Estimation results on the location error when using cable locator

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Abstract: A cable locator discovers the location as well as depth of underground pipes, cables and wires. Telecommunications services have been interrupted by cutting off underground telecommunications cables installed inside ducts during road construction. In order to prevent such an accident, it is necessary to identify the location of the cables. The system detecting a burial location of the cables is introduced by measuring the maximum magnetic field distribution on the earth surface generated by signaling current flowing through the cables installed inside the ducts. However, an error occurred in the burial location of the cables, when several ducts (it is called three kinds, a vinyl pipe, a cast iron pipe, and a steel pipe) are installed. Therefore, the magnetic field distributions depending on the duct arrangements were analyzed in order to estimate the errors using finite element method.

Key-Words: magnetic field, duct, telecommunication cable, burial location, finite element method

1 Introduction

EMC technologies have been introduced in the articles [1]-[8]. One of EMC problems is location errors when using cable locator. Telecommunications services have been interrupted by cutting off underground telecommunications cables installed inside ducts during road construction. In order to prevent such an accident, it is necessary to identify the location of the cables.

Cable locators are mainly divided into two categories. One is Ground Penetrating Radar (GPR). GPR is geophysical method that is designed to investigate the shallow subsurface up to 10m depth under the ground [9]-[11]. The frequency used in GPR is in the range of 100~2000 MHz. Reflections occur when the GPR wave encounters materials with contrasting dielectric permittivity. By analyzing the reflection pattern of the GPR wave, we can obtain the location profile of the buried materials. This technology is applicable for soil surveying utilities such as archaeology, agriculture and civil engineering. As this method is affected by the other materials such as water, cave and stones, it is not so suitable to identify the cable locations.

The other is injecting an electrical signal into the cable being located [12]-[13]. These kind of electrical signal locators are designed for detecting power cable, communication cables, water pipe and gas pipe. The frequency used in electrical signal is in the range of 0.5~50 kHz. By analyzing the magnetic field pattern of the electrical signal, we can obtain the location profile of the cable.

The key technology detecting a burial location of the cables is to measure the magnetic field distribution on the earth surface generated by signaling current flowing through the cables installed inside the ducts. However, an error occurred in the burial location of the cables, when several ducts (it is called three kinds, a vinyl pipe, a cast iron pipe, and a steel pipe) are installed.

It means that several ducts installed nearby distort the magnetic field distribution. As a result the location of the cable can be deviated from real position. Until now, there were no investigations on this location errors caused by several ducts. As telecom companies have plant records how several ducts are arranged, the magnetic field distribution depending on the duct arrangement is analyzed in order to estimate the error using finite element method.

The advantage of this method is to be able to compensate the location errors. As we will be able to obtain the exact location of the cables, the damage of the cables caused by road construction can be eliminated. Even there are no disadvantages of this method, experimental field tests have been caried out in order to evaluate the accuracy of this method.

2 Parameter of simulation models

2.1 A cable locator system

A cable locator discovers the location as well as depth of underground pipes, cables, and wires. One of cable locator systems is shown Fig.1.

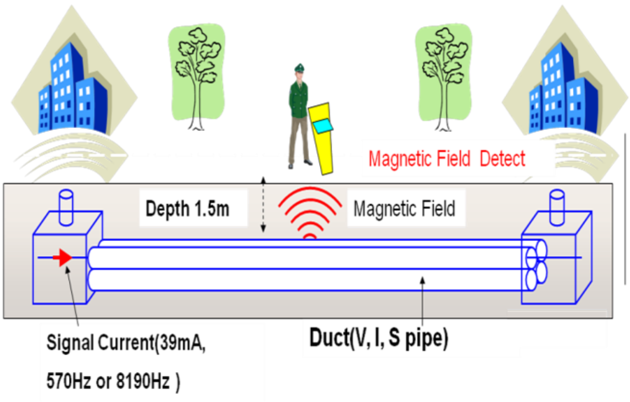

Fig. 1 A cable locator system

2.2 Experimented simulation models

The parameters obtained by this experiment were as follows.

(1) The effective value of the signal current which flows through the cable in ducts is 39mA.

(2) Selection of either 570Hz or 8190Hz is possible for signal frequency.

(3) The burial location of an underground telecommunication cable is about 150cm under earth surface.

2.3 The main examination items

The examination items analyzed by finite element method were as follows.

