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The Hilbert transform as a quality control tool in capacitive pressure transmitters

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ABSTRACT

The capacitive pressure transmitters consist of an isolating diaphragm connected to a sensing line through some inner tubes which contain silicone oil. The accuracy of the sensor is determined by the efficiency of the filling process with silicone oil in the transmitter inner chambers, so that the fact of not filling completely any of the transmitter chambers can affect the dynamic response of it. In fact, the oil loss syndrome is one of the most important breakdowns, since the sensor dynamic behaviour is no longer linear. In this work the Hilbert transform is applied to detect the non-linearity in the sensor response to a sinusoidal pressure wave. Such sensor suffers the oil loss syndrome at an incipient phase. The ill sensor is compared with a linear one and the efficiency of the analysis is proved for the detection of a non-linear behaviour as opposed to the traditional methods based on Fourier analysis. At last, a non-linear model taken from literature is validated with empirical data.

1. Introduction

The capacitive pressure transmitters, and specially the Rosemount type, are widely used in Nuclear Plants nowadays [1]. They are compound by an isolating diaphragm connected to a sensing line through some inner tubes which contain silicone oil [2]. The accuracy of the sensor is determined by the efficiency of the filling process with such silicone in the sensor inner chambers [3], so that the fact of not filling completely any of the sensor chambers can affect the dynamic response of it.

So, the oil loss syndrome is one of the most noticeable sensor breakdowns and consequently, the dynamic response of it is no longer linear. Several organizations, like EPRI and NUREG have studied the syndrome to understand it and detect it [4,5].

In this work the sensor response to a sinusoidal pressure wave is analyzed to detect a possible non-linear behaviour. To achieve that, the instantaneous amplitudes and frequencies diagram from a linear sensor will be compared with a non-linear one. Besides, a mathematical model will be established to justify such behaviour. In this way, the analysis through the Hilbert transform is proposed as a quality control test for sensors to evaluate the silicone oil filling process.

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2. The Hilbert transform

The Hilbert transform has demonstrated to be a good identifier of non-linearity in previous work [6–8] and also in the nuclear field, for detecting non-linearity in signals coming from neutron detectors [9]. The Hilbert transform is a function of time $f(t)$ and is defined by

$$H[f(t)] = \tilde{f}(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{f(\tau)}{t-\tau} d\tau \tag{1}$$

This transform permits us to represent signals using the complex exponential such as

$$Y(t) = y(t) + j\tilde{y}(t) = A(t)e^{j\psi(t)} \tag{2}$$

being $Y(t)$, the analytical signal of $y(t)$ and $\tilde{y}(t)$ its Hilbert transform. Then $A(t)$ is called instantaneous amplitude and $\psi(t)$ instantaneous phase. The instantaneous pulsation ω is defined as the phase derivative with respect to time.

The representation of the instantaneous amplitude against the instantaneous frequency characterizes the way a system is non-linear. Such representation is named backbone diagram. Although the modern Hilbert transform analysis [10] enables restoring not only a backbone but also the non-symmetric and non-linear characteristics, in this paper the backbone is enough.

The Hilbert transform is applied to oscillatory character signals. In the case of a type Rosemount pressure sensor, the analysis of the response to a pressure wave in the time domain is an experiment which has been carried out in other occasions in the laboratory [2] to study the sensor dynamic response. Nevertheless, a Hilbert transform analysis has much more potential, especially for the detection of a non-linear behaviour in newly manufactured sensors. In this way, a quality control test can be carried out previous to normal operation in nuclear plants.

Taking into account other author's models [11], the sensor follows a first order dynamic. Therefore, its response to a sinusoidal wave will result in just one point in the backbone diagram corresponding to unique instantaneous amplitude and frequency. If the sensor was not linear, other instantaneous frequencies and amplitudes, which could not be observed in a linear case, would appear.

3. A study case

In this epigraph the Hilbert transform will be applied to a sensor (Rosemount, model 1153) response to a sinusoidal pressure wave. The sensor under study has suffered the oil loss syndrome, that is, its inner chambers are not completely filled with silicone oil. Firstly, the pressure wave used has a large amplitude, whereas the second applied wave has a much lower one. The response to a large sinusoidal wave is shown in Fig. 1.

In Fig. 1 it is observed that the wave response is broken and the non-linearity can be appreciated at first sight. After performing a Hilbert transform analysis of this signal, the diagram shown in Fig. 2 is obtained, where the instantaneous frequencies and amplitudes are normalized by the apparent response frequency (0.2 Hz) and the maximum response amplitude.

In Fig. 2 it can be appreciated that the backbone corresponding to a linear response in grey and the case of a non-linear response in black. The linear behaviour is characterized by having a certain instantaneous amplitude and a certain instantaneous frequency, while the non-linear one, associated to the oil loss syndrome, comprises a wider amplitudes and frequencies range.

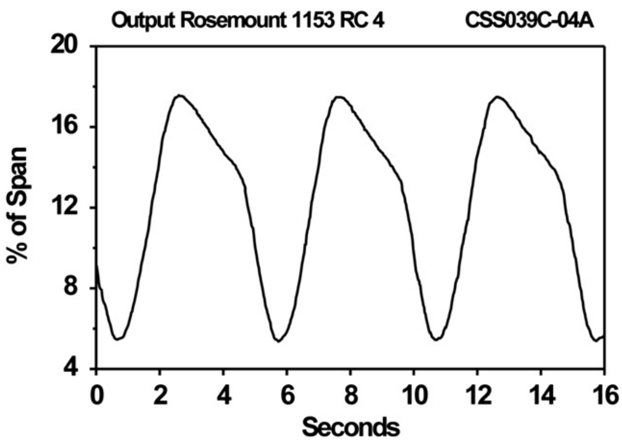

Fig. 1. Response from an oil capacitive pressure transmitter to a harmonic pressure wave. Taken from [2].