A study of characteristic signal propagation buried pipeline 1

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Keywords: distributed-parameter line , pipeline.

Abstract.

The propagation constant measurement system was developed for long distance pipelines based on a distributed constant theory for the purpose of maintenance and management of long distance pipelines buried underground, and it was applied for the first time to a 14-killometer pipeline buried underground. This system is based upon the application of the distributed constant theory, and includes facilities to apply an ac signal from the central part of the pipeline, and measure the actual values and phases of voltage and electric current of the ac signal running through the pipeline, at either both ends or between them. In order to accurately measure the phase difference between the two separate points, a reference signal fabricated at 1 PPS (1 pulse per sec) in a GPS (Global Positioning System) was used. With this system, direct measurement of the propagation constant and characteristic impedance of a pipeline buried underground was realized for the first time.

1. Introduction

Pipelines buried under underground are used for distribution of city gas, water and electricity, and for the protection of communication wires etc., so that they are important facilities to maintain city functions as social infrastructure such as energy provisions that are indispensable for living. If these functions are stopped because of an accident, it would cause considerable influence on many users who had been receiving the benefits of them, and the losses that would occur before restoration of the system would be tremendous. Therefore, maintenance and management of pipelines are very important, so many technologies for the maintenance and management and those of investigation and diagnosis have been developed and deployed. [1,2,3,4]. In order to explore the possibility of safety monitoring of high pressure gas pipelines buried in urban areas, author et al. aimed at structuring a system to instantly detect abnormalities in pipelines by steadily monitoring an electric signal at each point by applying an electronic signal to the pipeline, as the purpose of research. It was clarified by the signal propagation characteristics of a pipeline of several ten km being examined, that its electrical behavior showed a distributed-parameter line-like feature. [5]. (Therefore, the theory of a distributed-parameter line being applied to a long distance pipeline, a system designed to directly measure the distributed circuit constant (characteristic impedance and propagation constant) characteristic to each pipeline, was structured, and the distributed circuit constant was practically measured experimentally for the first time.

2. Pipeline

Generally in Japan, city gas distribution pipelines are made of polyethylene-coated tubes and these tubes are connected by welding. After their welded parts are covered, they are buried underground. For the purpose of corrosion prevention of these pipelines, in addition to the isolation of steel material from soil by a polyethylene cover, generally a cathodic protection method is also applied to protect the pipelines from corrosion even if the polyethylene cover is damaged and the pipes directly contact with soil. As for the cathodic protection method for the pipelines buried under the ground, there is a galvanic anode method and an impressed current method. As for the galvanic anode method, a metal with noble potential, such as magnesium, is connected to the pipeline as anode at certain intervals sectioned with insulation flange. As for the impressed current method, an electric source generating a direct current is fixed to the pipeline to forcibly pour the protection current. Recently, the impressed current method is increasingly being applied to newly installed pipelines because of the easiness of its corrosion prevention management.

Table 1 shows an outline of the pipeline that author et al. used for the experiment.

Pipe grade	STPG 410 Sch30
Outside diameter	318.5 mm
Nominal wall thickness	8.4 mm
Design internal gas pressure	1.77 Mpa
Coatings	Extruded polyethylene
Cathodic protection	Impressed current method
Section length	14.2 km

3. Application of the Distributed Constant Theory

Generally used in the field of power transmission, the propagation mode of a single-phase power transmission line is shown in formula (1). It has been clarified that in the case of a long-distance pipeline, its ac propagation mode has the characteristic as a distributed constant.

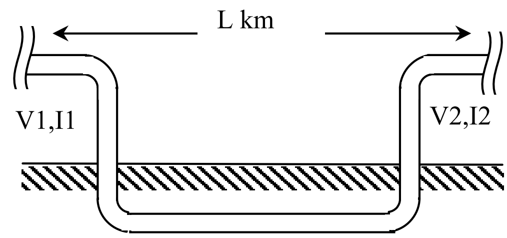


Fig. 1 Model of buried pipeline

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} \cosh \gamma L & Zo \sinh \gamma L \\ \frac{1}{Zo} \sinh \gamma L & \cosh \gamma L \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \tag{1}$$

