METHOD SELECTION AND ERROR EVALUATION FOR FAULT PLACE DETECTION IN UNDERGROUND HEAT DISTRIBUTION PIPES

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Abstract

The fault location technique for modern hot water transportation pipes used for hot water transfer was suggested. It is and alternative to time domain reflectometry measurements usually used in such type of task. Technique is capable of locating the fault place by using the measured EM field strength outside the pipe. The location of the pipe end using just peak of the emissions level is complicated. Therefore modified measurements procedure was suggested which is using two linear regression curves approximating the fields strength before the fault and after fault. Those curves interception point is the estimate of the fault position.

The position estimation example for the pipe buried at 1.2m depth was given. The resulting fault location estimation error was presented. It can be seen, that while digging the ground out and getting closer readings, less than 5cm location error is possible.

1. INTRODUCTION

Quality of water supply pipelines is of great importance: shortage of fresh water leads even to tension between the countries [1-3]. In particular, our interest lies in water transportation pipes. Corrosion, pressure differences lead to ruptures of pipes creating a water leak. Even a small leak might cause a lot of water to be lost. For example, in Chicago leak-related losses make 40 % [4].

Modern pipes [5] used for hot water transfer are encased in external cover from high density polyethylene and inner space is filled with plastic foam for a thermal insulation.

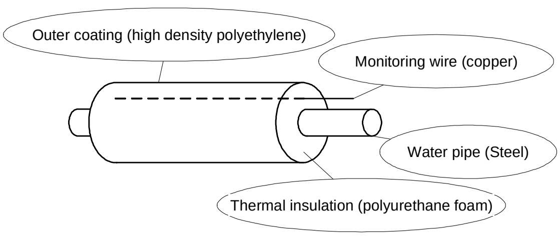

Fig. 1. Modern water pipe design

For inspection and monitoring purposes, wires are placed inside the thermal protection foam. Those wires together with a metal pipe represent a two-wire asymmetric transmission line which is used for definition of damage of a pipe at even weak leak of water. Impedance measurement is used for leakage event detection and time domain reflectometry (TDR) is used for leak location [6]: wet foam is disrupting the transmission line impedance, so reflection occurs at leakage point.

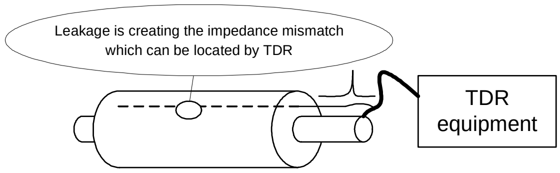

Fig. 2. Leakage location by TDR

Unfortunately, TDR location is prone to location errors due to reflection at the [4,7,8] closest point of fault and propagation speed estimation errors.

We are suggesting an alternative fault location technique, capable of locating the fault place by doing the electromagnetic (EM) field strength measurements outside the pipe.

2. FAULT LOCATION PRINCIPLE

The transmission line has losses; in particular caused by electromagnetic field radiation outside (outer conductor for shielding does not exist). We have decided to try to define the amount of this radiation and to try to use this effect for location of a damage place (Figure 3).

Arrangement of the radiated EM field measurement of the matched transmission line-type pipe is presented on Figure 4.

Termination was placed at the open pipe end. The outer shell diameter of the pipe used was 200 mm, inner steel pipe diameter was 50 mm. Pipe length was 3m. Pipe was hung in the laboratory to keep away from metal objects at least by 500mm. The RF generator injected the 50MHz 10Vp-p signal into the opposite end of the pipe. EM field strength was measured using whip antennae (500 mm length), level was registered using Thurbly Thundar Instruments PSA1301T spectrum analyzer. Measurements were taken at antennae located across the pipe direction. Measurement results are presented on Figure 5.

