Tracking all-dielectric fiber-optic cable route

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***Abstract*—The paper discusses a method for determining the route of laying an all-dielectric optical cable on a test site. The results of measurements and errors in determining the location of the cable by the method of source offset triangulation algorithm are presented.**

Keywords— distributed acoustic sensor, algorithm of simple triangulation, source offset triangulation algorithm, fiber-optic cable.

1. INTRODUCTION

Fiber-optic cable networks are the basis of modern digital infrastructure. Providing greater bandwidth and transmission range compared to copper cables, optical cables are also of great interest in terms of electrical safety and resistance to electromagnetic interference. In recent years, all-dielectric optical cable networks have been increasingly developed, however, methods for maintaining such networks require further research [1, 2]. In particular, the proper maintenance of an all-dielectric optical cable requires tracking methods for this cable and non-destructive monitoring of its condition. A very promising method for determining the location of an all-dielectric optical cable can be one based on determining the coordinates of the source of acoustic influence relative to the cable from the phase characteristics of the acoustic signal recorded by a system of distributed acoustic sensors (DAS) [3, 4]. The paper presents the results of testing the methodology for localizing a section of an all-dielectric optical cable on a test site.

2. CABLE TRACKING METHODS

The principle of searching for a cable laying route is explained by the diagram shown in Fig. 1.

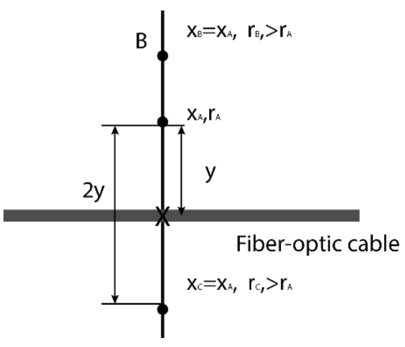

Fig. 1. Source offset triangulation algorithm for cable tracking

The tracking is performed as follows. The source of local harmonic acoustic impact is preliminarily placed at point A near the intended location for laying the optical cable. According to the results of processing the phase characteristics of the acoustic signal received by the DAS, estimates of the coordinates of the source relative to the cable are determined - along the axis of the optical fiber and the shortest distance from the source to the cable. By moving the source, point B is found, the coordinate along the fiber axis of which coincides with point A at a different distance from the cable. A straight line is drawn through points A and B, which is normal to the axis of the optical fiber of the cable. Move the source along the normal towards the cable. The direction can be determined by analyzing the amplitude characteristics of the acoustic signal received by DAS. Then cross the fiber axis and, moving along the normal, find point C, the coordinates of which coincide with the coordinates of point A. After that, the location of the point on the ground surface above the cable is determined in the middle of the segment connecting points A and C.

To determine the coordinates of the source from the phase characteristics of the received DAS signal, the ray method is recommended, which is used in conjunction with the triangulation method. The principle of determining the coordinates of the source is explained in Fig. 2.

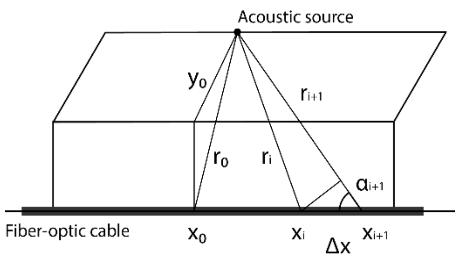

Fig. 2. Cable tracking with the algorithm of simple triangulation

For each discrete point along the axis of the DAS, for which an acoustic signal is recorded, the vector of angles of incidence α_i is calculated by the formula

$$\alpha_i = \arccos(\frac{\Delta\theta_i}{k \cdot \Delta x}) . \quad (1)$$

Here k = 2π/λ is the wave number; λ is the wavelength of sound; Δx is the phase-sensitive reflectometer sampling step of DAS; $\Delta\theta = \theta_{i+1} - \theta_i$ is the phase difference of acoustic signals (beams) recorded by DAS at points x_i and x_{i+1} of optic fiber. Then, the vector of estimates of the source coordinate along the fiber axis is calculated by the formula

$$x_{0i} = \frac{x_{i+1} tg(\alpha_{i+1}) - x_i tg(\alpha_i)}{tg(\alpha_{i+1}) - tg(\alpha_i)}\,, \qquad (2)$$