(1) Magnetic influence in the case of injecting signal current into any one of the duct of V pipe, I pipe, and S pipe.

(2) Magnetic influence in the case of changing the frequency of signal current to 570 Hz and 8190 Hz.

(3) Magnetic influence in the case of having arranged 1-3 I pipes horizontally around a signal current injecting pipe.

(4) Magnetic influence in the case of having arranged four-row and four-line pipes, and injecting signal current only into one duct in it.

(5) Magnetic influence in case the telecommunication cable made of a metal exists in a circumference duct.

(6) Magnetic influence in case a part of signal current carries out a return to other I pipes which are not injecting in current.

3 Problem Solution by using finite element method

3.1 Material characteristics of each duct

The material characteristics of each duct used for the analysis by finite element method are listed in Table 1, and the magnetizing properties of I pipe and S pipe are shown in Figs. 2 and 3.

Table 1 Material characteristics of each duct

Duct	The kind of material	Outer diameter [mm]	Thick-ness [mm]	Specific resistance [Ω・m]	Density [kg/m^3]
V pipe	Nonmagnetic material	96.0	6.5	1.0e+10	1400
I pipe	Ferromagnetic material	96.6	5.0	10.0e-08	7100
S pipe	Ferromagnetic material	89.2	4.2	20.6e-08	7700

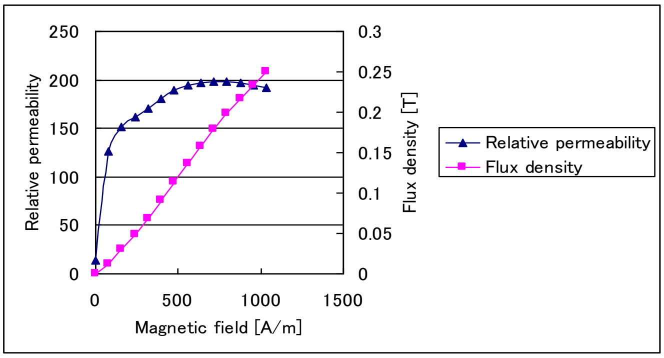

Fig. 2 I pipe magnetizing properties

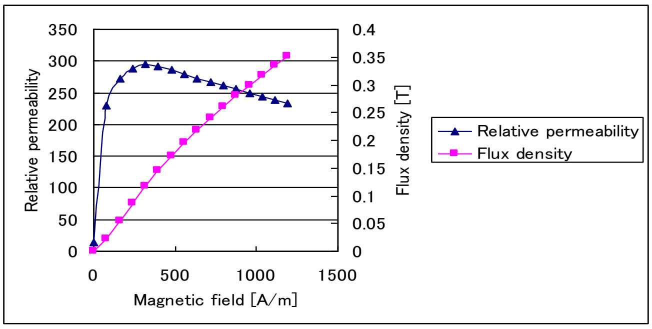

Fig. 3 S pipe magnetizing properties

3.2 Theoritical caluculationt method

A theoretical calculation value of magnetic flux density ***B*** becomes the following formula.

$$|B| = \frac{\mu I}{2\pi\ r} \quad (1)$$

3.3 Verification of the analysis accuracy by theoretical calculation

In order to verify the accuracy of the analysis by finite element method, the theoretical value of the magnetic field intensity generated when signal current is injected into V pipe was calculated, and it compared with the analysis result. Comparison of a theoretical calculation result and the analysis result by finite element method is listed in Table 2.

Table 2 Magnetic field intensity and flux density

The verification method	Magnetic field [A/m]	Flux density [T]
Theoretical calculation value	4.13803e-03	5.20000e-09
Analysis result	4.11000e-03	5.16478e-09

Some errors have been produced, but since it is less than 1% of error compared with a theoretical value, it is thought that finite element method is fully reliable.

3.4 Estimation results on the location errors

In each examination item, the flux density at the point of measurement and the ratio which receives the signal when comparing with other results, a gap of the level position of the magnetic field intensity produced when surveying, the relative error of the magnetic field maximum and measured value, seven items were examined.

3.4.1 Magnetic influences by duct classifications

As shown in Fig. 4, the magnetic influences in 150cm of duct top position at the time of injecting 39 mA of signal current into any one of V pipe, I pipe and the S pipe were examined.

