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Spectral Analysis for Detection of Leaks in Pipes Carrying Compressed Air

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Pipe networks constitute the means of transporting fluids widely used nowadays. Increasing the operational reliability of these systems is crucial to minimize the risk of leaks, which can cause serious pollution problems to the environment and have disastrous consequences if the leak occurs near residential areas. Considering the importance in developing efficient systems for detecting leaks in pipelines, this work aims to detect the characteristic frequencies (predominant) in case of leakage and no leakage. The methodology consisted of capturing the experimental data through a microphone installed inside the pipeline and coupled to a data acquisition card and a computer. The Fast Fourier Transform (FFT) was used as the mathematical approach to the signal analysis from the microphone, generating a frequency response (spectrum) which reveals the characteristic frequencies for each operating situation. The tests were carried out using distinct sizes of leaks, situations without leaks and cases with blows in the pipe caused by metal instruments. From the leakage tests, characteristic peaks were found in the FFT frequency spectrum using the signal generated by the microphone. Such peaks were not observed in situations with no leaks. Therewith, it was realized that it was possible to distinguish, through spectral analysis, an event of leakage from an event without leakage.

1. Introduction

Pipe networks are constructed with the aim the transporting different types of fluids such as liquids and gases over long distances. They present a safer and cheaper way compared to other types of transport, but subject to a lot of factors that can affect the integrity of these systems and cause leakages.

Leaks in a piping system are a serious problem, not only from the safety and environmental standpoints, but also loss of energy that greatly affects the company responsible for transport.

According to Bersani et al. (2010) some accidents that commonly occurs in industrial pipes are classified in five categories, third parties (that represent a damage caused by operations carried out by others in pipeline vicinity and not related to its management), corrosion, mechanical, operational error and natural events.

In recent years, many leak detection techniques have been implemented in several operating pipelines. Unfortunately, many of these techniques do not present satisfactory performance, frequently generating false alarms, presenting difficulties of interpretation by the pipeline operator and also expensive system maintenance.

Some authors have used Fast Fourier Transform (FFT) as a tool for signal processing aiming at the detection of leaks, which have shown promising and flexible results, constituting an incentive for the development of this work.

The Fourier Transform has been applied in various areas such as Engineering, Physics, Oceanography and Acoustics. It is an important mathematical tool that relates the time, space or model of a signal with variable frequency associated with it.

