OVERVIEW AND FUTURE DEVELOPMENT OF THE NEUTRON SENSOR SIGNAL SELF-VALIDATION (NSV) PROJECT

Jean-Christophe Trama, Alain Bourgerette, Eric Barat, Bernard Lescop
LETI (CEA - Advanced Technologies)
CEA/Saclay
DEIN/SPE B 451
91191 Gif-sur-Yvette Cedex
FRANCE

Abstract

The NSV project was initiated at the Electronics and Nuclear Instrumentation Department (DEIN) of the French Atomic Energy Agency (CEA) in 1994. The main goals were the development of new signal validation methods to be applied on-line to neutron sensors in nuclear power plants. The methods used today are based on the use of DC reference curves, e.g. saturation curves for boron ionisation chambers, which requires the inhibition of the measurement, and are frequently not sensitive enough to predict any future sensor degradation. Some theoretic work done on fission and boron ionisation chambers signal modelling proved that these signals carry very interesting information regarding the sensor integrity not only in the DC part, but also in the AC part. The reason for this is that the signal formation in the sensor is intrinsically due to high frequency phenomena such as electrons and positive ions transportation in an electric field.

Based on that, this paper presents the self-validation concept for the neutron sensors (NSV). Self-validation means that we do not use any kind of redundancy, nor any kind of process model, which makes the method reliable even in case of multiple sensor failure or in case of abnormal change in the supervised process. The basic idea is the supervision of the information carried by the AC signal, under the form of Fast Fourier Transform (FFT) spectra. Careful comparison are made between various records of these spectra, and sensor degradation may be detected very soon, for example before any visible change on the DC signal allowing a kind of predictive maintenance.

Two measurements campaigns are described that validate the NSV concept. The first campaign showed that the NSV procedure was very sensitive to one of the most frequent failure modes of neutron sensors, namely air intrusion. The second one was an expertise achieved in a non-laboratory environment, to detect one failed sensor out of two.

Finally, we introduce the new items that are under development in this signal validation field at DEIN: realisation of an electronic module that facilitates the branching of a NSV system on present neutron flux measurement lines, and refinement of the spectra comparison.

Introduction

The aim of a signal validation method in instrumentation is to provide an operator with information on the state of a sensor, thus on the degree of validity of the attached measurement. We first present the concept of self-validation and its interest vs. classical methods based on redundancy or on process model. We introduce the original idea of the NSV project: the use of wide band spectral information as a criterion for self-validation of neutron sensors in the nuclear industry. Then the measurement methodology used to validate this concept is described, followed by the presentation of two different experiments that underline its usefulness. Finally we give a brief view on the future developments of this project.

Self-validation concept

A large number of signal validation methods exists. The most common are based on redundancy, which means that a comparison between a certain number of identical measurements is performed, and a decision concerning the validity of the measurement is made on a logical rule basis, usually 2 out of 3 or 2 out of 4. This method has an advantage which is its simplicity, and a drawback which is that it will give an incorrect result in case of multiple sensor failure. Some other methods use a process model that links mathematically various different measurements. When the mathematical relationship does not hold due to one or a few measurements, these measurement are considered erroneous. The main drawback is the lack of robustness of this method against any abnormal change in the process which would not be taken into account by the model.

