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Window analysis to estimate frequency spectrum and its application in diagnosis of background leaks in water pipes

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Abstract

Background leak in water distribution systems causes a great loss of this natural resource, interrupts supply for long time and promoting proliferation of infectious diseases. Non-optimization of frequency spectrum increases spectral bias. This problem causes a misdiagnosis about background leak in water pipes. In this paper that gap in research is cover, showing a novel analysis that allows to optimize resolution of frequency spectrum using Welch-Bartlett periodogram estimator. Bartlett, Blackman, Hamming, Hanning and Kaiser Windows for this study were used. Optimization process consists of two steps. First step, a study in a simulation environment to select optimal window is carried out. Second step, experimentally validated selection of window through 5 scenarios with 30 signals each one. Results obtained showed that implementing Welch-Bartlett periodogram with Kaiser Window using form factor 6, optimizes frequency spectrum. It showing a leakage factor of 0.001 %, attenuation of sidelobes of 43.8 dB and frequency resolution of -1.26 dB.

Keywords: *Background leak water pipes, Power spectral density, Kaiser Window, Vibro-acoustic signal, Welch-Bartlett periodogram estimator.*

1. Introduction

This paper obtain a window function that allows to optimize resolution of frequency spectrum, having as a compromise criterion, leakage factor and attenuation of sidelobes, using Welch-Bartlett periodogram estimator. It reduces spectral bias [1].

World level water shortages require special attention. This is due to fact that this natural resource is essential for development, given it is material basis for sustainability and society. Controlling water loss in distribution systems supports solution of this problem. Water volume wasted might constitute a high percentage of water coming through the supply networks. Research reported in [2] states that in United States losses of 20 % are related to the occurrence of leaks in water supply. In [3] argues that in an aqueduct located in Canada, it is lost approximately 30% of the flow introduced into ducts. Researchers on [4] indicates that, influence of environment, aging of pipelines, excessive load traffic, assembling methods and combined action of these factors constitute main causes of leaks.

Reports made by [5–7] classify leaks into two categories, background leaks and burst leaks. Background leaks are small leaks that take place in storage tanks and in main or service pipeline. In contrast, burst leaks are ones sprout into surface as water columns, causing damage to streets and buildings. These types of leaks, as are visible, don't contribute to large water volume losses, since aqueduct rapidly activates repair mechanisms. However, background leaks lead to significant water losses, if we bear in mind the fact that it might exist for longer time periods. For such a reason, many background leak detection techniques to improve detection in water pipelines have been developed. These methods include: use of ground penetrating radars by [8] and thermography by [9] which are not convenient for low pressure pipeline background leak detection according to reports by [5,10]. Beside to these techniques, there are acoustic methods that to detect background leaks in water networks are used. Basically, these techniques on concept of Acoustic Emission (AE) are based. AE is a non-destructive supporting technique highly used for leak detection. These waves spread through the pipeline walls. It propagation effects depend on shape, material of conveying structure, fluid in pipeline, temperature and pipeline internal pressure [11,12]. Most frequently used devices to capture these vibro-acoustic waves are accelerometers [12–14].

Many papers various studies aimed at detecting background leaks in water pipes through frequency spectrum analysis have reported. In [4] they proposes an empirical evaluation of vibro-acoustic emission to detect and quantify leaks from underground pipes. Analysis carried out in this work is based on estimation of frequency spectrum using fast Fourier transform (FFT). Research in [13] shows a work aimed at detecting leaks in plastic pipelines using vibro-acoustic signal monitoring techniques, by mean power spectrum density (PSD) estimates. This paper use a Hann window to frequency analysis. In [14] they reported a work done on leak detections using correlators. After estimating PSD, they outlined that leak emission is less than 200 Hz. Research conducted in [15], carried out an experimental work to quantify the leak flow in water distribution networks. They affirm, by means PSD that many of leaks in plastic pipelines present low frequency content, among 20 Hz-250 Hz. Beside, state they detect leaks on a frequency range of 50 Hz-150 Hz using accelerometers. To carry out these experiments, they Hanning window are used. In [16] carried out a work focused on water network leak detection using frequency spectral analysis. The authors of [17] show a work about differentiation application process into correlation based leak detection in urban pipeline networks. In this work perform PSD and for this they use a Hanning window. Work reported in [18] aim at leak detection and localization under a noisy environment. These authors compute coherence to detect background leak generation. In [19] propose a method using linear prediction to detect leakage in water distribution systems. In this work it is stated that the linear prediction method is effective in capturing the effects of the Fourier spectrum composed of radiation. Paper reported in [20] conducted a study aimed at estimating the spectrum of leak in buried plastic water distribution pipes using acoustic or vibration measurements remote from the leak. These researchers use Hanning window linked to the Welch-Bartlett periodogram to estimate the frequency components belonging to the background leaks. In [21] they report a work aimed at Leak Location Based on PDS-VMD of Leakage-Induced Vibration Signal Under Low SNR in Water-Supply Pipelines, using FFT.