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The representation of a signal in the time domain is naturally present in industrial daily. However, certain operations become much simpler and better understanding if represented in the frequency domain, as that obtained from the Fourier Transform (FT).
The algorithm used to transform samples of the data from the time domain into the frequency domain is the discrete Fourier Transform (DFT). The DFT establishes the relationship between the samples of a signal in the time domain and their representation in the frequency domain.
The Discrete Fourier Transform involves many additions and multiplications of complex exponentials, requiring manipulation of calculation efficiently, for use in applications of digital signal processing.
In this paper, the Fast Fourier Transform (FFT) was used because instead of calculating the Discrete Fourier Transform (DFT) directly from its definition, FFT makes use of an algorithm that allows evaluating the DFT more quick and economically. Various commercial programmes have routines for calculating the fast Fourier transform, for example, LabView 2011 software used in this study.
Garcia et al. (2010) developed a research to detect characteristic vibration frequencies of occurrence of air leaks from the hull of a section of pipeline 2 feet long. The Discrete Fourier Transform was used by the authors for spectral analysis of time / frequency for the study of vibroacoustic characterization of leaks. The aim was to compare the spectra of frequencies for cases of leakage and no leakage of signal from an accelerometer installed in the pipe. The results obtained by analysis of the spectra permitted discern the occurrence of leakage because the moment that it happens stand out two vibration frequencies, one of 63 and another one of 80 kHz .The same was not observed for events “not leakage”, where they were observed only vibration frequencies up to 10 kHz.
Souza et al. (2000) developed a technique to detect leaks in pipelines. The technique was based on the spectral analysis of pressure signals where pipeline rupture occurred during the centrifugal pump start up or shutting down. Pressure transients were obtained by four transducers connected to a PC computer installed in a pipe 1250 meters long. The obtained results show that the spectral analyses of pressure transients, together with the knowledge of reflection points, provide a simple and efficient way of identifying leaks during transient operations of pumps in pipelines.
The study of Kim and Lee (2009) aimed at identifying the characteristics of the dispersive acoustic wave though analysis of the cut-off frequency, by using the time-frequency method experimentally and BEM (boundary element method) theoretically, for the development of an experimental tool to analyze the leak signals in steel pipes. The tool was based on experimental work and theoretical formulation of wave propagation in a fluid-filled pipe. The authors concluded that the time-frequency method is a useful tool for analysis of acoustic wave propagation and identifying cut-off frequencies for acoustic modes in a circular duct.
Shibata et al. (2009) proposed a leak detection system when analyzing the sound noise generated by leak occurrence in a pipeline transporting gas. In order to diagnose pipeline crash, sound noise data were sampled by applying Fast Fourier Transform. The sound noise data were obtained through a microphone inserted at a certain distance from the crash position, with artificial neural networks being used to classify the crash. The input to the neural model was the power spectrum of the noise sound data and the output were a number of noise sound patterns to be classified. The results showed that acoustic diagnosis can be used to classify a leakage sound noise in a pipeline.
Considering the importance of computational systems for detecting leaks in pipelines, the general aim of this work is to develop and test a technique to detect gas leaks in pipes based on acoustic sensor and spectral analysis through the Fast Fourier Transform, to detect the predominant frequencies in case of leakage and no leakage.
Acoustic sensors are highly versatile devices that begin to demonstrate their commercial potential. These sensors are so named because their detection mechanism is through a mechanical or acoustic wave. As the acoustic wave propagates in the material, any change in the characteristics of signal propagation, as when there is a leak in a pipeline, affects the speed and/or wave amplitude. Investigations in oil pipelines were performed by Avelino et al. (2009).

2. Methodology

In this paper, the characteristics of the sound noise generated by gas leakage in a pressure vessel – pipeline system has been analyzed. The sound from a microphone installed in the pressure vessel was analyzed by Fast Fourier Transform in order to characterize whether there is leakage.

2.1 System experimental data acquisition

Experimental data were obtained in the piping system located at the laboratory of the School of Chemical Engineering/UNICAMP. The pipeline consisted of galvanized iron with a length of 60 m and ½" in diameter. A domestic type LGP vessel has been used as pressure vessel. The pipeline was operated with a continuous feed of compressed air, which was fed through the pressure vessel, installed at the inlet of the pipeline. The operating pressure was monitored by a manometer installed at the inlet pipe. The leaks were triggered manually through an open (or a close) quick valve installed in the pipe. The magnitude or size of the leakages was controlled by the installation of the holes at 0 m from the beginning of the pipe, with diameters ranging between 1.0 and 5.0 mm. Thus, with these settings, it was possible simulate leaks with various magnitudes.

The monitoring of leaks was performed through a microphone installed inside the pressure vessel, connected to a microcomputer. Figure 1 shows the schematic draw of the experimental setup.