Vl, Il: Pipe-earth potential at sending terminal, electric current in pipeline
V2,I2: Pipe-earth potential at receiving terminal, electric current in pipeline
γ: Propagation constant
Zo: Characteristic impedance
L: Distance between sending and receiving terminals

For the purpose of simulating the signal propagation of the pipeline, the propagation constant,γ, and the characteristic impedance, Zo, defined as the distributed-parameter lines, should be known. From formula (1),γ between two points of an L km distance from each other can be obtained, and from formulas (2) and (3), Zo can be obtained.

$$\gamma = \frac{1}{L} \cos^{-1} h \frac{V_1 \cdot I_1 + V_2 I_2}{I_1 V_2 + I_2 V_1} \tag{2}$$

$$Zo = \sqrt{\frac{V_1^2 + V_2^2}{I_1^2 + I_2^2}} \quad (3)$$

In other words, the propagation constant,γ, and the characteristic impedance, Zo, can be calculated if the electric currents and voltages at both extreme ends of the target pipeline are obtained. The problem here is that electric current, I, and voltage, V, measured at the extreme ends, includes phase information and are expressed as complex numbers. For the purpose of measuring the phase, it is only necessary to measure how far the phases of the measured voltage or electric current were shifted from the standard signal with a lock-in amplifier etc..

However, there had been no measures to obtain identical reference signals at two points very distant from each other. For the purpose of solving this problem of analyzing signal propagation characteristics of the pipeline, author et al. established a reference system of remote and complete synchronization using GPS signals that can be accessed from anywhere on the earth

4. Measuring System

There was an isolated section of 26 km targeted for cathodic protection in the pipeline used for the experiment. An electric source used to apply monitoring signals was placed in a station roughly in the center of the pipeline, and the measurements were performed targeting the range of 14.2 km of downstream from the electric source. Fig. 2 shows the total outline of the system. Four stations were installed in the experiment section, and each station was equipped with a governor to reduce gas pressure and bifurcate. These parts of pipeline were exposed above the earth's surface so that the measurement systems were fixed in these four exposed parts of pipeline.

The details of measurement systems placed at each station are shown in Fig. 3, and a photo is shown in Photo 1. Every station can receive a highly synchronized 1PPS (1 pulse per sec) signal from the GPS receiving terminal and a 10MHz signal synchronized with the satellite signals. The accuracy of the frequency of these standard signals was 10^{-10}/min. between stations, and it achieved enough accuracy for the phase measurement of the electric signal of several hundred Hz. A function synthesizer

