Design and Implementation of 30" Geometry PIG

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This paper introduces the developed geometry PIG (Pipeline Inspection Gauge), one of several ILI (In-Line Inspection) tools, which provide a full picture of the pipeline from only single pass, and has compact size of the electronic device with not only low power consumption but also rapid response of sensors such as calipers, IMU and odometer. This tool is equipped with the several sensor systems. Caliper sensors measure the pipeline internal diameter, ovality and dent size and shape with high accuracy. The IMU (Inertial Measurement Unit) measures the precise trajectory of the PIG during its traverse of the pipeline. The IMU also provide three-dimensional coordination in space from measurement of inertial acceleration and angular rate. Three odometers mounted on the PIG body provide the distance moved along the line and instantaneous velocity during the PIG run. The datum measured by the sensor systems are stored in on-board solid state memory and magnetic tape devices. There is an electromagnetic transmitter at the back end of the tool, the transmitter enables the inspection operators to keep tracking the tool while it travels through the pipeline. An experiment was fulfilled in pull-rig facility and was adopted from Incheon LT (LNG Terminal) to Namdong GS (Governor Station) line, 13 km length.

Key Words: ILI (In-Line Inspection), Geometry PIG (Pipeline Inspection Gauge), IMU (Inertial Measurement Unit), Odometer, Caliper, Electromagnetic Transmitter

1. Introduction

Pipelines are the most common way and the most safe method to transport oil and gas products. They must be properly and regularly monitored to confirm the integrity of the pipeline. So it is needed to accurately establish the present state of the pipeline, and the detailed inspection should be carried out to obtain all the necessary technical information about the condition of the pipeline (Cordell and Vanzant, 1999). Many ILI tools have been used to obtain the detailed inspection. Caliper PIG (Pipeline Inspection Gauge) and mapping PIG among them have been used to measure internal pipeline geometry and pipeline trajectory respectively. To describe a full picture of the pipeline, it requires to obtain the information of both internal pipeline geometry such as dent, ovality, buckle, wrinkle, girth-weld, and thickness transition and pipeline trajectory including curvature, profile and radius and angle of bend. Caliper PIG generally provides only information of internal pipeline geometry and can not give the operator the information of the pipeline trajectory. In order to acquire a full picture of pipeline, mapping PIG should be adopted to the pipeline again which is already pigged by Caliper PIG. So, repeated pigging burdens the operator with heavy operating expense and there is always a finite risk that a foreign body introduced into the pipeline may become lodged, block the flow. Geometry PIG is used most frequently before in-line inspection such as MFL (Magnetic Flux Leakage) pigging including the detection of a cor-

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rosion and metal loss to ensure that the inspection tool can pass safely through the pipeline. So the body must be designed compact, about 60% of the internal diameter which combined with flexible cups allows the PIG to pass constrictions up to 15% of bore (Tiratsoo, 1992). Moreover many geometry PIGs commercially in use has the problem that the flow rate of the pipeline must be controlled below any boundary by Central control station for preventing the measured data from missing due to fast flow rate. Therefore, it is required to develop the geometry PIG which provide a full picture of the pipeline from only single pass, and has compact size of the electronic device with not only low power consumption but also rapid response of sensors such as calipers, IMU, and odometers.

This study introduces the developed geometry PIG which provides a full picture of the pipeline including internal pipeline geometry and pipeline trajectory. The PIG is also capable of ensuring that MFL PIG which inspects the corrosion and the metal loss can pass safely through the pipeline. The PIG was equipped with caliper sensors, IMU, odometer and tracking transmitter. Caliper sensors and IMU are designed that they have rapid sensing response so as to avoid controlling the pipeline flow rate carefully. The body was fabricated to compact that the PIG overcome critical constrictions such as 1.5D bend and large size dent. Electronic device is designed to consume power low and its size is compact. Run-time data which is recorded during the PIG run is transmitted to post-processing computer by FTP. The geometric information which is taken is estimated for detecting and locating anomalies or deformations of the pipeline by post-processing. To achieve the verification of the performance for the developed PIG, actual pigging is carried out in site, from Incheon LT to Namdong GS line, 13 km length.