Main drawback found in reported papers is that there is no study aimed at analyzing resolution of frequency spectrum in detection of background leaks. This research gap causes an increase in the frequency spectrum estimation bias.

Remainder of this manuscript is organized as follows. Second section, shows a study directed at theoretical background used in paper. Third section, shows development of experiment and instrumentation used. Fourth section, shows results and discussion obtained from analysis performed. Conclusions will be drawn in section 5.

2. Background Theory

In this section authors present the bases used in this study. They define Welch- Bartlett periodogram and influence of window on resolution of frequency spectrum; using leak spectral and sidelobe attenuation.

By means of an acquisition process, noise that is coupled from development environment affects the signal. Thus hindering obtainment of interest information on the system under analysis. By filtering signal, sensor response measuring process is modeled, as shown in Eq. (1)

$$x(t) = \int_{-\infty}^{\infty} \big(f(\eta) + Z(\eta)\big)\phi(t-\eta)d\eta \quad (1)$$

where: $x(t)$ is output signal, $f(\eta)$ is signal to estimate in frequency domain, $Z(\eta)$ represents coupled noise with Gaussian distribution (μ, σ^2), $\phi(t-\eta)$ is sensor response.
Many papers such as [22–25] make use of estimation of spectral components in stationary stochastic process. It allows to obtain information hidden in time domain by coupled noise. In [26] suggest that using parametric and non-parametric methods one can obtain frequency spectral estimate. First group assumes that available signal segment has been generated by a specific parametric model. In contrast, second group doesn't assume a functional form in particular, but it allows that form of estimator is determined entirely by data and it is based on the FFT of each segment of the signal or on its self-correlation sequence.

2.1 Estimation of the Power Spectral Density using the Welch-Bartlett method

Authors on [26] states that this method consists on dividing signal in overlapped segments, thus obtaining a periodogram to later one draw an average of estimate done. Periodogram for ith-segment is defined by Eq. (2)

$$\hat{R}_{x,i}(e^{j,\omega}) = \frac{1}{L}\left|\sum_{n=0}^{L-1} x_i(n)e^{-j\omega n}\right| \quad (2)$$

defining $x_i(n)$ as shown on Eq. (3)

$$x_i(n) = x(iD + n)w(n)\ \forall\ n \in [0, L-1] \text{ and } \forall\ i \in [0, K-1] \quad (3)$$

where: K corresponds to segments where sequence $x(n)$ is fragmented, $w(n)$ it is data window with L duration and D it is displacement distance.
Spectrum estimate is obtained by means of average of the K periodograms as shown on the Eq. (4)

$$\hat{R}_{x,i}(e^{j,\omega}) = \frac{1}{KL}\left|\sum_{i=0}^{K-1} x_i e^{-j\omega n}\right| \quad (4)$$

According to report in [26] this estimator have consistent property and its variance behavior depends on number of segments used, see Eq. (5)

$$\mathrm{var}\{\hat{R}_x(e^{j\omega})\} \approx \frac{1}{K}R_x^2(e^{j\omega}) \quad (5)$$

Note like for values of K $\rightarrow +\infty$ variance to zero is reduced.

2.2 Window function

Windows function have two important characteristics: leakage spectral and sidelobe attenuation. Leakage spectral occurs as energy or power leaks in a frequency range, cause erroneous impression of stronger or weaker frequency components. This problem originates in amplitude of sidelobes which can promote bias in spectral values, if not taken into account [26].

Another important factor in selecting time window is spectral resolution. When having signals presenting temporary sudden changes, a good resolution for narrow windows in time domain but a poor resolution in frequency is obtained. On the other hand, if selected window is temporarily very wide, a good resolution in frequency domain but a poor resolution in the time one is obtained. This problem on Heisenberg uncertainty principle is based. It indicates that is impossible to have an exact representation of a signal. Just one can know which frequency components are present in a given time interval. Heisenberg rectangle, has a size $\sigma_t \cdot \sigma_\omega$ being σ_t time variance and σ_ω frequency variance [27]. Figure. 1 shows a schematic representation of time-frequency domain and the Heisenberg rectangle

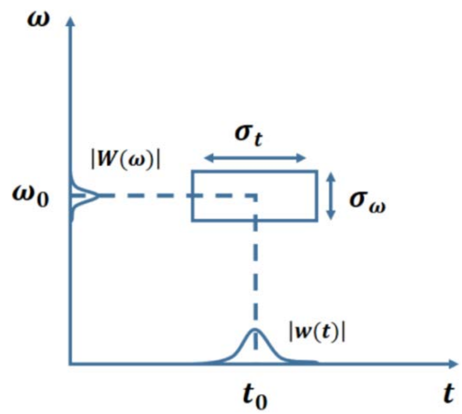

Fig. 1 Schematic representation of the time-frequency plane and Heisenberg-box. Abscissa axis represents time. Ordinate axis represents angular frequency. |W (ω)| is modulus of Fourier transform of |w (t)|. σ_ω is range of frequency components to represent and σ_t is analysis energy range

Figure. 1 depicts a window in vicinity t_0 used in estimating corresponding frequency of a signal, being ω_0 central frequency of estimated. As it can be seen time-frequency resolution depends on the area of the Heisenberg box which is minimum for a Gaussian window, taking a value of 0.5 [27].