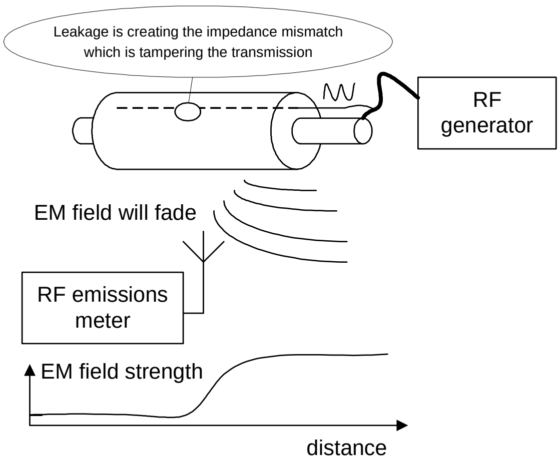

Fig. 3. Suggested location principle

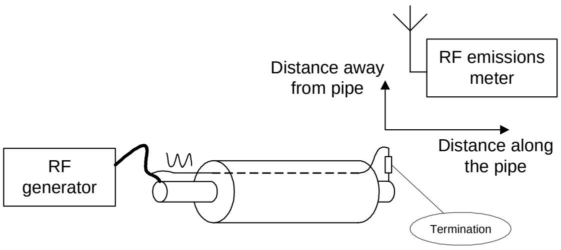

Fig. 4. Radiated EM fields measurement setup

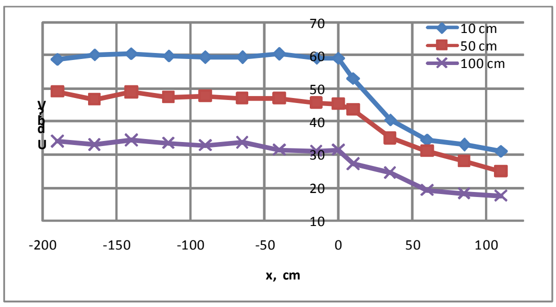

Fig. 5. Radiated 50MHz EM fields vs. distance from terminated end

It can be seen, that due to proper termination there is a radiated EM field decay in the area beyond the pipe. Experiment was carried out with transmission line being not terminated. Broken pipe case was simulated. Radiated EM fields measurement of the mismatched (open ended) transmission line is presented on Figure 6 and Figure 7.

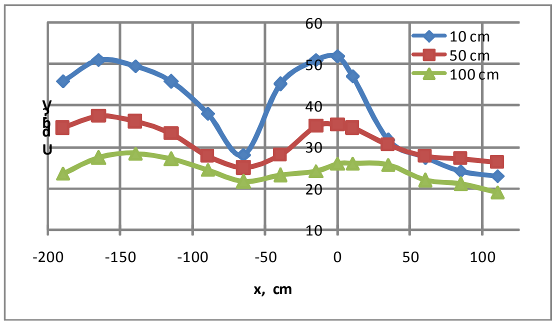

Fig. 6. Radiated 50MHz EM fields vs. distance from unterminated end

It can be seen, that due to standing waves location of fault place is complicated. Experiment was carried out at 50MHz (Fig. 6) and 10MHz (Fig. 7).

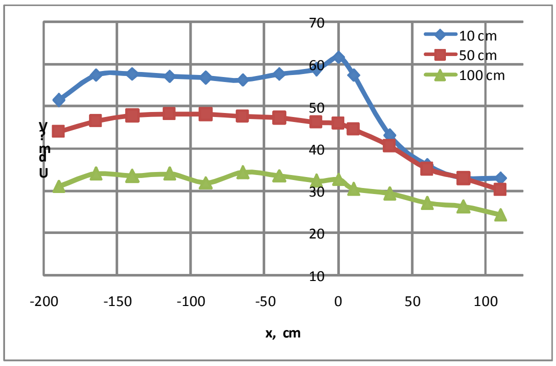

Fig. 7. Radiated 10MHz EM fields vs. distance from unterminated end

Such frequency was chosen intentionally, since suggested method should locate the buried pipe: higher frequencies will be largely attenuated in soil [8]. Using lower frequencies will give larger distance between standing waves and the accuracy or the measurement will be decreased.

Experiments were carried out on pipe buried 1,2m in soil (Figure 8). The pipe end was left open (unterminated case), polyethylene cap was applied on the open end. Pipe was buried in wet clay.

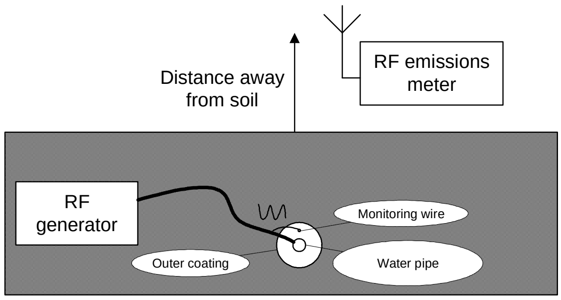

Fig. 8. Buried pipe radiated EM field above the soil @10MHz

Radiated EM fields measurements of the open ended transmission line at 10MHz frequency are presented on Figure 9.

