

AN INTUITIVE METHOD TO AUTOMATICALLY DETECT THE COMMON AND NOT COMMON FREQUENCIES FOR TWO OR MORE TIME-VARYING SIGNALS

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ABSTRACT

Sampling a time-varying signal and his spectral analysis are, both, subjected to theoretically compelling, such as Shannon's theorem and the objectively limiting of the frequency's resolution. After obtaining the signal's (Fourier) spectrum, this is processed and interpreted usually by a scientist who, presumably, has sufficient prior information about the monitored signal to conclude, for example, on the significant frequencies. Obviously, processing and interpretation of individual spectra are routine tasks that can be automated by suitable software (PC application). The problems complicate if we need to compare two or more spectra corresponding to different signals and/or phenomena. In the above context, this paper presents an intuitive method for automatic identification of the common and not common frequencies for two or more congruent spectra. The method is illustrated by numerical simulations, and by the results obtained in the analysis of the noise from some experimental measured signals.

Key words: *Signals' analysis; frequencies spectrum; automation process*

Introduction

It is known that sampling a time-varying signal and his spectral analysis are both subjected to theoretically compelling, such as Shannon's theorem and the objectively limiting of the frequency's resolution. After obtaining the signal's (Fourier) spectrum, this is processed and interpreted usually by a scientist who, presumably, has sufficient prior information about the monitored signal to conclude, for example, on the significant frequencies. In this case, a quickly discernment criterion is the magnitude of spectral lines, but also the change of the associated phases. Thus, it is accepted that *the more important frequency in signal has the greater magnitude from the spectral lines*.

Obviously, processing and interpretation of individual spectra are routine tasks that can be automated by transferring the magnitudes comparison to suitable software (PC application). The problems complicate if we need to compare two or more spectra corresponding to different signals and/or phenomena. In the above context, the next paragraphs present an intuitive method for automatic identification of the common and not common frequencies for two or more congruent spectra.

Two sentences

Let $s(t)$ be a time-varying signal. We can accept that the signal's *frequencies spectrum* is a collection $S(\nu) = \{ \nu_i, A(\nu_i) \}_{i=0, \dots, N}$ of N doublets $(\nu, A(\nu))$ where $A(\nu)$ is the magnitude of the *spectral line* having as abscise the frequency ν . The value $\Delta\nu = \nu_i - \nu_{i-1} = \text{const.}$ is the spectrum's *resolution*. We name two spectra $S_1(\nu_1)$ and $S_2(\nu_2)$ as *congruent* if they have the same resolution $\Delta\nu_1 = \Delta\nu_2 = \Delta\nu$. We also name the spectral lines $(\nu_k, A_1(\nu_k))$ and $(\nu_k, A_2(\nu_k))$ as *correspondent*.

Let $s_1(t)$ and $s_2(t)$ be two time-varying signals as in **Figure 1** and **Figure 2** (numerical simulations in Microsoft Office Excel with *sampling time* t_s , *sampling frequency* ν_s , and *number of samples* N_s).

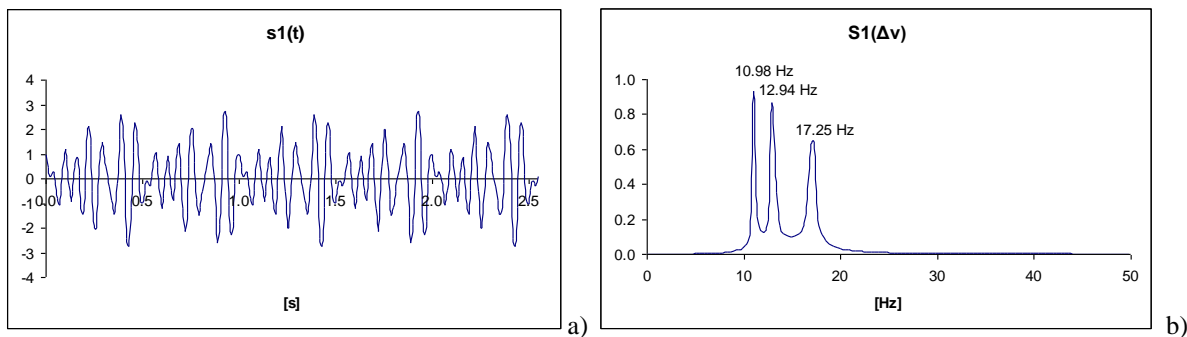


Figure 1 Signal $s_1(t) = \sin(\pi \cdot 11 \cdot t) \cdot \cos(\pi \cdot 13 \cdot t) \cdot \sin(\pi \cdot 17 \cdot t)$

a) sampling: $t_s = 2.55s; \nu_s = 100Hz; N_s = 256$; b) spectrum: $\Delta\nu = 0.392157 \text{ Hz}; N = 128$