2. System Hardware

Geometry PIG is used generally to investigate geometry surveys of the pipeline and to confirm that the pipeline is clear with minimum risk of jamming. To accomplish these abilities, the PIG must be satisfied with several design specification. The body has to be normally fabricated to compact, about 60% of the internal diameter which combined with flexible cups allows the PIG to pass constrictions up to 15% of bore. It must be designed to overcome critical condition such as 1.5D bend and large size dent. The developed PIG is sufficient to transit the pipeline with above mentioned specification in 30" diameters. The PIG was equipped with caliper sensors, IMU (Inertial Measurement Unit), odometer sensors for geometry surveys and tracking transmitter for location of the PIG. The geometry PIG is suspended in the pipeline on urethane disks at the front and rear of the canister, which allow the PIG to move close to and paralleled to the pipe centerline. Caliper sensors provide a full picture of the pipeline shape as an internal diameter, ovality, and dent size and shape. IMU provide the position and attitude of the PIG along its trajectory within the pipe. That is, caliper sensors and IMU acquire independent measurements, which are used to confirm the existence and location of an anomaly or a feature. Odometer sensors measure the distance moved along the pipeline and instantaneous velocity during the PIG run and are used to compensate error which result from the nature of inertial measurements.

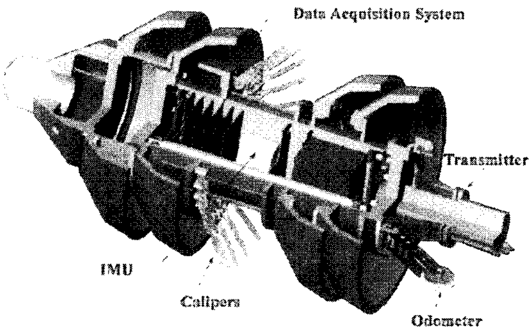

Fig. 1 Scheme of the geometry PIG

The scheme of the geometry PIG is shown in Fig. 1.

2.1 Caliper sensors

Calipers are principal components of the geometry PIG. Fig. 2 shows a ring shaped perma-

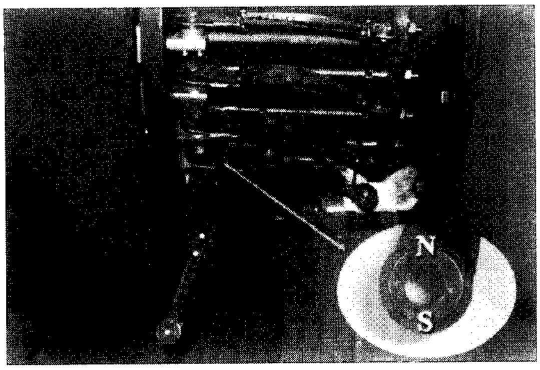

Fig. 2 Caliper sensors

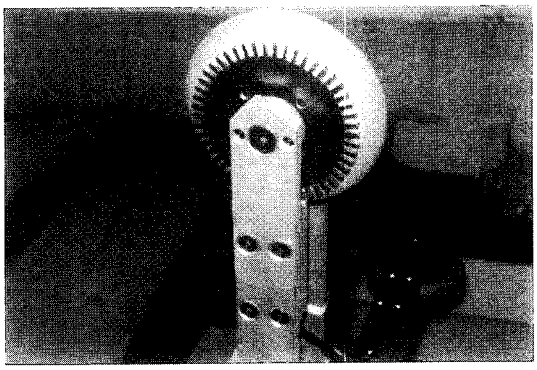

Fig. 3 Odometer wheels

nent magnet in sensing module and the fabricated caliper sensors which are mounted with the spring. They are in constant contact to the pipe wall by the spring tension. When the PIG pass through geometrical anomalies such as dent, wrinkle, girth weld and thickness transition, the strength of the magnetic field in the inner space of ring shaped magnet is changed. Changing magnetic field is measured by the linear hall effect sensor. The sensitivity of caliper sensors mainly depends on the magnitude of the magnetic field inside the sensing module. The developed geometry PIG is mounted 24 calipers at intervals of 99.1 mm, 15°, around the circumference of it. Spring-mounted mechanical finger's wheels keep in constant contact to the pipe wall. The accuracy of mechanical fingers is obtained ± 1 mm.

