Development of Third-Party Damage Monitoring System for Natural Gas Pipeline

Seung-Mok Shin*, **Jin-Ho Suh**, **Jae-Sung Im**, **Sang-Bong Kim**
Department of Mechanical Eng., College of Engineering, Pukyong National University, San 100, Yongdang-dong, Nam-gu, Busan 608-739, Korea
Hui-Ryong Yoo
Korea Gas Corporation 638, Il-Dong, Ansan-City, Kyunggi-Do, 425-790, Korea

In this paper, we develop a real time monitoring system to detect third-party damage on natural gas pipeline. When the damage due to third-party incidents causes an immediate rupture, the developed on-line monitoring system can help reducing the sequences of event at once. Moreover, since many third-party incidents cause damage that does not lead to immediate rupture but can grow with time, the developed on-line monitoring system can execute a significant role in reducing many third-party damage incidents. Also, when the damage is given at a point on natural gas pipeline, the acoustic wave is propagated very fast about 421.3 m/s. Therefore, the data processing time should be very short in order to detect precisely the impact position. Generally, the pipeline is laid under ground or sea and the length is very long. So a wireless data communication method is recommendable and the sensing positions are limited by laid circumstance and setting cost of sensors. The calculation and monitoring software is developed by an algorithm using the propagation speed of acoustic wave and data base system based on wireless communication and DSP systems. The developed monitoring system is examined by field testing at Balan pilot plant, KOGAS being done in order to demonstrate its validity through reactive detection of third-party contact with pipelines. Furthermore, the development system was set at the practical pipelines such as an offshore pipeline between two islands Yul-Do and Youngjong-Do, and a land branch of Pyoungtaek, Korea and it has been operating in real time.

Key Words : Third-Party Damage, Wireless Communication System, Pipeline, DSP

1. Introduction

Even though there are so many factors that endanger pipeline safety, we can be summarized into three factors that are corrosion, subsidence, third-party damage by considering documents and media. Here, the "third-party damage" is known as damages due directly to acts of man, such as the damage by contacting with the earth-mover equipment. Because the damages due to third-party incidents tend to be not reported immediately, it can grow with time. If that damaged part is laid without repairing, it can lead to the gas explosion due to the leakage of gas as causing the corrosion. Therefore, many researches on the real time monitoring of the third-party damage in the gas pipeline are being carried out. (R&D Center, Korea Gas Corporation, 2000; Park et. al., 2000)

Because the mechanical damage such as an anchor strike is localized around the contacted point, the bending and denting deformations can be quite localized and severe, leading to locally

* Corresponding Author,
E-mail : crackerm@dreamwiz.com
TEL : +82-51-620-1606; **FAX** : +82-51-621-1411
Department of Mechanical Eng., College of Engineering, Pukyong National University, San 100, Yongdang-dong, Nam-gu, Busan 608-739, Korea. (Manuscript **Received** June 27, 2002; **Revised** July 4, 2003)

quite high stresses. For this reason, damage that does not cause immediate failure is much more likely to grow by a stress-induced failure processes, such as stable tearing or fatigue as compared to the more widespread damage caused by acts of nature. Therefore acts of man-particularly unreported third-party damage are more likely to lead to a delayed failure. For these reasons, the works directed at either reducing the number of third-party incidents or limiting the consequences of mechanical damage are underway in several countries. (Brodetsky and Savic, 1993; GRI, 1997) Recently, the construction for high pressure pipeline of undersea is required to maximize the supply capability of natural gas. However, 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 the damage on pipeline at real time. Moreover we can get the benefit of early coping with the pipeline safety incidents by applying this system to gas pipeline and this is the development purpose of our research (Brodetsky and Savic, 1993; Leis et al., 1998).