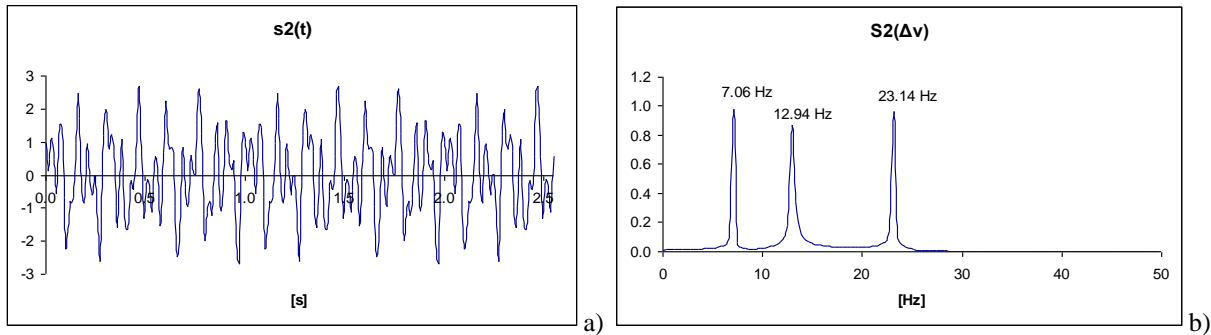


Figure 2 Signal $s_2(t) = \sin(\pi \cdot 7 \cdot t) \cdot \cos(\pi \cdot 13 \cdot t) \cdot \sin(\pi \cdot 23 \cdot t)$

a) sampling: $t_s = 2.55s; \nu_s = 100Hz; N_s = 256$; b) spectrum: $\Delta\nu = 0.392157 \text{ Hz}; N = 128$

If $S_1(\nu_1)$ and $S_2(\nu_2)$ are congruent, then the next two sentences are true:

1. The ratio of the correspondent spectral lines' magnitudes emphasizes especially the not common frequencies, significantly existing in the numerator spectrum; indeed, briefly, the value of the ratio $A_1(\nu_k) / A_2(\nu_k)$ amplifies when the value $A_1(\nu_k)$ increases (i.e. the frequency ν_k is significant in the numerator spectrum) and when the value $A_2(\nu_k)$ decreases (i.e. the frequency ν_k is insignificant in

the denominator spectrum) (Figure 3).

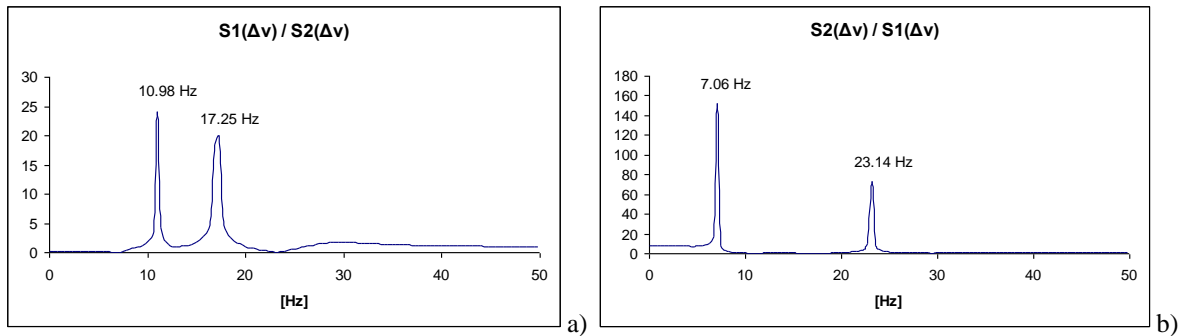


Figure 3 Not common frequencies:
 a) ratio $S_1(\Delta v) / S_2(\Delta v)$; b) ratio $S_2(\Delta v) / S_1(\Delta v)$

2. The product of the correspondent spectral lines' magnitudes emphasizes especially the common frequencies, significantly existing in the both spectra; indeed, briefly, the value of the product $A_1(\nu_k) \cdot A_2(\nu_k)$ amplifies when the both values $A_1(\nu_k)$ and $A_2(\nu_k)$ increase (i.e. the frequency ν_k is significant in the both spectra) (Figure 4).