2.2 IMU (Inertial Measurement Unit)

A Strapdown Inertial Measurement Unit locates the position of the PIG along its trajectory within the pipe. The IMU produces three dimensional measurements of inertial acceleration and angular rate directly from accelerometers and gyroscopes about three orthogonal axes. The information of their sensors is sent to the IMU processor (TMS320C26) where the datum are compensated for temperature-induced errors and outputted in SDLC format on an RS-485 serial data bus at a 400 Hz rate. The geometry PIG uses an inertial measurement unit built by Litton Industries, containing three fibre optic gyroscopes and three single-axis silicon accelerometers. The SIMU accelerometers and gyros are complementary sensors.

2.3 Odometer sensors

The geometry PIG is equipped with spring-mounted odometer wheels. They are in constant contact to the pipe wall by the spring tension. When the PIG traveled through interior to the pipeline, gear tooth of odometers which is fabricated as Fig. 3 are counted by a hall-effect adaptive gear-tooth sensors. Odometers give measurements of the distance along the pipe and velocity of the PIG is derived from these information. Because velocity is used in all aspects of processing collected data, high accuracy is required. In this work, an accuracy of 0.05% could be obtained in run time.

2.4 Auxiliary components

Other principal components integrated in the geometry PIG are as follows :

1) DAT (Digital Audio Tape) recording system, 20Gigabyte capacity,
2) DAU (Data Acquisition Unit) based on micro-processor controllers, lithium-Ion batteries,
3) An embedded board for managing data acquisition,
4) A power management module,

and, PIG tracking transmitter which generated electromagnetic wave.

Batteries allow the PIG to inspect the interior of a pipeline for 60 hours. A power management module is prohibit over charge and discharge, and is capable of shutting down the system stably. At the back end of the PIG is an electromagnetic transmitter so that the inspection operators can keep tracking the tool while it travels through the pipeline.

3. Data Processing

A main unit processing a data, DPU (Data Processing Unit), is based on an embedded personal computer (Celeron 366 MHz). This unit interfaces with bus types such as SCSI, ISA and PCI, and communicates with ethernet and serial port. The unit is composed of DAU and DRU (Data Recording Unit). DAU is implemented with using 32 bit micro-processor, 80C296SA. It gathers the data of 24 caliper sensors from an A/D conversion, and takes the data of three odometers from EPA function at a rate of 400 Hz. It also obtains IMU's data by SDLC synchronous communication. The gathered datum are saved in the dual port memory which is shared by DRU and DAU with ISA interface. The scheme of DPU of the geometry PIG is shown in Fig. 4.

3.1 Caliper sensors processing

The purpose of caliper sensor processing is to measure the pipeline internal diameter and to identify and size pipeline wall anomalies, including dent, ovality, buckle and wrinkle. That is achieved by measuring the distance from the PIG carrier to the pipe wall at several locations along the pipe circumference using 24 caliper sensors. The caliper information is processed to provide the internal shape and diameter of the pipe. The feature size D is calculated as follows :

$$D = D_{nom} - D_{min} - (D_{max} - D_{nom}) \qquad (1)$$

where, D is the feature depth, D_{nom} is the inner pipe diameter, D_{min} is the pipe diameter across the feature and D_{max} is the pipe diameter perpendicular to the feature axis as shown in Fig. 5.

3.2 SIMU processing

The principal aim of the inertial survey is the detection of physical anomalies in the pipeline, and the positioning of any location which threaten the integrity of the pipeline.