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 signal processing part including sensor and amplifier, communication networks, a data analysis & alarm system, a RF module, and a power supply device. Moreover the damaged position in the real time third-party damage monitoring system must be calculated more precisely and the damage of this position must be detected exactly (GRI, 1997). Therefore, although the research for reducing the third-party damage is being progressed continuously, the composition of whole system is not realized because each detailed system composing a whole system is in the basic step focused on the detection method of damage. Moreover, a third-party damage detecting system using anticorrosive potential is realized in Osaka Gas, Japan, but this system can be adapted only in Japan by the configuration conditions, and is not practical in many countries. Besides, the technologies introduced to many institutions in the world are not useful for a given circumstance of my country.

In this paper, we design and develop the systems as follows: i) DSP based system in order to obtain the satisfied processing time, ii) a microprocessor based wireless communication system using commercial wireless modem, iii) the calculation and monitoring software to detect the position of third-party damage. Especially, the calculation and monitoring software is developed by an algorithm using the propagation speed of acoustic wave and data base system.

This developed system is applied to two practical pipelines. One is an offshore pipeline between two islands of Yul-Do and Youngjong-Do, Korea and it is monitoring the third-party damage point in real time. Its length laid between two islands is about 4668.269 m. The other is an underground pipeline between two land branches of Pyoungtaek and Bugok. Its length laid between two land branches is about 10 km.

2. System Configuration and Third-Party Damage Detection Algorithm

2.1 System Configuration

In the natural gas pipeline, where the acoustic wave speed of the gas is about 421.3 m/s. So, we need a high speed signal processing system to detect precisely the impacted position between two sensors on pipeline. A typical real time monitoring system is composed of four generic elements as follows: i) uninterruptible power supply (UPS), ii) sensors and related signal conditioning, processing, and analysis of the related signals, iii) communication links, iv) evaluation, response, and control hierarchy.

The developed real time monitoring system for third-party damage is shown in Fig. 1. The developed system is composed of a wireless communication system, a data analysis & monitoring system, and a data acquisition/signal processing system. In the concrete, the communication system uses RS232C wireless module, and the com-

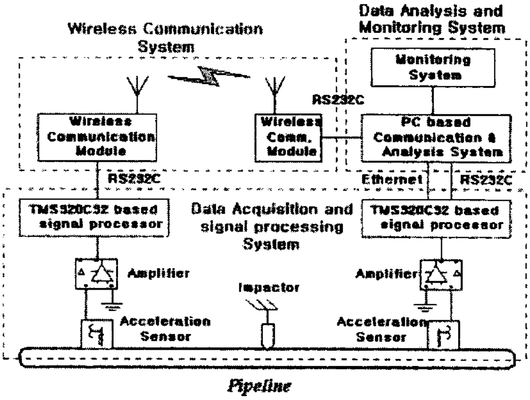


Fig. 1 Schematic diagram of the system to be developed

munication interface between data acquisition system of TMS320C32 based signal processor and PC based monitoring system is developed by using Intel 80C196KC microprocessor. The data acquisition and signal processing system is also developed by using DSP processor of TMS320-C32. Two accelerometers are used for detection of third-party damage.

2.2 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 loaded point 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 exerted. In acoustic media, there are losses due to heat conduction, viscosity, and

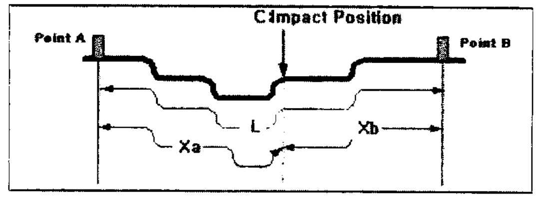


Fig. 2 Pipeline description

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, since this spreading will continue as the wave is propagated, the apparent loss should reach a limit as the individual modes are no longer overlap.

