Development of Third-Party Damage Monitoring System for Natural Gas Pipeline Using Acoustic Wave Detection Method

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Abstract

This paper presents a real time monitoring system for third-party damage on natural gas pipeline. When the damage due to third-party incidents causes an immediate rupture, on-line monitoring can help reduce the consequences of the event. However, because many third-party incidents cause damage that does not lead to immediate rupture but can grow with time, on-line monitoring can play a significant role in reducing the number of third-party damage incidents. When a damage is given at a point on natural gas pipeline, the acoustic wave is propagated very fast about 421.3m/s. The data processing time must be very short. Usually, the pipeline is laid under ground or sea and the length is very long. So a LAN data communication method is recommendable and the sensing positions are limited by laid circumstance and setting cost of sensors. The calculation and monitoring software for detecting the third-party damage is developed by an algorithm using the propagation speed of acoustic wave and data base system. This paper provides the field testing being done to demonstrate its utility for reactive detection of third-party contact with pipelines. Furthermore, the development system is set at practical offshore pipeline of Young-jong-Do, Korea and it is being operated in real time.

1. Introduction

Even though there are so many factors that endanger pipeline safety, we can divide into three factors that are corrosion, subsidence, third-party damage by considering documents and media. Here, “third-party damage” is known as damage due directly to acts of man, such as by contact with earthmoving equipment when inflicted by other that the owner of the pipeline. Because the damage due to third-party incidents tend to be reported not immediately, it can grow with time. If that damaged part is laid without repairing, it can lead to the gas explosion due to leakage of gas as causing a corrosion. Therefore, the research into real time monitoring of third-party damage in gas pipeline is being carried out.[2][3] [4]

The outside forces incident category has been the dominant category for transmission pipeline systems in the United States since formal record keeping and trending be gain in the 1970’s, A major fraction of the incidents in this category involve third-party contact, a portion of which involve delayed failure. Delayed failure occurs where unreported damage combines with time and cycle-dependent cracking (driven by pressure-induced high local stresses at a damage site and even modest pressure cycles) that promotes its growth to a critical-sized flaw. Whether this results in a leak or rupture depends on the shape and size of the flaw, the pressure in the pipeline, and the line-pipe’s mechanical and fracture properties. The consequences of a rupture, coupled with the extensive construction associated with urban expansion and the related encroachment on the right-of-way, lead to significant concern for third-party damage and the need to detect such damage or proactively warn of impending contact.

Recently, the construction of undersea high pressure pipeline is increasing for the maximization of supply capability. But it is more difficult than underground pipeline to detect and repair the damaged point on undersea pipeline at real time. So it is needed to detect a damage on pipeline at real time, and by applying this system to gas pipeline we can get the benefit of early coping with the pipeline safety incidents. That would be our purpose of development. [5] [6]

With regard to current technologies, hydrophone and accelerometer are being used at GRI(Gas Research Institute) in USA, and anticorrosive potential difference is being used in Japan for the real time detection of damage for gas pipeline. For detecting the damage for gas pipeline at real time, it is needed that the system is composed of acoustic wave processing part including sensor and amplifier, communications network, data analysis & alarm system. In real time third-party damage monitoring system it is required that the damaged position must be calculated more precisely as well as detecting a damage. [1]

This paper reports on that technology, which is based on the detection of the propagating acoustic pressure pulse that develops from the third-party contact. This paper provides an overview of the technology and the field testing being done to demonstrate its utility for reactive detection of third-party contact with pipelines. The results indicate that with only modest development the capability for real-time monitoring exists today.

