INFLUENCE OF AIR PRESSURE ON THE AMPLITUDE OF SOUND FREQUENCY SPECTRA WHEN SIMULATING A CRACK IN A PIPELINE

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Abstract

This paper intends to determine the influence that the amount of air pressure in a pipeline has on the amplitudes of the sound frequency spectra that occur when a pipeline cracks. In order to simulate the cracking of the pipe, in the experimental tests, a route was constructed with a pipe through which pressurized air flows and which has a removable section where portions of the pipe with holes of different diameters can be added. The hole represents the crack. Frequency spectrum measurements were made for FFT (Fast Fourier Transform), CPB (Constant Percentage Bandwith) and Overall spectral analysis. The Bruel & Kjær spectral acquisition and analysis system was used for the measurements, consisting of a signal analyzer, a microphone and a laptop with PulseLabshop software installed for processing the acquired signals.The obtained data can be a starting point for the design of a pipes crack detection/location system based on the spectral analysis of sound vibrations.

Keywords: *Crack detection, Spectral analyse, Fourier transform, Frequency, Sound vibrations*

Introduction

In nuclear installations there are pipes that carry cold water, hot water, air or steam at different pressure values. Cracking of such a pipe can lead to loss of working agent and damage to the installation. In order to prevent such incidents, the installation or piping system can be monitored.

Theoretically, cracking of a pipe through which a pressurised fluid flows leads to acoustic vibrations in the air and mechanical vibrations in the pipe body. Spectral analysis of sound waves generated by the cracking phenomenon is proposed as a monitoring method [1].

The purpose of experimental tests is to demonstrate that the acoustic vibrations that occur when a pipe cracks can be used as an indicator of its deterioration and to highlight a connection between FFT (Fast Fourier Transform), CPB (Constant Percentage Bandwith), and Overall frequency spectra and the cracking phenomenon. In experimental tests, through spectral analysis of sound vibrations, the size of frequency spectrum amplitudes and the frequency domain in which they occur are determined. By analyzing the spectral characteristics of sounds present around a fluid-pressurized pipe, the aim is to detect the cracking phenomenon.

In experimental test sound waves will be acquired, recorded and processed using the Bruel & Kjær spectral acquisition and analysis system. The signal analyzer in the spectral acquisition and analysis system will calculate and generate FFT, CPB and Overall frequency spectra.

Spectral analysis

What is spectral analysis of signals? Spectral analysis is, in fact, the transformation of information from amplitude-time to amplitude-frequency terms [2]. The frequency domain representation is shorter than the time domain representation, meaning a reduction of data. The information is the same in bothrepresentations but in the frequency domain it is more compact and individualised.

Fourier spectrum analysis

Fourier analysis is an important tool in the study of highly complex signals (acoustic signals, electrical signals, seismic waves, etc.). Time domain signals can be divided into two broad groups: deterministic signals those that have an evolution that can be predicted (predetermined) in time and random signals those that do not have a predictable evolution in time. Depending on this division of time domain signals there are also different dedicated categories of spectral analysis. Deterministic signals can be further classified into periodic (harmonic and random periodic) and non-periodic (quasi-periodic and transient) signals [3].

In the case of acoustic waves resulting from the cracking of a pipe, we are dealing with a random signal, which is a signal whose period can be considered to tend to infinity ($T \rightarrow \infty$). If in the case of periodic signals the transition of the signal from the time domain to the frequency domain is done by Fourier series development, in the case of non-periodic and random signals this transition is done by means of the Fourier transform.

There are two Fourier transforms: direct and inverse. The direct Fourier transform makes the transition from the time domain to the frequency domain and has the following mathematical formula:

$$S(jw)=F\{s(t)\}=\int_{-\infty}^{+\infty} s(t)\cdot e^{-j\cdot\omega\cdot\tau}dt \quad (1)$$

For the numerical processing of the acoustic signal by the signal analyzer it is first necessary to sample the analog signal followed by spectral analysis using the Discrete Fourier Transform or its more economical version in terms of computation time the Fast Fourier Transform. The Discrete Fourier Transform (DFT) transforms the discrete time-domain signal into a discrete frequency spectrum:

$$X(w)=\sum_{n=0}^{N-1} x(n)\cdot e^{-j\cdot 2\cdot\pi\cdot o\frac{n}{N}} \quad (2)$$

The Fast Fourier Transform is actually a variant of the discrete Fourier transform in which the number of arithmetic operations performed to calculate its value is minimal.

Constant percentage bandwith spectral analysis

Octave-band spectral analysis is, together with FFT spectral analysis, one of the possibilities for frequency processing of sound signals. FFT spectral analysis performs sound signal processing for each individual frequency value, i.e. it calculates the spectral amplitude values individually for each frequency.

