TREATMENT OF ELECTROCHEMICAL NOISE DATA BY THE HILBERT-HUANG TRANSFORM

Background

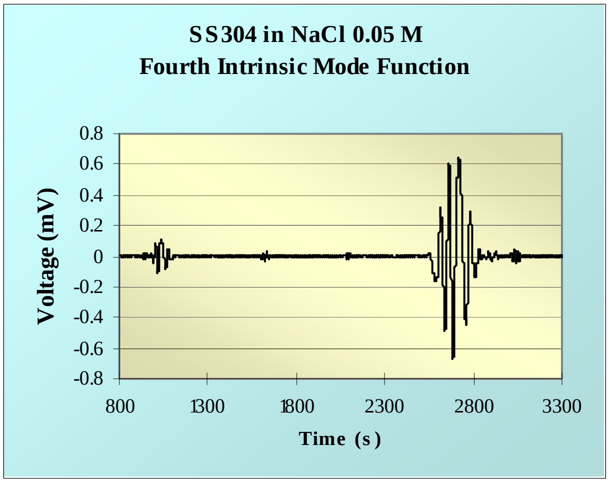
Most of the classical approaches for treating electro-chemical noise (ECN) data suffer from the non-linear and non steady-state character of the delivered signal. Very often, the link between time and the local corrosion events supposedly responsible for ECN data signatures is lost during treatment, as is obvious when using the classical Fourier Transform (FT), followed by an analysis of the response in the frequency domain. In this particular case, the information directly related to the corrosion events is distributed into the full spectra, thereby preventing the operator to derive clear and precise conclusions. In 2005, we suggested an alternative data treatment based on the Hilbert-Huang transform (HHT). The latter keeps track of the time variable and copes with non-linear and non steady-state behaviours of the system under examination. In 2006, we demonstrated the applicability of the newly proposed data treatment in the case of ECN data collected under BWR (Boiling Water Reactor) conditions. In 2007, we collected additional ECN data and started a preliminary investigation of two mathematical restrictions that are susceptible to impair the interpretation of the results. We discovered a possible modification of the Hilbert transform allowing generating controlled phase shifts that are different from $\pi/2$ as is always the case for the Hilbert transform.

Objectives

On the long term, we aim to start tracking the relations between ECN time signatures and their corresponding translation after the application of the HHT. The HHT delivers a series of functions called Intrinsic Mode Functions (IMF's), whose essential property is that the mean of their upper and lower envelopes is about zero (i.e. lower than a given threshold) for all abscissa. Having noted that the HHT answers often appear under the form of burst-like signals distributed among the different IMF's, we expect to face two mathematical restrictions. The first one was originally identified by Bedrosian (1963), who states that the Hilbert transform of the product of two functions is the product of one of these functions by the Hilbert transform of the second function if and only if the Fourier spectra of both functions are totally disjoint in the frequency domain. The frequency content of the non-transformed function has to be located below the frequency content of the transformed function. The interpretation of burst-like signals may be impaired when the FT spectra of the envelope and of the underlying frequencies are not disjoined. The second restriction has been discovered by Nuttall (1966) who states that the Hilbert transform of a cosine with an arbitrary phase function is not necessarily the sine with the same phase function. This causes some difficulties in analysing the complex plane responses derived from the analytic signals. Therefore, we collected additional ECN data and located one burst in the HHT signatures. We aim to simulate the burst by a function resulting from the product of a Gaussian envelope and a sine of controlled frequency and phase.

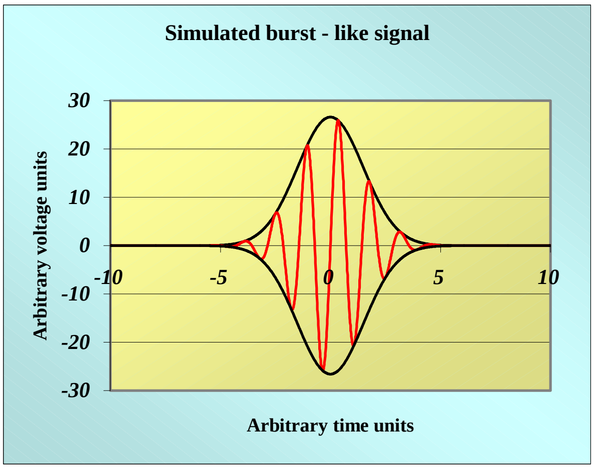
Principal results

SS304 steel rod shaped samples were immersed in an electrolyte containing 0.05 M NaCl. ECN data were taken using three identical electrodes, the first one acting as working electrode, the second one being used as reference electrode and the third one being grounded. The sampling frequency was 2 Hz and the duration was fixed at 4096 s. Typical metastable pitting signatures were observed in the potential time series. The latter were submitted to the HHT, delivering 12 intrinsic mode functions and one residual function. As is shown on the figure, experimental burst-like signatures are observed in the intrinsic mode functions. Note that the original time signatures translated into several burst-like answers distributed among the different intrinsic mode functions. At present, there subsists much controversy about the physico-chemical interpretation of the original time signatures associated to metastable pitting. Relating these interpretations to the shape of the burst-like answers as well as to their particular distribution among the IMF's will require further work. For now, we aim to focus on the mathematical restrictions defined above.



Experimental signal observed after treatment

On-going work is presently devoted to the Bedrosian restriction. For this purpose, we constructed a function simulating burst-like answers. Such function is depicted on the figure and can be visually compared with the HHT signatures observed in practice. The simulating function results from the product of a Gaussian envelope and a sine function. We are now in the process of submitting this simulated function to the HHT in order to analyse the Bedrosian restriction in terms of FT spectra of the sine and the Gaussian envelope using different parameter sets. Furthermore, the Nuttall restriction is also being examined. In our home-made code, the Hilbert transform has been implemented on a very classical way, observing that the Hilbert transform is a convolution with 1/(πt), the FT of which being –j.sign(f), with $j = \sqrt{(-1)}$ and f being the frequency in the Fourier domain. Thereby, the Hilbert transform of a function can be obtained by multiplying its Fourier transform by (–j.sign(f)) and calculating the inverse Fourier transform of the result. However, we observed that replacing –j by a more general complex number z = a + j.b allows controlling the phase shift between the original function and its transform. We are now in the process of examining the constraints to apply on z in order to keep the amplitude constant while generating controlled phase shift transforms. To our opinion, this approach could help coping with the Nuttall restriction in some cases. Finally, one useful figure delivered by the HHT is the so-called instantaneous frequency. The latter is generally defined as the first derivative of the phase angle associated to the complex analytical signal whose real part is the original function and the imaginary part is the Hilbert transform of the original function. This definition is questionable by virtue of the Nuttall restriction. Part of our future work will be devoted to the interpretation of the instantaneous frequency as defined above and to the eventual proposal of an alternative way for calculating these instantaneous frequencies.



Simulated function

Future work

Future work will be devoted to:

- the further analysis of the Bedrosian restriction by applying the Hilbert transform and its modified version to the simulated burst signal;
- the further analysis of the Nuttal restriction by applying the modified Hilbert transform to a simulated signal involving known phase shifts;
- an attempt to define an enhanced way to calculate instantaneous frequencies;
- a very first attempt to associate the HHT output to the ECN signature in the case of metastable pits.

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Main reference

A. Rahier, R. W. Bosch, "Treatment of ECN data by the Hilbert-Huang transform", Restricted contract report R-4291 (January 2006)