The SIMU is ideally suited to these task. SIMU processing consists of position and velocity com-

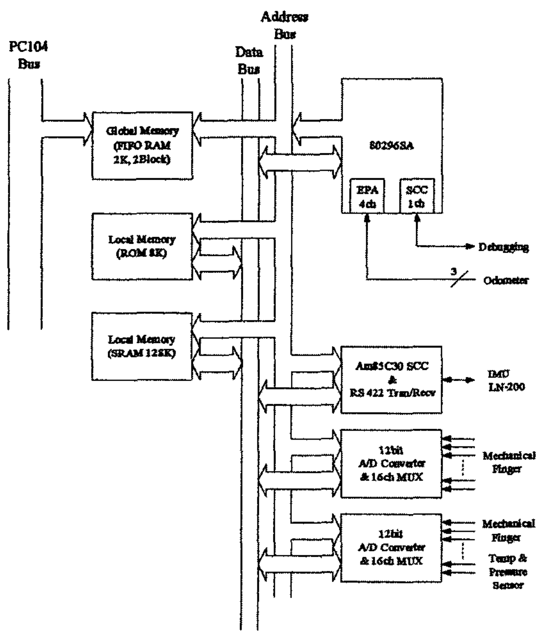

Fig. 4 Scheme of DPU of the geometry PIG

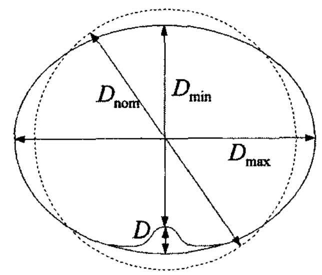

Fig. 5 Computation of the feature size

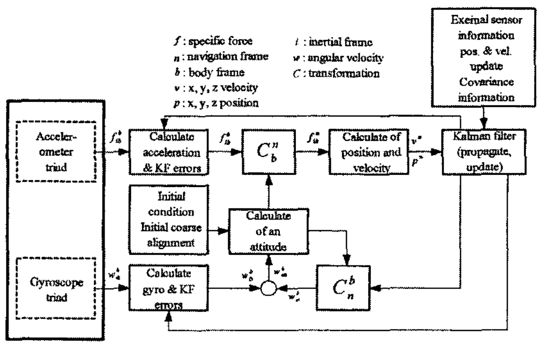

Fig. 6 SIMU processing

putation algorithm, initial coarse alignment algorithm, and Kalman filtering modules for compensating the PIG's attitude as illustrated in Fig. 6. The pipeline position is provided in terms of Northing, Esting and height in a selected mapping projection (usually UTM) and a specified datum. SIMU also provide the information of attitude of the PIG (pitch, roll, yaw).

3.3 Additional processing

The inertial unit have the nature of time drift generally. The accuracy of measurement unit is used in this study is a gyro drift 1°/hr. Additional sensors processing are necessary to stabilize the integration of the linear acceleration and angular velocity of the IMU, and to detect pipeline deformations exactly. That is, odometer which updates the velocity of the PIG and GPS (Global Positioning System) point which updates the coordinate of the PIG is essential when the inertial algorithm is executed. Update points called as "tie points" and "control points" are typically selected at traps, valves, welds, bends, wall thickness transitions, or external points that can be taken directly from the GPS (Global Positioning System). In actual pigging, GPS coordinates of external points is known before the PIG is launched. Once launched, the transmitter mounted on the PIG continuously generates the electromagnetic wave, which is detected by TBMS (Time Based Marker System), CD47B. As the transmitter passes directly below CD47B, the strength of the noise channel suddenly drops off to zero. As the trans mitter passes directly above or below CD47B, the strength of the signal channel is at its maximum. Fig. 7 illustrates this concept.