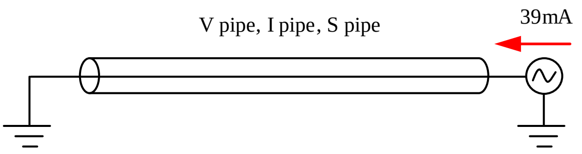

Fig. 4 The model of one duct

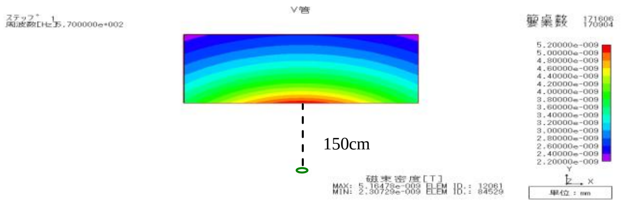

Fig. 5 A magnetic field distribution in one duct (in the case of V pipe)

A flux density distribution example in one duct is shown in Fig. 5. It shows the analysis result of the model in the case of V pipe. The magnetic influence analysis results in V pipe, I pipe and S pipe are listed in Table 3.

Table 3 Magnetic influences by duct classification (570Hz)

Signal current injecting duct	Flux density at the point of measurement [T]	Receiving ratio	A gap of a magnetic field level position [mm]	The relative error of measured value[%]
V pipe	5.16478e-09	1	0	0
I pipe	3.90956e-13	0.000076	-48	-0.063
S pipe	2.61032e-12	0.00051	0	0

(Sign = left : +, right : - from the direction which current flows)

As a V pipe is nonmetallic, there is no magnetic field screening effect. For this reason, the ratio concerning the magnetic field does not change. Moreover, the error of a horizontal position is not produced, either. However, in the case of I pipe and S pipe, a magnetic field decreases according to a magnetic field screening effect. In the case of I pipe, a gap of a level position produced by a magnetic field distortion. Since the relative error of measured value is very small, it is disregarded. On the other hand, since magnetic field distribution of S pipe is symmetrical, a gap of a level position is not produced. When I pipe was compared with S pipe, it became clear that a receiving ratio is set to 0.000076 and 0.00051, respectively.

3.4.2 Magnetic influence in the case of changing frequency

The magnetic influence analysis results with high frequency up to 8190Hz are listed in Table 4.

When frequency became high with 570 to 8190Hz, in the case of I pipe, magnetic field intensity became weak, and the result that in the case of S pipe magnetic field intensity was set to 0T, and it could not detect was obtained. The skin effect of eddy current shows up strongly by high frequency, and this is considered for generating only a small magnetic field in the exterior of a duct. Therefore, it is easier to use the frequency of 570Hz rather than the frequency of 8190Hz, when sending signal current through the telecommunication cable accommodated in metal ducts, such as I pipe and S pipe.

Table 4 Magnetic influences by duct classification (8190Hz)

Signal current injecting duct	Flux density at the point of measurement [T]	Receiving ratio	A gap of a magnetic field level position [mm]	The relative error of measured value[%]
V pipe	**5.16478e-09**	**1**	**0**	**0**
I pipe	**1.04071e-24**	**2e-16**	**-36**	**-0.055**
S pipe	**0**			

(Sign = left : +, right : - from the direction which current flows)

3.4.3 Magnetic field influences by surrounding metal ducts

When signal current was injected into any one of V pipe, I pipe, and the S pipe, one I pipe had been arranged to the horizontal direction of this duct and a total of two had been arranged on the other side, as shown in Fig. 6.

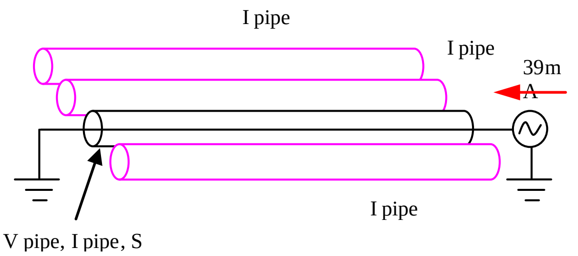

Fig. 6 Three I pipe model

The examples of magnetic field distributions in the case of having arranged I pipe are shown in Fig. 7 , 8 and 9. These are the analysis results of the models which we have arranged 1~3 I pipes in the vicinity of the pipe injected with signal current.

