A study of characteristic signal propagation buried pipeline 2

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Abstract.

It was reported in the previous report that the propagation constant measuring system for long distance pipelines was produced based upon the distribution constant theory for the purpose of maintenance and management of long distance pipelines buried underground and to have a system to directly measure the propagation constants and characteristic impedance of the pipeline buried underground. This time, a simulator for the signal propagation of a pipeline, referring to these actual measurement values, was constructed and various signal modes were simulated. On the prediction of accidents where heavy-construction equipment, such as backhoe or boring machine, has contact with a pipeline and damages the coating of pipeline, the damage simulations with a backhoe and boring machine were performed and the fault resistances of these heavy-construction pieces of equipment at the time of accidents were identified. As a result, it was revealed that the fault resistance generated by the metal-to-metal contact caused by the boring machine, which damages pipeline the most, was approximately 20-50Ω when water was used, and that caused by the backhoe was approximately 100Ω. In order to verify the detectable property of this system, a simulation was performed to determine how each distributed constant changed when this degree of grounding faults occurred in the monitoring section of the pipeline, and validated it with an actual pipeline.

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. 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] 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-constant line-like feature. [5] A system designed to directly measure the distributed-constant line constant was practically measured experimentally for the first time. A simulator was constructed based upon the distributed-constant circuit constant using measurement results from previous study, and each propagation mode and the distributed constant variations at the time of a grounding fault equivalent to the contact with a heavy-construction equipment occurred were simulated and the results were compared with actual data.

2. Fault Phenomena in Distributed-constant line

In previous research it was reported that the targeted pipeline showed a distributed constant behavior. If the burying condition of the pipeline with uniform quality materials and uniform ground is averaged, the distributed-constant line follows the following formula (1).

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

V1, I1 : Pipe by soil potential at sending terminal, electric current in pipeline
V2, I2 : Pipe by soil potential at receiving terminal, electric current in pipeline
γ : Propagation constant
Zo : Characteristic impedance
L : Distance between sending and receiving terminals

If electric current and electric voltage can be measured at both ends of the pipeline, the propagation constant and characteristic impedance can be calculated from formulas (2) and (3), as a result of formula (1) being developed

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

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

Here, if the isolation between the pipeline and soil is broken at the point X km distant from the signal applying point and the earth fault and earth connection occur at that part, this condition becomes equivalent to the model shown in Fig.1, and the grounding fault matrix can be substituted to the formula (1) from the viewpoint of an electrical circuit and explained in Formula (4).

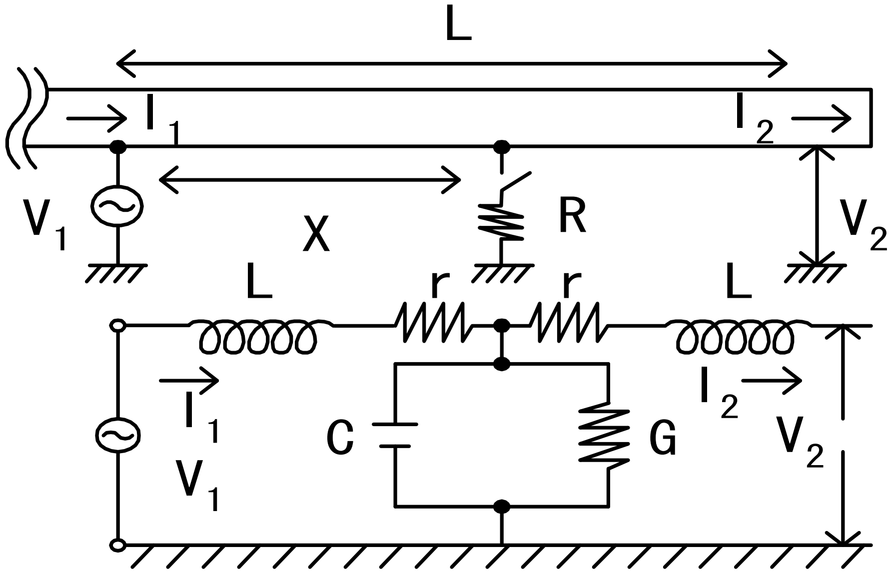


Fig.1 equivalent model buried pipeline

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} \cosh\gamma X & Zo\sinh\gamma X \\ \frac{1}{Zo}\sinh\gamma X & \cosh\gamma X \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \frac{1}{R} & 1 \end{bmatrix} \begin{bmatrix} \cosh\gamma(L-X) & Zo\sinh\gamma(L-X) \\ \frac{1}{Zo}\sinh\gamma(L-X) & \cosh\gamma(L-X) \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad \mathbf{(4)}$$