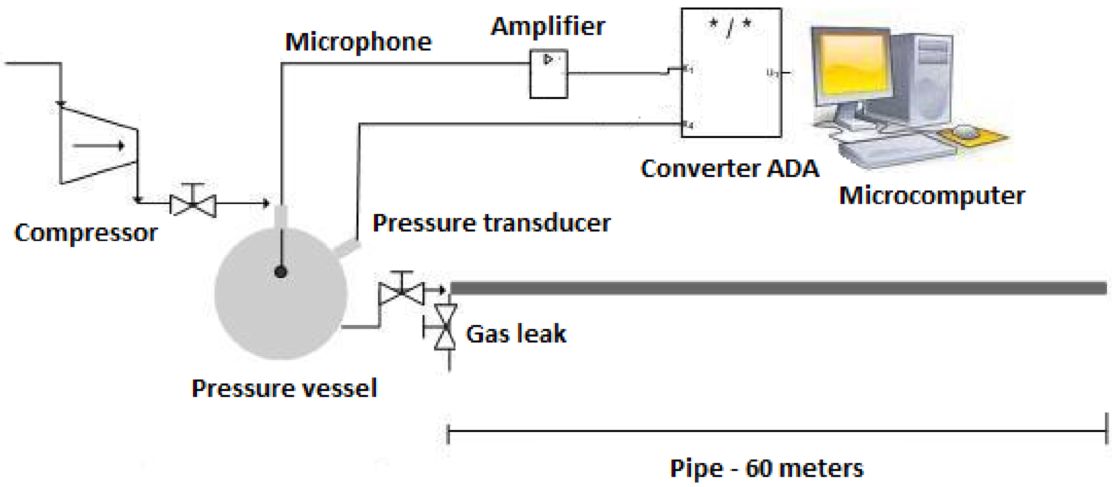

Figure 1: Experimental setup with the microphone installed in the pressure vessel

The signal from the microphone passes first through the preamplifier signal and then converting the analogy signals into digital signals.

The data acquisition system consisted of a microphone and a pressure transducer, preamplifier, ADA converter card and LabView software, in order to monitoring the plant in real time. The pressure transducer is used to measure the variation of pressure in the pipe and the microphone to capture the noise generated by leakage along the pipeline.

The data acquisition system of the present work was managed by a converter card, called NI cDAQ - 9178 with 8 slots, from National instruments (NI), as well as the LabVew 2011 software. The program allowed the user to monitor the process under study and is responsible for storing the signals emitted by the sensors in data files, which can be consulted later.

In each experiment the pipeline was set to operate with a continuous feed of air, at a pressure of 6 bars. After the data acquisition software was ready to record noises, leaks in the pipeline were simulated by opening the valves located at the inlet of the pipeline.

Sound waves are defined as longitudinal mechanical waves that can propagate in solid, liquid and gas. They are mechanical because require a propagation medium and longitudinal because the material particles responsible for its transmission oscillate parallel to the direction of propagation.

The sound wave results from a disturbance (vibration on structures, leaks in pipes) in a fluid medium at rest, which propagates along the middle mechanically.

Such disturbance can be characterized in various ways, for example by pressure variation in the propagation of the wave around a reference value corresponding to atmospheric pressure 101.350 Pa.

The sound pressure corresponds to the difference, at a given instant in time, between the in the presence of sound waves P(t) and atmospheric pressure P_0:

$$p(t) = P(t) - P_0 \tag{1}$$

Where,

p(t) – Sound pressure (Pa);
P(t) - Instantaneous pressure of the air (Pa);
P_0 – Atmospheric pressure (Pa).

The microphone can produce an electrical signal that is proportional to the variation of the sound pressure of the air immediately in front of the microphone. The microphone used to measure sound pressure in this study was an electret condenser microphone, extremely cheap and with a frequency response of 50 Hz to 16 KHz.
In practical applications it is interesting to have a sound pressure constant value which is representative of the effect of the same variable signal, known as the effective value. Thus, the effective sound pressure (also called pressure RMS, abbreviation for root mean square) according to Bistafa (2006) is:

$$\mathrm{PRMS} = \left(\frac{1}{T}\int_0^T p^2(t)dt\right)^{\frac{1}{2}} \tag{2}$$

Where:RMS –Effective sound pressure; T – Pressure variation time.

2.2 Leak detection
The methodology consisted of capturing the experimental data through a microphone installed inside the pipeline and coupled to a data acquisition card and a computer. As the mathematical approach to the signal analysis from the microphone it was used the Fast Fourier Transform, generating a frequency response (spectrum) which reveals the characteristic frequencies (predominant frequency) for each operating situation. The tests were carried out using distinct sizes of leaks, situations without leaks and cases with blows to the pipe caused by metal instruments, in order to distinguish such situations, according to Table 1.

Table 1: Operating conditions the pressure of 6 bars.

Experiment	Situations
1	Leaks with diameters of 1 to 5 mm.
2	No leaks - only noise coming from the lab, air conditioning on and people walking.
3	No leaks - Constant blows with a metallic instrument in the pressure vessel.

The Fast Fourier Transform was applied to the signal from the microphone in real time via software Labview. Labview is a graphical computational tool originally from National Instruments presenting a friendly graphical interface. It has FFT blocks, facilitating the analysis of frequency domain signal in real time.