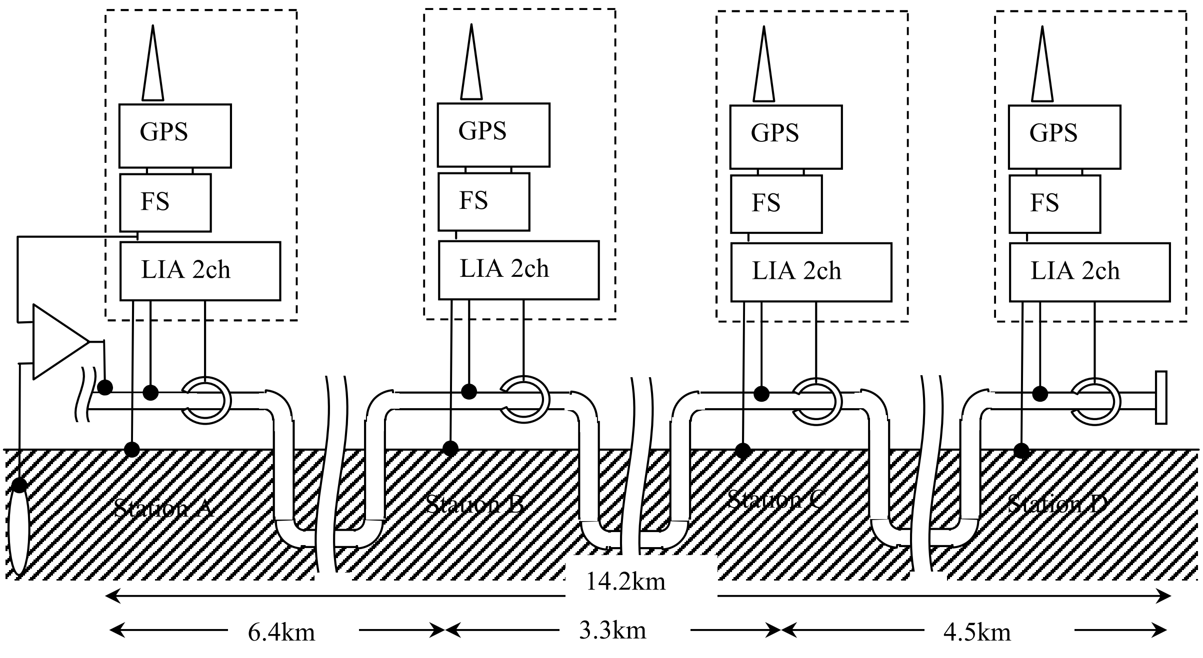


Fig. 2 Measuring system (whole image)

self-made the function to divide the 10MHz signal into the frequency of a monitoring signal using the rising of this 1PPS signal as a trigger. The current value of the electric signal running through the pipe was measured by measuring the signal frequency component of the output of the current transformer (hereinafter referred to as CT) developed for pipelines, which is shown in Photo 2 using a lock-in amplifier. The phase of the electric current was defined by measuring the phase difference with the reference signal issued from a function synthesizer.
As for electric potential, the actual value and phase were measured by directly imputing the voltage signals from the pipeline for earth connection into a lock-in amplifier, as in the case of electric current. In the signal applying station, the protection current was superimposed with a reference signal from function synthesizer through the power amplifier and the monitoring signal was applied. These measurement results were automatically recorded through the GP-IP using a PC for communication by the timing of the 1PPS signal, and they were gathered in one place over telephone lines.
The information of voltage, phase of electric current and actual value collected from each station were substituted into formulas (2) and (3), and the propagation multiplier factor,γ, and characteristic impedance, Zo, were culculated.

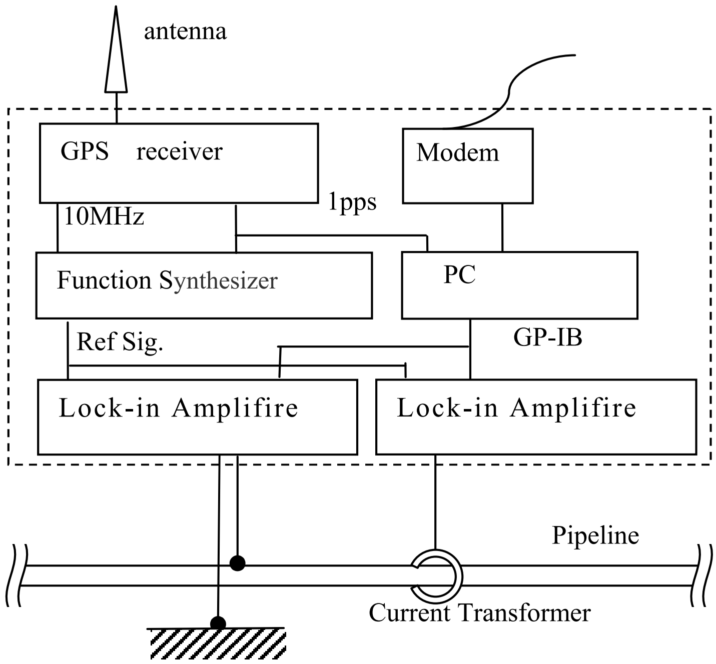
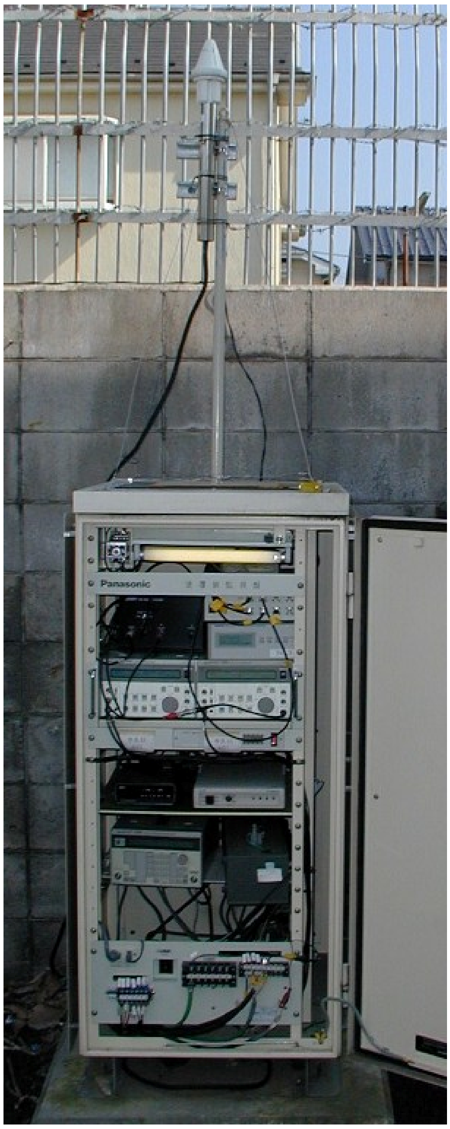