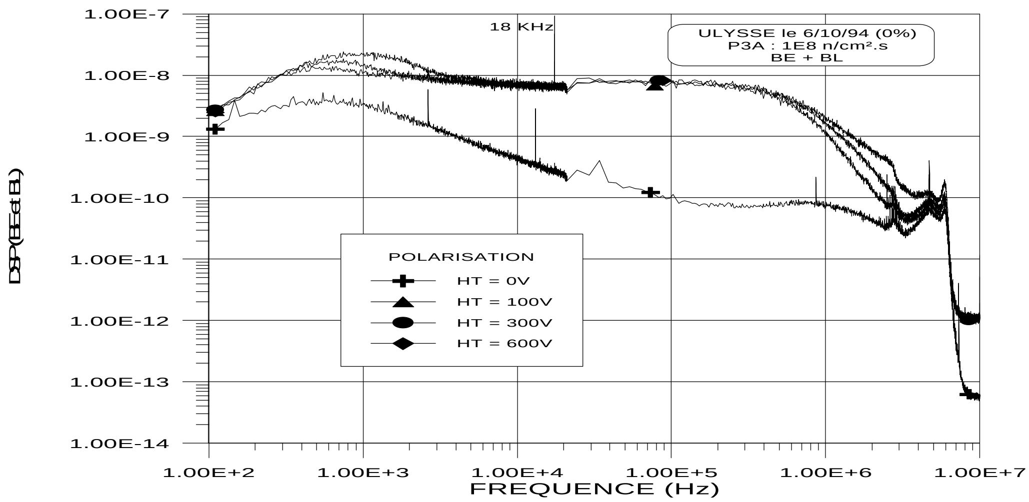
We have developed a self-validation method to be used with neutron sensor signals, which avoids these disadvantages The basic idea is to use only the signal coming from one sensor to validate this sensor. To achieve that we have to extract from the signal a criterion representative of the state of the sensor. If we consider the case of the technique used today for ionisation chamber, the criterion is a curve presenting the DC current vs. different bias voltages called the saturation curve. Unfortunately the DC values are not informative enough on the chamber signal. Indeed the signal formation inside the chamber, i.e. the creation of ionised pairs and their motion through an electrical field, is intrinsically a signal presenting an AC large band in the spectral sense [1,2,3]. Moreover this AC information being an image of the signal formation is of huge interest as far as the signal validation is concerned. Therefore we propose a new validation methodology based on the examination of this AC part of the signal. This examination may even be performed on-line, avoiding the measurement inhibition that is necessary for the DC saturation curve procedure.

Measurement methodology

The ionisation chambers are generally operated with a DC mode. That means that to get the AC part some change has to be made on the electronics module. During the first NSV project phase we replaced the DC classical electronics by an AC one. Then we put an anti-aliasing filter, followed by a 8 bits analogue to digital converter and an acquisition unit (LECROY 9354L). To get a precise enough spectral information for both charge carriers – ions and electrons – we had to choose two different sampling frequencies. The reason for this is the huge discrepancy between the mobility of these two elements. The ions, either positive or negative, being 1000 times slower than the electrons in the chamber gas, present their spectral information in a band whose maximum frequency is much lower than the electrons one, respectively some kHz and some MHz. To account for that, the anti-aliasing filter cut-off frequency and the sampling frequency were set to 20 kHz and 50 kHz (ions) and 5 MHz and 20 MHz (electrons). Then we compute some FFT spectra on both acquisitions. This procedure was repeated at various fluxes levels (from some 10^5 to some 10^{10} nv; 1 nv = 1 neutron per cm^2 per second), and for various bias voltages (including 0V), on the Saclay research centre Ulysse facility. These spectra were then recorded, and served as a comparison criterion between the various measurement campaigns [4]. A typical curve, with ionic and electronic spectra, is shown in Figure 1.

After each spectral acquisition, a DC acquisition was also performed to allow comparison between the present DC validation routine and our new one.

Figure 1. FFT spectra of a normal CC80 ionisation chamber for various bias voltages



NSV concept validation on two experiments

Ionisation chamber with air intrusion

To prove the NSV interest, we worked with a CC80 ionisation chamber from Schneider Electric. This is the type of chamber used by EDF (Electricité de France, the French utility) on the intermediary neutron lines on the French PWR. Our chamber was a slightly modified one, which permited the introduction of known quantities of oxygen. The air intrusion into the chamber being one of the most important failure modes of these sensors, this experiment allowed us to see at what oxygen quantities inside the chamber the DC method and the NSV one would detect a problem. The first step was a measurement campaign at 0% of oxygen, then at 0.1, 1 and 10%. As shown in Figure 2 the DC saturation curves were still acceptable at 10%, while the NSV shows an anomaly at 1%. Indeed, a simple comparison between Figure 1 and Figure 3 reveals a much greater evolution of the spectra vs. the bias voltage, together with a decrease of the electronic part of the spectra on the 1% case. This effect was awaited, because oxygen tends to attach