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. Therefore, we should be assumed the following conditions for calculation of third-party damage :

(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

The practical pipeline length, L can be calculated as follows :

$$L = vt_T \qquad (1)$$

where v is a velocity of acoustic wave. Moreover, the transmitted distance of the impact signal can

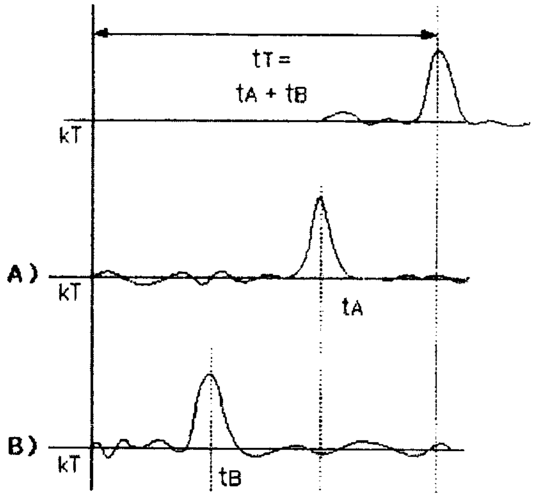


Fig. 3 Propagation time chart

be calculated by time chart as follows:

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

where v_A and v_B are the velocity of acoustic wave between A and C and the velocity of acoustic wave between B and C, respectively.

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

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

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

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

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

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 $\Delta T = | t_B - t_A |$ and

t_A : sampling time of signal processor at A point
t_B : sampling time of signal processor at B point

Then, eq. (5) and eq. (6) can be rewritten 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 as follows:

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

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

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

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

3. System Composition

In this chapter, we illustrate the system compositions about hardware and software, respectively.

3.1 Hardware composition

3.1.1 Data acquisition and signal processing system

Accelerometers mounted on the pipeline or immediately adjacent to it can detect the acoustic vibration and transform it into a voltage. Signal conditioning provides for the transformation of the detected raw response into useful information about the process or event. Signal processing and analysis may be as simple as filtering of this signal to remove background noise. The application of signal processing and analysis also includes signal enhancement to better discriminate between impending damage and noise or other features apparent in the recorded analog signal that does not represent a genuine threat to avoid false alarms. Signature analysis is one aspect of signal processing and analysis.

Generally, the required specifications in the gas industry are composed as follows: i) the state mediation of signal related with danger of sensor output, ii) processing, and iii) the organization in order to appraise analysis. Therefore, the system in this paper should be emphasized the following two conditions:

(1) A public and an environmental safety

(2) A financial burdens by shutting off the supply of gas to many industrial users

Therefore, the element of monitoring system called on an evaluation, response, and control hierarchy is more important than the others elements such as sensor & signal processes, communications, and UPS.

[1] Shock wave detection by accelerometer and interface circuit

We use the accelerometer of voltage output type made in B&K company. Especially, the composed accelerometer can change the supply voltage from 18 to 24 V freely, and the output signal increases proportionally to output voltage. The electrical noise of the accelerometer is very low about 0.02 mVrms. Moreover, since the output signal of this sensor is very weak, if the signal is transmitted directly through a long cable, it is easy to be affected by much noise. Therefore, we compose the system that directly amplifies output signal of sensor at sensor point in order to avoid this problem, and then this system transmits the amplified signal to signal processor. An amplifier circuit of sensor is composed of the specification of amplifier such as model of B&K Acclerometer 4378 with charge sensitivity 312pC/g, and 10 ms data processing time for sensors.

[2] H/W and S/W development of TMS320 C32 based signal processor

We will use the general purposed DSP processor of TMS320C32, that is, high performance 32-bit floating-point processor as the CPU of signal processor in order to develop hardware and software based on the signal processor. The TMS320C32 is the processor developed for the very high speed performance of operation at real time in the field of digital signal process. Also, TMS320C32 has internal interface devices such as 2 DMA(Direct Memory Access)controller, 2 timers of 32 bits, 1 serial port, and 3 bus control registers.

In this paper, we need the design of peripheral interface circuits in order to develop a signal processing system with function that changes the input analog obtained by sensor of digital signal, RS-232C, RS-485, and Ethernet communications as shown in Fig. 4. Furthermore, this figure