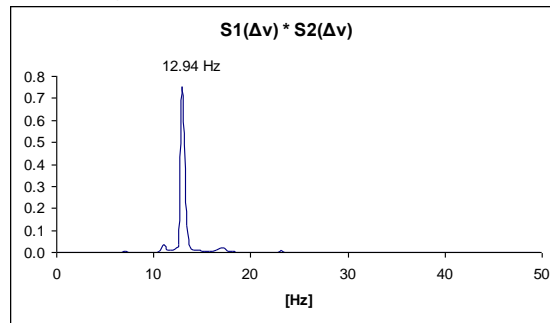


Figure 4 Common frequency: product $S_1(\Delta v) \cdot S_2(\Delta v)$

Applications for the noise of some experimental measured signals

The two above sentences were applied in the analysis of the noise from some experimental measured signals for two absolute pressure transducers installed at the ends of a pipe through which water circulates [1].

Testing conditions: pipe's parameters: $L=10m$, $EI=1.8 \times 10^5 Nm^2$, $\rho A=7.333kg/m$; mass of water filling the pipe: $m=5.281kg/m$; measurement instruments: two ENDEVCO i-TEDS accelerometers installed in $L/2$ and $L/4$ points; two absolute pressure transducers FEPA Barlad FE1GM $\sim 14 \text{ bar} / \sim 20 \text{ mA}$, installed at the upstream and downstream pipe's ends; data acquisition hardware: Bruel & Kjaer Rack 3560C (6 channels); data processing software (PC application): Bruel & Kjaer PULSE LabShop Versions 12.5.1.

Experimental results: are presented as graphics in Figure 5 – Figure 14.

- In the case of the pipe filled with water, pressurized, but without flow (background signals)

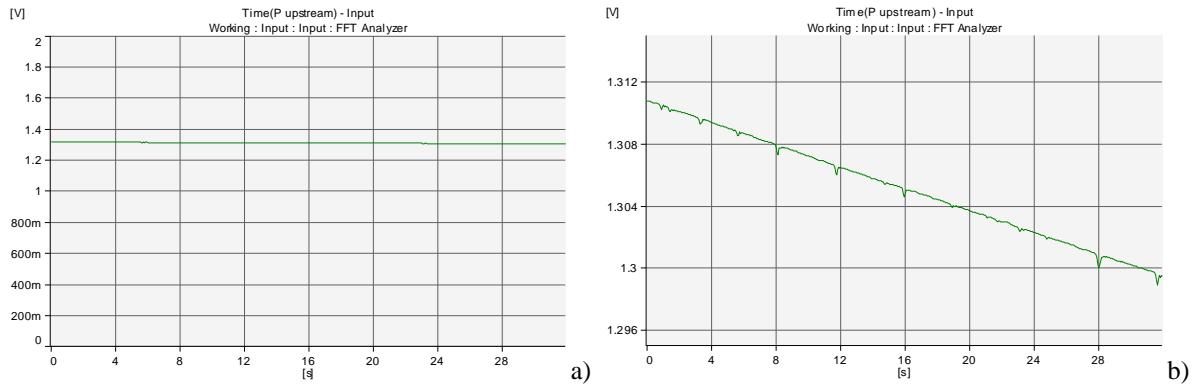


Figure 5 Background (no flow): pressure transducer installed at the pipe's upstream end
 a) time-varying signal; b) time-varying signal (zoom)

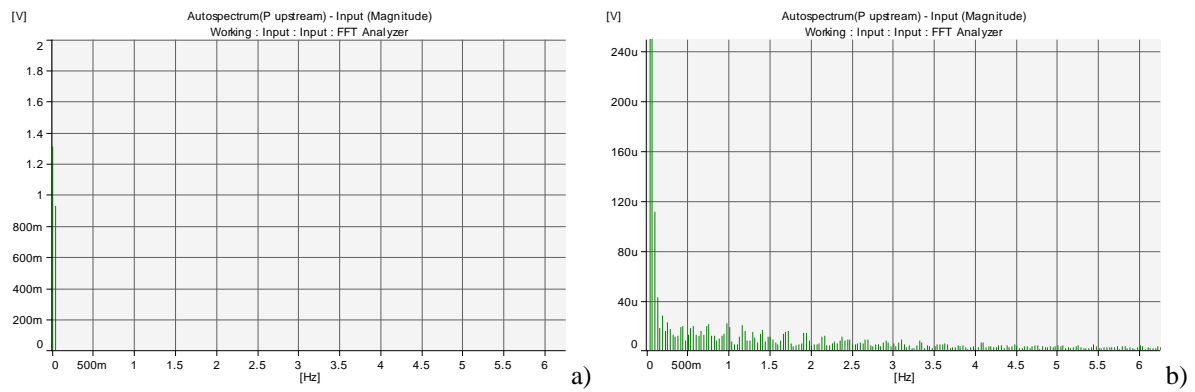


Figure 6 Background (no flow): pressure transducer installed at the pipe's upstream end
 a) frequencies spectrum; b) frequencies spectrum (zoom)