Fig. 3 Installation structure of station



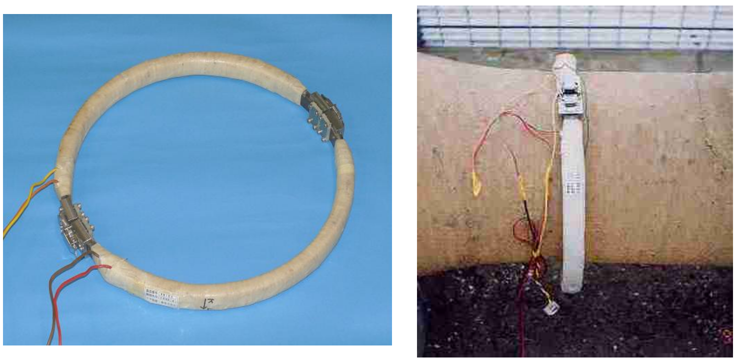


Photo2 Current transformer

Photo1 Station System

5. Measurement Experimentation and Results

Measurement of Signal Propagation Characteristics.
The measurement was performed with the above measurement system under the following conditions.

5.1 **Experiment conditions**

For the purpose of improving the S/N of the measurement system, commercial frequency for electricity (50Hz) and its higher harmonic frequencies were avoided for monitoring signal frequencies, and the sign curves of the six frequencies of 15 Hz, 70 Hz, 170 Hz, 220 Hz, 420 Hz and 820 Hz were applied to the circuit pipes. The power outlet which voltage does not disturb cathodic protection was presumed to be 0.8Vp-p. The measurement of the signal propagating condition was performed at each station after all protective earth connections were removed from the pipeline and the pipeline was isolated from the earth.
Figs. 4 and 5 shows signal propagating modes due to the difference of each frequency.
The impedance of the pipeline seen from electric source is different by frequency, and the output current also changed accordingly. Therefore, for the purpose of comparing signal propagating modes simply caused by the difference of frequency, electric currents and voltages where a power outlet is presumed as 1, plotted the relative signal intensity of each station.
This verified that the signal intensity varies by the differences in frequency and distance, and clarified the characteristics as a distributed constant of the pipeline targeted for measurement.