3. Experimental development

Study of vibro-acoustic signals of background leak at low pressures, out in a section of 2 m long high-density polyethylene pipeline with a 160 mm interior diameter coupled to a 10 m tank of constant load and static fluid conditions was carried. Figure. 2 shows the installation outline.

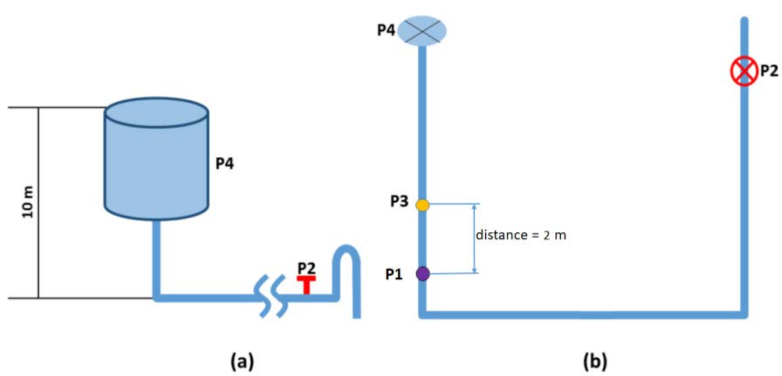

Fig. 2 Installation outline. P1 - Position where sensors were located. P2 - Valve to control the main flow rate. P3 - Place where background leak was generated. P4 - Constant head tank

For acquisition of vibro-acoustic signal, a virtual instrument (VI) was used which is composed of an accelerometer PCB Piezotronic, that presents a 100 mV/g sensibility and a measuring range of ± 50 g. This sensor to a signal conditioner formed by a band-pass active filter in configuration Butterworth with 20 dBv gain and a cut frequency ranging from 1 Hz to 500 Hz is coupled. Conditioned signals by means a data acquisition card NI-6212, with a sampling frequency set at 1 kHz and a ± 1 V input voltage range was acquired. A graphic interface from LabVIEW for card handling was used.

To carry out analysis of background leaks 5 scenarios were used. First one corresponds to noise floor. Second one, background leaks using a 3/4 inch metal butterfly valve is generated. In third one, a background leak with a balloon 3/4 inch plastic valve was generated. In fourth, background leak in a pipe derivation forming a 3/4 inch leak was generated and in the fifth scenario, background leaks through a branch that presented a cross-section were generated. Figure. 3 shows signals in time domain

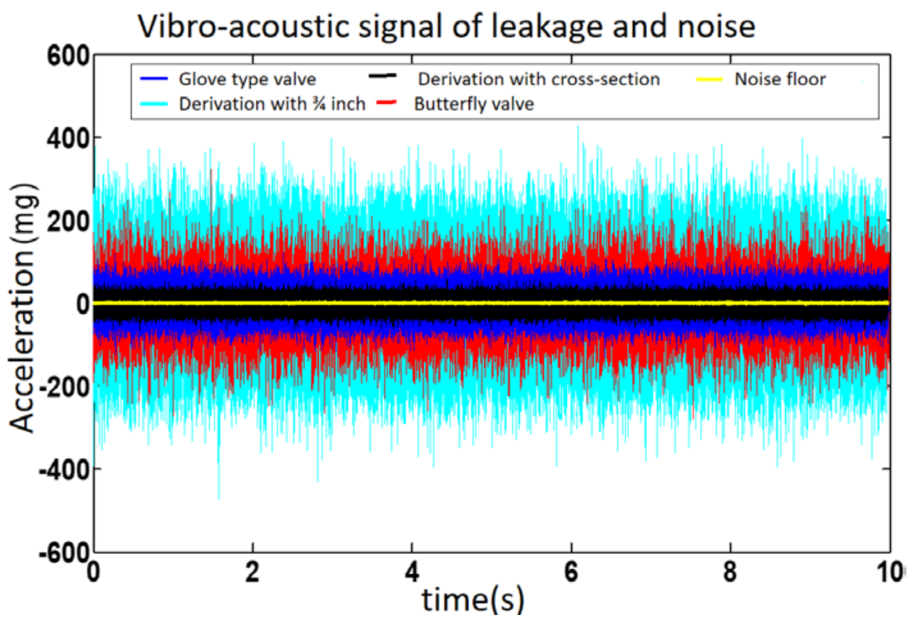

Fig. 3 Acquired vibro-acoustic signals

As it in Figure. 3 is observed, there is a notable increase in signal amplitude. It allows distinguishing their characteristics present in the time domain. Analysis of the behavior of a signal in time domain is not to be trusted because any physical phenomenon that causes color noise will create uncertainty on presence of a leak. For this reason it is more convenient to carry out analysis of signal in frequency domain, allowing identifying occurrence of an event.