When I pipe was arranged at the circumference of a level position, it became clear that a gap arises to the horizontal direction of magnetic field intensity. This is because of the eddy current. Since the eddy current produced a new magnetic field, it affected an original magnetic field. This is considered as follows.

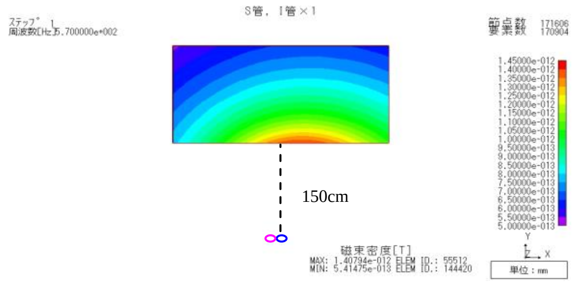

Fig. 7 The magnetic field distribution (in the case of one I pipe)

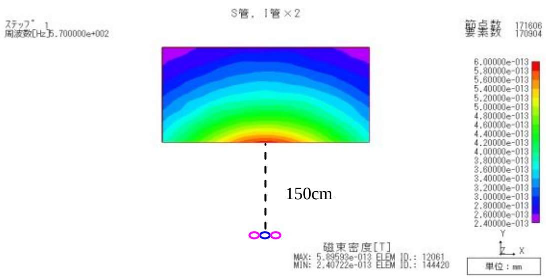

Fig. 8 The magnetic field distribution (in the case of two I pipes)

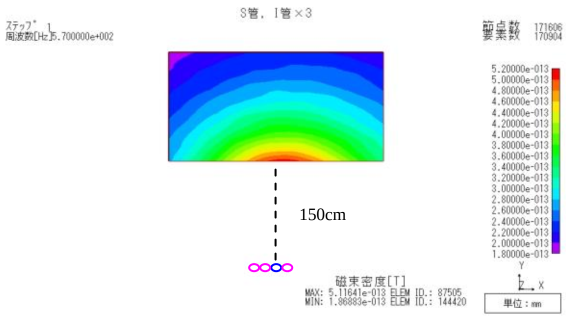

Fig. 9 The magnetic field distribution (in the case of three I pipes)

The magnetic influence analysis results in the case of having arranged I pipe are listed in Table 5.

Table 5 Magnetic influences by two or more pipes (570Hz)

Signal current injecting duct	The number of arranged I pipe	Flux density at the point of measurement [T]	Receiving ratio	A gap of a magnetic field level position [mm]	The relative error of measured value[%]
V pipe	0	5.16478e-09	1	0	0
	1	1.67337e-09	0.32	234	1.47
	2	6.86703e-10	0.13	0	0
	3	5.79544e-10	0.11	102	0.34
I pipe	0	3.90956e-13	0.000076	-48	-0.063
	1	2.45497e-13	0.000048	244	1.27
	2	1.44800e-13	0.000028	36	0.19
	3	1.20647e-13	0.000023	166	0.85
S pipe	0	2.61032e-12	0.00051	0	0
	1	1.37603e-12	0.00027	290	2.27
	2	5.89593e-13	0.00011	0	0
	3	5.09518e-13	0.00010	94	0.41

(Sign = left : +, right : - from the direction which current flows)

An eddy current magnetic field is generated in the same vector direction as a signal current magnetic field. Therefore, the magnetic field distribution maximum appears in the position which I pipe and the signal injecting pipe by the side of opposite left 234mm. When two I pipes are arranged, in order to negate the eddy current magnetic field of I pipe of both sides mutually, a signal current magnetic field is distributed symmetrically. When three I pipes are arranged, I pipe described above is the same as 1 arrangement, and the magnetic field distribution maximum serves as a position distant from I pipe and the signal injecting pipe by the side of opposite, but since the magnetic field intensity which one more I pipe makes is small, the position from V pipe becomes small with 102mm. When metal ducts, such as I pipe and S pipe, existed in the both sides of the duct which injects in signal current from this, and these ducts chose as right and left the conditions arranged equally, it became clear that the error of a level position can be abolished.

3.4.5 Magnetic influences at the time of S pipe four-row and four-line burial

As shown in Fig. 10, the magnetic influences at the time of 16 having been arranged were examined under the condituion of injecting signal current into inside one of the S pipes.

