrium state, which is already defined by a DC offset for the system. This circuit is a simple proportional system, but the HD signal is integrated a little to prevent from effect of fast spark. Another point is that the fluxes due to vertical field goes through the feedback coil, so a sample of vertical field (I_V) must be added to main signal in control system, to compensate the effects of unwanted pickups. A block diagram of feedback system is shown in Figure 3.

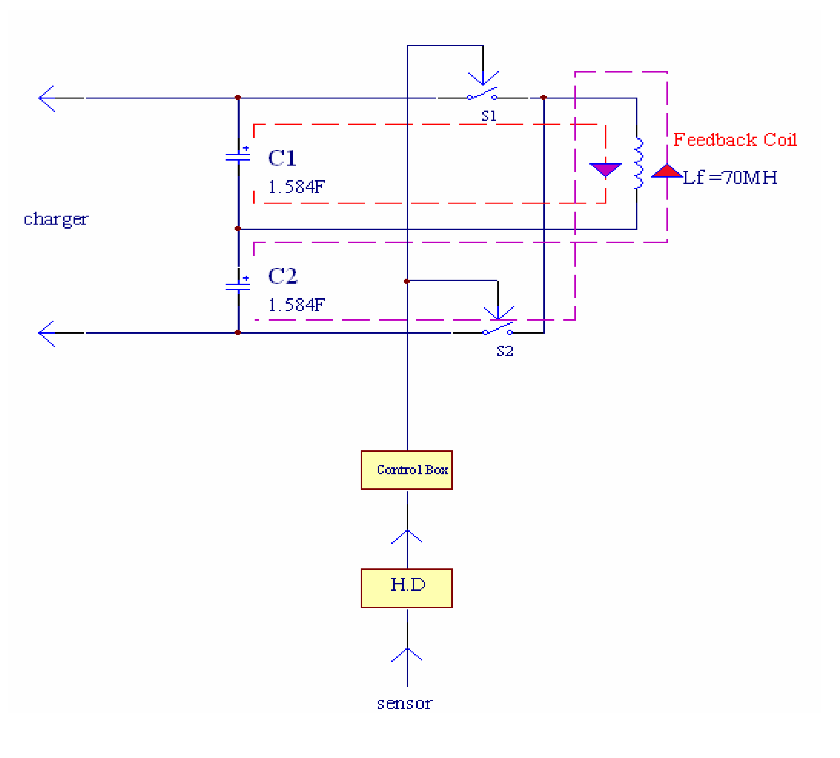

FIGURE 3. Block Diagram of Feedback System

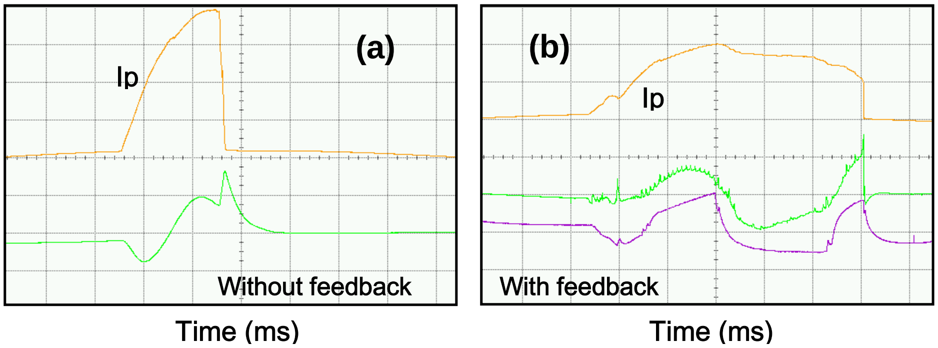

FIGURE 4. Plasma current and horizontal displacement a) without and b) with applying auxiliary vertical field.

Figure 4 shows a typical discharge of IR-T1 tokamak describe Plasma current and horizontal displacement with and without applying auxiliary vertical field. As it is clear in the figure, we can see an increase in the plasma duration and realizes repetitive discharges.

CONCLUSION

In the IR-T1 tokamak, a combination of two cosine coils and two saddle sine coils is used for horizontal displacement measurement. A new circuit for adding these signals to feedback system designed and unwanted effects of other fields in final output compensated. In the experiment, a good linear proportionality between displacement and output signal observed by applying an appropriate feedback field, the linger confinement time in IR-T1 tokamak obtained. Using this system during discharges increases the plasma duration and realizes repetitive discharges.

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