4. Results and Discussion

4.1 Window function selection

To select window function, authors used background theory shown in subsection 2.2. First step in detecting background leakage, is to select a window that allows to optimize resolution of the frequency spectrum without deteriorating the leakage factor nor the attenuation of sidelobes. In Table 1 window functions to be analyzed are shown where M is window length.

Table 1: Windows functions [1]

Window function	Time-domain sequence $h(n)\ \forall\ n \in\ [0, M-1]$
Bartlett	$1-\frac{2\left\|n-\frac{M-1}{2}\right\|}{M-1}$
Blackman	$0.42-0.5\cos\left(\frac{2\pi n}{M-1}\right)+0.08\cos(\frac{4\pi n}{M-1})$
Hamming	$0.54-0.46\cos(\frac{2\pi n}{M-1})$
Hanning	$0.5(1-\cos(\frac{2\pi n}{M-1}))$
Kaiser	$\frac{I_0[\beta\sqrt{\left(\frac{M-1}{2}\right)^2-\left(n-\frac{M-1}{2}\right)^2}]}{I_0[\beta\left(\frac{M-1}{2}\right)]}$

Figure. 4 shows frequency resolution of windows shown in Table 1. To carry out this analysis, the authors simulated a stationary signal and varied the duration of the window functions from 16 samples to 2048 samples.

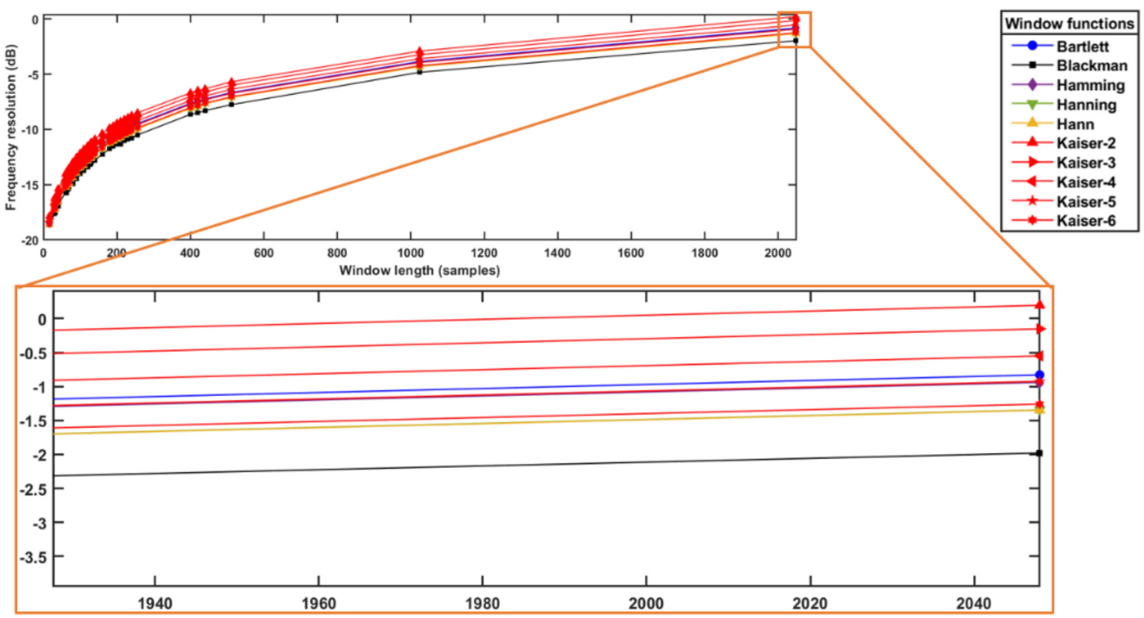

Fig. 4 Heisenberg-box resolution in frequency domain. In abscissa axis length of window. On ordinate axis resolution in frequency

Note in Figure. 4 as length of window increases, so does frequency resolution. According to Figure. 4 window that optimizes the resolution is Kaiser-2. Final step in window selection is to analyze attenuation of sidelobes and leakage factor provided by windows. Table 2 shows result obtained after analyzing factor β of Kaiser Window.

Table 2: Comparison of factor β in Kaiser Window

β	Leakage Factor (%)	Sidelobe Attenuation (dB)
1	6.512	14.7
2	2.527	18.5
3	0.654	23.8
4	0.135	30
5	0.021	36.7
6	0.001	43.8

