Magnetic field measurements using the galvanomagnetic devices on Tore Supra and CASTOR tokamaks

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Introduction

Use of various configurations of flux loops for measurement of magnetic field in fusion devices is inherently limited by the pulsed operation of these machines. A principally new diagnostic method must be developed for magnetic measurements in true steady state regime of operation of fusion reactor. One of the options is the use of diagnostics based on Hall sensors. This technique is well established for many applications in experimental physics as well as industry, although it is rarely implemented in the experimental plasma physics. The use of Hall sensors in ITER is presently limited by their questionable radiation and thermal stability, as well as by a little experience with their performance in tokamak environment. The later issue is addressed in the paper reviewing the recent measurements of magnetic field using Hall probes on Tore Supra and CASTOR tokamaks.

3D Hall probe on Tore Supra tokamak

The performance of a magnetometric system based on a 3D Hall probe was recently tested on Tore Supra tokamak taking advantage of its long pulse capabilities. The system was developed by Lviv Polytechnic University, Ukraine. The probe head consists from three Hall sensors perpendicular to each other that allow full 3D measurement of a magnetic field vector in a single "point" ($<1cm^3$) of space. The system allows measurement of magnetic fields from 0.1mT up to 5T. Sensitivity of each Hall sensor is 0.287 V/T. A miniature magnetic coil with a total area of 0.1 cm^2 is attached to each Hall sensor to allow periodic in-situ recalibration and self correction during the experiment. The system offers high precision of 0.1% and good frequency response up to 12.5 kHz. The maximum precision of 0.01% can be achieved for a single Hall sensor by application of in-situ recalibration technique; however, there is a trade-off between the precision and frequency response, which is about 1 Hz in this case. The maximum operation temperature of the probe is 100°C which is satisfactory for measurements outside the Tore Supra vacuum vessel. Different type of Hall sensors must be used for the envisaged future internal measurements because the Tore Supra vessel is baked to 200°C as a part of wall conditioning procedures.

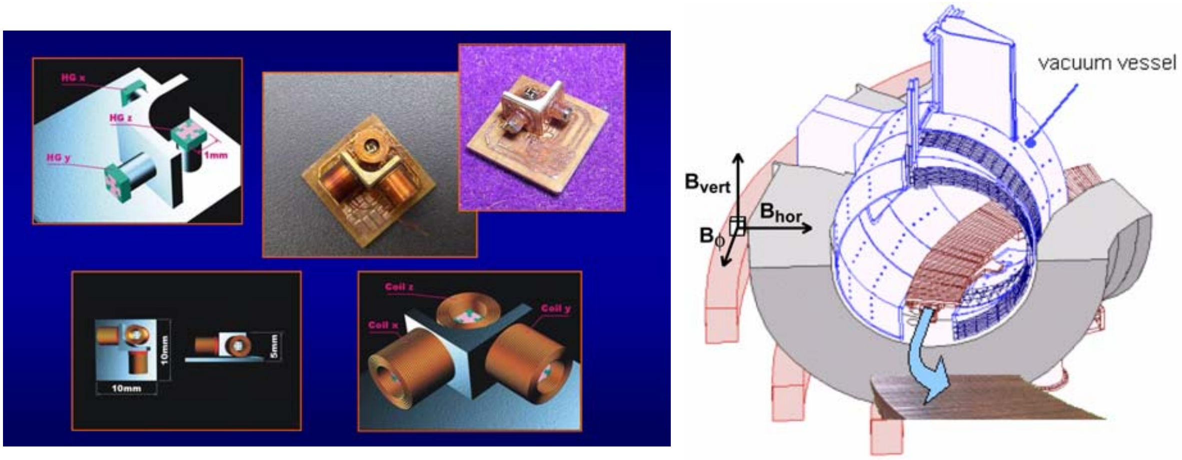


Fig. 1: Left panel – set-up of the magnetic probe used on Tore Supra combining three perpendicular Hall sensors with a miniature coil attached to each of them. Right panel – schematic layout of the experiment showing the location and orientation of the magnetic probe on the poloidal field coil of the Tore Supra tokamak.

The probe head was installed just outside the Tore Supra vacuum vessel onto the poloidal magnetic field coil (see fig. 1, right panel), where the magnetic field vector is well known. The sensors were oriented to measure toroidal B_ϕ, horizontal B_{hor}, and vertical B_{vert} components of the total magnetic field. The support electronics box was placed nearby in the tokamak hall and it was optically connected to the control PC which was placed in the control room. The system was fully autonomous and it was not synchronized with the Tore Supra DAQ system.