CPB spectral analysis performs this spectral amplitude calculation over a range of values that has a well-established central frequency. The spectral amplitude value for a range will be given by the sum of all discrete spectral amplitude values that are part of the reference range. To achieve this the sound signal is passed through a series of bandpass filters mounted in parallel that divide the entire frequency spectrum of the signal into several frequency bands [4]. These frequency bands have constant bandwidth relative to the value of the centre frequency of the range. Therefore the graphical representation of the spectral analysis will consist of vertical bars with bandwidth proportional to the value of the corresponding central frequency.

The calculation of centre frequencies for octave bands is given by the general formula:

$$F_c=1000\cdot 2^{i\cdot b} \quad (3)$$

where i = ...-2, -1, 0, 1, 2, ..., and b – number of octave. For b = 1 we have octave band analyser, and for b = 1/3 we have 1/3 octave band analyser.

Spectral analysis Overall

Overall vibration spectral analysis is a summary of all instantaneous vibrations existing in a chosen frequency range. The analysis does not refer to a particular frequency, but rather to a global level of Overall vibrations [5].

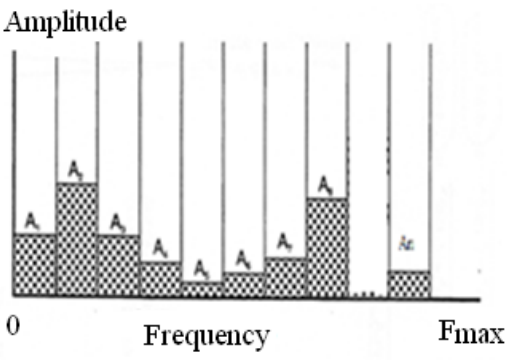


Fig. 1. Overall frequency spectrum graph

In the figure above we have the representation of a frequency spectrum in the range (0 , Fmax), which has amplitude values from A1 to An. The overall spectrum level for this example is given by the formula:

$$O=\frac{\sqrt{\sum_{i=1}^{n} A_i^2}}{\sqrt{N_B}} \quad (3)$$

where, O - is the overall vibration level, n - number of samples, NB - noise band for the chosen weighting function.

To notice in connection with the Overall spectral analysis is the fact that it is not a spectrum of frequencies as expected but a value of all individual spectra calculated according to the above formulas.

Experimental tests

The cracking phenomenon was simulated by passing pressurized air through a pipe section with a hole of known diameter. The section can be detached and replaced by another one to simulate cracks of several sizes.

The experimental tests presented were carried out for crack size 0.53 mm. Also the air pressure in the pipe had different values: 1 bar, 2 bar, 3 bar, 4 bar, 5 bar and 6 bar.

The Bruel & Kjær spectral acquisition and analysis system consists of a unidirectional microphone mode 4191-C-001 with measuring range 3 Hz - 40 kHz, the acquisition module model 356 ^{0}C with six analogue signal acquisition channels and the laptop on which the Pulse LabShop software version 19.0.0 is installed to perform spectral analysis and recording of the acquired signals.

Each recording lasts 60 seconds and consists of storing the signals acquired from the microphone. Based on these signals, FFT, CPB and Overall spectral analysis of the sound signal is performed.

The FFT spectral analysis is performed over the full range of the Bruel & Kjaer 25.6 kHzinstrument and the CPB spectral analysis over 1/3 octave.

The first test was carried out to establish the background of sound vibrations existing in the environment of the experiment and the reference point to which the other tests will be referred. This test can be considered as a crack where the pressure in the pipe is 0 bar.

The graphical recordings made over the durations of the experimental tests shown below are for the 0.53 mm crack and 3 bar pressure for FFT spectral analysis (Fig. 2), CPB spectral analysis (Fig. 3) and Overall spectral analysis (Fig. 4).