In this case, if the whole pipeline is seen as a distributed-constant line, the monitoring signal runs through the damaged part as well because of the signal propagation mode. Therefore, the constants characterizing the signal propagation obtained from the formula (2) and (3) are uniquely changed by the values of R and X.

Because the constant can be defined as the damage to coating and can occur anywhere in the isolated section, the unknowns are X and R, that is the fault resistance.

Because the measurable data are the pipe by soil potential at the sending terminal and the electric current in the pipe, and the pipe by soil potentials at the receiving terminal and the electric current in pipe, it is possible to obtain distance X and fault resistance R by developing the formulas (4) and analyzing them as a simultaneous equation.

3. **Experiment of Damage caused by Heavy Machine**

When the coating is damaged by a heavy machine, because the sharp edge of the machine touches the steel of the pipeline, the circuit is opened between the pipeline and the heavy machine and the fault resistance of the damaged part of the pipeline becomes equivalent to the earth resistance of the heavy machine. The earth resistance of the heavy machine and the fault resistance of the pipeline were measured when damaged, and the experiment was conducted to determine to what extent the monitoring system of pipeline should have the ability to detect the fault resistance.

A monitoring signal was applied to the tested pipeline buried underground, and a piece of heavy machinery contacted the pipeline to measure the fault resistance of the pipeline at the point of contact. Examples of the measurement of earth resistance of the heavy machines are as follows, Fig. 2 shows the change of fault resistance by the change of the depth of bit , and Fig. 3 shows the change of earth fault current when a backhoe drilled into the earth.

