Preliminary results from magnetic measurement by using hall sensors in the KSTAR tokamak

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The linear integrating drift was typically observed in the signal of the inductive magnetic sensor for a plasma control during a plasma discharge with a time of less than ~20 sec in the KSTAR tokamak, and it was easily compensated by using linear fit on the baseline of the signal. However, it was found that there was the nonlinear integrating drift in the signal of the magnetic sensor for a long-pulsed plasma with a duration of longer than 30 s (see Fig. 1). The nonlinear drift was clearly observed in the sensor located at the outer midplane (OMP) side, which was mostly caused by the heat-up of the sensor itself due to the radiation from plasma because the sensor was opened to the plasma at the OMP side [1].

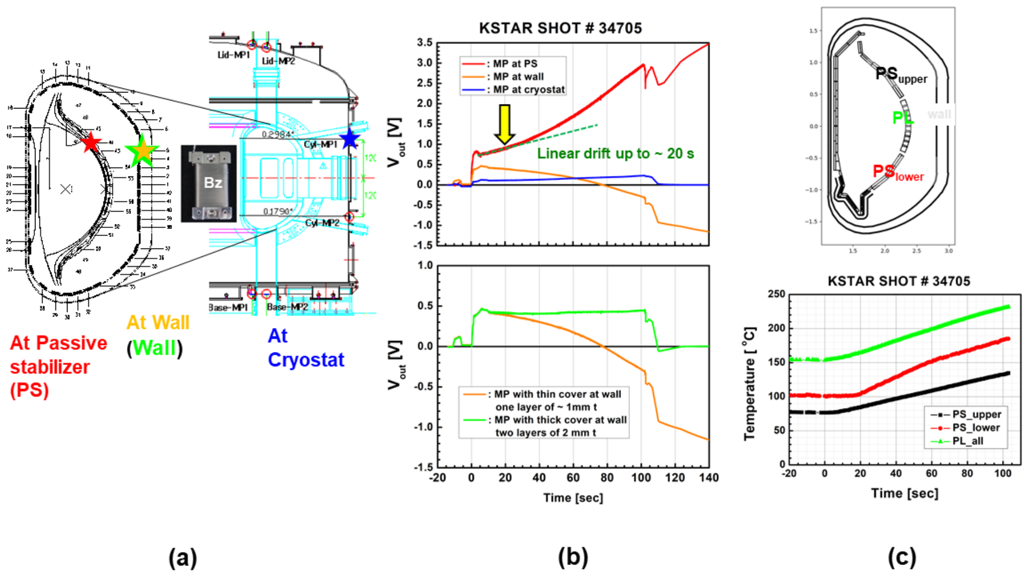
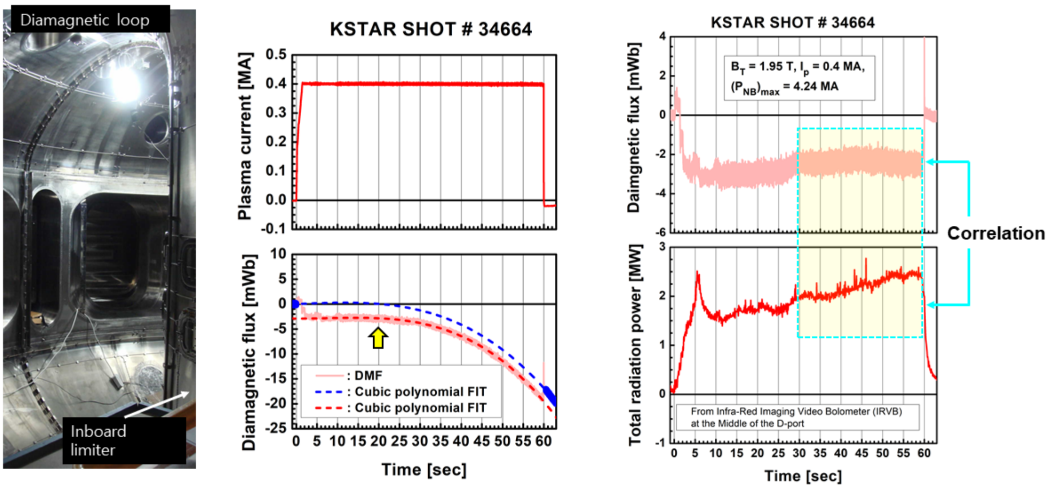


Fig. 1. (a) Poloidal cross-section of the vacuum vessel (VV) and the cryostat (C), together with the magnetic probes mounted on the walls of the VV and the C, (b) time evolutions of three magnetic probes at different radial locations and two magnetic probes at the same radial locations and (c) poloidal cross-section of the VV together with the plasma facing components (PFCs) and time evolution of temperatures on the PFCs at three different locations.