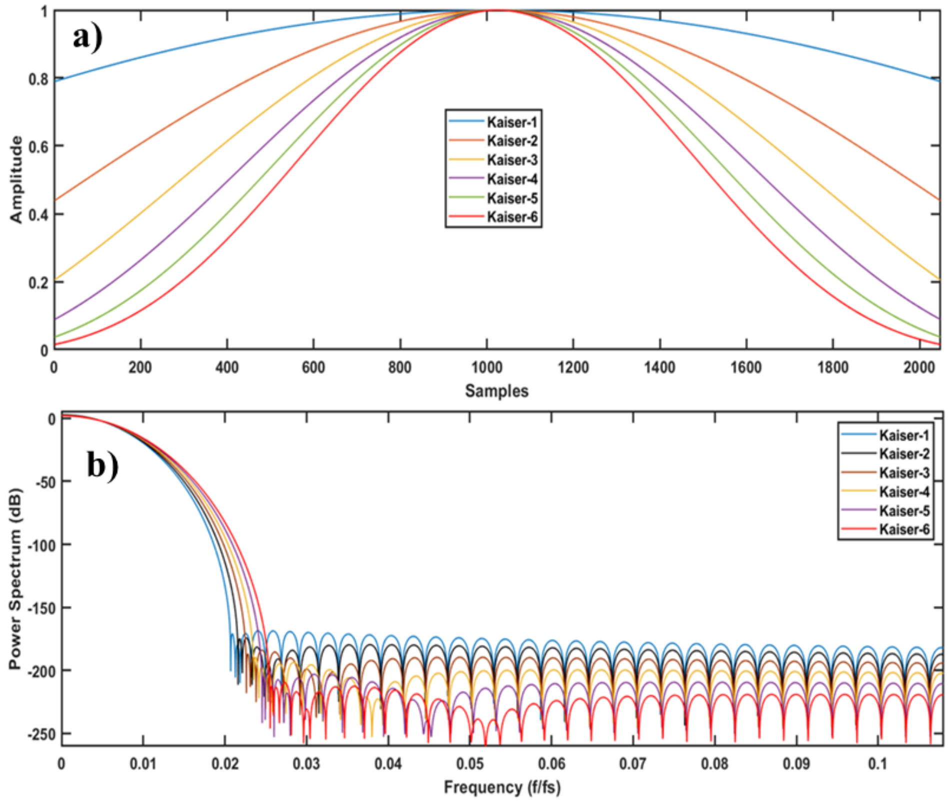

Fig. 5 Kaiser Window with form factor among 1-6, a) represent the time domain in sample and in b) represent normalized frequency domain

Authors in this work, later obtaining results shown in Table 2 and Figure 5, selected β = 6. Since for this form factor, Kaiser Window maximizes resolution in time domain. It maximizes attenuation sidelobes and minimizes leakage spectral. After having made selection of time window to estimate frequency components. Next step is to obtain the frequency spectrum of the background leakage. These results are observed in subsection 4.2.

4.2 Detection and Identification in the frequency domain

Figure. 6, Figure. 7, Figure. 8, Figure. 9 show frequency spectra of signals shown in Figure. 3

