A Hardware for Processing Magnetic Pressure Sensor Signals from Leak Detection in Waterworks

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ABSTRACT

Leaks in pipelines and waterworks are detected using different methods and among them spectral analysis is one of the most interesting ones. Sources of signals to be processed are different, for example: reflected signals from ground penetrating radar and acoustic sources, signals from dedicated sensors mounted on pipelines, etc... In the latter case, magnetic pressure sensors located on the pipeline acquire vibrations and oscillations of liquids (e.g. water) in the pipeline, following a leak in the pipeline. These vibrations and oscillations are transformed in electrical signal and processed using different methods and techniques like FFT (Fast Fourier Transform), ANN (Artificial Neural Network), STFT (Short-Term Fourier Transform), and Impedance Method (IM). But there are other advanced methodical approaches that can improve the quality of the signal related to the leak; one of them is FDM (Filter Diagonalization Method). Even in presence of an advanced method, recovered signal displays undesired attenuation and noisy behavior due to different reasons, namely, hardware, background noise, materials used for pipeline construction, sensors, etc.. This paper presents a complementary hardware for processing the above signals. The hardware is based on innovating approach that minimizes additional noisy components.

Keywords: Hardware, Leak, Magnetic Pressure Sensors, Pipelines, Processing, Waterworks

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1. INTRODUCTION

Water resource is generally conveyed and transported by pipelines from sources and plant production to the area of utilization. A leak in a pipe causes partial reflections of wave fronts that become small pressure discontinuities in the original pressure trace and increase the damping of the overall pressure signal (Wang, et al. 2011). Such partial reflections act to divert energy away from the main waveform and increase the decay rate of the transient signal. The behavior of this pressure trace is, therefore, indicative of leaks within the system and can be used as a means of leak detection, e.g. those that use inverse methods to determine parameters in transient models by comparison with observed data (inverse transient analysis), transient damping—free-vibrational analysis, and also methods that use the time of arrival and magnitude of leak-reflected signals to determine leak location. All these published fluid transient leak detection methods share a common theme in that a small amplitude disturbance - a fluid (Khulief, et al., 2012) transient - is initiated in a pipe and the subsequent pressure response is measured and analyzed to derive system information. This type of analysis is more commonly known as system response extraction and forms the basis of well established methodologies used to extract dynamic responses (Kuang, 2012) of complex mechanical and electrical systems. Whereas resonance frequencies reinforce and transmit input signals, other frequencies are absorbed within the system (Zia Ur Rahman, et al., 2013). In this paper we deal with signal disturbance due to intrinsic magnetic pressure sensors located on the pipeline. Even if advances are noticed in the area of magnetic sensors used for capturing vibrations and oscillations, many pipelines are using common magnetic sensors due to the cost of sophisticated ones like orthogonal fluxgate sensors that have been introduced for the first time by (Alldredge, 1958). An orthogonal fluxgate based on a composite wire was also proposed in (Takeuchi et al., 1977) after which orthogonal fluxgates were almost forgotten. The development and improvement of techniques for the production of microwires obtained in the last decades (Vázquez, et al., 2011) have made it now possible to manufacture soft magnetic wires with an extremely narrow diameter (50-100 μm) and high permeability. Thanks to this, the principle of the orthogonal fluxgate has been rediscovered. Other improvements can be also reached using devices based on carbon nanotubes film (Lee et al., 2013).

2. SIGNAL FEATURES AND EXPERIMENTAL ARCHITECTURE

As recalled in the abstract, spectral analysis of signals, from magnetic sensors for the purposes of this experimental research, can be performed using FFT, STFT, and FDM. Since STFT can consider as a direct consequence of FFT, the application of this method is included in (Lay-Ekuakille, et al., 2009) while the impedance method is based on the search of characteristic impedance of the pipe in any instant for locating the leak (Lay-Ekuakille, et al., 2010; Lay-Ekuakille, et al., 2010). Hence the main comparison about magnetic sensor signal featuring is between FFT and FDM. An effective spectral representation allows to obtain information from a spectral function \( f(\hat{\Omega}) \) of operator \( \hat{\Omega} \) for which eigenvalues and eigenvectors are known:

\[
f(\hat{\Omega}) = \sum_k f(\omega_k) | \omega_k \rangle \langle \omega_k | \tag{1}
\]

The function \( f(\hat{\Omega}) \) is also an operator, with eigenvalues \( f(\omega_k) \) and eigenvectors \( | \omega_k \rangle \). The signal coming from the magnetic sensor located on the pipe is an exponentially damped one that is defined as \( c_n = C(t_n) \), included in a set of equidistant time intervals \( t_n = n \tau, n = 0,1,...,N - 1 \) as a sum of damped sinusoids:
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