After that, the actual value of the coordinate is determined by the vector of its estimates as

$$x_0 = \Phi(\langle x_{0i} \rangle)\,, \qquad (3)$$

where $\Phi(\langle x_{0i} \rangle)$ is the evaluation vector processing algorithm. In this work, we used the algorithm proposed by R. Nigmatullin [5]. The vector of estimates of the shortest distance from the source to the cable is determined by the formula

$$r_{0,i} = (x_i - x_0) \cdot tg(\alpha_i)\,. \qquad (4)$$

The actual value of the coordinate according to the vector of estimates of this value is also determined using the algorithm of R. Nigmatullin

$$r_0 = \Phi(\langle r_{0,i} \rangle)\,. \qquad (5)$$

Fig. 3 shows the results of measurements of the phase of a harmonic acoustic signal from a local source.

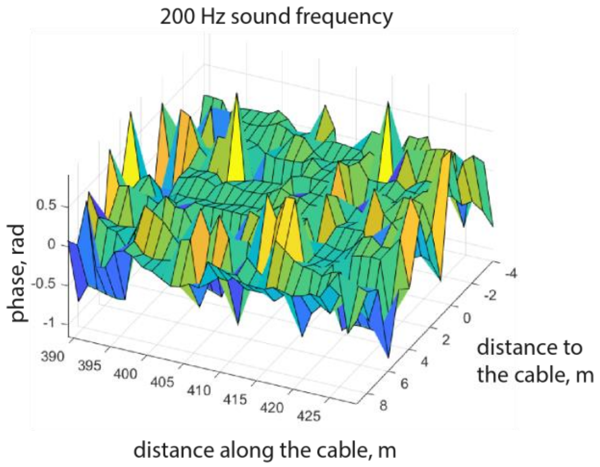

Fig. 3. Phase distribution of a harmonic acoustic signal from a local source

Fig. 4 shows the absolute errors in the estimates of the coordinates of the sound source along the fiber axis.

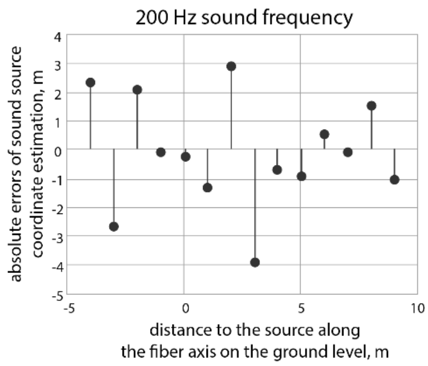

Fig. 4. Error rate of the sound source coordinate estimation along the fiber axis

Cable location estimates using the bisection method when approaching the far-field are quite satisfactory (Fig. 5).

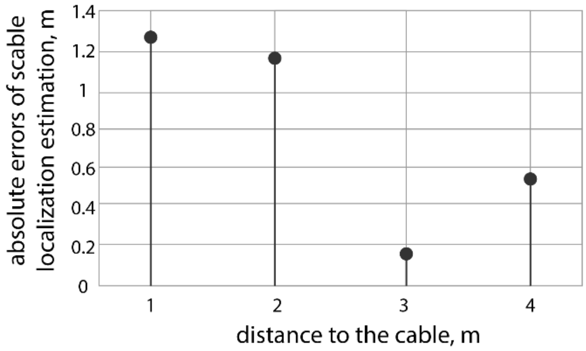

Fig. 5. The bit error rate versus the imbalance of power between the modes

For distances from the source of 3 m and 4 m, the errors are 0.15 m and 0.51 m, respectively. Here, the errors in determining the location of the cable were determined by the formula

$$\left| \Delta r_A - \Delta r_C \right| / 2\,, \qquad (6)$$

where Δr_A and Δr_C are the absolute errors of estimated distances from points A and C, respectively, determined by the phase characteristics of the measured DAS acoustic signals.

3. Conclusion

Testing the method of searching the route of an all-dielectric cable based on the analysis of the phase characteristics of the acoustic signal gave ambiguous results. On the one hand, unacceptable values of errors in the estimates of coordinates were obtained due to the violation of the conditions for applying the method for processing the measurement results. On the other hand, even in given conditions, the application of the proposed search technique using the bisection method, when the distances from the source to the cable approaches the far zone, gives very good results.

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