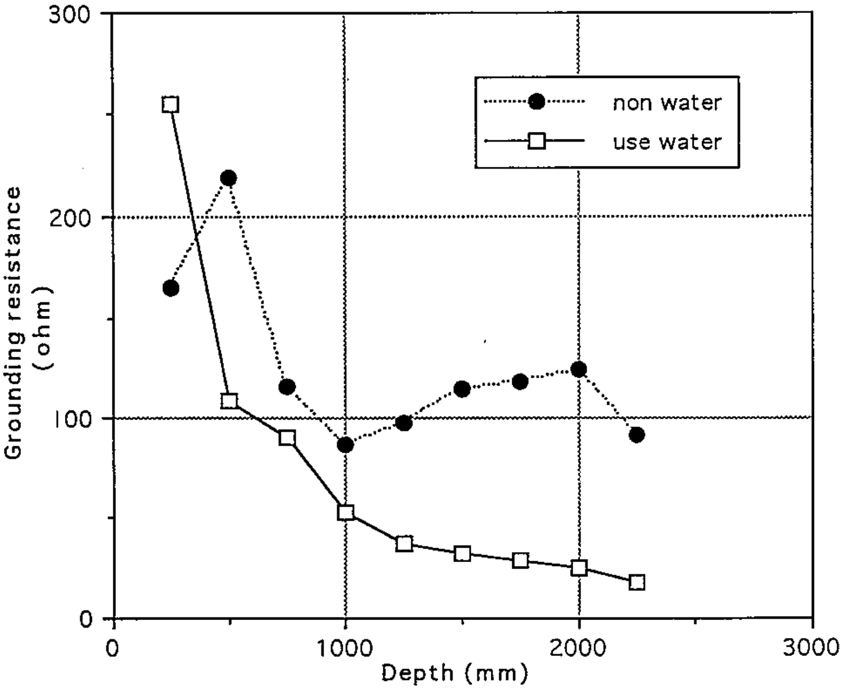


Fig.2 Relationship between drilling depths and fault resistance values

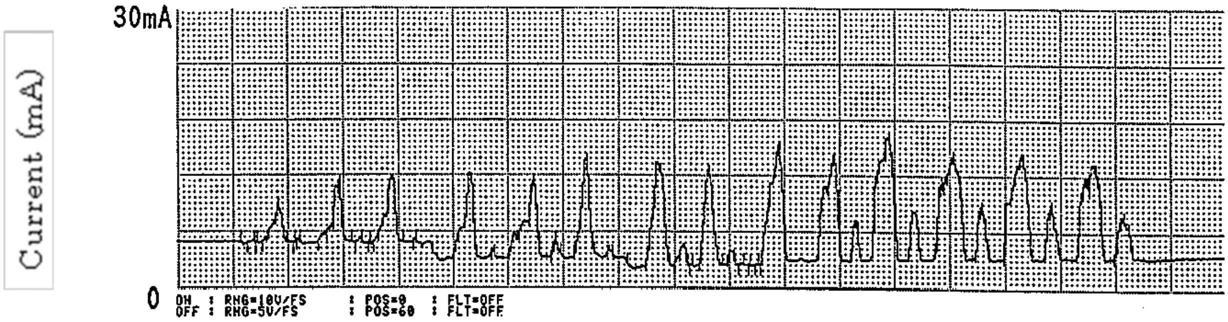


Fig. 3 Earth fault current while a backhoe drilled into the earth ((@220 Hz 0.7V)

Furthermore, in this experiment, damage experiments by backhoe and boring machine were conducted as shown in Photos 1-5. Summary of experimental results are shown in Table 1, omitting details.

Table 1 Heavy machines used in the experiment and fault resistance (Frequency of signal: 220 Hz)

Heavy Machines		Contact resistance	Contact time
Backhoe	hit	53～120Ω	～5sec
	scratch	41～165Ω	1～15sec
Boring Machine	non water	58～112Ω	＞3sec
	use water	25～40Ω	＞3sec

From the above results, the target detection of this system was set at less than 150Ωof the fault resistance to know the grounding fault due to accidental contact by heavy machines.

Photo 1　Backhoe

Photo 2　Damage by backhoe

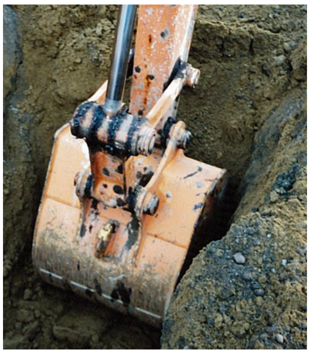


Photo 3　Bucket

Photo 4　Boring machine

Photo 5　Damage by boring machine

4. Construction of Signal Propagation Simulator

A signal propagation simulator was constructed based on the formulas (4) showing signal propagation to simulate the signal propagation modes when a grounding fault caused by a heavy machine at an arbitrary point in the section targeted for monitoring.

4.1 Construction of Simulator

The simulator is structured with a sound part of a propagation matrix with 1 km unit connected with a damage matrix at its borderline, as shown in Fig. 4, and if all of the line is sound, the fault resistance value of the damage matrix is regarded as the insulation resistance value of coating (larger than 10,000Ω). This simulator can simulate various signal propagation characteristics with various distances and of various pipelines by adding and reducing per unit length , adding blanches in parallel .

This simulator is structured to calculate the pipeline impedance including the damage matrix at the beginning, obtain the electric current at the signal applying point of the electric signal generating device, a low-voltage source, and simulate electric voltage and electric current propagation modes sequentially down downstream.