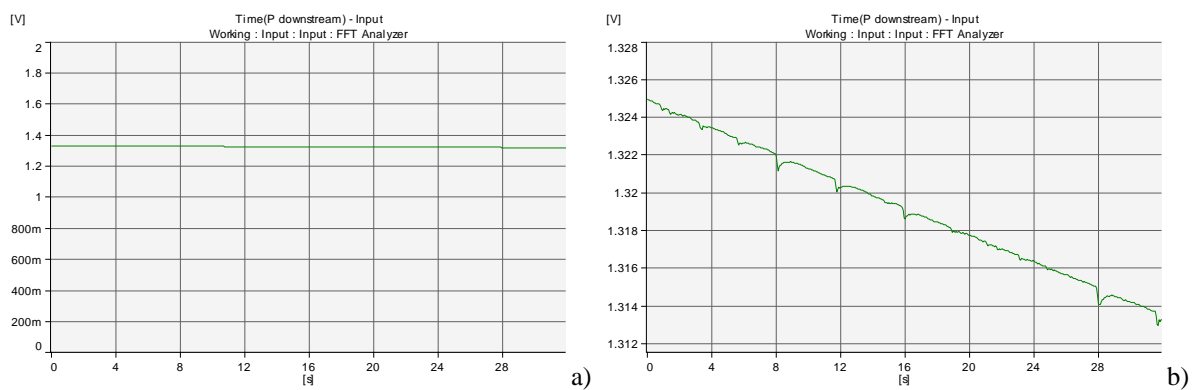


Figure 7 Background (no flow): pressure transducer installed at the pipe's downstream end
 a) time-varying signal; b) time-varying signal (zoom)

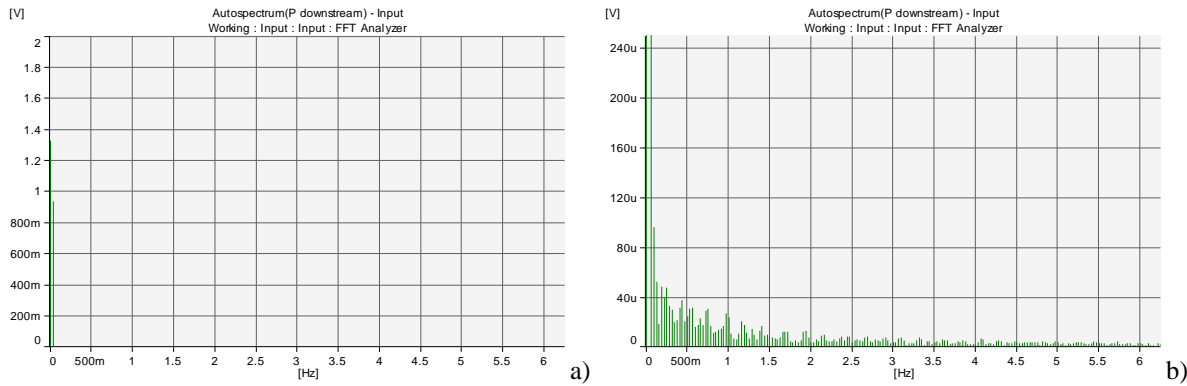


Figure 8 Background (no flow): pressure transducer installed at the pipe's **downstream end**
 a) frequencies spectrum; b) frequencies spectrum (zoom)

All measured signals were FFT analysed using the Bruel & Kjaer PULSE software (PC application) with: sampling time $t_s = 32s$; sampling frequency $\nu_s = 16Hz$; number of samples $N_s = 512$; span frequency $\nu_{max} = 6.25Hz$; number of spectral lines $N = 200$; spectral resolution $\Delta\nu = 0.03125Hz$;

- Repeating the same above measurements in the case of the pipe filled with water and flow at $70m^3/h$ (flow induced vibrations)