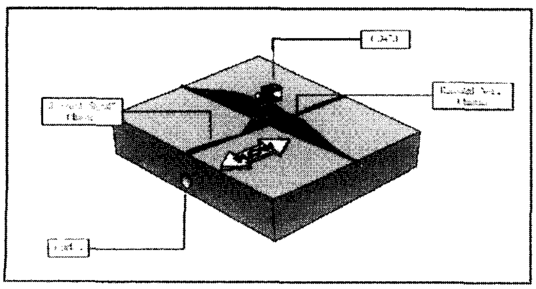

Fig. 7 PIG detection by CD47B

By this concept, the GPS time that the PIG pass through any external point is recorded exactly. Obtained GPS time is used to synchronize the system clock of DPU for updating several information of traveled distance and velocity of PIG.

4. Experiment and Consideration

The developed PIG must be designed to be used under the environment of actual pipeline that an operation pressure is about 100 bar and there are so many vibrations of the transmission material, natural gas, and also is fabricated that the PIG can pass through a critical bend such 1.5D bend. Fig. 8 shows the geometry PIG which is produced from this study. A dent sizing accuracy of calipers is +/−0.5 mm. A distance accuracy of the odometer is 1 : 2000.

4.1 Performance test in pull-rig facility

Experiment of the developed PIG was fulfilled in pull-rig facility firstly which is 30 inch, 35 m

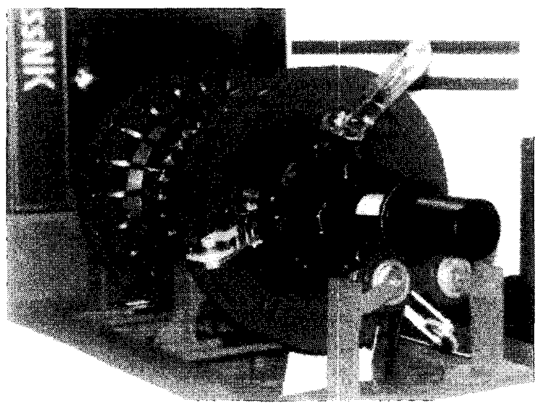

Fig. 8 Developed geometry PIG

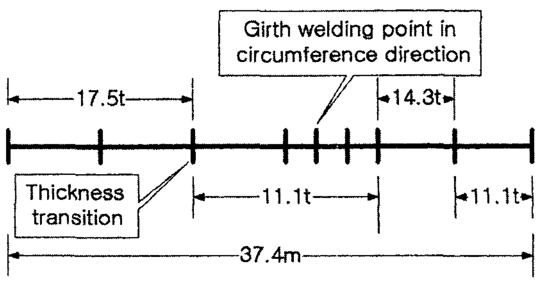

Fig. 9 Anomalies of pull-rig facility

length and is operated by an electronic winch. The winch was designed to pull the PIG at a velocity of 1 m/s and was welded as illustrated in Fig. 9 for certifying the performance of the PIG. Completed pull-rig facility is shown in Fig. 10.

Fig. 11 shows an experimental result in pull-rig facility. All thickness transition and girth weld in circumference direction is detected excellently.

4.2 Time-based marker

An electromagnetic transmitter mounted on the back end of the PIG in order to keep tracking the tool and compensate the inertial error while it travels through the pipeline. The transmitter continuously generates the electromagnetic wave, which is detected by marker instruments, CD47B. Fig. 12 shows recorded GPS time when the PIG passes directly below CD47B at any control point.