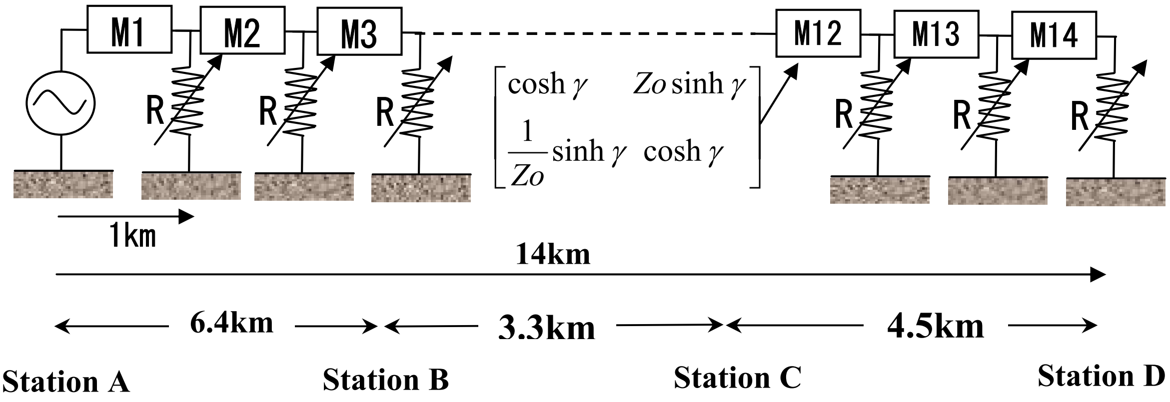


Fig. 4 Simulation model

4.2 Simulation – the setting of targeted pipeline

The targeted pipeline in this report has a distributed constant measuring system structure and it is the same pipeline used in the experimental field. Because the details of the pipeline were described in the previous report, only specifications are shown in Tables 2 and 3.

Table2 Specifications of the test section of the pipeline.

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

Table 3 Distributed values set up for simulation (220 Hz)

Station	γ(Np/km)	Z(Ω/km)
A-B	0.1309-0.1369i	12.8077+6.5668i
B-C	0.1206-0.1985i	8.1640+6.9114i
C-D	0.0531-0.1280i	9.6162+2.4268i

4.3 Simulation

The propagation modes for cases where fault resistances from 10-100Ω were inserted at every 1 km throughout the pipeline were simulated. As examples, the simulation results of signal propagation modes of electric voltage and electric current in cases where fault resistances of 20Ωand 100Ω were inserted at the points 6.8 km distant from the signal applying point and those in cases of sound condition are shown in Figs. 5 and 6.

The simulation results for cases without damage (dotted lines) agree well with the actual measured values, but they are largely deviated from the actual measured values at the damage case of 20Ω.

The simulation results of electric current are qualitatively similar to the actual measured values, but do not numerically conform to them. This is because although the burying conditions were not always the same, the simulation was conducted presuming the distributed constant between stations were almost the same. The presumptions for simulation should be changed and should take into consideration the pipeline's burying conditions.