We have studied the LH driven shot #34085, with modest peak plasma current of 640 kA and a strong MHD activity. The measured traces of the magnetic field vector components are plotted in the fig. 2 (left panel). The DC offset of each trace is caused by the permanent toroidal magnetic field penetrating outside the radius of the toroidal magnetic field coils. As expected, the variations of the magnetic field vector at the Tore Supra poloidal field coil are dominated by the current flowing through this coil which is plotted in Fig. 2 (right panel) for comparison.

Additionally, we have compared the measurement of a 3D Hall probe with a standard Tore Supra 3D coil with low drift integrators located at the equivalent locations onto the poloidal field coil. Almost perfect quantitative agreement in the total magnetic field amplitude measured by both methods was obtained. Of course the DC component had to be removed

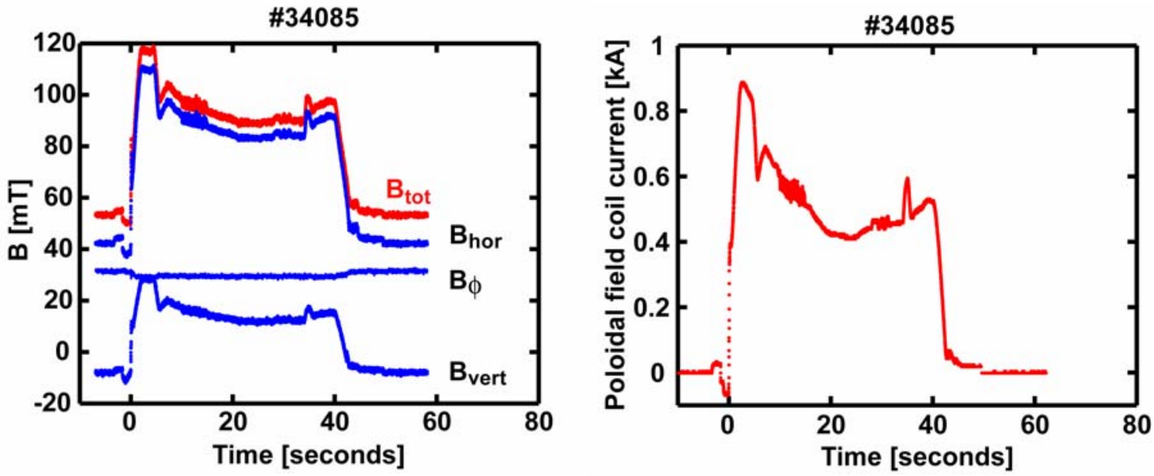
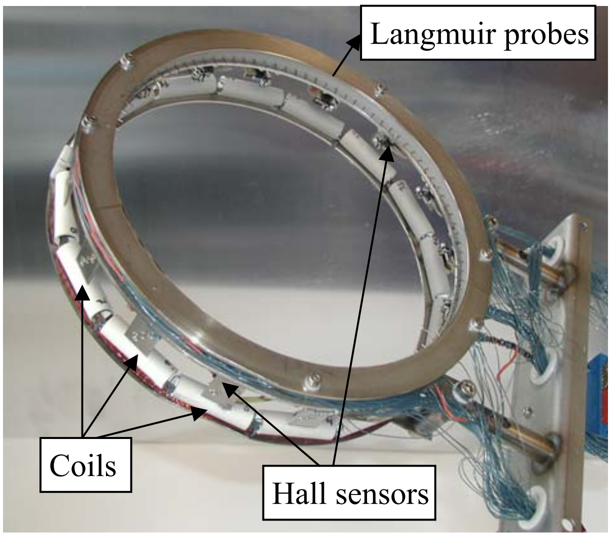


Fig. 2: Left panel - 3D Hall record of the shot #34085 with the maximum plasma current of 640 kA. Measured components of the magnetic field Bϕ, Bhor, and Bvert are plotted by blue, while the computed amplitude of the total magnetic field at the probe location is plotted by red. The right panel shows the current flowing through the poloidal field coil**.**

from the Hall probes signal, as coils are insensitive to it. The only discrepancy between the both methods of the order of 1 mT in magnitude was systematically observed at the plasma start-up phase during initial rapid oscillation. The possible reasons for this slight difference might be some local phenomena (e.g. some power line near one location) taking place in the beginning of discharge. Besides this minor uncertainty, the very good agreement between both methods proves compatibility of the Hall sensors with the out-of-vessel tokamak environment and motivates further exploitation of this technique on Tore Supra.