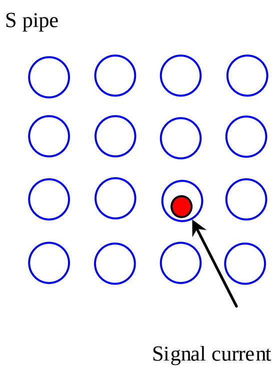

Fig 10 S pipe four-row four line model

In four-row and four-line S pipes, the examples of magnetic field distributions in the case of changing a signal current injecting position are shown in Figs. 11 , Fig12, Fig.13 and Fig.14.

In four-row and four-line S pipes, the magnetic influence analysis results at the case of changing a signal current injecting position were collectively listed in Table 6.

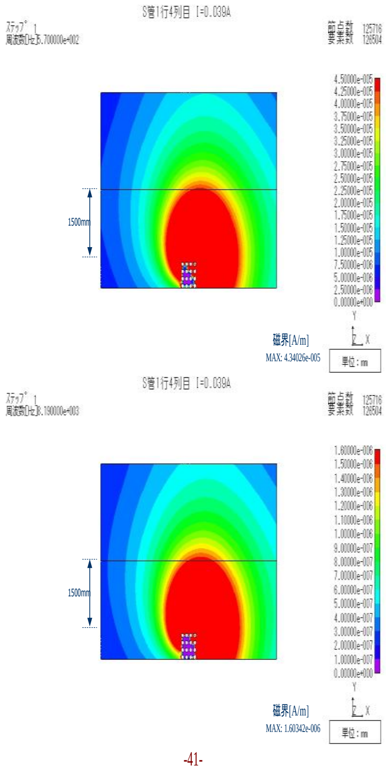

Fig. 11 Magnetic field distribution (in the case of the 1st row of fourth line)

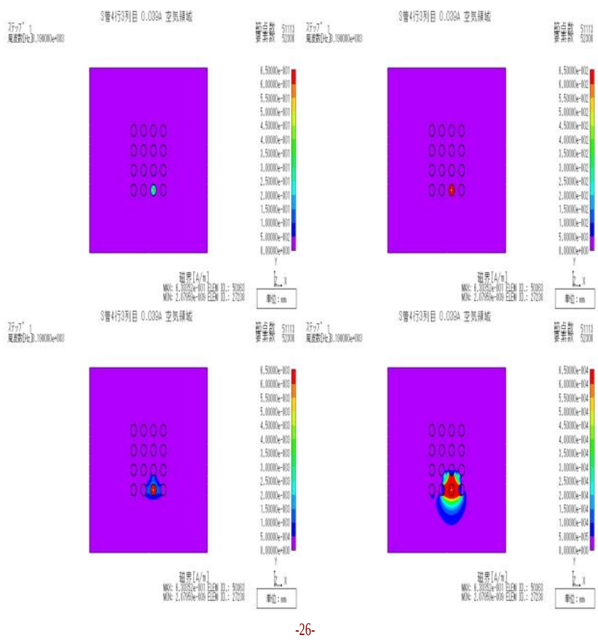

Fig. 12 Magnetic field distribution (in the case of the 4th row of 3rd line)

Table 6 Magnetic influences by two or more pipes (570Hz)

Signal current injecting position	Flux density at the point of measurement [T]	Receiving ratio	A gap of a magnetic field level position [mm]	The relative error of measured value[%]
The 4th row of first line	1.12811e-12	1	122	1.04
The 4th row of second line	4.61945e-13	0.41	452	6.61
The 4th row of third line	3.74310e-13	0.33	666	11.1
The 4th row of fourth line	1.78945e-13	0.16	624	11.87
The 3rd row of first line	5.65753e-13	0.50	75	0.12
The 3rd row of second line	3.44723e-14	0.031	-34	-0.5
The 3rd row of third line	3.32601e-14	0.029	612	5.15
The 3rd row of fourth line	1.28631e-14	0.011	846	15.5

(Sign = left : +, right : - from the direction which current flows)