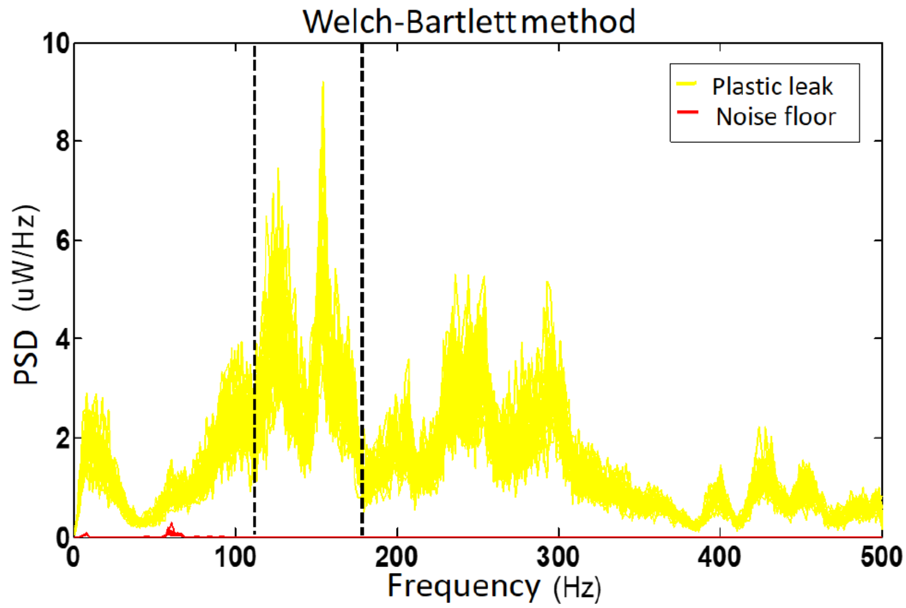

Fig. 6 PSD of the plastic nature background leak generated with the globe valve

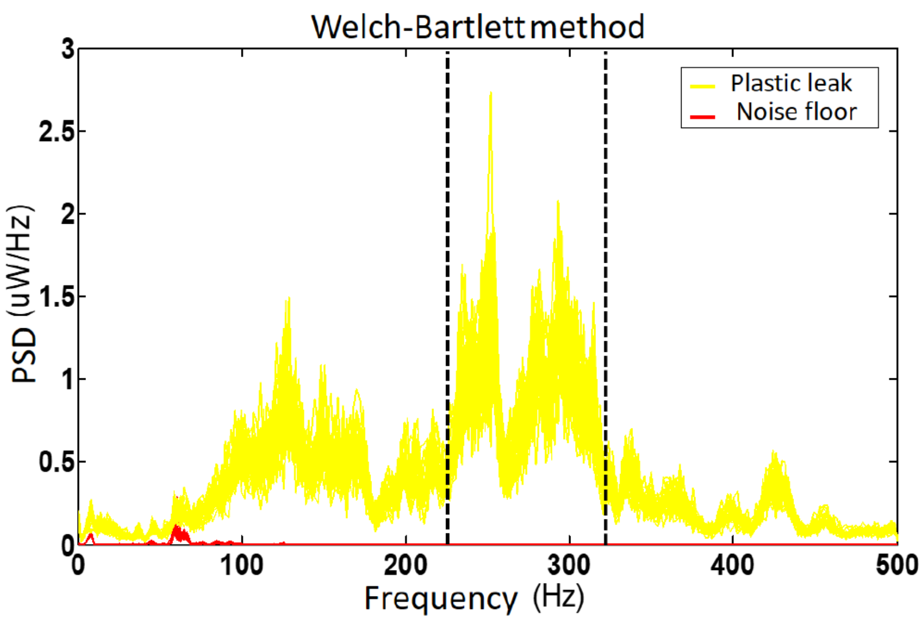

Fig. 7 Background leak corresponding to a branch with a cross-section

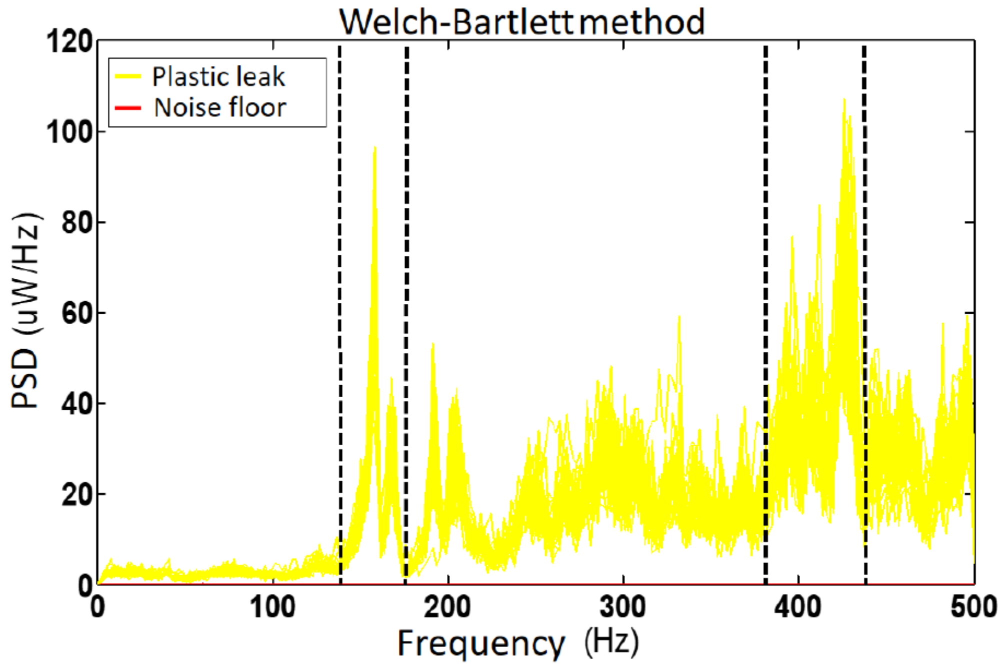

Fig. 8 Background leak generated by a branch

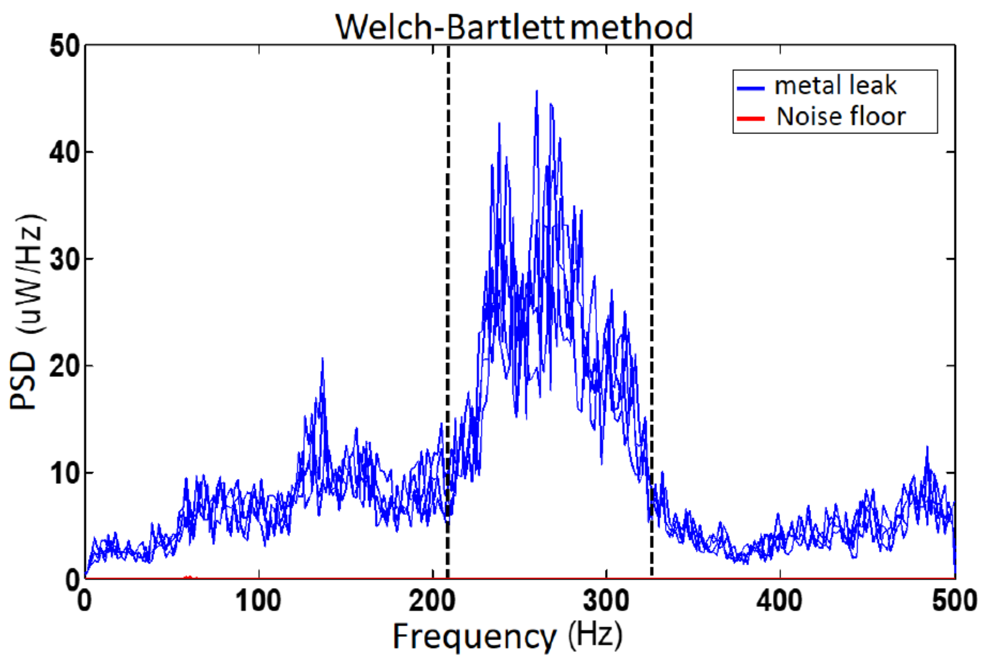

Fig. 9 Metal background leak generated with butterfly valve

Notice in Figure 6 as greatest power in a range from 115 Hz and 177.7 Hz is concentrated. It revealing frequency band corresponding to vibro-acoustics signal for this leakage. In case of Figure 7, see as after leak shape changes, there is a displacement in the frequency spectrum, concentrating power between 224.6 Hz and 320.3 Hz. In Figure 8 you can notice that vibro-acoustics signal presents spectrum components of high energy value in two frequency bands. First one is among 138.7 Hz - 175.8 Hz and the second one is between 380.9 Hz and 439.5 Hz. Notice in Figure 9 that for this leak, power concentration is between 209 Hz and 326.2 Hz. Frequency interval displacement is directly related with the shape and the nature (plastic or metallic) of the leakage. Thus enabling the identification of the frequency in the leakage.

4. Conclusions

This paper showed a study aimed at optimizing resolution of frequency spectrum using Welch-Bartlett periodogram. Kaiser-6 window was shown to be adequate with a leakage factor of 0.001 %, attenuation of sidelobes of 43.8 dB and frequency resolution of -1.26 dB. For validation process, 5 scenarios were used, each one with 30 signals. Different vibro-acoustic signatures for different forms of leaks were shown. In next study, a new method should be analyzed allowing automation under a false positive probability that maximizes detection and identification of background leaks.

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References

[1] Time Frequency Analysis using CWT - File Exchange - MATLAB Central, (n.d.). https://www.mathworks.com/matlabcentral/fileexchange/64860-time-frequency-analysis-using-cwt (accessed December 26, 2020).

