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Experimental analysis of the whistling of an industrial riser

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Abstract – The acoustic field induced by a flow in a corrugated pipe has been studied for a long time. There has been renewed interest in the development of offshore gas exploitation using long riser lengths for gas transport. On such installations, the phenomenon can lead to a failure of the equipment adjacent to the risers. In this context, a Flow-Induced Pulsations (FLIP) test was performed in a 6" internal diameter and 18-meter-long flexible pipe. This riser was equipped with upstream and downstream measuring couplers on which were fixed hot wire velocity sensors, pressure sensors and microphones. A series of tests was conducted for various internal pressures and flow rates.

We present a time-frequency analysis of the signals resulting from these tests as well as a correlation study between the various sensors. We observed that the signals measured in the whistling condition showed significant temporal and frequency fluctuations. We were able to show that the frequency fluctuations were related to the geometry of the riser. In addition, these analyses made it possible to show that the whistling exists at transverse acoustic frequencies of the riser while propagating at the convective velocity of the flow.

Key words: Aeroacoustics/Singing Risers/Time-Frequency Analysis.

1 Introduction

The acoustic field induced by a flow in a corrugated pipe has been studied for a long time[1-2]. There has been renewed interest in the development of offshore gas exploitation using long riser lengths for gas transport [3]. On such installations, the phenomenon can lead to a failure of the equipment adjacent to the risers. In this context, a Flow-Induced Pulsations (FLIP) joint test involving TOTAL E&P, IRPHE, LMA and TechnipFMC was conducted end of 2016 at CESAME Poitiers (France). The test was performed in a 6'' internal diameter and 18-meter-long TechnipFMC flexible pipe. The series of experiments conducted aimed to observe the FLIP phenomenon on an industrial riser under various experimental configurations of internal pressure and flow rates.

The time-frequency analysis of the signals resulting from these tests as well as a correlation study between the various sensors shows that the signals measured in the whistling condition showed significant temporal and frequency fluctuations. We were able to correlate the frequency fluctuations to the geometry of the riser. In addition, these analyses made it possible to show that the whistling exists at transverse acoustic frequencies (i.e. propagating at acoustic velocity) of the riser while propagating at the convective velocity of the flow.

2 Experimental fixture.

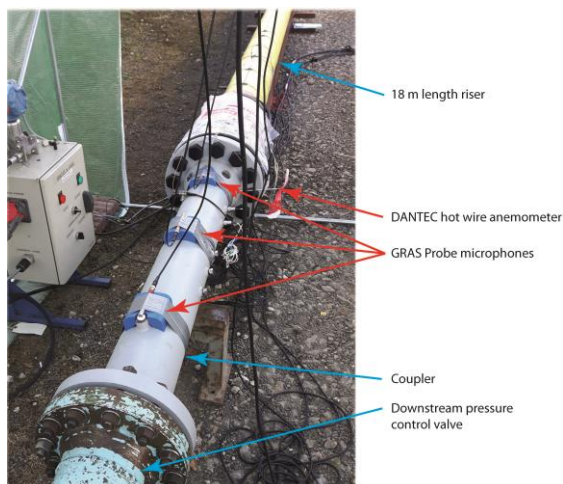


Figure 1. The downstream equipped coupler.

This experiment was conducted at CESAME facility in Poitiers (France). The 18-meter-long pipe is connected upstream to a 200 m³ reservoir filled with pressurized air at 200 bars and downstream to a pressure valve. The series of tests was conducted

for internal pressures varying from 1 bar to 42 bars and flow velocity varying from 5 m/s to 80 m/s.

At each of its end, the riser was equipped with couplers (see Figure 1) on each of which were fixed one Dantec hot wire velocity sensor, a temperature probe, a pressure sensors and 3 GRAS probe microphones separated by 0.4 m and 0.5 m (see Figure 2). All the signal were digitalized using a synchronous multi-channels analyser NetDB (01dB-Metravib) at a sampling rate of 25 600 Hz. For each test, the velocity of the flow inside the pipe was increased step by step until the desired maximum and then maintained constant to allow long time records. The duration of each test approaches 10 minutes. The first analysis of the recorded signals reveals that during the whistling process, not only a strong acoustics field (170 dB SPL) inside the riser appears at frequencies that are close to the transverse acoustic resonance of the pipe (ie 1250 Hz, 2110 Hz and 2650 Hz), but also that this sound field shows significant time and frequency fluctuations. Then, we decided to analyse these signals using Gabor-wavelet time-frequency and Hilbert transform analysis in order to catch the fine structure of the whistling.

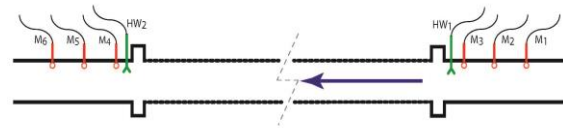


Figure 2. : The 6 microphones and the two hot wire anemometers.

In the following analysis, the maximum flow velocity inside the pipe was close to 70 m/s and the internal pressure was close to 1.5 bar.