2. System Configuration

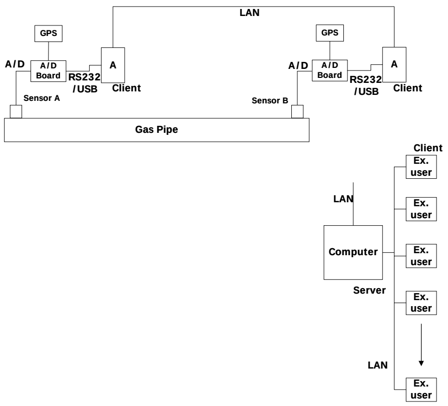

Fig.1 Schematic diagram of the system to be developed

Fig.1 shows the real time monitoring system of third-party damage to be developed. The system was designed to demonstrate the basic functionality of a Real Time Monitoring system. In order to meet these requirements the system had to:

1. Transmit data from a remote site to a central location,
2. Reliably detect third-party contact in a noisy urban environment,
3. Operate for long periods of time with little or no maintenance, and
4. Be able to be accessed remotely.

The system was based upon having a industrial computer to acquire and analyze all of the data. Sensors were placed remotely and local to this computer. The accelerometers for both sites were attached on the pipe and two accelerometers buried on either side of the pipe.

3. Third Party Damage Detection Algorithm

3.1 Algorithm calculating third-party damage

When a transient load, such as an impact, acts on a structure, transient elastic waves are generated. These waves propagate from the point of loading throughout the structure, and the characteristics of the propagation depend on both the material properties and geometry of the structure. In infinite elastic solids, the modes of propagation are longitudinal and shear waves. In gases and liquids, there are no shear waves, because the material does not support shear loads. Elastic energy propagates away from the source and spreads throughout the structure. This geometric spreading acts as an attenuation factor, because the signal strength at any one point decreases the further the observation point is from the source. In structures, some energy can go into non-propagating modes called evanescent waves. These die out very quickly from the source. There are other loss mechanisms that the material exerts. In acoustic media, there are losses due to heat conduction, viscosity, and relaxation mechanisms. The effect of dispersion can also be considered a type of loss, even though no loss actually occurs. In this case, the signal spreads out in time so that overall signal amplitude decreases. Broadly speaking this spreading will continue as the wave propagates, but the apparent loss should reach a limit once the individual modes no longer overlap.

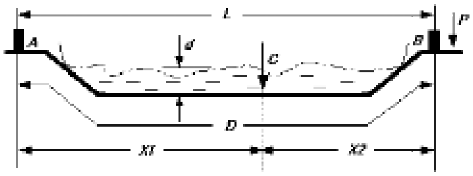

Fig.2 Schematic configuration of gas pipeline

The acceleration sensors are set at both sides of the gas pipeline as shown in Fig.2 and the damaged position is calculated by the time difference between the detected signals at both side sensors. For calculation of third-party damage, the following conditions are assumed.

1. The gas in pipeline is identical
2. The gas has identical distribution that is the signal transmission speed is constant.
3. Two signal processors have the same clock time.

In the case of synchronized in constant sampling interval, the impact signals at A, B points can be expressed at sampling time, kT as a time chart shown in Fig.3
Here,
t : sampling time
t_A : time detected at A point
t_B : time detected at B point
t_T : $t_A + t_B$
x_A : practical pipeline length between A and C points
x_B : practical pipeline length between B and C points

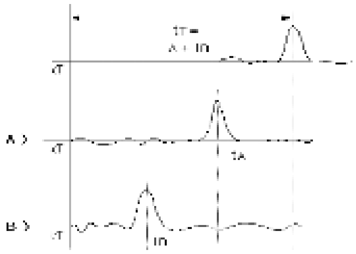

Fig.3 Propagation time chart

The practical pipeline length can be calculated by the following[4]:

$$L = vt_T \tag{1}$$

where
x : ratio of specific heats[1.32]
R : universal gas constant[8,318J/kmol • K]
T : absolute temperature[291K]
M : molecular weight[18kg/kmol]

