

## Impact of neutron irradiation on ITER candidate Hall sensors

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### *Introduction*

The need for the steady state magnetic field detectors becomes obvious especially for ITER pulses longer than 1000 s. Therefore, the Hall sensors which measure directly the absolute value of magnetic field could be an attractive solution. Their use in ITER environment is presently limited by their questionable radiation and thermal stability. Survival temperature of these sensors on ITER must be at least 220 °C which is the maximum allowance for baking temperature. Up to now, none of the commercially produced Hall sensors meet this requirement. Typically, the maximum operation temperature of commercial transducers is 150 °C. The total neutron lifetime (4700 h) fluence accumulated by these sensors on ITER will be at least  $2.5 \times 10^{17} \text{ cm}^{-2}$ . Such fluence can cause significant radiation damage especially in semiconductor type Hall sensors [1]. In the past, radiation stability of a representative set of available Hall sensors was measured on LVR-15 reactor. The most radiation stable sensor was the special InSb Hall sensor, manufactured by MSL, Lviv, Ukraine, showing decay of sensitivity at ITER target fluence of  $2.5 \times 10^{17} \text{ cm}^{-2}$  of only a few per cent.

The new, high temperature-resistant Hall sensors, compatible with temperatures up to 200 °C were recently developed in Magnetic Sensor Laboratory in Lviv. The aim of the contribution is to describe the recent pair of experiments done in order to determine the influence of neutron irradiation on these ITER candidate Hall sensors.

### *Experimental set-up and temperature characteristics of the tested Hall sensors*

For this purpose, two irradiation facilities were used: cyclotron U-120M located at NPI ASCR in Řež which provides white-spectrum neutron field ( $E < 35 \text{ MeV}$ ) with the fluence rate up to  $3 \times 10^{11} \text{ cm}^{-2} \text{ s}^{-1}$  and experimental fission reactor LVR-15 located at NRI in Řež which provides during 20 days long reactor campaign the total neutron fluence of about  $10^{18} \text{ n/cm}^{-2}$ .

At first, the dependence of sensitivity of the MSLx\_05 sensors, see Tab. 1, on temperature

was measured for each sensor. In the case of the cyclotron experiment, the simple irradiation head consists of MSL1\_05 sensor with winded PT-100 temperature sensor located together in a calibration solenoid driven by 8 Amperes. In reactor experiment, special aluminum irradiation head with plasma sprayed isolating alumina surfaces was prepared in order to allow irradiation at ITER target temperature range (100 – 150) °C. In this head there were located 3 Hall sensors, 6 PT-100 temperature sensors, and 5 thermocouples.

Specifications of MSLx_05 sensor	Units	No. 1	No. 6	No. 7	No. 8
Magnetic sensitivity (30 °C)	mV.T <sup>-1</sup>	670	680	690	690

Table 1: Technical characteristics of MSL sensors with nominal control current at 30 °C = 30 mA and at 200 °C = 8 mA; and with mean temperature coefficient of magnetic sensitivity around 200 °C = 0.5 % . °C<sup>-1</sup>.

The output voltages of the Hall sensors and thermocouples were collected with the rate 1 sample/s. The PT-100 output voltages were collected by PC oriented DAQ system with the same rate. The calibration solenoid inside the irradiation head was driven by power source of 320W, 0-30V, 0-30A. The PC-controlled switch was used to switch on/off the current to the calibration coil at pre-defined time intervals of 10 seconds. During separate measurement of

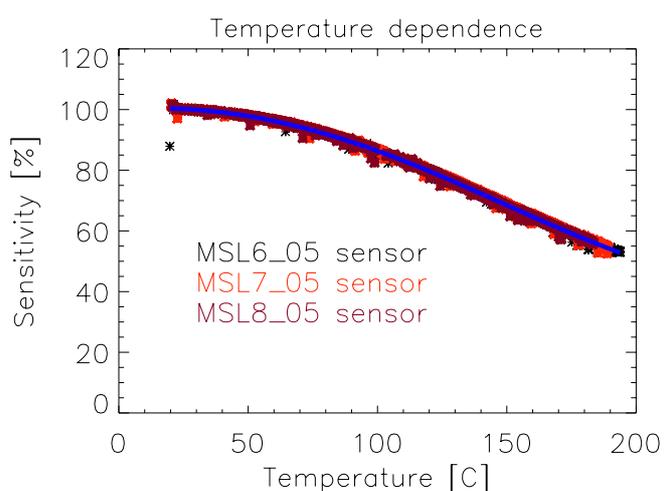


Figure 1: Dependence of sensitivity on temperature for MSL sensors.

the dependence of all Hall sensors on temperature, the irradiation heads were slowly heated up to 200 °C by pressurized hot air station, and then cooled down.