3 Time frequency analysis

A Gabor wavelet time-frequency analysis is given in Figure 3. It corresponds to 10 s of the signal

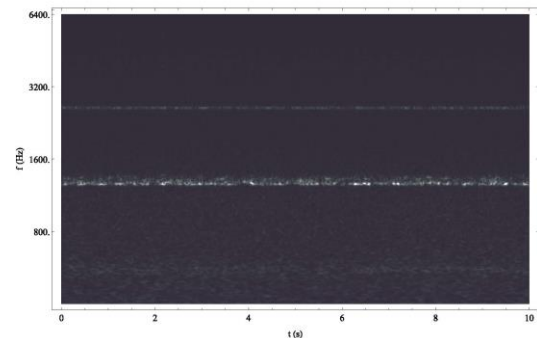


Figure 3. : Wavelet analysis during the whistling phase recorded on microphone N°4.

recorded on microphone 4 (the downstream riser's end closest microphone) during the maximum whistling of the riser. The signal is clearly

composed by two main frequency components around the first modes of the riser (ie 1250 Hz and 2500 Hz for a riser with constant radius $R=7.62$ cm). It is also obvious that this whistling processes strong variations in time and frequency. To see it more clearly, one applies a Hilbert transform of the signal filtered around the first mode to compute its instantaneous frequency [4]. The result is given in Figure 4. In that case, the amplitude is normalised to the maximum recorded during that interval and the curve is plotted with an intensity of the grey corresponding to its amplitude. This helps to see that both amplitude and frequency vary strongly, even on that short time interval.

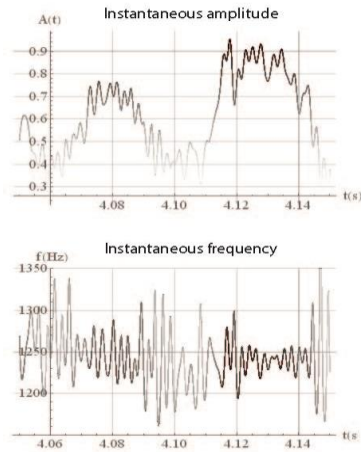


Figure 4. : Instantaneous amplitude and frequency during the whistling phase recorded on microphone N°4.

As it is easy to see in Figure 4, the frequency fluctuates around that of the first transversal mode ($f \in [1190; 1290]$ Hz) with a fluctuation corresponding quite exactly to the variation of the inner radius caused by the corrugation ($R \in [7.4; 8.1]$ cm).

4 Correlations analysis

In the following, a Pearson's correlation analysis is conducted between two microphones of the downstream coupler. To save place, we only give results for the correlation study between the microphones 4 and 5. To do this, for the whole test duration, one computes the correlation between the signal recorded by the microphone 5 and that recorded by microphone 4 shifted by n samples, with $n \in [1, 25600]$, corresponding to an estimation of correlation of a maximal time shift of 1 s. Because of the whistling, the correlation oscillates at a period corresponding to the frequency of the whistling. Two maxima are of interest, the first one is given in figure 5 and the absolute one is given in figure 6. The time corresponding to these two extrema is used to deduce a characteristic speed (obtained by dividing a characteristics d_c distance by this time). Two distances were tested: the pitch of the corrugation $L_c = 0.022$ m in figure 5 and the

inter-microphone distance: $L_c = 0.4$ m in Figure 6. The whistling starts around $t = 340$ s and ends close to $t = 550$ s. In these two figures, the dotted red curve corresponds to the wave velocity and the other two red curves to the wave velocity corrected by plus or minus the convective flow velocity, plotted in black dotted curve.

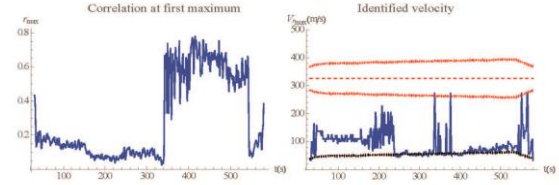


Figure 5. : First correlation maximum. $L_c = 0.022$ m.

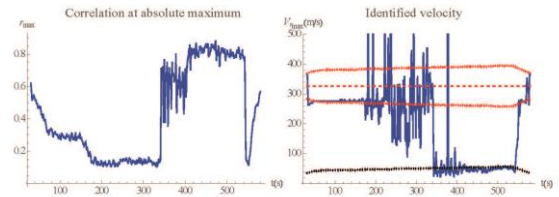


Figure 6. : Absolute correlation maximum. $L_c = 0.4$ m.

In these two figures, it is obvious that the correlation is significant only during whistling. Figure 5 reveals that the first correlation maximum depends only on the corrugation size, confirming that the whistling is strongly dependent of the corrugations. The figure 6 reveals a unusual fact: during whistling the signal propagates along the pipe at the convective flow velocity while its frequency corresponds to a transverse acoustics resonance, which indicates a transverse propagation at wave speed, five times greater than that of convective flow.

5 References

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