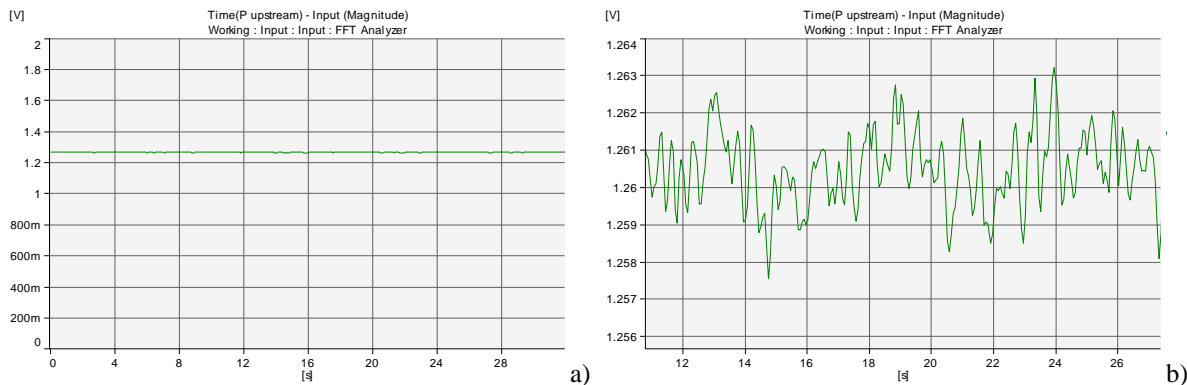


Figure 9 Flow induced vibrations: pressure transducer installed at the pipe's **upstream end**
 a) time-varying signal; b) time-varying signal (zoom)

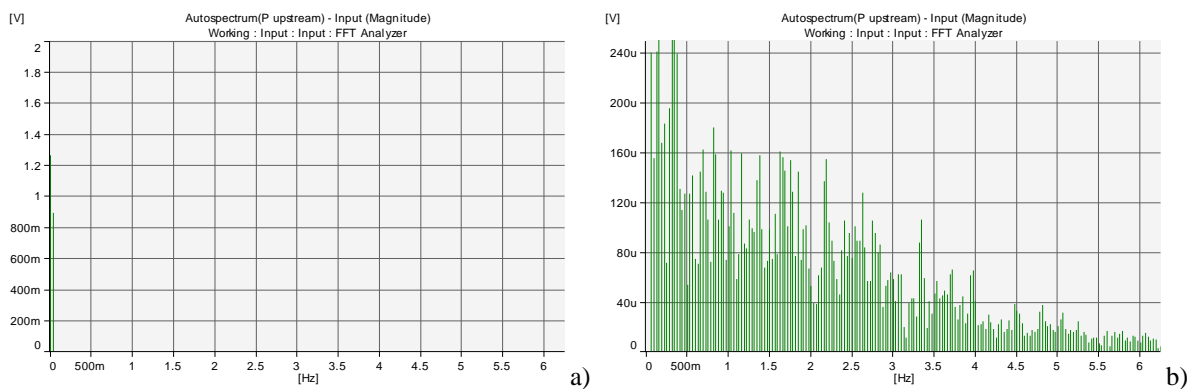


Figure 10 Flow induced vibrations: pressure transducer installed at the pipe's **upstream end**
 a) frequencies spectrum; b) frequencies spectrum (zoom)

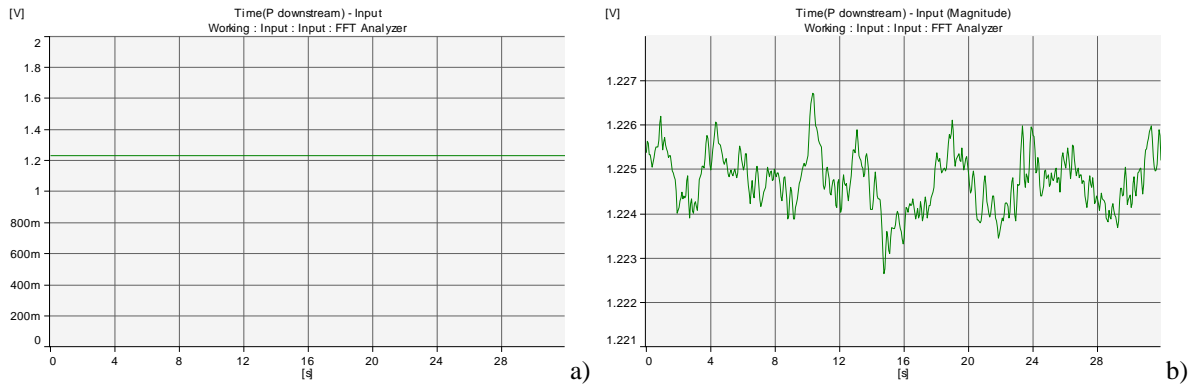


Figure 11 Flow induced vibrations: pressure transducer installed at the pipe's downstream end
 a) time-varying signal; b) time-varying signal (zoom)

