1. Introduction

High-pressure gas pipeline coating can be damaged by various causes. A damage monitoring system automatically detects and locates such damage and immediately calls a control center. For pipelines consisting of steel pipe coated with polyethylene or similar high-insulation material and cathodically protected using a single external power supply unit, coating damage caused by interference from machinery operated for earthworks of other companies can be detected by changes in the cathodic protection current.

Osaka Gas has been using this system in some of its gas pipelines as one measure for monitoring interference caused by earthworks of other companies. However, in areas crowded with stray currents, such as current leaking from railway tracks and cathodic protection current for other underground structures, the system has great difficulty detecting coating damage due to electric noise disturbance.

To cope with this problem, we studied the possibility of using an alternate current as a signal current exclusively for damage detection, and have successfully developed a new damage monitoring system that features high noise immunity and greatly improved detection accuracy.

The work of introducing this new system to the Kinki Western Trunk Line II (4 sections, total length of 158 km) and the Kinki Western Trunk Line III (total length of 73 km) commenced in 1998 and was completed in May 2002. (See Fig. 1.)
2. Detection Principle & System Configuration

Since 1972, Osaka Gas has been using polyethylene-coated steel piping in the construction of high-pressure gas pipelines. The polyethylene coating of the pipelines, such as for the Western Trunk Line II, provides high insulation resistance ($10^6 \Omega \cdot m^2$ or higher) as measured underground, thanks also to its improved construction technology. In the cathodically protected polyethylene-coated pipeline, damage to the coating caused by metal contact of construction machinery operated for earthworks of other companies results in decreased equivalent resistance in the pipeline as observed from the external power supply unit. With the damaged point as a boundary, the current flowing in the pipeline section closer to the external power supply unit increases, while that in the section opposite the unit decreases. The damage monitoring system operates on this principle to detect and locate damage. Fig. 2 above shows the system configuration.

**System arrangement on pipeline**

Master-station equipment is installed at a station provided with an external power supply unit, and substation equipment at other stations (excluding the station at the pipeline end).

**Master-station equipment**

The station having an external power supply unit for cathodic protection, which serves as a master station, is provided with the following equipment:

1. AC voltage surveillance unit: constantly monitors AC voltage between the pipeline and ground, and detects damage if the voltage exceeds a specified value;
2. Coil sensors: one each installed above the ground on the upstream and downstream sides of the pipeline to constantly monitor AC current flowing through the pipe body. If damage is detected, its location (whether upstream or downstream of the master station) can be determined based on coil-sensor signals. Fig. 3 shows the waveform of the AC current (flowing through the pipe body) at the damage point. Fig. 4 explains the damage locating method.

![Fig. 3 Waveform of the AC current](image)

![Fig. 4 Explaination of damage locating method](image)
(3) Personal computer (PC) for communication with substations: Communicates with each substation to collect AC current data at the moment of damage detection and locates the damage (i.e., between which stations the pipeline is damaged).
(4) Reporting PC: Produces and sends damage detection signal to the supervisory control and data acquisition (SCADA) system, and transmits damage location data via PC communication to the supervisory PC installed at the supervisory station.

Substation equipment

One coil sensor is installed on the pipeline above the ground to continuously monitor AC current flowing through the pipe body. In response to requests via PC communication from the master station, the substation coil sensor sends AC current data to the master station at the moment damage is detected.

Frequency of AC voltage

AC voltage is applied between the pipeline and ground as superposed over cathodic protection voltage (DC) applied from the external power supply unit. To prevent AC corrosion, the AC voltage crest is set at 2 V or lower. The AC voltage frequency is set at 15 Hz. This frequency has been selected to meet the requirements of low electrical noise and high damage response. The AC voltage frequency may be set at 8 Hz, depending on the electrical properties of the pipeline on which the damage monitoring system is installed.

The photographs below (Photos 1 through 4) show, from left to right, the master-station equipment, substation equipment, coil sensor, and reporting PC's screen that reports damage.

3. System Verification

3.1 System verification by experiment using a boring machine

The detection performance of the system was verified experimentally using a boring machine, as follows. Of all heavy-duty construction machinery, damage caused by a boring machine is the most difficult to detect. In addition, since earth boring is often conducted without prior notice, gas pipeline damage is most likely to occur during earthworks using boring machines.

The verification experiment was conducted in the 86 km section between Himeji and Sanda along the Western Trunk Line II on which the system was installed for the first time. The photographs below (Photos 5 through 7) show, from left to right, the scene of operating a boring machine to cause damage for the experiment, the scene of burying test specimens underground, and the test specimens damaged in the experiment.

Experimental method

(1) In preparation, test specimens were created by cutting pieces of steel from the same material as the pipeline, which were then buried underground on the station premises, using the same method as for pipeline installation. The buried specimens were electrically connected with the pipeline.
(2) A ground-surveying boring machine was operated on the ground to damage the specimens.
(3) The experiment was carried out at two stations, with ten specimens buried at each station.
Experimental results
(1) The system was capable of detecting and locating damage when the boring machine contacted a specimen for two continuous seconds or longer.
(2) When the boring machine contacted a specimen, the equivalent resistance in the pipeline, observed from the detection AC voltage application unit, was $100 \, \Omega$.

3.2 System verification using a dummy resistor

The abovementioned experiment revealed that the pipeline provides resistance equivalent to $100 \, \Omega$ when it contacts a boring machine. Based on this experimental result, we set the condition for verification testing before commencement of system operation as follows.

Conditions for verification before commencing system operation
A dummy resistor is connected for 30 s to each pipeline section between stations, and then disconnected. This cycle is repeated 200 times. A dummy resistor of 200 $\Omega$ is used for this purpose, allowing a safety margin.

Detection performance measured at each section
The detection performance of the system measured at each pipeline section under the abovementioned conditions is given in Table 1 below. Later, the 86 km section between Himeji and Sanda along Western Trunk Line II was electrically divided at the approximate center into two subsections electrically isolated from each other. As a result, the damage detection rate and damage location success rate now exceed 95% for all sections.

<table>
<thead>
<tr>
<th>Section Outline</th>
<th>Line</th>
<th>Western Trunk Line II</th>
<th>Western Trunk Line III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start</td>
<td>Himeji Works</td>
<td>Sanda GS</td>
<td>Nishibetuin VS</td>
</tr>
<tr>
<td>End</td>
<td>Sanda GS</td>
<td>Nishibetuin VS</td>
<td>Fushimi GS</td>
</tr>
<tr>
<td>Distance</td>
<td>86.4 km</td>
<td>41.7 km</td>
<td>30.4 km</td>
</tr>
<tr>
<td>Detection rate</td>
<td>94%</td>
<td>100%</td>
<td>98%</td>
</tr>
<tr>
<td>Section-judging success rate</td>
<td>83%</td>
<td>99%</td>
<td>96%</td>
</tr>
</tbody>
</table>

Note) GS: governor station; VS: valve station

Table 1 Detection performance of the system

4. Conclusion

This new damage monitoring system has been introduced on all pipelines along Western Trunk Lines II and III, with system adjustment and verification completed in May 2002. In the future, we will seek to promote widespread use of the system, thereby enhancing the safety of gas pipelines.