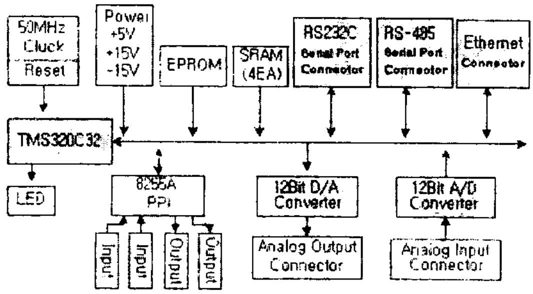


Fig. 4 Developed DSP TMS320C32 Board

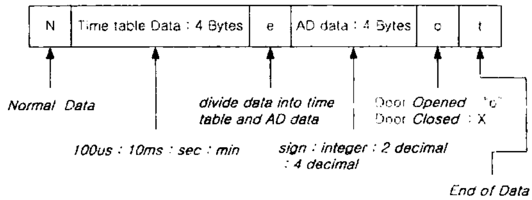
shows the hardware composition of developed DSP TMS320C32 board.

3.1.2 Wireless communication system

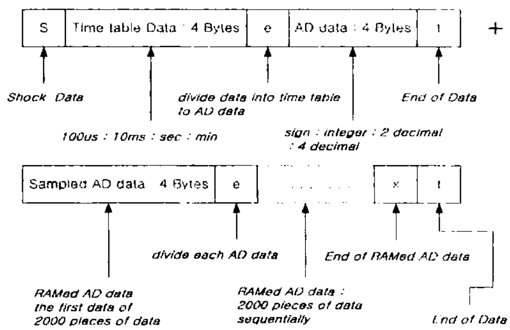
In this system, two accelerometers are used for third-party damage detection and a DSP based signal processing system for each side is set up. The data of the remote side in processing system is sent to the PC based monitoring system by wireless communication modem. The used wireless module is a model of RATA-20U made in Korea RF data company Ltd. Moreover, the module can be connected to industrial devices by RS-232c un-synchronous communication port, and it can also be done to LAN between wireless modules. The communication distance is about 10 km and it is robust under noise.

3.2 Software composition

The signal processor will process data which is acquisitioned from acceleration sensor in the prescribed sampling time. Moreover, since the sensor data and its corresponding time data are very important, this information is shaped as data table called as time table, and these data are transmitted to the PC based data analysis system by wireless communication. After comparing the digital signal obtained by A/D converter with the threshold value, if this signal value satisfies the range of the prescribed threshold value, then impact routine is operated and data are also stored in memory RAM. Besides, when this RAM is full, impact data are transmitted to the monitoring PC. This impact inspection routine is repeatedly processed. The developed main monitoring software has various



(a) Data Format when shock is not detected



(b) Data Format when shock is detected

Fig. 5 Data format of monitoring S/W

functions such as weekly report, monthly report, communication data analysis, and software configuration setting, and so on. Also, we design the form which restores software configuration in order to specify the minimum value of data used for making report.

The data format of monitoring software system is shown in Fig. 5. shows the data formats when the shock is not detected and is detected, respectively. Especially, the meanings of symbols and bytes are concretely described in Fig. 5.

4. Experimental Results

The developed third-party damage monitoring system is shown in Fig. 6. The 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 an idled 400 mm diameter, Balan pilot plant, KOGAS. 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.

Fig. 6 Developed third-party damage monitoring system

Fig. 7 Practical pipeline and impact detection sensors

Figure 7 shows the practical pipeline and it set up impact detection sensors. The structure of an exposed pipeline for impact experiment is shown in Fig. 8. This is located at 2 m under ground and the center of pipeline. The total length of pipeline is 360 m. The impact is given by dropping of 10 kg weight, and the position of impacting pipeline is 180 m from point A. The sensors are able to detect the impact, even at the lowest height, over the entire length of the pipeline segment. A 10 kg weight is dropped from 2.5 m to provide an extremely low-level signal that could be compared with the earlier results observed by KOGAS.

