Present-day Experience In The Use of Galvanomagnetic Radiation Hard Transducers in Fusion Devices

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Abstract. The paper describes a new concept of probes for magnetic field measurements in tokamaks. The developed instrumentation is based on radiation hard galvanomagnetic transducers with the capability of self calibrating during the operation, so that to compensate the changes of characteristics due to the neutrons and temperature. The calibration is realized by periodical correction of the signal from the Hall transducer, so as to make it consistent with a test magnetic field generated by 1-2 mm solenoid integrated in the probe. Prototype probes were installed and tested in the TORE-SUPRA and JET tokamaks (www.jet.efda.org). Some results are presented in the paper.

Keywords: galvanomagnetic transducers, Hall probes, fusion devices, radiation hardness.
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INTRODUCTION

Controlled fusion is one of the most important long-term options for energy supply. As a positive result of past and present day experiments carried out following the tokamak approach to fusion, the construction of ITER has been started (International Thermonuclear Experimental Reactor, www.iter.org). An important feature of the magnetic diagnostics in ITER will be the capability of measuring the magnetic fields in quasi steady state conditions, since the current in the plasma will remain constant throughout a pulse lasting for several thousands of seconds. Besides, the probes must withstand the neutron fluxes resulting from the D-T fusion reactions.

Traditional inductive methods based on pickup coils [1] are extensively used in existing experimental fusion facilities, because the length of the discharges is compatible with the limits of the integrators and is equal to several tens of seconds. On the contrary, the long duration of the discharge expected in ITER-like devices, nearly approaching steady state condition, would imply that the field measurements from pickup coils are affected by intolerable errors due to the drift of the integrators. For these reasons direct field measurement are needed in ITER-like devices. In this respect, galvanomagnetic transducers, namely transducers based on the Hall effect, appear to be a promising solution, provided that it is proven that they are sufficiently radiation hard, so to withstand the severe neutron flux expected in a D-T fusion reactor. In this way the traditional Magnetic Diagnostics system, based on pickup coils and flux loops can be complemented by probes based on Hall effect.

The Hall probe concept described in the paper is characterized by high stability under intense energy neutrons irradiation [2, 3] in a high temperature environment. However, the time scale of the stability of these probes is short compared to the operational life of the device, where neutrons as well as periodic changes of temperature are the factors of destabilization. For this reason a periodic recalibration of the sensors as well as the correction of the signals are needed. In the ITER case, this calibration must be done in-situ, so that to exclude reinstallation of the sensors.

For this, special electronic instrumentation was developed, which, together with the radiation hard sensors as primary transducers, represents a multifunctional magnetic measuring system. This instrumentation provides for in-situ self-diagnosis. The other requirements to the magnetic field diagnostic instrumentation consist in wide-band magnetic field measurement, multi-channel measurement mode, high precision of measurement under considerable noise conditions and signal transfer over long distances etc.

THE METHOD OF IN-SITU MAGNETOMETRIC INSTRUMENATION WITH SELF-DIAGNOSIS

In a number of our previous works we proposed a self-diagnostic method applying functionally integrated magnetometric transducers [4, 5]. These detectors comprise two elements – a Hall transducer (HT) and a small-size solenoid with a coil's diameter of 1÷2 mm, which is wound around the Hall sensor and acts as an actuator (Fig.1, a).

The advantage of this approach is the possibility of periodical calibration; as a consequence the detectors based on this technique can provide high accuracy measurements at steady state and in hostile environments. The test field, which is periodically generated in the coil, is the reference for such self-calibration. This field is formed by the AC driven through the coil of the microsolenoid, and the differential component of the signal is being extracted by synchronous detection (T-mode). This method of in-situ calibration was successfully applied to three-dimensional magnetometric transducers for the measurement of three orthogonal components B_X, B_Y, B_Z of the magnetic field induction vector (Fig.1, b).

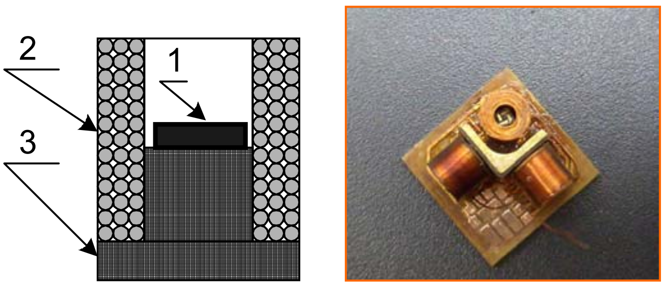
GALVANOMAGNETIC TRANSDUCERS FOR WIDEBAND MEASUREMENTS

In fusion machines, magnetic measurements have to be performed with a bandwidth of several hundreds kHz in an environment affected by very significant electromagnetic noise. The design of magnetometers for this application is therefore particularly demanding and a lot of attention must be devoted to the topology of the detectors and the laboratory equipments for the bench tests.