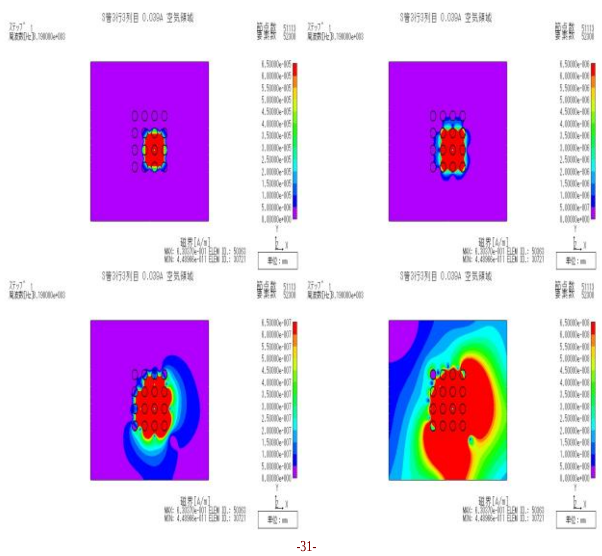

Fig. 13 Magnetic field distribution (in the case of the 3rd row of 3rd line)

Since the magnetic field maximum in the position of 150cm of upper parts is detected, when a signal current injecting position is the first row of the ducts, there is no big influence. Moreover, a gap of a magnetic field level position is small at the time of injecting signal current into the pipe inside the case where it injects into an outside pipe. Furthermore, measured value becomes low under the influence of distance or a pipe as a signal position becomes deep.

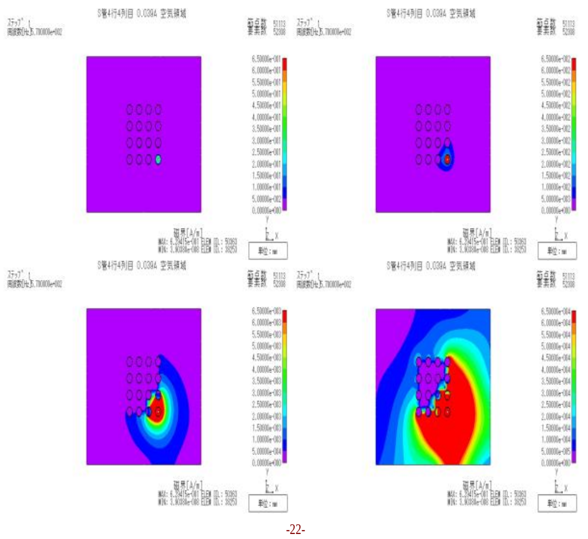

Fig. 14 Magnetic field distribution (in the case of the 4th row of fourth line)

On the other hand, when the surroundings which the signal position called the 3rd row of 3rd line and the 4th row of 3rd line were surrounded by many S pipes, it became clear that disorder of a magnetic field becomes large. Therefore, it became clear that an error can be lessened if signal current is injected in from the inner side of the first row of a pipe in the case of actual measurement, and measured value cannot become low easily, either.

3.4.6 Influence of the metal telecommunication cables installed in a circumference ducts

There are metal cables in the duct in many cases. As shown in Fig. 15, signal current was injected into one V pipe. Then the magnetic field influence in the case where a metal cable is installed either in V pipe or in S pipe was compared.

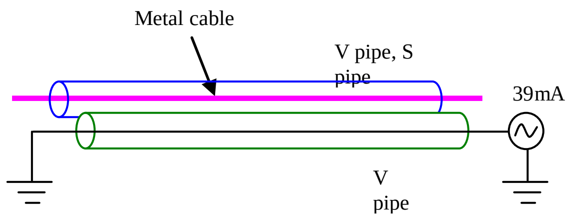

Fig. 15 Metal cable model

A magnetic influence analysis results when a metal cable is accommodated in the adjoining duct are listed in Table 7.

Table7 Magnetic influences by a metal cable (570Hz)

Pipe	Metal cable	Flux density at the point of measurement [T]	Receiving ratio	A gap of a magnetic field level position [mm]	The relative error of measured value[%]
V pipe	Nothing	5.16477e-09	1	0	0
	Lead	1.91168e-09	0.37	202	1.02
	Belt	3.37427e-09	0.65	80	0.12
	Alpeth	1.50270e-09	0.29	252	1.73
	Stalpeth	2.76438e-09	0.54	122	0.34
S pipe	Nothing	2.21586e-09	0.43	174	0.75
	Lead	2.21587e-09	0.43	174	0.75
	Belt	2.21586e-09	0.43	174	0.75
	Alpeth	2.21586e-09	0.43	174	0.75
	Stalpeth	2.21586e-09	0.43	174	0.75

(Sign = left : +, right : - from the direction which current flows)