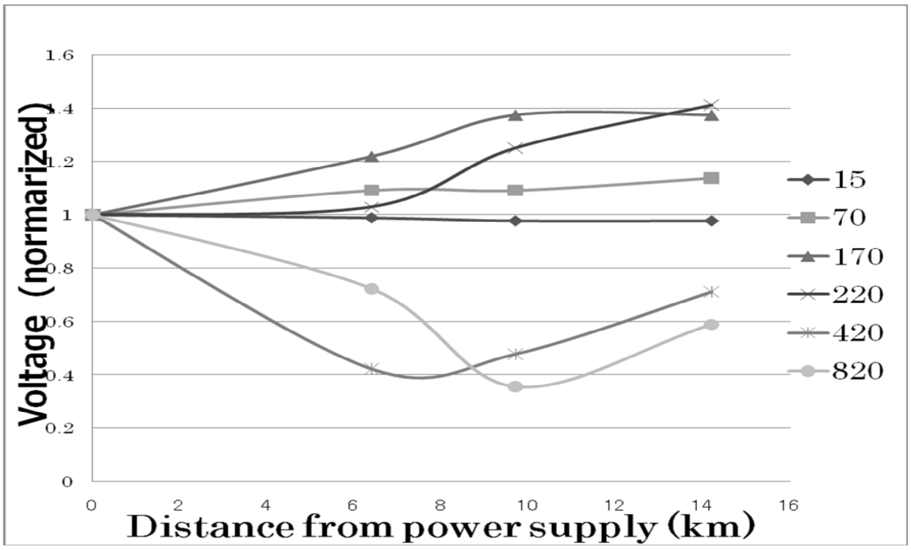


Fig. 4 Voltage propagation characteristics

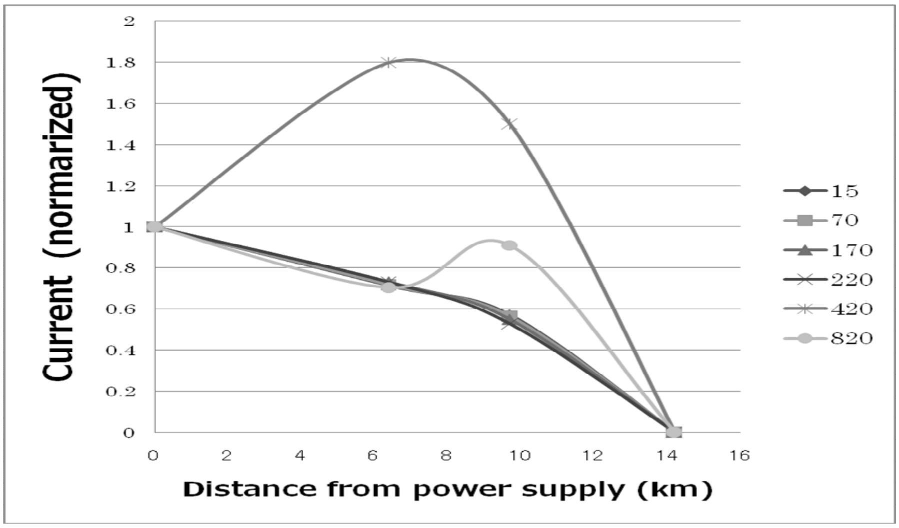


Fig. 5 Electric current propagation characteristics

5.2 Measurement of the Distributed Constant

Table 2 shows the propagation constants and characteristic impedances between each station when frequencies were 220 Hz and 15 Hz, calculated from formulas (2) and (3) as representative examples. Although there are variations in the figures among each station, they remained in a specific limited range. It is considered that these variances were caused by the differences in the buried conditions of the pipeline such as a crossing river.

Table 2 The propagation constants and characteristic impedances

	220Hz		15Hz	
	γ (Np/km)	Z(Ω/km)	γ (Np/km)	Z(Ω/km)
A-B	0.1309-0.1369i	12.8077+6.5668i	0.0941-0.0444i	3.5359-5.7680i
B-C	0.1206-0.1985i	8.1640+6.9114i	0.0220-0.0687i	6.0142-9.3642i
C-D	0.0531-0.1280i	9.6162+2.4268i	0.0390-0.0033i	2.9904-6.1539i

6. Conclusion

For the purpose of monitoring the coating condition of pipelines buried underground, a distributed constant measurement system with the application of the distributed constant theory was structured. As it is possible to obtain highly synchronized reference signals at several distance points by using the output from a GPS receiver, the measurement of the phase difference between the points was able to be performed successfully. It is scheduled to perform a simulation of this propagation using the measured distributed constants and develop a system to detect the occurrence of abnormal coating conditions in the future.

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