The transmitted distance of the impact signal can be calculated by time chart as:

$$vt_T = v_A t_A + v_B t_B \tag{2}$$

Substituting eq.(1) into (2) and arranging, we can get x_A or x_B :

$$L = v_A t_A + v_B t_B \tag{3}$$

$$v_A t_A = L - v_B t_B \tag{4}$$

$$x_A = L - v_B t_B \tag{5}$$

$$x_B = L - v_A t_A \tag{6}$$

If the synchronized error is given as ΔT in the sampling interval, eq.(2) can be rearranged by the following :

$$vt_T = v_A (t_A \pm \Delta T) + v_B t_B \tag{7}$$

or

$$vt_T = v_A t_A + v_B (t_B \pm \Delta T) \tag{8}$$

where
T_A : sampling time of signal processor at A point
T_B : sampling time of signal processor at B point
and $\Delta T = |T_B - T_A|$.

Then, eqs. (4) and (6) can be calculated as follows :

$$x_A = L - v_B (t_B \pm \Delta T) \tag{9}$$

$$x_B = L - v_A (t_A \pm \Delta T) \tag{10}$$

In the case of time clock check without synchronizing in constant sampling interval, we can express

$$2x_A = v_A t_A - v_B t_B + L \tag{11}$$

$$2x_B = v_B t_B - v_A t_A + L \tag{12}$$

$$x_A = \frac{(v_A t_A - v_B t_B) + L}{2} \tag{13}$$

$$x_B = \frac{(v_B t_B - v_A t_A) + L}{2} \tag{14}$$

3.2 Algorithm detecting third-party damage

The data analysis was carried out in parallel with the data acquisition. The purpose of the analysis portion of the program was to cull the data for false calls that resulted from trigger sources outside of the pipe. This reduced the data to manageable portions and allowed the possible impacts to be retrieved and analyzed off line. The data was taken out of the queue from the data acquisition portion on a first in, and first out basis. The queue allowed all of the data to be analyzed even if the analysis portion of the program could not keep up with the acquired data. The data analysis compared the acquired data from dummy sensor of the pipe to make a determination if the signal was external to the pipe or internal to the pipe.

The comparison algorithm was made with three sub-algorithms. Such as dual domain detection algorithm(DDDA), comparison algorithm of delay time(CADT) and frequency delay time(CAFDT).

The DDDA algorithm is implemented with the time domain signal and the frequency domain signal processing. This algorithm is considered as S/N ratio magnitudes of the time and frequency domain signals. If any domain's S/N value exceeds a sitting ratio, then a detection event is generated.

In this algorithm, the S/N(Signal-to-Noise) ratio can be calculated by the following:

Time domain:

$$V_{S/N} = 20\log(V_s / V_n) \qquad (15)$$

V_s, V_n can be expressed as follows:

$$V_s = \frac{v_n + v_{n-1} + \cdots + v_{n-(m-1)}}{m} = \frac{\sum_{k=n-(m-1)}^{n} v_k}{m}$$

if $n / T_k = 0$, T_k : Calculation period

$$V_n = \frac{v_i + v_{i-1} + \cdots + v_{i-(k-1)}}{k} = \frac{\sum_{j=i-(k-1)}^{i} v_j}{k}$$

where

V_s : moving average transformation value of m times for measured signal,

V_n : moving average transformation value of k times for noise signal,

v_n : measured transformation value of m times,

v_i : measured transformation value of i times.

Frequency domain:

$$F_{S/N} = 20\log(F_s / F_n) \qquad (16)$$

F_s, F_n can be expressed as follows:

$$F_s = \frac{\sum_{k=n-(m-1)}^{n} f_{(r,k)}}{m}$$

if $n / T_k = 0$, T_k : Calculation period

$$F_n = \frac{\sum_{j=i-(k-1)}^{i} f_{(r,j)}}{k}$$

where

$$f_r = \frac{f_{(n,c)} + f_{(n-1,c)} + \cdots + f_{(n-(m-1),c)}}{m} = \frac{\sum_{k=n-(m-1)}^{n} f_{(k,c)}}{m}$$

f_r : moving average frequency power value in fixed frequency boundary(n-m [Hz]),

F_s : moving average frequency power value in fixed frequency boundary of m times for measured signal,

F_n : moving average frequency power value in fixed frequency boundary of k times for measured noise signal.

