A Positioning Method of the Partial Stretch of Spiral Parallel Cable

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Abstract. How to identify the partial deformation position is an important issue in the use of the time domain reflection technique based on spiral parallel cables to monitor the hazards of landslide, debris flow and other geotechnical engineering. Hence, this paper presents a new method to identify the edge of partial tensile deformation of the spiral parallel cable. Firstly, the reflected voltage waveform of the spiral parallel cable is recorded before the partial tensile deformation, and then the reflected voltage waveform of the spiral parallel cable is recorded after partial tensile deformation. Subsequently, the waveform of the deformation is subtracted from the waveform before the deformation, and the difference waveform is obtained. Finally, the measurement blind zone in the difference waveform is removed. In that case, the minimum point of the remaining closed range corresponds to the left edge of the tensile deformation, the first extreme point behind the minimum point corresponds to the right edge of the tensile deformation.

Introduction

Each occurrence of geological disasters will lead to serious losses, so people pay attention increasingly to the prevention of geological disasters.

Spiral parallel cable is a new type of sensor used in geological disaster monitoring. Because it has the characteristics of large amount of deformation, tensile resistance and so on, it solves the problem that the fiber is easy to break and the coaxial cable deformation is small. Therefore, it is significant in geological hazard prevention and monitoring. Time Domain Reflectometry (TDR) has traditionally been used for locating faults in cables. With TDR, the deformation of the ground surface can be detected by using the spiral parallel cable, and the deformation position and the size of the deformation can be obtained.

Due to the sensor's application environment and other external factors, it is difficult to analyze the surface condition through the simple observation of the voltage waveform of TDR reflection, which will affect the positioning accuracy. In view of the difficult positioning, this paper proposes a new positioning method, which can solve the problem of positioning accuracy, and the ability to resist interference is strong. The positioning method makes the cable has more advantages in practical application.
**Structure and Circuit Model of Spiral Parallel Cable**

This method is based on the spiral parallel cable as sensing element. And the sensor is a kind of distributed component, which can sense the deformation information in the whole measurement range. Due to the nature of its own structure, making it difficult to be broken in the measurement of large deformation.

The structure of the spiral parallel cable is shown in Fig.1, which is mainly composed of copper wire and flexible insulation. The structure of the spiral parallel cable is to circle the inner coil of the single enameled wire on the cylinder of the elastic insulators with circular cross section, and then outside the inner coil of the enameled wire wrap an insulation layer with flexible middle part, which is then twisted by the outer coil of the single enameled wire surrounded by an insulation layer with flexible outside and of the same direction and line space as the inner coil, and thus to form the spiral line sensor with the inner and outer parts of the enameled wire coils [1].

Uniform transmission line is a transmission line of resistance, inductance, conductance and capacitance is uniformly distributed transmission line. Ideal spiral parallel cable without drawing can be seen as a uniform transmission line. Equivalent circuit of the micro segment $dx$ of uniform transmission line is shown in Fig.2.

According to the circuit model, we can get the Eq.1, where $R_0$ is the resistance of unit length—come and back—transmission line; $L_0$ is the inductance of unit length transmission line; $G_0$ is the leakage conductance of unit length transmission line; $C_0$ is the capacitance of unit length transmission line.

\[
\begin{align*}
\frac{\partial u}{\partial x} &= R_0 i + L_0 \frac{\partial i}{\partial t} \\
\frac{\partial i}{\partial x} &= G_0 u + C_0 \frac{\partial u}{\partial t}
\end{align*}
\]

Based on the established model, the characteristic impedance of the uniform transmission line can be expressed by Eq.2.
\[ Z_c = \frac{R_0 + j\omega L_0}{\sqrt{G_0 + j\omega C_0}} \]  
(2)

If \( \omega \) is large enough, \( R_0 \) and \( G_0 \) can be ignored compared with \( j\omega L_0 \) and \( j\omega C_0 \) [2]. Therefore the Eq.2 can be simplified as Eq.3.

\[ Z_c = \frac{L_0}{\sqrt{C_0}} \]  
(3)

Figure 3. The Partially Stretched Spiral Parallel Cable.

As shown in Fig.3, when the helical parallel cable is locally stretched, the inductance of the stretched wire will be reduced, while the capacitance change is relatively small. Hence, according to the Eq.3 we can draw the conclusion that the impedance of the stretched section will decrease when the spiral parallel cable is stretched.

**Time Domain Reflectometry (TDR) Based on Spiral Parallel Cable**

Time Domain Reflectometry has traditionally been used for locating faults in cables. TDR measurements has two types of single-ended TDR measurements and differential TDR measurements, the following is a brief introduction of single-ended measurements. Fig.4 is a typical waveform shapes of single-ended TDR measurement, which \( Z_0 \) is the characteristic impedance (50 Ohm) of the TDR measurement system, and \( Z_{DUT} \) is the impedance of the Device Under Test (DUT).