The results, see Fig. 1, have shown that the sensitivity of all MSL sensors decreased from the nominal 100% at 30 °C to 51% at 200 °C. This decrease is well described by the 4<sup>th</sup> order polynomial. Further optimization of the sensors properties should lead to suppression of this temperature dependence well below 1%. As the dependence of sensitivity is practically identical for all 4 sensors, it is concluded that it is independent on fine differences in doping of individual sensors.

#### Cyclotron experiment – high energy neutrons irradiation

After the temperature calibration, the experimental setup mentioned above was relocated to

NG2 station in the U120-M cyclotron hall. System parameters and sample rates remained the same as previously described, only there was no heating of the HS applied by additional external sources. This way we measured only the natural temperature increase due to the presence of calibration current and radiation heating and this way we achieved the target irradiation temperature slightly above 100°C.

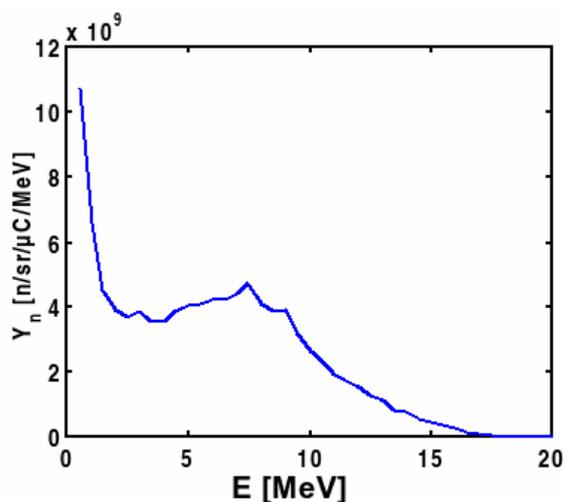


Figure 2: Spectral neutron yield.

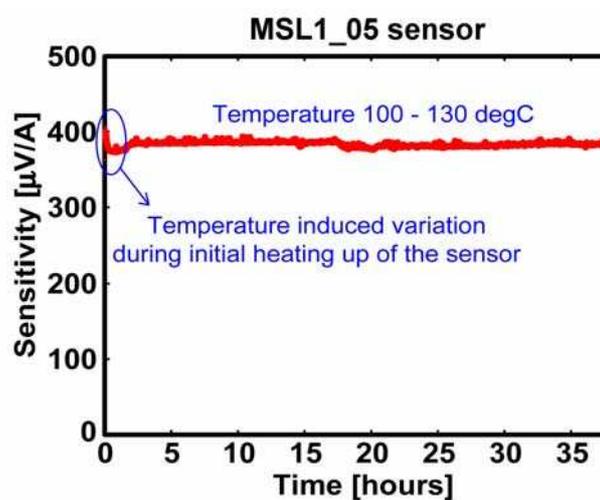


Figure 3: Sensitivity per unit of calibration current.

The MSL1\_05 sensor was irradiated for 38 hours and the total neutron fluence of  $1.55 \times 10^{16}$  n/cm<sup>2</sup> has been accumulated. This fluence is comparable to that of 200 ITER discharges each 3000 s long. Spectrum of the incident neutrons in terms of neutron spectral yield is shown in Fig. 2. The time evaluation of the Hall voltage  $U_H$  measured during the irradiation is shown in Fig. 3. Initial decay of  $U_H$  is due to the heating up of the sensor in the beginning of irradiation. Despite the observed minor variations of  $U_H$  along the irradiation, it was concluded that there is no significant effect (within 2 %) of high energy neutrons on the sensitivity of tested sensor. The observed variations of  $U_H$  are expected to be caused by high frequency stray fields associated with cyclotron operation. Additional source of uncertainty is the temperature monitoring of the sensor during irradiation because winded ‘radiation hard’ PT-100 turned out to be vulnerable to high energy neutron flux. As a result, fine details of temperature evolution were not well followed and, contributions to measured voltage from temperature changes and radiation could not be fully separated.