The wideband magnetometer is based on the original galvanomagnetic transducer (Fig.2), which integrates in a single crystal traditional HT (I), highly sensitive HT (II) and the loop for the electromagnetic compensation (III) [6].

For the high-frequency magnetic field measurements two signals are used. The first signal, being formed on the outputs 4 and 6 of the highly sensitive HT (II) has two components: a useful galvanomagnetic signal and electromagnetic pickup. The other signal appears at the outputs of the loop for the electromagnetic compensations (III) and has only the electromagnetic component. This allows to take into account the electromagnetic component in the useful signal, and significantly decrease the electromagnetic spurious pickup, and therefore improve the accuracy of the rapidly changing magnetic field measurements.

The improvement of the HT sensitivity (II) is achieved by decreasing its active part thickness to 0.2 μm. Besides, taking into consideration the insufficient stability of thin layer of the HT (II), it is periodically calibrated by means of the HT signal. Such the periodical calibration of the HT (II) is performed when the magnetic field is almost stable (during dry runs), and consequently the electromagnetic pickup can be neglected.



a) b)

FIGURE 1. Functionally integrated magnetometric transducer (1 – HT, 2 – coil, 3 – base)

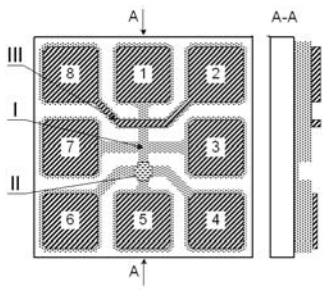


FIGURE 2. Galvanomagnetic wide-band transducer topology.

FUNCTIONAL CHARACTERISTICS AND INSTRUMENTATION STRUCTURE

On the basis of the above mentioned approaches, the magnetic field measuring instrumentation was developed, which, due to its all functional characteristics, meets the requirements of so-called “intelligent” devices of new generation, as it possesses the functions of self-diagnosis and automatic useful signal correction. The main instrumentation functions are:

- high precision measurement of magnetic field induction (HA-mode);
- wideband measurement of magnetic field induction (HF-mode);
- formation and measurement of test magnetic field (T-mode);
- correction of measured field induction magnitude;
- temperature and electromagnetic field measurement applying coils (the temperature is obtained by measuring the coil’s resistance change due to the temperature; and the electromagnetic field by the fast A/D transduction of the induced electromotive force on the coil’s outputs)

The instrumentation (Fig. 3) is comprised of: MX – multiplexer; CN – drive unit; CS1, 2 – current sources; SD – synchrodetector; HA – wideband amplifier; HC – wideband analog to digital transducer; LA – narrowband amplifier; LC – narrowband analog to digital transducer; ST –stabilizer; SI – serial interface; OP – optical isolator unit; PS – supply unit; IMT – integrated magnetometric transducer; TL1, 2 – signals transfer lines.

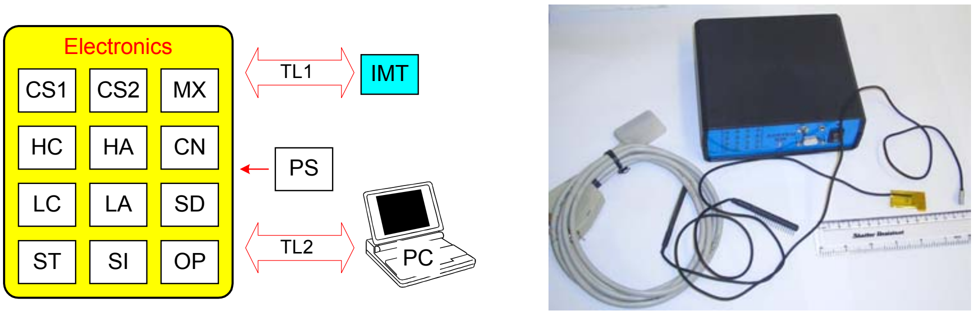


FIGURE 3. Structure and appearance of magnetic field diagnostics instrumentation.