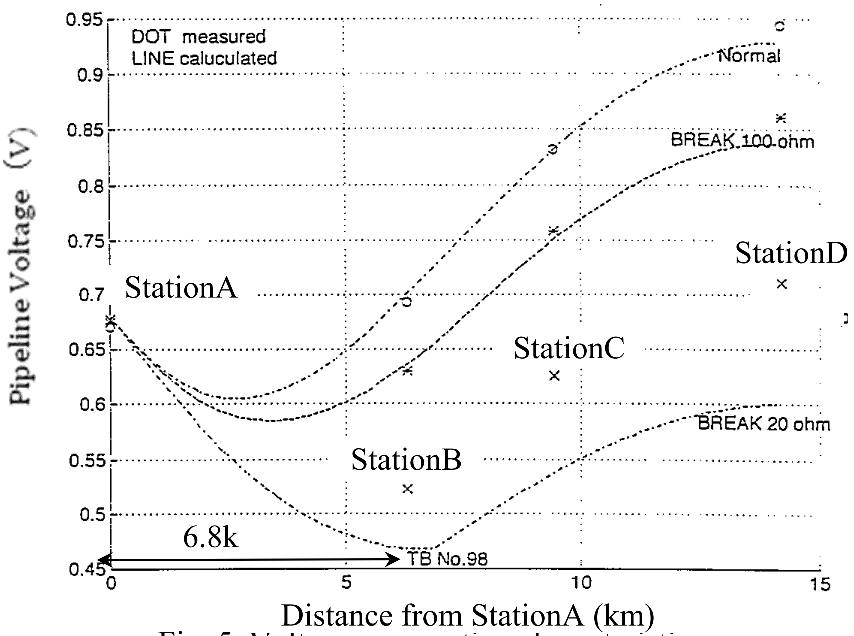


Fig. 5 Voltage propagation characteristics

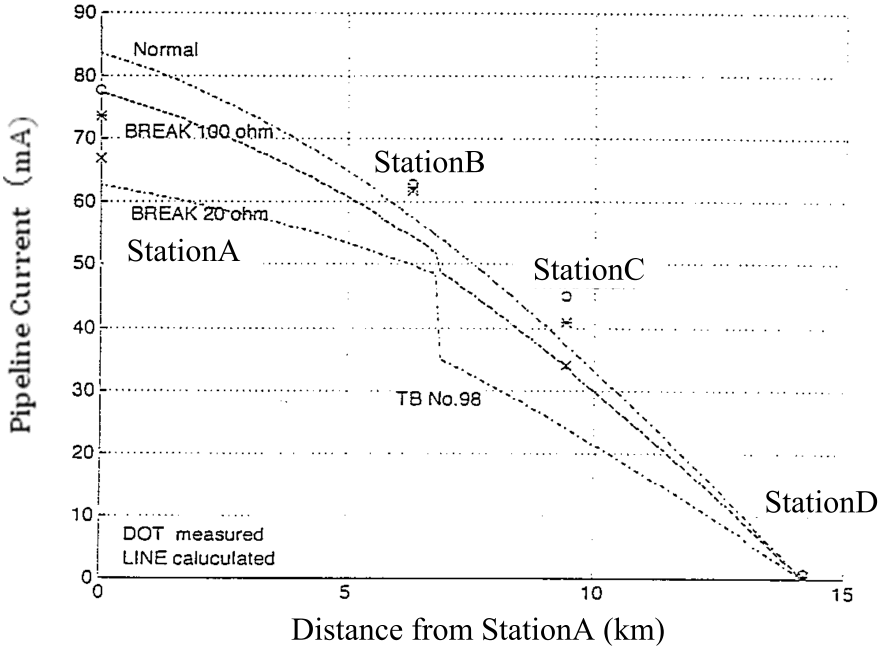
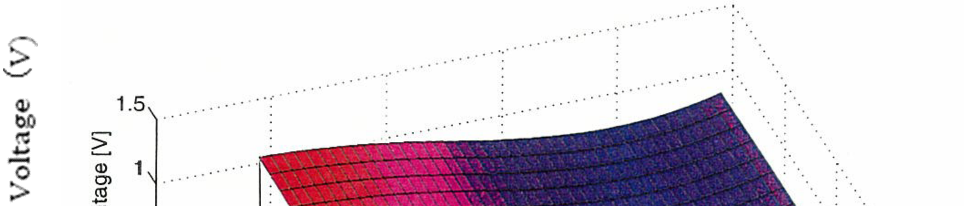