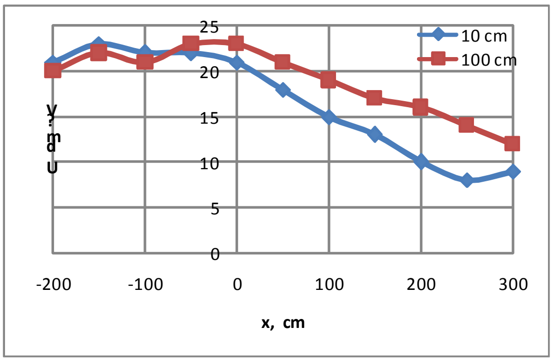

Fig. 9. Radiated 10MHz EM fields vs. distance from buried pipe @10MHz

It can be seen that there are two curves prevailing: standing wave profile created field along the pipe with transmission line and decaying EM field at the end of the pipe. The location of the pipe end using peak of the emission is complicated. Therefore modified measurements procedure was suggested.

3. THE MODIFIED PROCEDURE

We suggest using two linear regression curves approximating the aforementioned fields' strength. Left hand side (standing wave profile along the pipe with transmission line):

$$y_1 = a_1 x + b_1 . \qquad (1)$$

And the right – hand side curve (field along the pipe without transmission line):

$$y_2 = a_2 x + b_2 . \qquad (2)$$

Then curves interception point can be determined by equating (1) to (2):

$$a_1 x + b_1 = a_2 x + b_2 . \qquad (3)$$

The solution *x* for the equation (3) is the estimate of the fault position:

$$x = \frac{b_2 - b_1}{a_1 - a_2} . \qquad (4)$$

Equation (4) was used on Figure 8 and Figure 9 data to locate the fault position (Figure 10).

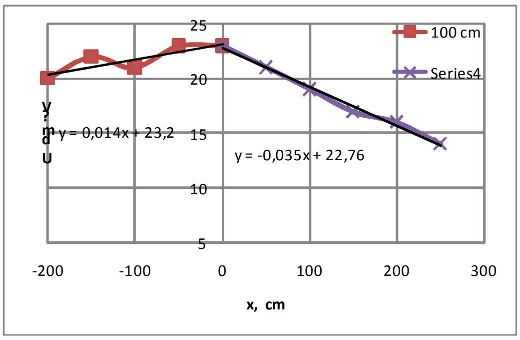

Fig. 10. Radiated 10MHz EM fields vs. distance from buried pipe @10MHz

Coefficients used and error obtained are presented in Table 1.

Table 1. Fault position estimation data

Away from soil, cm	a_1	b_1	a_2	b_2	Δx, cm
10	0,015	59,6	-0,4	60,6	2,16
50	0,004	47,2	-0,16	45,9	7,39
100	0,002	33,3	-0,07	31,8	19,44
120	-0,002	21,6	-0,05	20,7	18,80

The resulting fault location estimation error is presented in Figure 11.

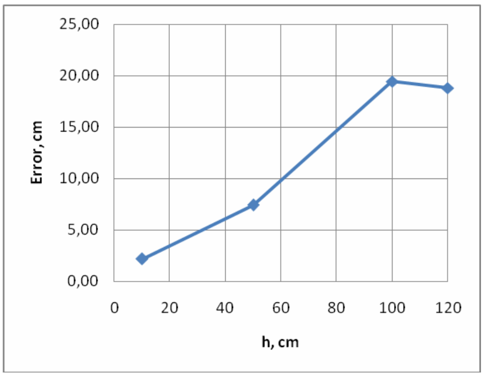

Fig. 11. Buried pipe fault location error vs. distance from soil @10MHz

4. CONCLUSIONS

A TDR alternative fault location technique for modern hot water transportation pipes by using the measured EM field strength outside the pipe was suggested. It has been shown that the location of the pipe end using just peak of the emissions level is complicated. Therefore modified measurements procedure using two linear regression curves approximating the fields' strength before the fault and after fault was suggested.

The position estimation example for the pipe buried at 1.2m depth given suggests that the resulting fault location estimation error can be less than 5cm.

References

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