Figure 2. DC saturation curves acceptable for 0, 1 and 10% O^2 concentration

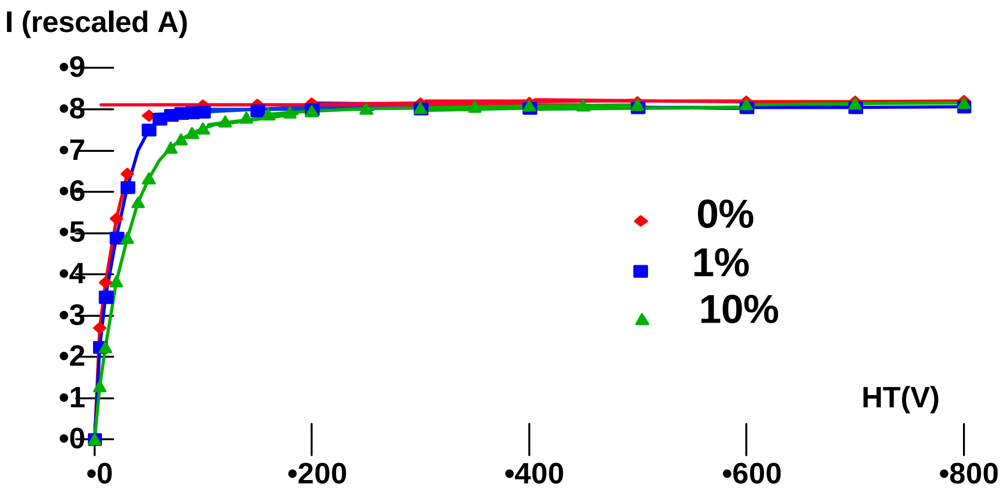
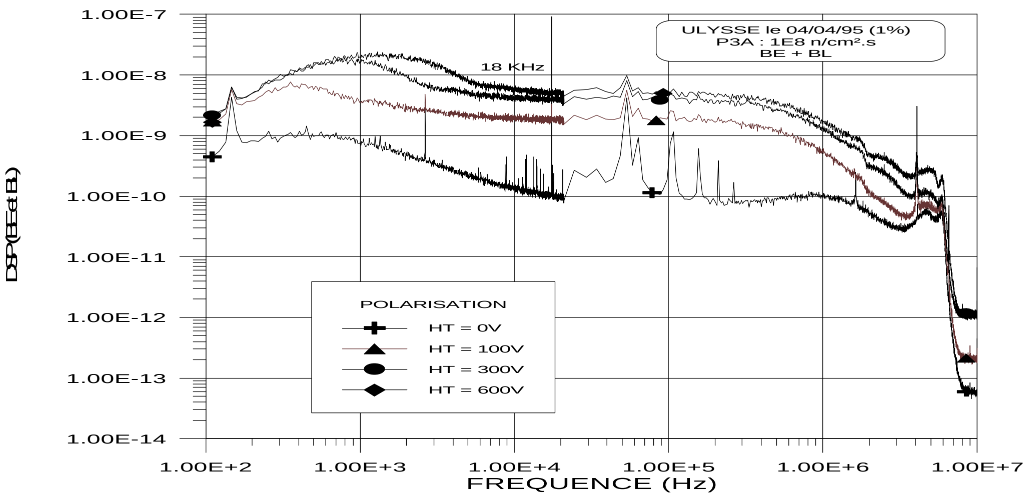


Figure 3. FFT spectra of a CC80 ionisation with 1% O^2 oxygen intrusion for various bias voltages



electrons, which gives birth to slower negative ions, thus reducing the number of fast charge carriers contributing to the high frequency part (electronic part) of the spectra. Moreover there is great evidence that a similar anomaly was detected by the NSV at 0.1% but, as measurement uncertainties were found at this concentration, it cannot be mentioned with absolute certainty.