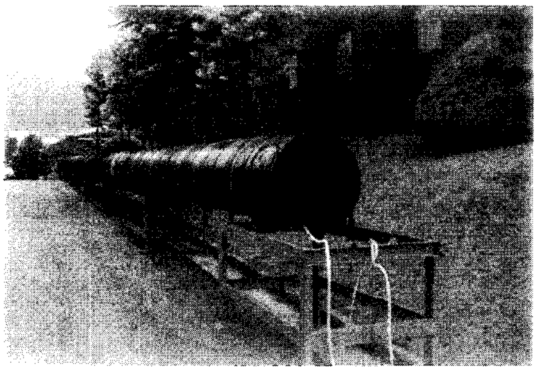

Fig. 10 Pull-rig facility

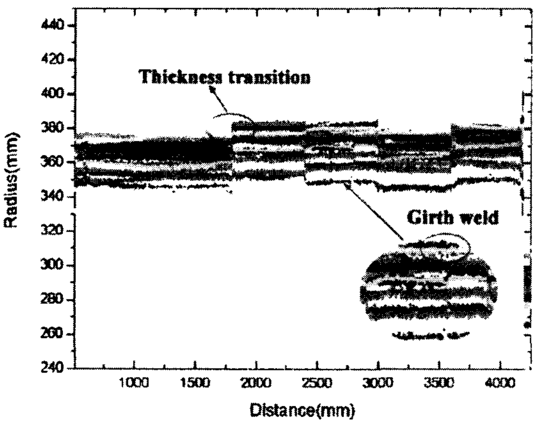

Fig. 11 Experimental result in pull-rig facility

4.3 Actual pigging

Actual pigging was carried out one pipeline segment in the KOGAS high pressure system from Incheon LT (LNG Terminal) to Namdong GS (Governor Station) line. The main characteristics of the pipeline are summarized below.

Nominal diameter	30"
Year of construction	1997
Length	13 km
Type of pipes	Longitudinally Welded
Maximum allowable operating pressure	70 bar.

Operating condition which was controlled by Central control station of KOGAS was the following.

Flow rate	Q=520 ton/hr,
Inlet pressure	p=58 bar
Flow velocity	u=3.5 m/s
Flow temperature	T=0-5℃