The CADT algorithm is implemented with the time domain signal processing and calculation of delay time. In this algorithm, we consider tremor of impact signal using the calculated time delay after first trigger. Fig.4 shows delay time after first trigger.

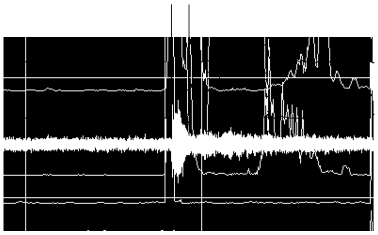

Fig.4 Delay time description

The CAFDT algorithm is implemented with the frequency domain signal processing and recognition of pattern. In this algorithm, we consider tremor of impact signal using the special pattern after first trigger. The special pattern is verified by the S/N ratio of frequency domain. The special pattern is sown in Fig.5 and Fig.6.

Here,

$F(1)$: real time S/N ratio of frequency domain at 250-375 Hz,

$F(2)$: real time S/N ratio of frequency domain at 375-500 Hz,

$F(3)$: real time S/N ratio of frequency domain at 500-625 Hz

$F(4)$: real time S/N ratio of frequency domain at 625-750 Hz.

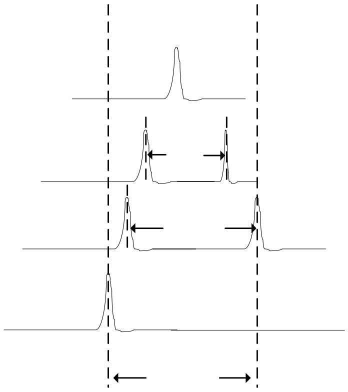

Fig.5 S/N ratio of frequency domain description

The special pattern detecting condition is as the following:

$$T_{\max} > T(1) > T(2) \qquad (17)$$

Fig.6 shows real generated special impact pattern after first trigger.

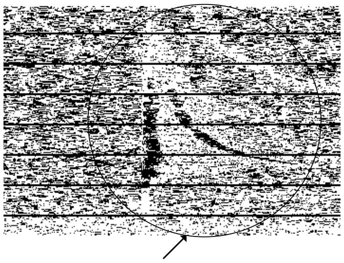

Fig.6 Experimental special impact pattern description

4. Experimental Results

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A series of field experiments were carried out to assess the feasibility of using commercially available accelerometers, along with related signal conditioning and analysis techniques, to detect impact loads like those involved with some third-party damage incidents. These experiments were performed on real pipeline. Commercially available accelerometers and hydrophones were placed at eight locations along the isolated segment. The accelerometers were placed on the outside diameter of the pipeline of Youngjong-Do in Korea. Moreover, commercially available accelerometers were placed at two locations on pipeline as shown in Fig.1. Also, the accelerometers were placed on the outside diameter of the pipe. The total length of pipeline is 5.6Km. The impact is given by dropping of 20kg, 40kg weights, and the position of impacting pipeline is nearby point A. And the evaluation was based on external noise. The external noise was made by human, such that voice, sound of footsteps and traffic sound.