RESULTS OF EXPERIMENTS ON TORE SUPRA AND JET

Developed instrumentation was tested during steady-state experiments, which were performed in 2004-2005 by the scientific staff of Magnetic Sensor Laboratory of Lviv Polytechnic National University on the TORE SUPRA (France) and JET (UK) tokamaks. On JET the 3D-sensor was located on the P3U poloidal field coil at Oct.8 (Fig.4).

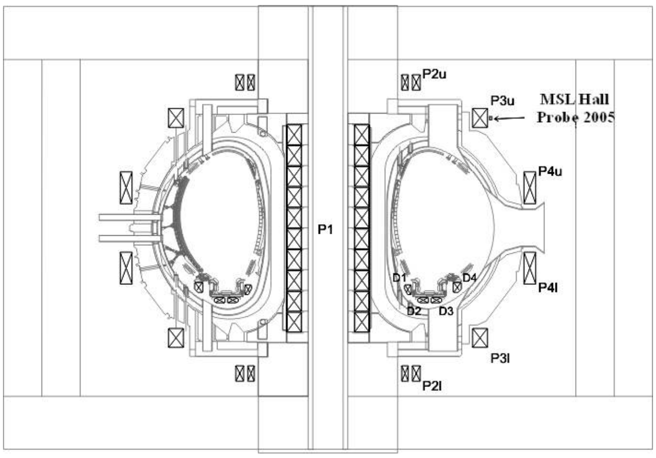
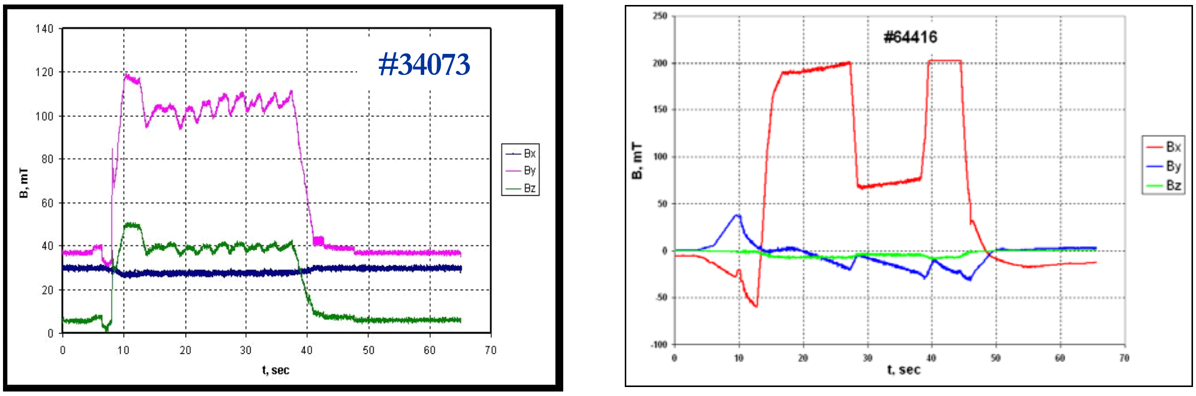


FIGURE 4. The location of the 3D-sensor on the JET.

The example of measurement results of the three orthogonal components B_X, B_Y, B_Z of magnetic field in a discharge of TORE SUPRA is shown in Fig.5, a (plasma pulse #34073). The observed oscillations in the case of TORE SUPRA shot are due to the internal dynamics of the plasma, causing periodic variations of the field. The results of the orthogonal components B_X (vertical), B_Y (radial), B_Z (toroidal component) measurements on the tokamak JET is shown in Fig. 5, b (plasma pulse #64416). The duration of the quasi-stationary phase in the two devices is several tens of seconds.



a) b)

FIGURE 5. The results of magnetic field measurement on the tokamaks TORE SUPRA (a) and JET (b).

CONCLUSIONS

The problem of quasi-stationary magnetic field measurements in fusion devices can be efficiently solved by using Hall-type galvanomagnetic transducers. Contrary to the traditional measuring coils, the HT can measure the steady-state and the alternating magnetic fields with sufficiently high accuracy. Proposed principles of instrumentation construction for quasi-stationary magnetic field measurements, based on the developed radiation hard HTs and original signal processing electronics, meet the requirements of extreme operation conditions on fusion reactors of new generation.

The galvanomagnetic transducers and the based-on instrumentation being presented in the work, were used during the experiments with quasi steady-state magnetic fields on the tokamaks TORE SUPRA (France) and JET (UK).

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