This means that the NSV technique is in this case predictive, in the sense that it is able to detect an anomaly even before the anomaly has a negative effect on the DC signal. That allows an easier maintenance, and may avoids some non-scheduled shut-down of the plant for instrumentation default if the future faulty chamber is replaced during a normal maintenance shut-down. These first results were very interesting in that they were the first experimental proof of this new concept [4].

Expertise on two ionisation chambers

On the Siloé facility (Grenoble, CEA research centre), two identical DC neutronic measurement lines using ionisation chambers serve to monitor the flux. One day an evolution of one the lines was detected, whereas absolutely no change have had been done on the instrumentation. The DEIN experts were able to discard the hypothesis of an electronic origin of the problem. The NSV measurements were then done by the DEIN, which clearly indicated thanks to the abnormal shape of its ionic spectrum that one chamber was defective. What is important in this second demonstration is that the experiment was done in an industrial environment, without taking care of the environment EMC, which demonstrates the industrial potential of the method [5].

New developments and perspectives

Splitter module

In order to install a NSV system on actual measurement lines, DEIN will develop a splitter module. This module will extract the AC information to be sent to the NSV system, without distorting the chamber signal, which will allow a parallel running of both the classical DC analog line and the NSV unit.

NSV criterion

As stated previously during the first phase of the NSV project, we used the whole spectra as a characteristic curve of the sensor. The next step is now to extract a parameter from this curve. This parameter would ideally concentrate the information concerning the difference between two spectra. Two directions are possible: on the one hand we could compute the energy present in a certain band of the spectrum. The choice of this band would be driven by physical characteristic of the chamber (for example, we could study the low frequency band corresponding to the motion of ionised ions in the inner gas, this choice allowing us to work on lesser frequencies than today). On the other hand we could rely on a more theoretical spectral distance, but presenting less relationship with the physical aspects [6].

Conclusion and perspectives

There is a growing interest in the nuclear community for advanced signal processing algorithms [7]. These new techniques involving some more sophisticated computations are now possible thanks to the micro-electronics progress (powerful DSP are now available at low cost). Moreover they allow the enhancement of measurement lines already existing, avoiding some new expensive R&D on the sensor itself. This remark typically applies to the neutron sensors, like the ionisation chambers, which have been giving satisfactory results for many years. The basic idea we promote relies upon a better use of the sensor signal, i.e. not only the DC part, but also the whole AC part. This AC part being closely related to the signal formation inside the sensor is a very good criterion for signal validation, and may be used in a predictive maintenance perspective. Moreover such a technique does not rely on any kind of redundancy, nor on any kind of process model, which makes it equally robust against multiple sensor failures and abnormal changes in the process.

REFERENCES

[1] S. RAMO, *Currents Induced by Electron Motion*, Proceedings of the IRE, **27**, p. 584, 1939.

[2] E. BARAT, J.-C. TRAMA, A. BOURGERETTE*, Impulse Response Model for a Pulse Ionisation Chamber*, Proceedings of the Ninth Power Plant Dynamics Control and Testing Symposium, Knoxville, Tennessee, 5/95.

[3] E. BARAT, J.-C. TRAMA, *Neutron Sensors Signal Validation*, SMORN VII, Avignon, France, 6/95.

[4] A. BOURGERETTE, B. LESCOP, T. DOMENECH, *Influence de la modification du gaz sur le spectre du signal d'une chambre à dépôt de bore*, CEA technical reports.

[5] A. BOURGERETTE, T. DOMENECH*, Test d'une chambre d'ionisation à dépôt de bore CC54*, CEA technical reports.

[6] M. BASSEVILLE, *Distance Measures for Signal Processing and Pattern Recognition*, Signal Processing, **V18**, n 4, 12/89, p. 349-369.

[7] *Advances in Safety Related Diagnostics and Early Failure Detection Systems*, Report of Technical Committee Meeting, IAEA-J4-TC698, Vienna, 20-24/11/95, p. 4-13.