3. Results

Figure 2 shows the change in the amplitude of the sound pressure generated by gas leakage in the pipeline through orifices of 2 mm and 5 mm of diameter. At (0m) the beginning of the pipeline, the operating pressure was 6kgf/cm². These are the transient profile plots which allow the operator to notice the occurrence of a leakage. Figure 2 also shows that, when the leak occurs, the amplitude of the sound pressure changes directly and very heavily so that it is very easy to detect a leak. Leaks with sizes of 1, 3 and 4 mm had the same behaviour as seen in Figure 2.
In all leakage situations, a peak at the moment of disturbance (occurrence of leak) was observed and then the amplitude declines and stabilizes at a certain value, varying only in relation to the size of the leak. It is believed that the peak was caused due to sudden movement of the valve to cause the leak in the piping.
From the leakage tests, characteristic peaks were found in the frequency spectrum obtained by the Fast Fourier Transform (FFT) applied to the signal generated by the microphone. Such peaks were not observed in situations with no leaks. Therewith, it was realized that it was possible to distinguish, through spectral analysis, an event of leakage from an event without leakage.
Through the processing of the signal by the Fast Fourier Transform the signal was obtained in frequency domain (spectrum), as shown in Figures 3 and 4.

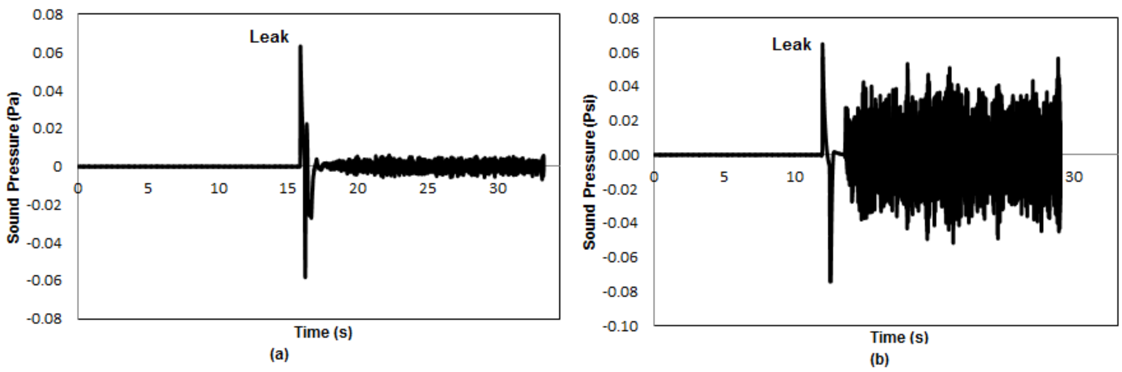

Figure 2:Microphone signal (in sound pressure) in the time domain. a) Leak size with 2 mm b) Leak size with 5 mm

Figure 3 shows two cases of the signal from the microphone installed in the pipe without the occurrence of leakage. Figure 3 (a) shows the case without perturbation in the system, only background noise (usual noise from the laboratory)and verifies that the dominant frequency is low and small amplitude (sound pressure low). Figure 3 (b) shows the case where the system suffered constant blows with a metallic instrument in the pressure vessel and the results showed a unique predominant frequency in such a situation.

