Pipeline acoustic monitoring

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ABSTRACT

Multi-point Acoustic Sensing (MAS) technology makes use of hydrophone sensors placed at discrete distances along pipelines in order to detect third party interference (TPI) and leaks. In fact, any interaction with the pipe generates pressure waves that are guided within the fluid for long distances, carrying information on the source event. Pressure propagation is mainly governed by the absorption coefficient and the sound speed. These parameters are in turn complicated functions of the frequency, the geometrical and elastic parameters of the pipe shell, the elastic parameters of the surrounding medium, and the acoustic and thermodynamic properties of the transported fluid.

We have designed several experimental campaigns on oil and gas transportation pipelines, instrumented with a proprietary MAS system. We have defined and simulated an exhaustive set of TPI and leak tests, taking care of the quantitative characterization of the dynamic parameters, especially at the source point. In this paper we describe the experimental work, and we discuss the data processing for the detection of pipe/flow anomalies. The results are also used for the validation of mathematical models of pressure waves propagation in fluid filled pipes.

1. NATURAL GAS PIPELINE

1.1. Field test setup

During the second half of year 2009 we performed a long term monitoring campaign on the TMPC – Trans Mediterranean offshore pipeline, carrying natural gas from the Tunisian station in Cape-Bon to the Italian station in Mazara del Vallo (Giunta et al., 2011a). This 20" pipeline section crosses the Mediterranean sea for a length of around 150km. We installed a multisensor vibroacoustic station on the Italian terminal (Mazara del Vallo), for continuous measurement and recording of natural gas pressure variations and vibrations of the pipe shell. Figure 1 shows a satellite map with the approximate pipeline track (left), a hydrophone mounted on a junction connected to the main pipe (right), and the pressure (around 90 bars) during normal gas flow (zoom on right). We have collected more than six months, seven channels high frequency data. During the
campaign, the pipeline went through several maintenance operations, comprising pumping stop/start, pigging, normal flow variations. We present here some results regarding pigging procedures. Figure 5 is the pressure signal when a pig is approaching Mazara del Vallo terminal station. In the zoomed windows it is possible to distinguish the wavelets generated by the sealing cups of the pig crossing the welding dents, around 12 m apart one from the other. We count 12-14 events per minute, corresponding to a pig velocity of 9-10 km/h. The velocity was very stable, at least when this events become visible, some hours before the pig arrival (distance around 30 km).

Figure 5. Pressure signal when a pig is approaching Mazara del Vallo terminal station. In the zoomed windows it is possible to distinguish the wavelets generated by the sealing cups of the pig crossing the welding dents, around 12 m apart one from the other. We count 12-14 events per minute, corresponding to a pig velocity of 9-10 km/h. The velocity was very stable, at least when this events become visible, some hours before the pig arrival (distance around 30 km).

1.2. Sound attenuation in gas-filled cylindrical pipes

The acoustic signals generated by the pig carry information on the source (pig) and on the transmission channel. By comparing the wavelets produced at different distances (Figure 2), we can for example compute the acoustic wave propagation parameters within the natural gas in the pipeline. Mathematical models propose in this situation a wide tube approximation: the attenuation term $\alpha$ is (Blackstock, 2000)

$$\alpha = \frac{1}{a} \sqrt{\frac{\omega \mu}{2 \rho_0 V_0^2 \left(1 + \frac{\gamma - 1}{\sqrt{\Pr}}\right)^2}},$$

where $a$ is the pipe radius, $\omega$ the angular frequency, $\mu$ the fluid viscosity, $V_0$ the sound velocity in the free medium, $\rho_0$ the static fluid density, $\gamma$ the ratio between the constant pressure and constant volume specific heat, $Pr$ the Prandtl number.
Figure 2. Pig signal (left) and power spectral density (right) at different distances from the receiving station.

Figure 3 compares the theoretical and the experimental attenuation factor. The analytical curve has been computed with the properties of the natural gas mixture at 100 bars. The match is very good: discrepancies can be related to the noise generated by the gas flow, amplitude variations for the emissions at the welds (although the experimental result is averaged over 10 wavelets), approximations in the thermodynamic properties of the gas mixture.

Figure 3. Theoretical and experimental attenuation factor.
2. **CRUDE OIL PIPELINE**

2.1. **Field test setup**

In December 2010 we have performed a field test campaign of a MAS monitoring system (Figure 4) in a controlled scenario, where third party interference and leaks have been artificially produced on a service oil-line, managed by eni r&m division, in the north of Italy (Giunta et al., 2011b). The monitoring system is deployed along the 100km pipeline: pipe diameter is 16”, oil pressure varies between 70 bars at the pumping station, down to 4 bars at the receiving terminal, flow rate is about 400 m$^3$/h. Two vibroacoustic monitoring stations are located at the pipe ends, and two along the pipeline, at an intermediate distance of around 30km. Recorded signals are vibrations of the pipe shell, and pressure variations within the fluid.

*Figure 4. Multi-point Acoustic Sensing (MAS) system.*

*Figure 5. Satellite map of the oil pipeline route (red line) and measurement stations (yellow pins).*
2.2. **Acoustic data analysis**

As an example, Figure 6 shows the spectrogram of the pressure signal recorded at two stations for an impact test (around 300J): the impact (~37s in the time axis) produces a high bandwidth spectrum at the hit point, while only a small portion of the bandwidth remains visible at some km of distance, due to attenuation during propagation within the pipeline.

Figure 7 is an example of the pressure transients produced by a sequence of three 1s valve opening at the spilling station. Very low frequency components (<100Hz) are related to pump pressure oscillations, so that SNR varies along the frequency axis.

Data processing results give a range of detection up to 5-10 km for impacts around 300J, and 20-30 km for spilling flow rate of 0.3 l/s (Figure 8).

We are testing different approaches in order to detect, localize and possibly classify anomalous events.

*Figure 6. Impact test (300J effective). Spectrogram of the pressure signal: (a) at the hit station, (b) 2100 m from the hit station (downstream).*
Figure 7. Spilling test (three 1s valve openings). Spectrogram of the pressure signal: (a) 500m from the spilling station (upstream), (b) 1500m from the spilling station (downstream).

Figure 8. Spilling test (three 1s valve openings). Pressure signal at 25km from the spilling station (downstream) after data processing.
3. CONCLUSIONS

Acoustic/pressure sensing is an emerging technology for pipeline monitoring, for the remote detection of leaks and third party interference. In this framework eni is running several experimental campaigns in order to assess the performance of this approach, and to develop new detection and classification algorithms. Artificially generated pipeline interference has been produced on both oil and gas transportation pipelines. Data processing results show the efficacy of remote monitoring, at distances of many kilometers from the source point.

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5. REFERENCES


Giunta, G, Dionigi, F., Bernasconi, G., Del Giudice, S., Rovetta, D., Vibroacoustic monitoring of pigging operations in subsea gas transportation pipelines, ASNT Fall Conference, Palms Spring (CA), USA, 2011a.