The non-linear drift in the sensor was able to be reduced down to almost zero (see the lower-sided of Fig.1(b)), which was done by covering a stainless plate on the sensor in order to prevent the heat-up of the sensor from the radiation. In addition, there was an activity for finding a method for compensating the nonlinear drift in the sensor signal during a long-pulsed plasma (see Fig. 2). Here, the nonlinear drift as a baseline was subtracted well by using a cubic polynomial fit on two end regions of the sensor signal. The reduction in the drift-compensated diamagnetic flux was clearly observed from 30 s to the end of the plasma discharge, which might correlate to the increase of the total radiation power due to the impurity influx during the same time interval.



(a) **(b)** **(c)**

Fig. 2. (a) Diamagnetic loop consisting of main and compensation loops inside the VV of the KSTAR [2], (b) time evolutions of plasma current and diamagnetic flux with non-linear drift as a baseline during a long-pulsed plasma and (c) time evolutions of the drift-compensated diamagnetic flux and total radiation power during the same shot shown in (b).

In parallel with the activity mentioned above, we tried to apply the method by using hall sensor for the magnetic measurement in the KSTAR. Considerable progress on the research and development of the hall sensors have been carried out in the Institute of plasma physics (IPP) of Czech Academy of Science (CAS) for applying them to the magnetic measurements in the future machines such as the ITER and DEMO [3, 4]. Several hall sensors were provided by the IPP-CAS as the international collaboration, so the performance test of three hall sensors was carried out during the experimental campaign in the KSTAR. Which is thought as the first step for applying the hall sensor to the magnetic measurement in a long-pulsed plasma in order to resolve the nonlinear drift issue. The sensitivities of the three hall sensors, which were named as hall sensor-1, hall sensor-2 and hall sensor-3 just for convenience, were 364.8 mV/T, 271.3 mV/T and 259.0 mV/T, respectively. Here, the amplification factor and maximum supply current in the controller for the hall sensor measurement were 1140 and 4 mA, respectively. The hall sensor-1 was installed at a certain position located from the outside of the VV for measuring B_Z together with a typical inductive magnetic probe (see Fig. 3(a)), and the hall sensor-2 and hall sensor-3 were mounted on the backplate of the passive stabilizer (PS) inside the VV for measuring B_R and B_T, respectively (see Fig. 3(b)). In the hall sensor measurements during the campaign of 2023 ~ 2024, the noise level obtained from standard deviation of the hall sensor signal was mostly 1.6 ~ 1.8 mV and the offset in the sensor signal measured under the condition without any magnetic field was 22 ~ 25 mV (see Fig. 3(c)). The noise level in the hall sensor measurements was within the value guaranteed by the IPP-CAS collaborator.

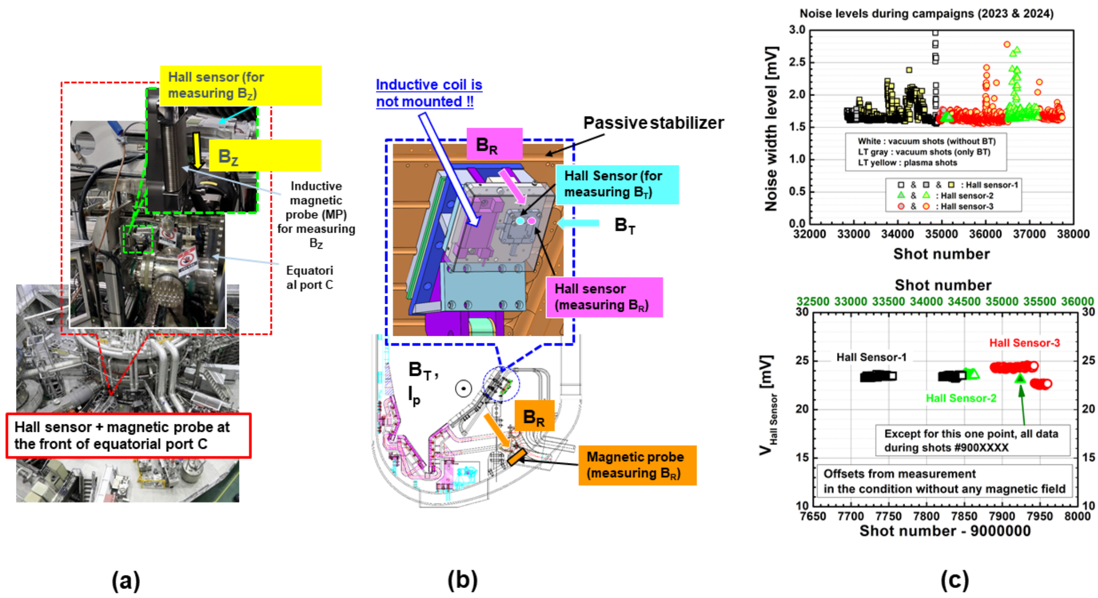


Fig. 3. (a) Hall sensor and magnetic probe for measuring B_Z at the same radial location from the outside of the VV, (b) two hall sensors mounted on the backplate for the PS for measuring B_R and B_T inside of the VV, (c) noise level and offset in the three hall sensor signals obtained during the experimental campaign from 2023 to 2024.