Fig. 8 Exposed pipeline for impact experiment

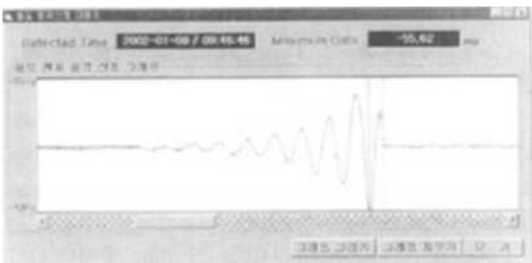


Fig. 9 The detected impact data at point A

Fig. 10 The detected impact data at point B

Figures 9 and 10 show the graphs of the acquired data that include 2000 pieces sampling data at 100 μs sampling time before and after impact moment in this experiment, respectively. In these figures, dotted line means the time of impact detection, and connected line means the maximum data of entire acquisitioned data.

The real time monitoring system for the impacted position in gas pipeline is shown in Fig. 11. When the impact is detected at both two data acquisition and signal processing system, we can calculate the impact position out of the time

Fig. 11 The impacted position

table data by using the algorithm shown in section 2.1, and we can see the times of impact detection at point A and point B through a time difference between point A and point B and distance of impact position from point A.

As each parameter of eq. (13) in section 2.1 is defined as follows:

$$t_A = 7.852 \text{ sec}, \qquad t_B = 7.842 \text{ sec}$$
$$L = 360 \text{ m}, \qquad v_A = v_B = 340 \text{ m/s}$$

x_A is given by:

$$x_A = = \frac{(v_A t_A - v_B t_B) + L}{2} = 181.7 \text{ m}$$

In this experiment, the error of calculating impact position is about 1.7 m and this error is less than 0.5% of whole length of pipeline. Moreover, the developed system can report the acquired data and print out the reported data as shown in Fig. 12.

The development system was set at the practical pipelines such as an offshore pipeline between two islands Yul-Do and Youngjong-Do, and a land branch of Pyoungtaek, Korea and it has been operating in real time. For example, the system configuration constructed between Youngjong-Do and Yul-Do is shown in Fig. 13. This figure represents the apparatus of data acquisition and signal processing system set up at Youngjong-Do and the length of pipeline laid between two islands is about 4668.269 m.

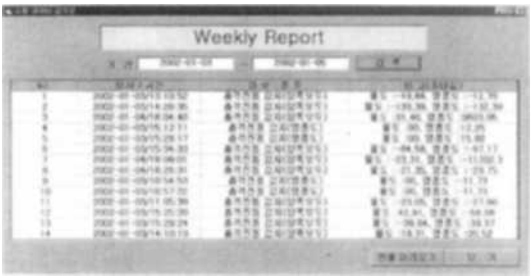


Fig. 12 Reporting data screen

Fig. 13 The photograph of an applied system in Youngjong-Do

5. Conclusions

In this paper, we developed a real time monitoring system for third-party damage on natural gas pipeline by using DSP TMS320C32 signal processor, wireless communication, and database system. The developed system can monitor the status of pipeline damage and detect the third-party damage in real time. When the damages are detected by this system at both sides in gas pipeline, this system can not only calculate the impact positions of pipeline with low error but also display the impacted positions of pipeline in the screen at real time.

The practicality of developed system is shown by the results of field experiments at Balan pilot plant, KOGAS. The developed systems set up at two practical pipelines have been operating with good performance. Therefore, the developed system proved very useful for monitoring third-party damage on natural gas pipeline.

From now on, it is necessary to expend the application filed of the developed system.

References

GRI, 1997, *Real-Time Monitoring to Detect Third-Party Damage*, GRI-1996.

Igal Brodetsky and Michael Savic, 1993, "Leak Monitoring System for Gas Pipelines," *In Proceedings of IEEE Acoustic, Speech, and Signal Processing*, Vol. 3, pp. 17~20.

Leis, B. N. Francini, R. B. Stulen, F. B. and Hyatt, R. W., 1998, "Real-time Monitoring to Detect Third-Party Damage," In Proceedings of the Eighth International Offshore and Polar Engineering Conference, pp. 34~38.

Park, S. S., et. al., 2000, "Development of Real Time Monitoring System for Third Party Damage Detection Using Wireless Data Communicating," *Journal of KIGAS*, Vol. 4, No. 3.

R&D Center, Korea Gas Corporation, 2000, *A study on the real-time monitoring to detect third-party damage on subsea pipelines in Masan Bay*, Research Report.