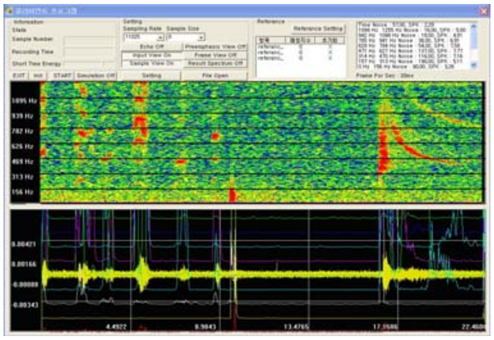

Fig.7 Dropping of 20kg from 1m height

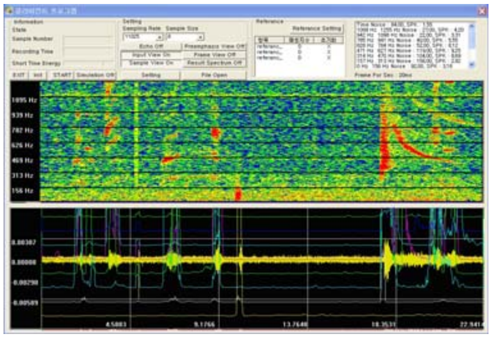

Fig.8 Dropping of 20kg from 2m height

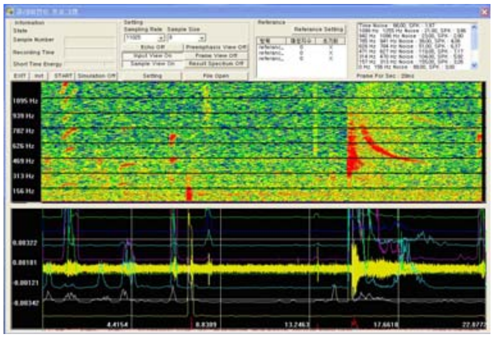

Fig.9 Dropping of 40kg from 1m height

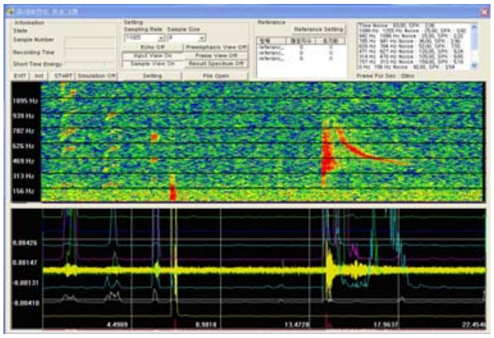

Fig.10 Dropping of 40kg from 2m height

Figs. 7-10 show the graphs of the acquired data that include time domain signal, the frequency domain signal and compare delay time signal before and after impact moment in this experiment, respectively. In these figures, first graph is frequency domain graph and second graph is time domain and delay time signal graph, and the software is demo program for implementation of comparison algorithm. In this experiment, we can find special pattern for impact signal, and verify the sub-algorithms (CADT, CAFDT).

Fig.11 shows the developed client program on main screen.

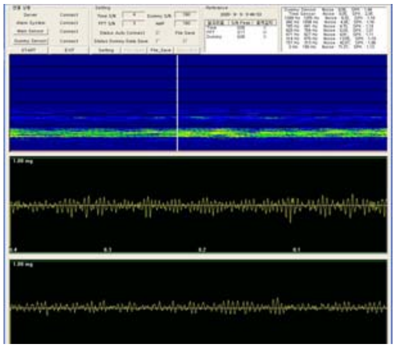

Fig.11 Developed client program on main screen

Fig.12 Developed server program on main screen

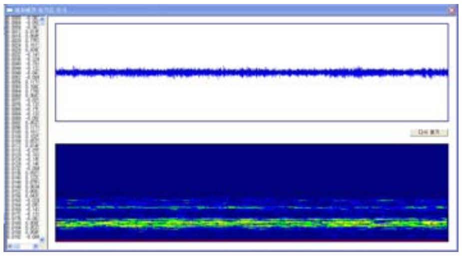

Fig.13 Data acquisition screen

Fig.14 Data reporting screen

Fig.12 shows the developed server program on main screen. In Fig.12, we can see the times of impact detection at point A and point B respectively, and time difference between point A and point B, and distance of impact position from A. Figs. 13 and 14 show data acquisition and data report, respectively.

5. **Conclusions**

In this paper we developed a real time monitoring system for third-party damage on natural gas pipeline by signal processor, LAN communication, and database system. We can monitor the status of pipeline damage and detect the third-party damage, and calculate the impact position in pipeline at real time by using the developed system. The effectiveness of the developed system is proven through the experimental results for the practical natural gas pipeline.

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