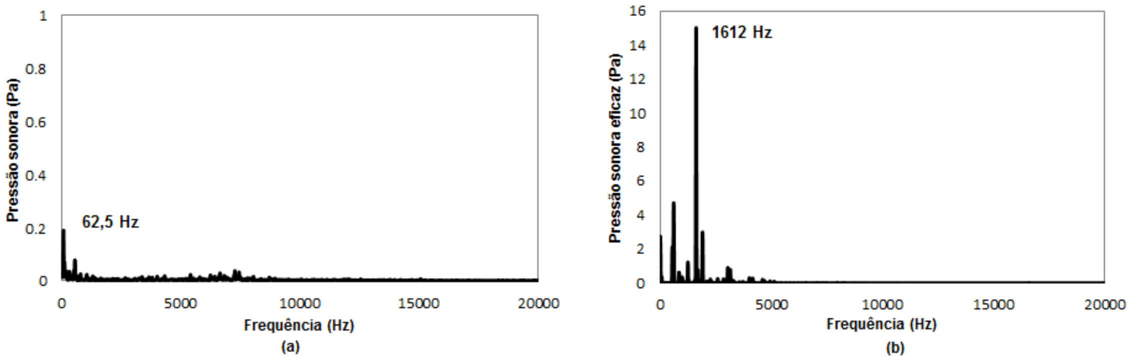

Figure 3:Microphone signal in the frequency domain without leaks. a) Only noise coming from the lab, air conditioning on and people walking. b)Constant blows with a metallic instrument in the pressure vessel

Figure 4 shows the microphone signal, in the frequency domain, with the occurrence of leaks.In all leakage situations (orifices of 1, 2, 3, 4 and 5 mm of diameter)it was observed that there is no dominant frequency, but a region that keeps predominant over time.

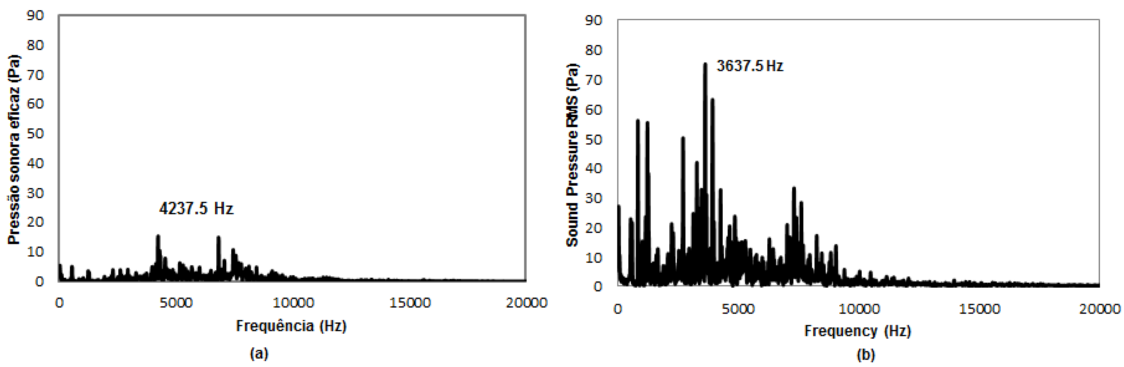

Figure 4: Microphone signal in the frequency domain with leaks. a) Leak size with 2 mm. b) Leak size with 5 mm

According to Figure 4, it is noticed that for the leak orifice of 2 mm in diameter, the predominant frequency domain was in the range of 4 kHz to 7 kHz. In case of leakage sized 5 mm diameter, the predominant frequency range was 500 Hz to 4 kHz, showing a lower frequency sound.
In general it was found that the greater the size of the leak, the lower the frequency, so the leakage is more potentially dangerous.

4. Conclusions

The experimental results showed that the acoustic method allows detecting leaks in gas pipelines, since there was a sharp increase in the amplitude of sound pressure in the presence of the leak.
From the leakage tests, characteristic peaks were found in the frequency spectrum obtained by the Fast Fourier Transform (FFT) applied to the signal generated by the microphone Such peaks were not observed in “no leak” situations. Therewith, it was realized that it was possible to distinguish, through spectral analysis, an event of leakage from an event without leakage.
Situations with and without occurrence of leaks showed different characteristics in the frequency domain. In all leakage situations (orifices of 1, 2, 3, 4 and 5 mm of diameter),it was observed that there is no dominant frequency but a region that keeps predominant over time. In cases without occurrence of leak there was no predominant frequency region. On the other hand, for the case in which blows were caused with a metallic instrument, a unique predominant peak of frequency appeared, different from the cases with leak occurrence.
The present research is in early stage. However, from the preliminary results, it is noticed that it is possible to distinguish between “occurrence” and “not occurrence” of a leakage by using the frequency spectrum of the microphone signal. In addition, it was proved that the spectrum predominant frequency band is related to the magnitude of the leakage, indicating the potential demage of the situation. Thus the method presented in this paper is worth further study.

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