Buckling detection within subsea pipeline laying using Acoustic Emission technique

M. F. SHEHADEH, M. Abdel GELIEL, A. EL-ARABY
Arab Academy for Science, Technology and maritime Transport (AASTMT), Engineering College, Marine Engineering Dept., Alexandria, Egypt; ezzfahmy@aast.edu

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Abstract

The most critical factor on operation of subsea pipeline installation is control of stresses (e.g. buckling, bending, fatigue etc.) in pipeline as it travels from the pipeline laying barge to the sea floor. Hence, online monitoring for pipeline laying is an important task for early detection for abnormal situation that may lead to catastrophic accident. This paper focuses on early detection of buckling stresses produced by the subsea pipeline at the laying operation using AE technique. The sensing configurations and signal analysis are carried out experimentally into a pipeline system in the lab. The results have shown that AE technique can be used for early detection of pipes buckling and bending.

Introduction

Pipes are of major importance for transport of liquids and gases mainly for natural gas and oil either in shore or offshore. Subsea pipeline assembly is laid from a vessel into a body of water by passing the pipeline through the water in a substantially vertical path for a substantial portion of its descending travel.

The source of the acoustic emission energy is the elastic stress field in the material. Without stress, there is no emission. Therefore, an acoustic emission (AE) inspection is usually carried out during a controlled loading of the structure. This can be a proof load before service, a controlled variation of load while the structure is in service, a fatigue test, a buckling test, or a complex loading program. AE inspection is used because it gives valuable additional information about the performance of the structure under load. Other times, AE inspection is selected for reasons of economy or safety, and a special loading procedure is arranged to meet the needs of the AE test [1].

To keep up with the discovery of deepwater oil and gas fields, the J-lay system for pipeline installation was invented. This method has been developed as an alternative method to install a pipeline in very deep waters [2]. The pipeline leaves the vessel from a nearly vertical position, as shown schematically in Fig.1 on the way down to the seabed; it acquires the characteristic J-shape from which the name J-lay is derived. This case generates complex loading conditions which influence the pipeline design.

The loads experienced by the pipe during such deepwater J-lay are as illustrated schematically in Fig.1. High tension and relatively small external pressure close to the surface of the sea, progressively increasing pressure and decreasing tension further down the long suspended section, high external pressure and bending in the sagbend, and essentially hydrostatic pressure on a
flat seabed [3]. The structural integrity of the pipeline moving from the launching ramp to the touch down point has to be controlled in real time [4]. As the AE is defined in ASTM E1316 terminology for Nondestructive Examinations by the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from localized sources within a material, this method can be used for real time monitoring at the laying operation.

At the pipeline laying process buckling stress, due to failure in installation system and/or rough sea condition, switches the pipe from the straight, stiff configuration to the bent one that has very small stiffness the transformation take place at a certain load which is known as the critical buckling load. The most familiar example of structural buckling is the column. A column loaded within its design specifications is straight and carries axial compression by undergoing membrane deformations on reaching a critical load; a bent configuration becomes energetically.

The diagnosis of pipelines such as buckling and bending is carried out using Fault Detection and Diagnosis (FDD) techniques [5]. FDD techniques are classified into model based and signal based [6]. The selection of an FDD technique is based on the system characteristics and available information. Since detection of pipeline buckling, in this paper, is done using AE signal, detection of buckling, here, is classified as a signal based FDD method. Signal based FDD methods vary from simple method such as limit checking and trend checking to a very advanced method based on new techniques such as Principle Component Analysis (PMC) 7, Wavelet Analysis (WA) [8] etc. This paper focuses on using the AE method for early detection of the critical pipeline buckles load.

Acoustic Emission system

Two USB AE node acquisition systems have been used in this work. The USB AE node has internal AE preamplifier along with the capability for powering a low power line of external preamplifiers and/or Integral Preamplifier sensors, which give the ability to select between the use of the internal and external preamplifier via software. Two sensors types WSa are used, the “a” stands for Alpha series of sensors. These sensors have built-in amplifiers and a fairly flat frequency
response but with two bands of relatively high sensitivity at around 100 kHz and 1000 kHz and they have an operating temperature from -65 C to 175 C. The sensors are 19 mm in diameter, 21 mm high and 32 gm, the surface was kept smooth and clean and silicone grease was used as couplet to fill any gaps caused by surface roughness and to eliminate air gaps which might otherwise impair AE transmission.

Series of experiments were carried out to investigate the propagation of AE from simulated (pencil lead break) and real (buckling) sources to an array of sensors. The overall purpose was to evaluate the potential of AE monitoring to be used in real pipe laying systems. Given the size of actual pipelines, full scale testing is difficult and can be prohibitively expensive. The approach taken in most of the research studies use scaling in order to reduce the size of the specimens tested. Dimensional analysis considerations easily show that a key geometric non-dimensional variable is the diameter to thickness ratio (D/t). Therefore, experimental results obtained using small scale tubes and pipes are transferable to actual large diameter structures with the same D/t. Regarding material properties, the elastic modulus/yield strength ratio and the hardening exponent are often key non-dimensional variables. When scaling is adopted in analyzing structural instabilities, it is also important to differentiate between ones that are elastic and those that occur in the plastic range of the material. A seamless steel (ASTM A106 Grade B) pipe was used in all experiments. The pipe was 1.5m long, with a diameter of 50.8 mm (2”) and wall thickness of 4.5mm.