#### Reactor experiment – irradiation by fission neutron spectrum

Further, special aluminum irradiation head with 3 Hall sensors was irradiated in LVR-15 reactor. The irradiation head was placed in cadmium shielded irradiation channel to suppress thermal neutrons. The irradiation was done in normal air at atmospheric pressure. The sensors

were separated 25 mm vertically. Position of the bottom MSL6\_05 sensor was 330 mm above the active zone. The campaign itself started on 23<sup>rd</sup> April 2007 with the reactor power of 6.5

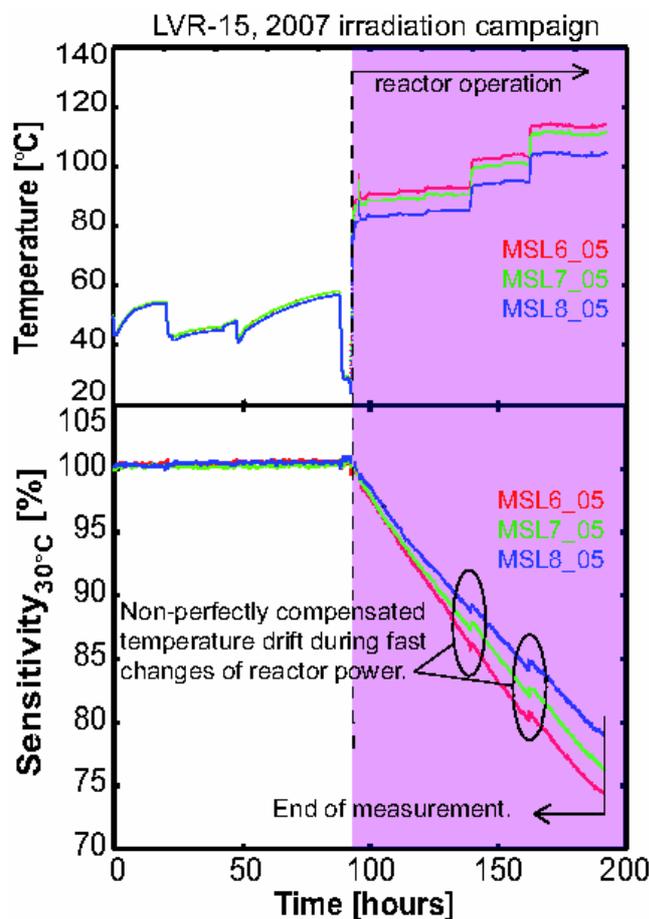


Figure 4: Top panel: time evolution of temperature. Bottom panel: Time evolution of sensitivity normalized at 30°C.

variations during these relatively fast transient periods. Estimated neutron fluence accumulated during 100 hours of irradiation has been approximately  $3\text{-}5 \times 10^{16} \text{ n/cm}^2$ .

### Conclusions and discussion

In both experiments has been accumulated approximately the same neutron flux. In the cyclotron experiment has this flux only minor influence on sensor's sensitivity. On the contrary, in the reactor experiment, the impact has been significant. It seems that the thermal neutrons (transmutation) are mainly responsible for decay of sensitivity of this type of Hall sensor while fast neutrons (structural defects) have minor impact on sensitivity.

### Literature

[1] G. A. Wurden et al: Steady-State Position Control for the Tokamak Physics Experiment (TPX), 62-940825-LANL, Nov. 1997

MW. The Hall sensors output voltages and their temperatures were monitored and analyzed with the same temporal resolution of 1 second.

Fig. 4 shows the time evolution of the sensitivity of each Hall sensor normalized to its value at 30°C during irradiation. The purple area denotes the period, where the reactor was activated. The sensitivity is significantly decreasing with the increasing neutron fluence for each sensor falling by about 20% after 100 hours of reactor operation. The time instances with sudden sensitivity perturbation are concurrent with the reactor power changes (see temperature traces for comparison – Fig. 4 top panel). The origin of these perturbations is imperfect compensation of temperature induced sensitivity