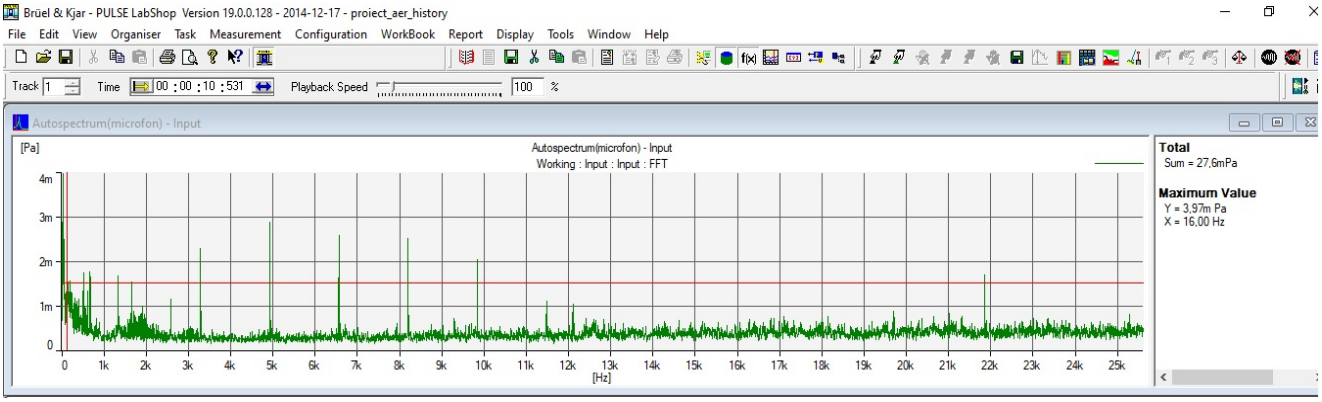


Fig.2. Graphical representation of the FFT frequency spectrum

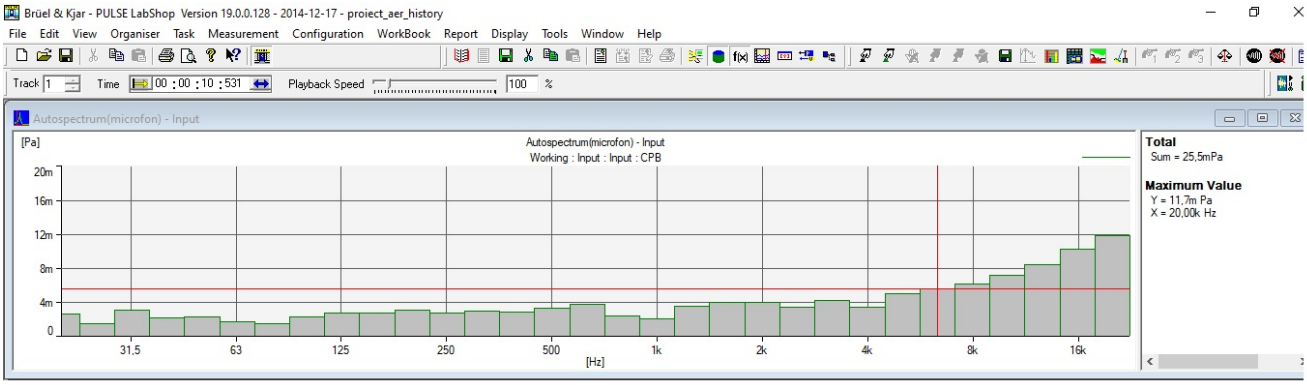


Fig.3. Graphical representation of the CPB frequency spectrum

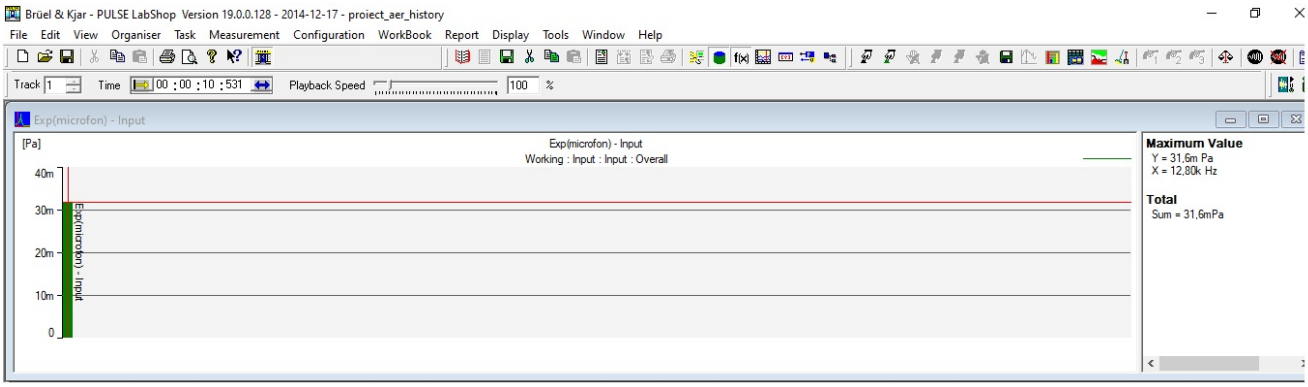


Fig.3. Graphical representation of the Overall value spectrum

Results

In order to get an overview of the data and to better observe the values of the spectral amplitudes obtained from the FFT, CPB and Overall spectral analyses, tables and graphs have been prepared to present the results obtained in a concise and conclusive way. The tables and graphs show the values obtained forthe simulated crack with a diameter of 0.53 mm and pressures ranging from 1 bar to 6 bar [6].