[2] H.E. Mutikanga, S.K. Sharma, K. Vairavamoorthy, Methods and tools for managing losses in water distribution systems, J. Water Resour. Plan. Manag. 139 (2013) 166–174. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000245.

[3] G. Ebacher, M.C. Besner, M. Prévost, D. Allard, Negative pressure events in water distribution systems: Public health risk assessment based on transient analysis outputs, in: Water Distrib. Syst. Anal. 2010 - Proc. 12th Int. Conf. WDSA 2010, 2012: pp. 471–483. https://doi.org/10.1061/41203(425)45.

[4] A. Kadri, E. Yaacoub, M. Mushtaha, Empirical evaluation of acoustical signals for leakage detection in underground plastic pipes, in: Proc. Mediterr. Electrotech. Conf. - MELECON, IEEE, 2014: pp. 54–58. https://doi.org/10.1109/MELCON.2014.6820506.

[5] A. Martini, M. Troncossi, A. Rivola, Vibration Monitoring as a Tool for Leak Detection in Water Distribution Networks, in: Ciri Din, 2014: pp. 1–9. https://doi.org/10.1007/978-3-642-39348-8.

[6] E. Trutié-Carrero, D. Valdés-Santiago, Á. León-Mećias, J. Raḿirez-Beltrán, Deteccíon y Localizacíon de Ruptura Śubita mediante Transformada Wavelet Discreta y Correlacíon Cruzada, RIAI - Rev. Iberoam. Autom. e Inform. Ind. 15 (2018) 211–216. https://doi.org/10.4995/riai.2017.8738.

[7] E. Trutié-Carrero, Y. Cabrera-Hernández, A. Hernández-González, J. Ramírez-Beltrán, Automatic detection of burst in water distribution systems by Lipschitz exponent and Wavelet correlation criterion, Meas. J. Int. Meas. Confed. 151 (2020). https://doi.org/10.1016/j.measurement.2019.107195.

[8] J.L. Perez Medina, J. Vanderdonckt, A. De Coster, S. Lambot, Mobile direct visualization of pipes, apexes, and water leaks in water distribution networks, in: 2019 6th Int. Conf. EDemocracy EGovernment, ICEDEG 2019, 2019: pp. 172–179. https://doi.org/10.1109/ICEDEG.2019.8734376.

[9] Z. Lu, F. Zhu, L. Shi, F. Wang, P. Zeng, J. Hu, X. Liu, Y. Xu, Q. Chen, Automatic seepage detection in cable tunnels using infrared thermography, Meas. Sci. Technol. 30 (2019) 115902. https://doi.org/10.1088/1361-6501/ab30d9.