Fig. 6 Current propagation characteristics



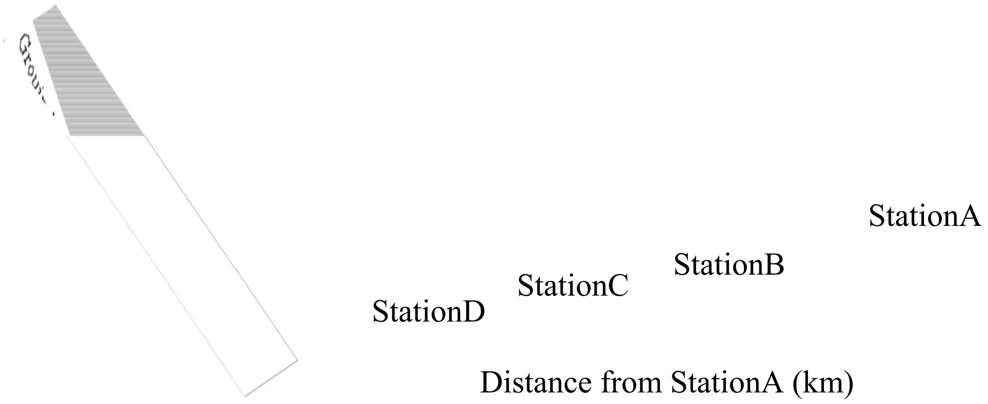


Fig. 7 3D view of the voltage propagation mode

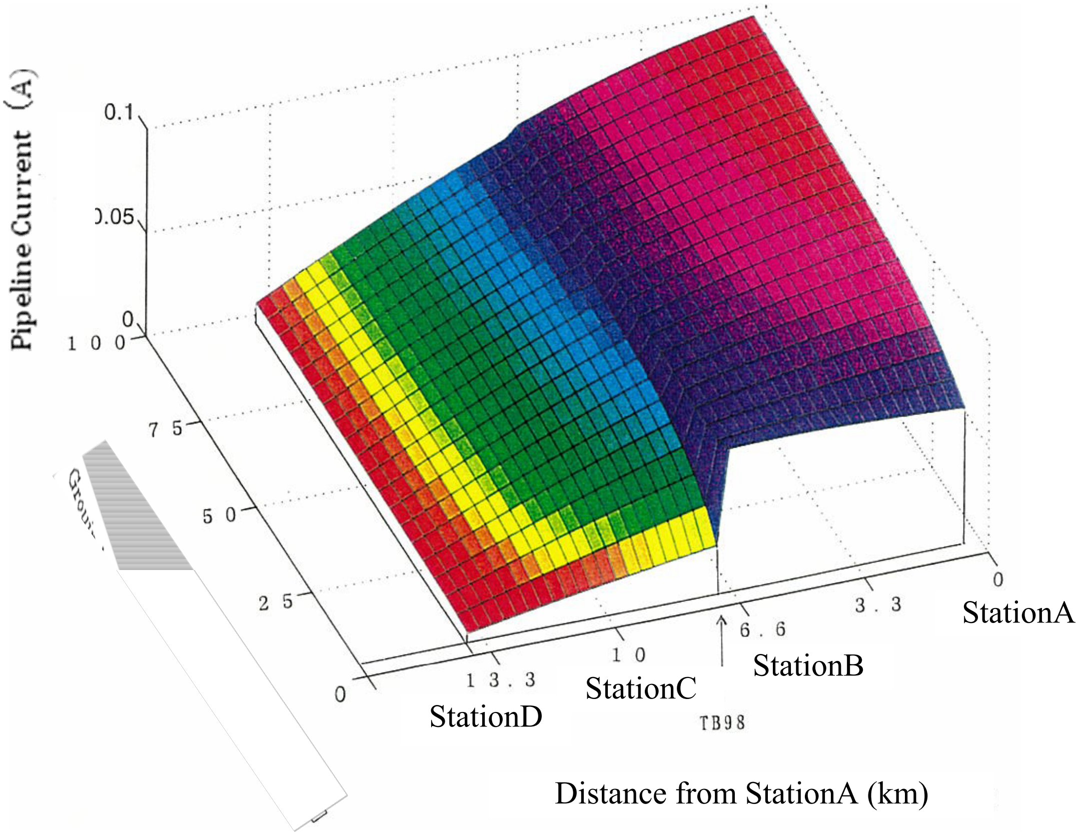


Fig. 8 3D view of the current propagation mode

Figs. 7 and 8 above show the 3D views of the propagation modes of voltage and current when a fault resistance at the same point was continuously changed, which show that the lower Y coordinate the propagation modes of voltage and current come to, the smaller the earth fault becomes, and the voltage and current drastically change in the neighborhood of the damaged part

5. Conclusion

In order to confirm the possibility of a system to constantly monitor the soundness of the distributed-constant line measuring system for pipelines buried underground, a contact experiment was simulated using a real heavy machine and the fault resistance was measured. As a result, it was revealed that the pipeline was slightly damaged by the contact by the heavy machine, but the coating was damaged. Also, the fault resistance caused by damage was around from 20Ω to 150Ω, depending on the soil properties and moisture.

A simulator to simulate the signal propagation was constructed, and actual measured distributed constants and the signal propagation mode when a fault resistance equivalent to the above damage was inserted and they were simulated and compared, and a qualitative similarity was observed between them. As a result, it was confirmed that the monitoring system that has been constructed responds to the damage of around 100Ω, therefore, the possibility of using this monitoring system was found to be high

A function to obtain the point where a grounding fault occurs is a required ability of this system. It was found that this function is available in the system that has been constructed.

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