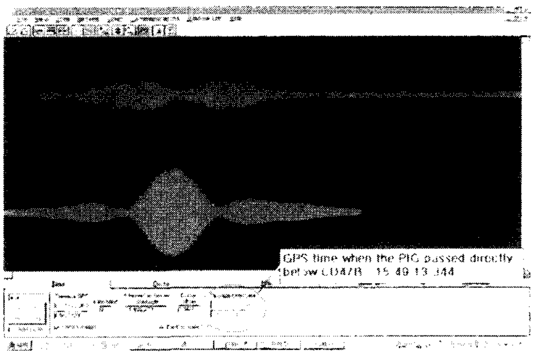

Fig. 12 PIG detection using CD47B

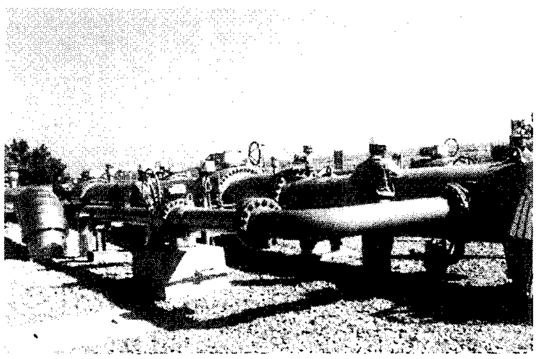

Fig. 13 Launcher in Incheon LT

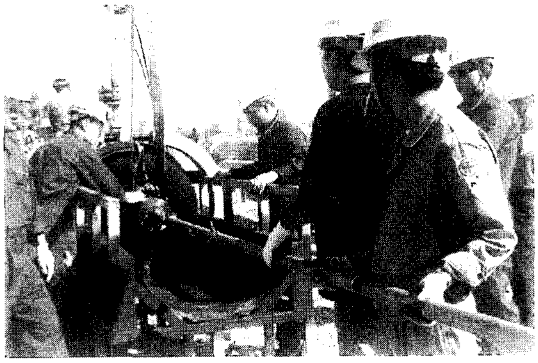

Fig. 14 Injecting the PIG into the pipeline

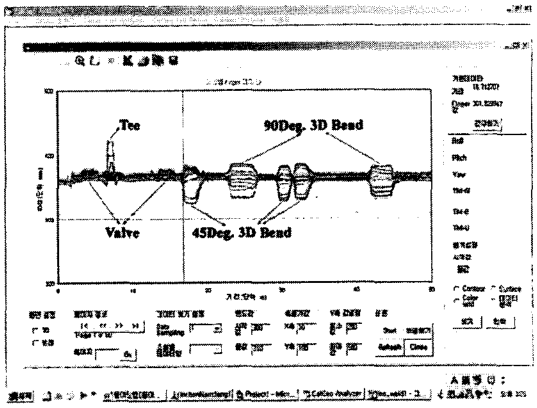

Fig. 15 Results of caliper survey

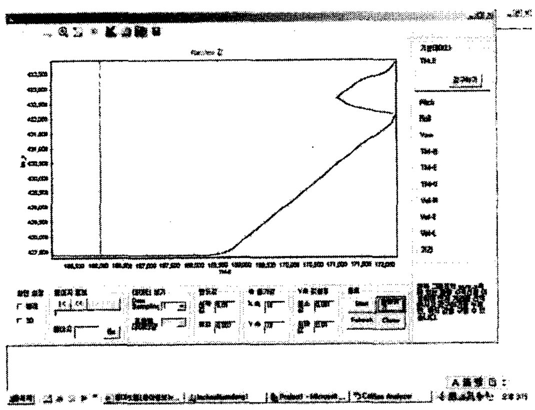

Fig. 16 Plan view from IMU survey

The site where the PIG was launched is shown in Fig. 13. The PIG was injected into the pipeline by a truck as *Fig. 14* shows.

Fig. 15~Fig. 17 show results of the caliper survey and IMU of actual pigging. In first pipeline section of a length of 50 m, thickness transition in valves and tee, and several bends is detected sufficiently as Fig. 15 shows. The signal of caliper sensors describes that the pipeline diameter expends a little in the valve section and the PIG runs leaning to one side by inertia. Fig. 16 shows the Northing (latitude) and Easting (longitude) of the pipeline viewed from on the surface of the earth. Fig. 17 shows to be able to certain that accelerometer signal of IMU is changed in girth weld that there is usually every 6 m. Grith weld points were detected surely at the front and rear driving cup of the PIG. But the magnitude of some signals in girth weld is smaller than others. The reason is why the large signals are welded by hand in the field and the small signals are welded by the machine when the pipeline was fabricated.

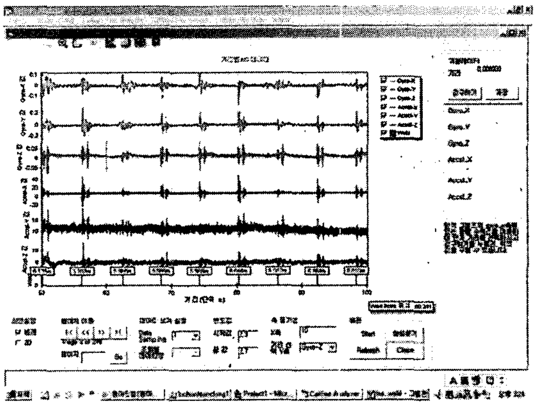

Fig. 17 Results of IMU survey

5. Conclusion

Geometry PIG for geometry survey of the pipeline was developed in this research. The tool provides a full picture of the pipeline from only single pass, and has compact size of the electronic device with not only low power consumption but also rapid response of sensors such as calipers, IMU and odometers. This system gives operators information for monitoring their pipelines and assessing geometric anomalies such as dents, buckles and wrinkles that may threaten pipeline integrity. These characteristics are able to expect to reduce maintenance costs and to verify the integrity of the pipeline. To achieve the verification of the performance for the developed PIG actual pigging was fulfilled adventurously although there is always a finite risk that a foreign body introduced into the pipeline may become lodged, block the flow. The operation of the PIG is not easy, specially it is the first try in Republic of Korea. In spite of these difficulties, actual pigging was carried out successfully by incorporating with operational technology of the PIG. From experimental results, it is obvious that the developed PIG operates in stable with good performance. It is also expected that the tool can be used to adapt other pipeline with a commercial goal.

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