The pressure column of 0 bar represents the sound background that exists and is due to noise in the surrounding environment where the experimental tests are performed with no connection to the crack simulation. Sound vibrations due to crack simulation add to this pre-existing sound background.

Table 1. Variation of FFT total spectral amplitude as a function of pressure

Pressure [bar]	0	1	2	3	4	5	6
Total amplitude FFT spectrum [mPa]	17.9	24.1	26.3	27.6	32.6	40.1	44.8

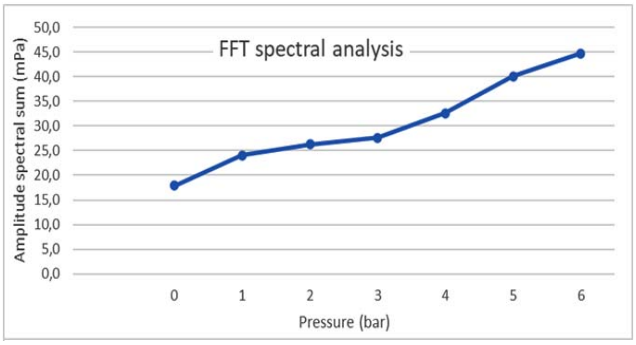


Fig. 5. Graphical representation of FFT spectral amplitude variation as a function of pressure

Table 2. Variation of CPB total spectral amplitude as a function of pressure

Pressure [bar]	0	1	2	3	4	5	6
Total amplitude CPB spectrum [mPa]	17.0	22.8	24.3	25.5	29.9	34.5	40.4

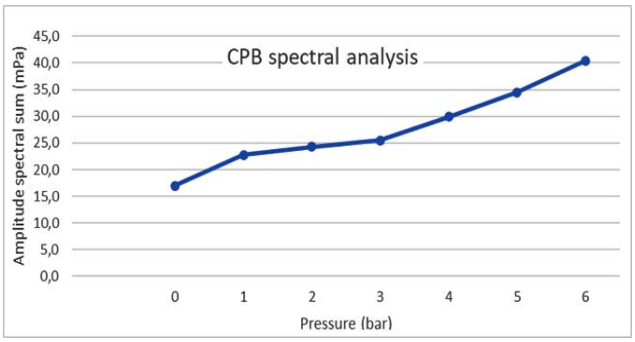


Fig. 6. Graphical representation of CPB spectral amplitude variation as a function of pressure

Table 3. Variation of the Overall spectral amplitude as a function of pressure

Pressure [bar]	0	1	2	3	4	5	6
Total amplitude CPB spectrum [mPa]	17.0	22.8	24.3	25.5	29.9	34.5	40.4

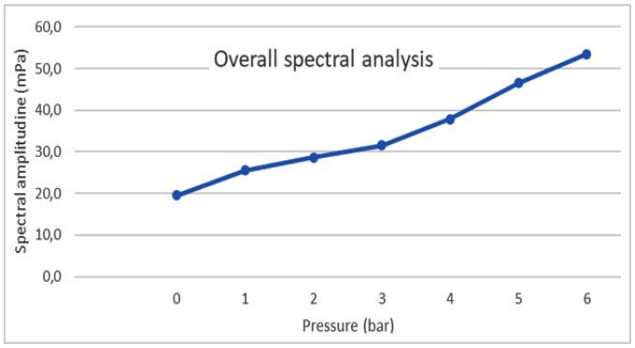


Fig. 7. Graphical representation of the Overall spectral amplitude variation as a function of pressure

Conclusions

The present paper aim was to study the influence of air pressure in a cracked pipeline on the amplitudes of the sound frequency spectra.

In the conditions of a crack occurence in a pipeline, the measurements of the sound frequency spectrum for FFT (Fast Fourier Transform), CPB (Constant Percentage Bandwith) and Overall spectral analysis were performed.

The spectral amplitude values for FFT, CPB and Overall spectral analysis obtained from the experimental tests and their graphical representations as function of pressure conducted to several conclusions, as follows:

(C1) For all three types of spectral analysis performed an increase in the spectral amplitude as a function of the pipe pressure was noticed.

(C2) The amplitude value of the frequency spectrum can be considered a parameter to be monitored as it indicates the occurrence of a crack.

(C3) Crack detection and/or location can be done based on FFT, CPB or Overall spectral analysis by monitoring the sound vibration level in an area of interest using multiple microphones.

(C4) The influence of air pressure in a pipeline on the amplitude of sound frequency spectra obtained when simulating the occurrence of a crack depends on several factors, including the nature of the crack, the pipeline material, the sound propagation characteristics, and the measurement equipment used.

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