Full poloidal ring of 16 Hall sensors on CASTOR tokamak

The full poloidal ring of 16 Hall sensors, 16 magnetic coils, and 96 Langmuir probes uniformly distributed in the SOL encircling the whole poloidal circumference of the CASTOR tokamak (R=0.4m, a=0.085m, I_p=10kA, B_T=1.2T, n_e=$10^{19}$$m^{-3}$, T_e~150eV) was recently put in operation (see fig. 3). All magnetic sensors are aligned to measure poloidal component of the magnetic field B_θ. We used the low cost commercially available Hall sensors Allegro A1322LUA. These sensors contain BiCMOS monolithic circuit which integrates a Hall element, temperature compensating circuitry, small-signal high-gain amplifier, and a rail-to-rail low impedance output stage. The nominal sensitivity of the sensors is 31.25 mV/mT and a good frequency response is provided up to 10 kHz. Maximum allowed operational temperature is 150°C.



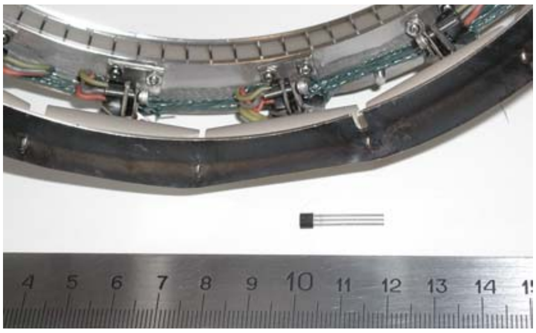


Fig. 3: Left panel – overall picture of the poloidal ring. Right panel – detailed view. A single Allegro Hall sensor is shown before its final mounting into the ring.

The example of the first results obtained using this diagnostics is shown in fig.4. The left panel shows the record of B_θ (measured by Hall probe No.5). Using the Fourier decomposition of the Hall sensors data, the vertical position of plasma column was deduced. Very good agreement with the vertical position measured by the CASTOR standard magnetics is seen (fig.4 – right panel).

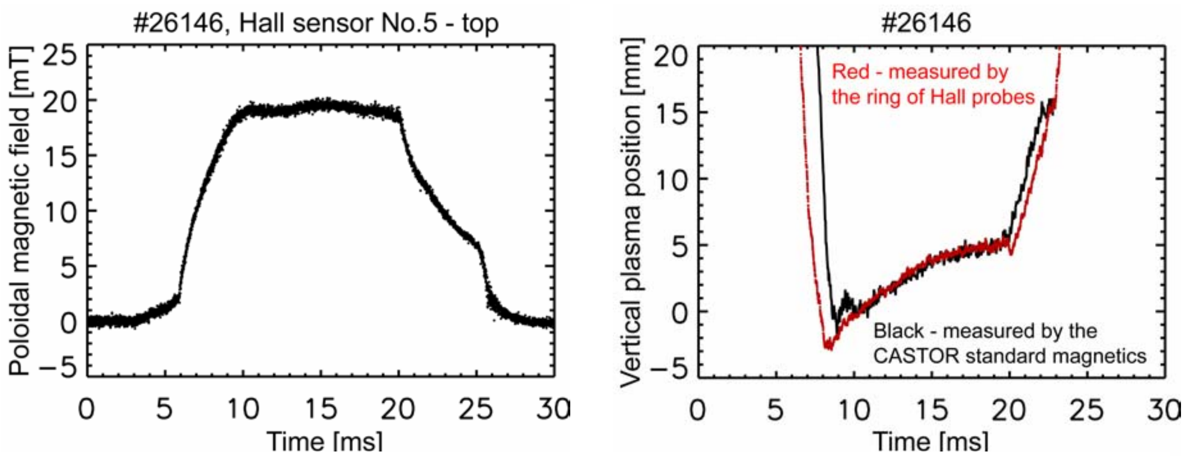


Fig. 4: Left panel – record of the B_θ during discharge #26146 as measured by the Allegro Hall sensor located at the top of the CASTOR vessel. Right panel – comparison of vertical plasma position deduced from the CASTOR standard magnetics (black), and from the ring of 16 Hall probes (red).

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