![Figure 4. Typical Waveform Shapes of TDR.](image-url)
Fig. 4(a) is a typical waveform shapes of step input of the TDR measurement. When the impedance of the DUT is greater than $Z_0$, the sampling voltage will be higher than $V_{\text{incident}}$. Conversely, when the impedance of DUT is less than $Z_0$, the sampling voltage will be less than $V_{\text{incident}}$. The variables are satisfied as the Eq. 4, where $\rho$ is the reflection coefficient.

$$\rho = \frac{V_{\text{reflected}}}{V_{\text{incident}}} = \frac{Z_{\text{DUT}} - Z_0}{Z_{\text{DUT}} + Z_0}$$ (4)

Fig. 4(b) is a typical waveform shapes of pulse input of the TDR measurement. When the impedance of DUT is greater than $Z_0$, sampling voltage at the intersection will have a positive pulse. Conversely, when the impedance of DUT is less than $Z_0$, sampling voltage at the intersection will have a negative pulse. Therefore, we can obtain the impedance distribution at any moment of the spiral parallel cable with a certain length by using TDR.

We can choose the step output or pulse output of the TDR instrument, The pulse output type TDR instrument is used in this paper.

**Positioning Experiments of Partial Stretch**

In practice, due to the plastic deformation, the production process, the external environment and other reasons, the impedance distribution of the spiral parallel cables is not extremely uniform. It is difficult to directly get the position of its partial stretch just by a TDR waveform. To solve this problem, the following method are proposed.

As shown in Fig. 5, the spiral parallel cable is connected to the TDR meter for positioning experiment. TDR meter used in this experiment is a pulse signal output, the spiral parallel cable length is 360cm. Firstly, the reflected voltage waveform of the spiral parallel cable is recorded before the partial stretch. Then, partial stretching the spiral parallel cable at 150cm~178cm and recording the reflected voltage waveform of the spiral parallel cable after partial stretch. Subsequently, the waveform of partially stretched cable is subtracted from the waveform before stretched, and the difference waveform is obtained. We get the waveforms shown in fig. 6. Finally, the measurement blind zone in the difference waveform is removed.

From Fig. 6 we can see that the waveform before stretching is not an ideal straight line because of plastic deformation, extrusion and other reasons. But after tension, the impedance of the stretched position becomes smaller. Thereby, the impedance of the right side of the point A becomes smaller. According to the Eq. 4, the absolute value of $\rho_A$ ($\rho_A < 0$) becomes larger. Similarly, $\rho_B$ of the point B becomes larger.

Using the computer to get the difference waveform. Then, we can get the minimum point A in 81ns and the point B in 96ns. In addition, the scope of the spiral parallel cable is 0ns~194ns (0ns=8ns-8ns, 194ns=202ns-8ns). Consequently, the positioning result of A point is $(81\div194\times360)\text{cm}=150.31\text{cm}$, the positioning result of B point is $(96\div194\times360)\text{cm}=178.14\text{cm}$.
In order to verify the effectiveness of this method, we use this method to carry out numerous experiments of repetitiveness and accuracy. Table 1 is the point A results of 10 repeated experiments in the 100.03cm, According to the Bessel formula, the repetitiveness of the positioning results is 0.48cm. Table 2 is the point A results of 10 different stretching positions. The maximum absolute error is ±3.6cm. The above data show that the method can accurately and effectively identify the partial tensile deformation position of the spiral parallel cable.

Table 1. The Positioning Results of 10 Repeated Experiments in 100.03cm.

<table>
<thead>
<tr>
<th>NUM</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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</thead>
<tbody>
<tr>
<td>Value/cm</td>
<td>100.1</td>
<td>100.7</td>
<td>100.7</td>
<td>101.0</td>
<td>100.3</td>
<td>100.0</td>
<td>101.3</td>
<td>101.0</td>
<td>100.8</td>
<td>99.9</td>
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Table 2. The Positioning Results of 10 Different Locations.

<table>
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<th>Actual position/cm</th>
<th>Measuring position/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.3</td>
<td>100.0</td>
</tr>
<tr>
<td>114.2</td>
<td>114.8</td>
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<tr>
<td>125.2</td>
<td>124.1</td>
</tr>
<tr>
<td>136.8</td>
<td>133.3</td>
</tr>
<tr>
<td>148.0</td>
<td>146.3</td>
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<tr>
<td>160.3</td>
<td>157.7</td>
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<tr>
<td>170.4</td>
<td>167.3</td>
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<tr>
<td>179.3</td>
<td>176.9</td>
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<td>190.1</td>
<td>186.5</td>
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<tr>
<td>202.6</td>
<td>200.0</td>
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</table>

Conclusions

As a new type of sensor for the detection of geological disasters such as landslides and ground collapse, the spiral parallel cable has the advantages of tensile resistance and large deformation capacity. This paper is a kind of method to solve the problem of localization of partial deformation. This method can accurately and effectively identify the partial tensile deformation
position of the spiral parallel cable. The experiments shows that the method can basically satisfy the engineering application. But there are still some problems that need to be solved in practical application. For example, how to better prevent outside interference, how to further improve the accuracy, and so on.

Acknowledgments
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References