Wave speed estimation

The wave speed of AE propagation in structures can be treated theoretically as a variety of pure modes implying simple sources and structures, even though the theoretical approach considers the structure to be a homogeneous elastic continuum and without attenuation effects, which may not be applicable to pipes in real applications. The experiment shown schematically in Fig.2 was held to experimentally estimate the AE wave speed, where the first sensor was mounted 40 cm from one end of the pipe, while the other sensor was incrementally moved axially along the pipe. The data were sampled at 10 MSPS. Pencil lead breaks were performed on the surface of the pipe beside the trigger sensor, as shown in Fig.2. The spacing between the sensor (S1) and the second sensor (S2) is increasing with a constant interval of 20 cm for all of the locations. A total of 4 positions were used, the experiment being repeated 5 times at each position. A common equation used for linear estimation:

\[ x = \frac{1}{2} \left( D - v \cdot \Delta t \right) \quad (1) \]

where \( D \) is the distance between sensors; \( v \) is the constant wave velocity; \( \Delta t \) is the time difference between hits; and \( x \) is the source location measured from the first hit sensor. For each AE test the time differences (\( \Delta t \)) in ms was recorded, the averages of wave speeds were calculated manually and found to be 5000 m/s.

Experimental Procedures

Universal testing machine (i.e. max load 294kN) was used to compress the pipe of nominal length of 60cm. The pipe was prepared for destructive testing by pined joint at both ends as shown in Fig.3. An axial compression load was applied incrementally until the pipe is totally deformed. The critical buckling load (\( P_{cr} \)) can be calculated by formula:

\[ P_{cr} = \pi^2 E I / L^2 \quad (2) \]
where $P_c$ is the critical load; $E$ is the modulus of elasticity; $I$ is the second moment of area; and $L$ is the effective length.

![Schematic layout of positions for source-sensor distances](image)

Fig. 2: Schematic layout of positions for source-sensor distances

The abnormal situation of pipeline is detected if its magnitude or/and energy exceeds certain threshold [6] determined experimentally. Two sensors were positioned 10 cm away axially from the mid-span. The AE signal was recorded with sampling rate of 10MHz, 40dB as a threshold and the accusation timing was set up as 300µs for Peak Definition Time (PDT), 600µs for Hit Definition Time (HDT) 4 and 1000µs for Hit Lookout Time (HLT) are timing parameters of the signal measurement process. A proper setting of the PDT ensures correct identification of the signal peak for rise time and peak amplitude measurements. Proper setting of the HDT ensures that each AE signal from the structure is reported as one and only one hit. With proper setting of the HLT, spurious measurements during the signal decay are avoided and data acquisition speed can be increased.

**Results and Discussions**

The analyses are based mostly on signal processing [5] techniques on sensor 1 using commercial software. The main objective of the analysis was to understand the behavior of the pipeline under axial compression loading along with early detection of buckling. The loads increased gradually to check the behavior of AE signal during the elastic and plastic mode of pipelines operation as shown in Fig.3. The two channels have the typical distribution with time difference which are based on the sensors position.

To correlate the collapse behavior with AE parameters, for elastic steel structures three typical modes were considered. The load and the energy distribution during the entire test are shown in Fig.4. The deformation mode is changing from the elastic type (zone A), to plastic type (zone B); with the progress of collapse in (zone C). From the previous discussion, the curve may hypothetically be divided into three main zones:

- Zone A: Elastic deformation zone.
- Zone B: Plastic deformation.
- Zone C: collapse zone.

Since, Zone B is the most important stage of the test period which the material transforms from elastic to plastic states. As shown in Fig.4, the critical buckling load has been clearly observed and achieved at the highest AE signal energy (i.e. 116154 N). In practice another characteristic is used more often that is called the amplitude distribution of pulses, shown in Fig.5, which is the AE activity during the whole test, again, the highest AE amplitude between the critical buckling load and pipe collapse.
The signal flow can be characterized (i.e. finger print) by the mean frequency of events, this characteristics is directly related to the condition and type of deformation, as shown in Fig. 6. Fig.7 shows the AE hits and the amplitude for the hypothetical three zones. Zone A has the highest AE hits with small amplitudes, while Zone B has highest amplitudes. Zone C where collapse takes place and the hits increased although it has small amplitude. The origination, motion and growth of defects are accompanied by changes in the microstructure and stress-strain state. Given this, the elastic energy is redistributed that results in AE signal emission. In general, AE activity accompanied with plastic deformation growth is high and referred to as primary AE activity, and it can be clearly observed from Fig.8b (i.e. the highest AE signal amplitude and counts). The AE signal amplitude and counts is relatively low, as shown in Figs.8a and 8c, for elastic and collapse modes referred to as secondary AE activity.
Conclusions

Early diagnosis of pipelines enhances the pipeline dependability, decreases the loss of production and increases the system safety. This paper focuses on early buckling detection of pipelines. During pipeline deformation three different modes have been defined. The pipeline deformed in three consecutive stages and can be clearly observed by the AE technique. The AE signals distributions are sensitive to all stages of pipe deformation. Hence, buckling is at highest AE Activity and can be monitored using AE technique. Studying the effects of different faults and internal/external environment of pipelines on AE signal and the modeling are the main points for future work.

![Fig. 5 The entire test amplitude of AE signal with time](image)

![Fig. 6a AE power spectrum for zone A](image)  ![Fig. 6b AE power spectrum for zone B](image)  ![Fig. 6c AE power spectrum for zone C](image)
Fig. 7a AE Hits (y) Vs Amplitude (x) for zone A

Fig. 7b AE Hits (y) Vs Amplitude (x) for zone B

Fig. 7c AE Hits (y) Vs Amplitude (x) for zone C

Fig. 8a. Secondary AE activity for zone A

Fig. 8b. Primary AE activity for zone B

Fig. 8c. Secondary AE activity for zone C
References