It will be the normalized 1 the signal reception ratio in the case of the V pipe next to no metal cable exists. And if the metal cable is present, the result which serves as a receiving ratio of 0.29-0.65 by classification was obtained. This is because the error of the level position shifted from 80-252mm and the magnetic field intensity detected became weak by existence of the metal cable in V pipe. On the other hand, when a metal cable was in the next S pipe, each receiving ratio was set to 0.43, and since the screening effect of S pipe was large. It became clear that it is not dependent on the classification of a metal cable. Therefore, when the metal cable was accommodated in V pipe, the error of magnetic field intensity needed to be taken into consideration according to the kind of cable, and when the metal cable was accommodated in S pipe, it became clear that it is not necessary to take an inner cable into consideration.

3.4.7 Influence of return current

When signal current is injected into any one of V pipe, I pipe, and the S pipe, one I pipe has been arranged to the horizontal direction of this duct and a total of two have been arranged on the other side, as shown in Fig. 16. Then, the return current of the half of 39mA of signal current assumed that it flowed into surrounding I pipes equally. We examined those magneticfield distribution.

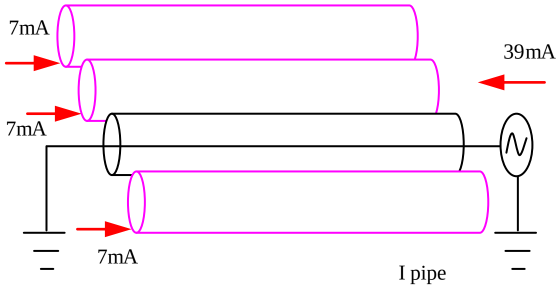

Fig. 16 Two or more I pipe model having return currents

A magnetic influence analysis results when return current flows in are listed in Table 8. There is no magnetic field screening effect by a duct when the telecommunication cable which sent signal current is in V pipe.

Table 8 Magnetic influences by return current (570Hz)

Signal current injecting duct	The number of arranged I pipe	Flux density at the point of measurement [T]	Ratio	A gap of a magnetic field level position [mm]	The relative error of measured value[%]
V pipe	1	2.56984e-09	1	150	0.54
	2	3.87013e-09	1.51	0	0
	3	4.27986e-09	1.67	24	0.0076
I pipe	1	8.62867e-10	0.34	-394	-4.13
	2	4.12266e-10	0.16	0	0
	3	3.21760e-10	0.13	-336	-2.23
S pipe	1	1.12857e-09	0.44	-336	-2.77
	2	5.46555e-10	0.21	0	0
	3	4.08066e-10	0.16	-268	-1.34

(Sign = left : +, right : - from the direction which current flows)

The magnetic field which the return current flowing into I pipe makes is smaller than the original magnetic field which signal current generates. When the telecommunication cable which sent signal current is in I pipe and S pipe, the magnetic field which return current makes strong.

4 Conclusions

The following results were obtained by analyzing magnetic field distribution of the signal current which flows into the cable by finite element method.

(1)Both I pipe and S pipe have a large magnetic field screening effect. For this reason, it is better to send signal current through the telecommunication cable in nonmetallic V pipe.

(2) In the case of a metallic duct, if it becomes high frequency, the measurement magnetic field in earth surface will become small under the influence of a skin effect. Therefore, when sending signal current through the telecommunication cable in a metallic duct, using a 570 Hz frequency signal is better than using a 8190 Hz frequency signal.

(3) When the metalic duct is arranged at the horizontal direction of the signal current injecting duct, the level position of a measurement magnetic field shifts. It is better to send signal current through the cable near a center if possible, since a gap of a level position will become small if the metallic duct of the same number as both sides is arranged.

(4) When a metallic duct is arranged at four-row four-line and signal current is surrounded by many metallic ducts, the error of measurement in earth surface becomes large. For this reason, it is better to send signal current through the telecommunication cable of the duct near the center of the first row.

(5) When the metal cable is accommodated in the surrounding nonmetallic duct, a measurement magnetic field produces the error of a detection position horizontal about 80-250mm.

(6) When return current flows into a circumference metallic duct, the error of a measurement magnetic field becomes an opposite direction depending on the duct classification such as metal and nonmetal. However, such an error of measurement can be disregarded by sending signal current through the cable of a pipe with which the metallic duct of the same number as both sides is arranged.

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