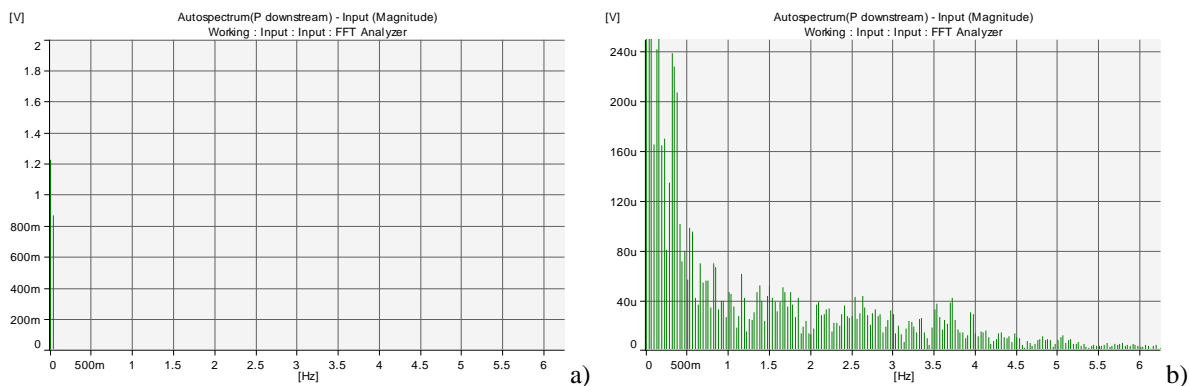


Figure 12 Flow induced vibrations: pressure transducer installed at the pipe's downstream end
 a) frequencies spectrum; b) frequencies spectrum (zoom)

All these above numerical experimental data were copied in a Microsoft Office Excel Worksheet and, applying the two above sentences on the experimental congruent spectra, we obtained:

- The ratio between the magnitudes of the correspondent flow-induced-vibrations spectral lines (as numerator) and background spectral lines (as denominator) emphasized the significant vibrations frequencies from the both absolute pressure transducers' signals (**Figure 13**)

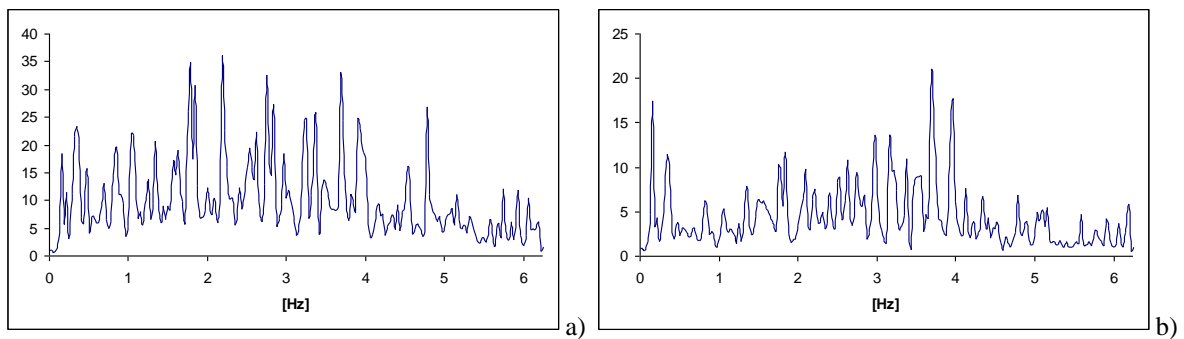


Figure 13 Not common frequencies: ratios vibrations / background; emphasized vibrations frequencies for:
 a) upstream pressure transducer; b) downstream pressure transducer

- The product between the magnitudes of the correspondent emphasized spectral lines (**Figure 13**) accentuated the common vibrations frequencies for the both absolute pressure transducers' signals (**Figure 14**)

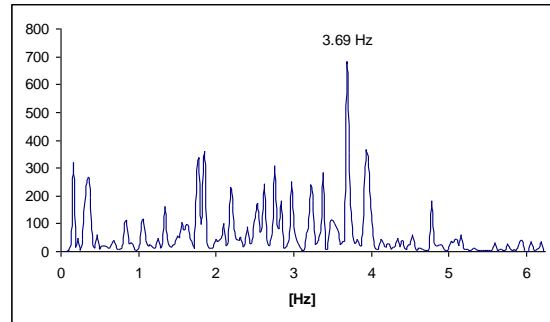


Figure 14 Common frequencies: product *upstream***downstream*; emphasized vibrations frequencies; the most significant common frequency: $\nu = 3.69\text{ Hz}$ ($\Delta\nu = 0.03125\text{ Hz}$)

The common frequency $\nu = 3.69\text{ Hz}$ is very near-by the measured first significant frequency of oscillation $\nu = 3.76\text{ Hz}$ in the case of the water-filled pipe's bending vibrations (**Figure 15** and **Figure 16**).