[10] A. Kadri, A. Abu-Dayya, R. Stefanelli, D. Trinchero, Characterization of an acoustic wireless sensor for water leakage detection in underground pipes, in: 2013 1st Int. Conf. Commun. Signal Process. Their Appl. ICCSPA 2013, IEEE, 2013: pp. 1–5. https://doi.org/10.1109/ICCSPA.2013.6487255.

[11] M. Shehadeh, J.A. Steel, R.L. Reuben, Acoustic emission source location for steel pipe and pipeline applications: The role of arrival time estimation, Proc. Inst. Mech. Eng. Part E J. Process Mech. Eng. 220

(2006) 121–133. https://doi.org/10.1243/095440806X78829.
[12] A. Mostafapour, S. Davoudi, Analysis of leakage in high pressure pipe using acoustic emission method, Appl. Acoust. 74 (2013) 335–342. https://doi.org/10.1016/j.apacoust.2012.07.012.
[13] A. Martini, M. Troncossi, A. Rivola, Automatic Leak Detection in Buried Plastic Pipes of Water Supply Networks by Means of Vibration Measurements, Shock Vib. 2015 (2015). https://doi.org/10.1155/2015/165304.
[14] M.J. Brennan, F. Kroll De Lima, F.C.L. De Almeida, P.F. Joseph, A.T. Paschoalini, A virtual pipe rig for testing acoustic leak detection correlators: Proof of concept, Appl. Acoust. 102 (2016) 137–145. https://doi.org/10.1016/j.apacoust.2015.09.015.
[15] J.D. Butterfield, A. Krynkin, R.P. Collins, S.B.M. Beck, Experimental investigation into vibro-acoustic emission signal processing techniques to quantify leak flow rate in plastic water distribution pipes, Appl. Acoust. 119 (2017) 146–155. https://doi.org/10.1016/j.apacoust.2017.01.002.
[16] R. Cody, J. Harmouche, S. Narasimhan, Leak detection in water distribution pipes using singular spectrum analysis, Urban Water J. 15 (2018) 636–644. https://doi.org/10.1080/1573062X.2018.1532016.
[17] Y. Gao, Y. Liu, Y. Ma, X. Cheng, J. Yang, Application of the differentiation process into the correlation-based leak detection in urban pipeline networks, Mech. Syst. Signal Process. 112 (2018) 251–264. https://doi.org/10.1016/j.ymssp.2018.04.036.
[18] E. Trutié-Carrero, L.A. Delgado-Hernández, C. González-Zamora, J. Ramírez-Beltrán, Detección y localización de fuga de fondo en tuberías plásticas de agua bajo un ambiente ruidoso, Ing. Electrónica, Automática y Comun. 40 (2019) 1–15.
[19] R.A. Cody, P. Dey, S. Narasimhan, Linear Prediction for Leak Detection in Water Distribution Networks, J. Pipeline Syst. Eng. Pract. 11 (2020) 4019043. https://doi.org/10.1061/(ASCE)PS.1949-1204.0000415.
[20] O. Scussel, M.J. Brennan, F.C.L. Almeida, J.M. Muggleton, E. Rustighi, P.F. Joseph, Estimating the spectrum of leak noise in buried plastic water distribution pipes using acoustic or vibration measurements remote from the leak, Mech. Syst. Signal Process. 147 (2021) 107059. https://doi.org/10.1016/j.ymssp.2020.107059.
[21] S. Li, C. Xia, Z. Cheng, W. Mao, Y. Liu, D. Habibi, Leak Location Based on PDS-VMD of Leakage-Induced Vibration Signal under Low SNR in Water-Supply Pipelines, IEEE Access. 8 (2020) 68091–68102. https://doi.org/10.1109/ACCESS.2020.2984640.
[22] M. Pedram, A. Esfandiari, M.R. Khedmati, Frequency domain damage detection of plate and shell structures by finite element model updating, Inverse Probl. Sci. Eng. 26 (2018) 100–132. https://doi.org/10.1080/17415977.2017.1309398.
[23] A. Tributsch, C. Adam, An enhanced energy vibration-based approach for damage detection and localization, Struct. Control Heal. Monit. 25 (2018) e2047. https://doi.org/10.1002/stc.2047.
[24] L.S.S. Pillarisetti, R. Talreja, On quantifying damage severity in composite materials by an ultrasonic method, Compos. Struct. 216 (2019) 213–221. https://doi.org/10.1016/j.compstruct.2019.02.087.
[25] V. Marrocco, F. Modica, I. Fassi, Analysis of discharge pulses in micro-EDM milling of Si3N4-TiN composite workpiece by means of power spectral density (PSD), J. Manuf. Process. 43 (2019) 112–118. https://doi.org/10.1016/j.jmapro.2019.05.017.
[26] J.G. Proakis, Digital signal processing: principles algorithms and applications, Pearson Education India, 2001.
[27] S. Mallat, A Wavelet Tour of Signal Processing, Third, Elsevier, 2009. https://doi.org/10.1016/B978-0-12-374370-1.X0001-8.

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