Fig. 4 (a) and 4(b) show the comparison between hall sensor measurement B_{HS} and inductive coil one B_{MP} at the same radial location from the outside of the VV for all shots during two campaigns of 2023 and 2024. The difference between the two measured values $< \Delta B>$ was mostly within +/- 1 mT. Here, $< \Delta B >$ means the averaged value of B_{HS} - B_{MP}. Thus, it could be expected that the hall sensor measurements agreed with the inductive coil ones within their discrepancy of 5 % from the comparison. The toroidal magnetic field was also measured by hall sensor at a certain radial position R (= 2.319 m) inside the VV during vacuum and plasma shots, and the value at the major radius of magnetic axis R_0 (= 1.8 m) was estimated from the hall sensor measurement by using the relationship as $B_{T0,estimate} = B_{HS} * R/R_0$. The toroidal field at R_0 was also calculated by using the applied TF coil current I_{TF} from a simple formula as $B_{T0,app} = \mu_0 N_{TOT} N_{TF} I_{TF} /(2\pi R_0)$ where N_{TOT} is the total number of the TF coil in the toroidal direction and N_{TF} is the number of turns in each TF coil. The linear correlation between $B_{T0,estimate}$ and $B_{T0,app}$ can be well-confirmed from the linear fit as shown in Fig. 4(c).

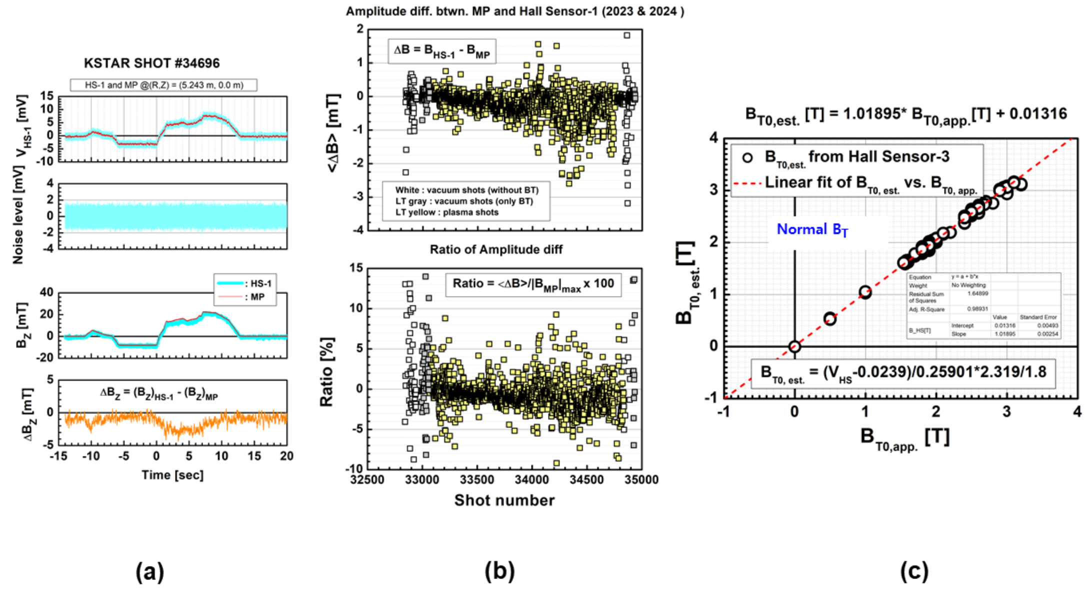


Fig. 4. (a) Time evolutions of tangential component of the poloidal field measured by hall sensor-1 and magnetic probe at the outside of the VV, together with the difference between the two sensor measurements and time evolution of the noise level in the hall sensor signal, (b) the difference between the two sensor measurements and its ratio from shot # 33000 to shot # 35000 and (c) toroidal field (TF) measured with hall sensor-3 versus TF calculated by using the current applied to the TF coil. Here, the two sensor measurements in 1621 plasma shots are used for showing <B> and ratio versus shot number in (b), and plasma current and toroidal field are mostly 0.5 ~ 0.52 MA and 1.75 ~ 1.85 T, respectively.

In this work, the nonlinear drift in the inductive sensor signal for the long-pulsed plasma of up to 60 s was able to be well-compensated by using a cubic polynomial fit on two end regions in the sensor signal. From the performance test of the hall sensors during vacuum and plasma shots in the KSTAR, it was well-confirmed that the noise level in the hall sensor measurements was within the guaranteed value from the IPP-CAS collaborator, and the toroidal field obtained from the hall sensor measurement matched with the calculated value using the TF coil current well.

As the next step for the application of hall sensors to the KSTAR, several works for the next step such as the optimization of set parameters for the hall sensor measurement, the investigation of the temperature effect on the hall sensor sensitivity including its characteristics for long-pulsed plasmas will be carried out.

References

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