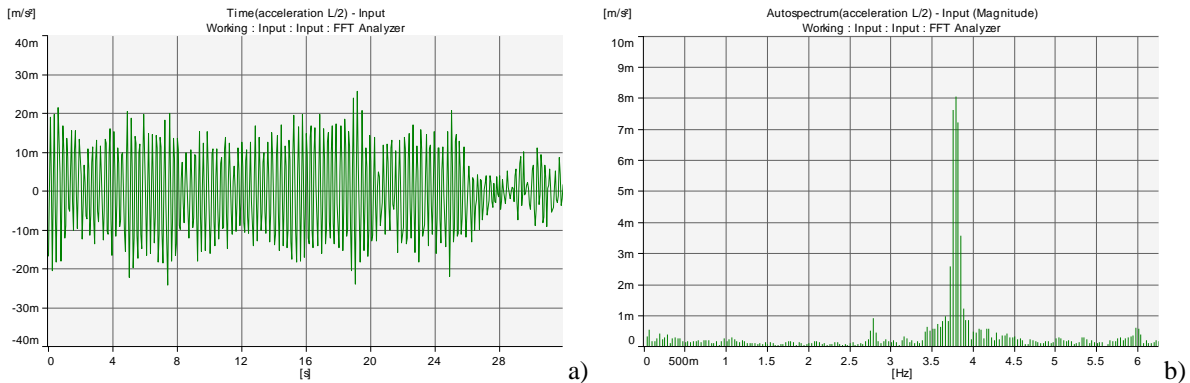


Figure 15 Water-filled pipe's bending vibrations: accelerometers in the point $L/2$
 a) flow induced vibrations signal; b) significant frequency $\nu = 3.76\text{ Hz}$ ($\Delta\nu = 0.03125\text{ Hz}$)

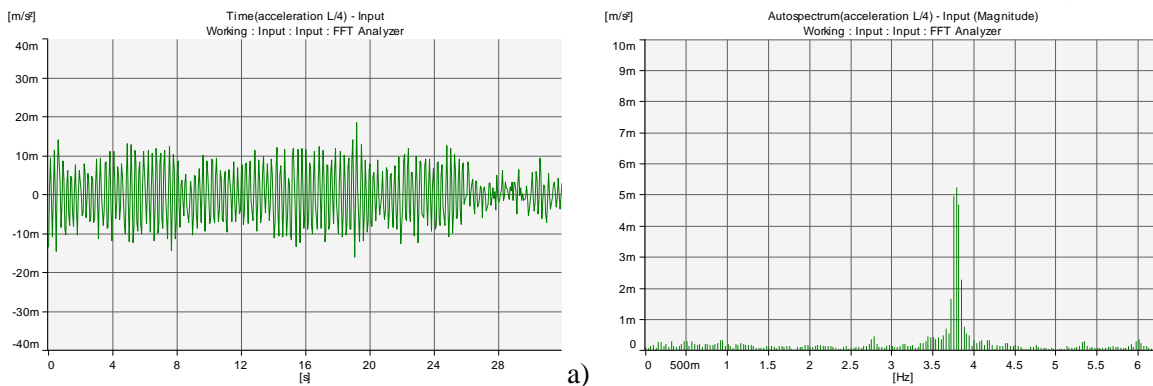


Figure 16 Water-filled pipe's bending vibrations: accelerometer in the point $L/4$
 a) flow induced vibrations signal; b) significant frequency $\nu = 3.76\text{ Hz}$ ($\Delta\nu = 0.03125\text{ Hz}$)

In this moment we don't have enough information to undoubtedly correlate the two values $\nu = 3.69Hz$ and $\nu = 3.76Hz$. Anyway, the next pictures show four simultaneously measured signals for the bending vibrations of the water-filled pipe subjected to a mechanical shock.

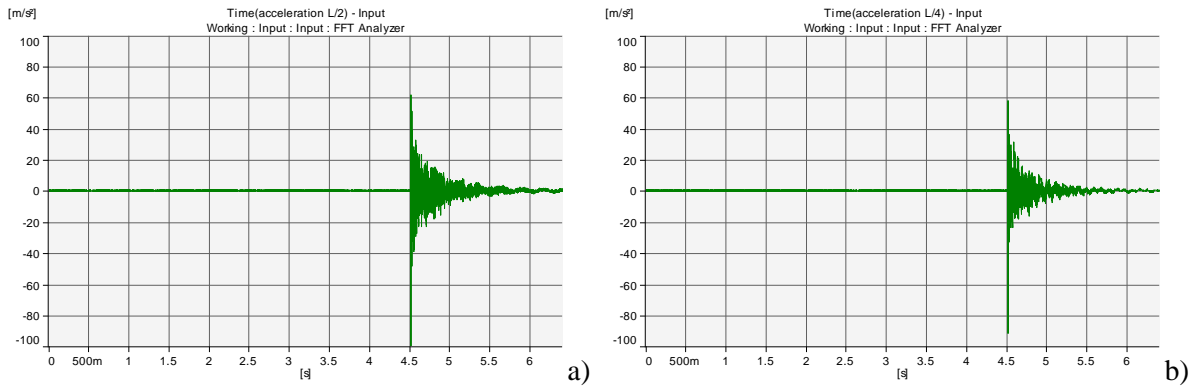


Figure 17 Experimental: water-filled pipe's bending vibrations at shock
 a) accelerometer's signal in the point $L/2$; b) accelerometer's signal in the point $L/4$

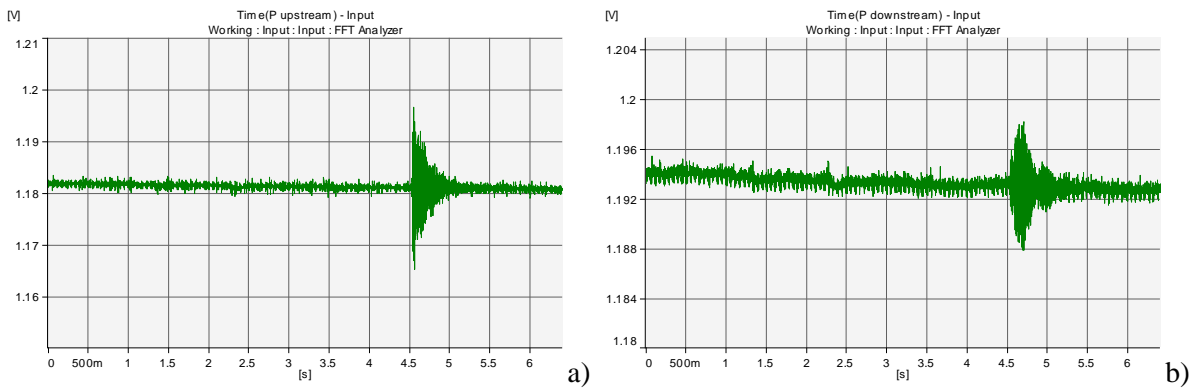


Figure 18 Experimental: signals for the shock "felt" by the absolute pressure transducers (zoom)
 a) installed at the pipe's upstream end; b) installed at the pipe's downstream end

In the graphical results from **Figure 17** and **Figure 18** we can see that the both absolute pressure transducers "felt" the mechanical shock.

Having, in the case of shock tests, the sampling frequency $\nu_s = 2kHz$, we also can see that there is a detectable delay $\Delta t = t_p - t_a = 0.02s$ between the shock time-moment for the accelerometers $(t_a = 4.506s)$ and the shock time-moment for the absolute pressure transducers $(t_p = 4.526s)$.

More precise data, more justified questions!

These days we are preparing new needed tests.

Conclusions

- The paper started with four unconventional definitions for *frequencies spectrum*, *spectral line*, *congruent spectra* and *correspondent spectral lines*.
- Then the paper presented an intuitive method for the detection of common and not common frequencies from two or more congruent spectra, based on the mathematical demonstration of the next two sentences:
 1. *The ratio of the correspondent spectral lines' magnitudes emphasizes especially the not common frequencies, significantly existing in the numerator spectrum, and*
 2. *The product of the correspondent spectral lines' magnitudes emphasizes especially the common frequencies, significantly existing in the both spectra.*
- The method was illustrated by numerical simulations made using the Microsoft Office Excel mathematical tools, and by the results obtained in the analysis of the noise existing in the experimental measured signals of two absolute pressure transducers installed at the ends of a pipe through which water circulates.
- For the experimental cases, we don't have (yet) enough information to undoubtedly correlate the significant value $\nu = 3.69\text{Hz}$ emphasized in the signals' noise, and the measured value $\nu = 3.76\text{Hz}$ characteristic for the flow induced vibrations of the testing pipe, both obtained with the resolution $\Delta\nu = 0.03125\text{Hz}$.
- Forcing the limits:

$$\nu_1 = 3.69 + 0.03\text{Hz} = 3.72\text{Hz} \quad (\text{for absolute pressure transducers' signals});$$

$$\nu_2 = 3.76 - 0.03\text{Hz} = 3.73\text{Hz} \quad (\text{for accelerometers' signals});$$

$$\nu_2 - \nu_1 = 3.73 - 3.72\text{Hz} = 0.01\text{Hz} .$$
- We need (and are preparing) new texts.
- Sure enough, the method presented in this paper can be easily implemented in any automated vibrations monitoring task (i.e. using a PC application), with an adequately degree of reliability.
- Sometimes, more important than *at what we look* is *what we see*.

References

- [1] I. Tebeică, C. Doca, G. Dună, N. Anghel, E. Pantilie and C. Tudor, "Measurements and analyses of the noise from absolute pressure transducers' signals", Internal Report 9288/2011, SCN Pitești (in Romanian)