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PLATEAU ALTITUDE DISASTER PREVENTION AND REDUCTION PLATFORM BASED ON BEIDOU SYSTEM

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Abstract. This project is based on the Beidou satellite navigation and positioning technology developed by China. The integrated analysis method is used to obtain the monitoring data of high-precision power cables in high-altitude areas with high-precision millimeters to realize the whole process of monitoring various disasters. An early warning system for power line swing and tower bottom geological hazards is established. The track data of cable swing is obtained by using single-frequency dynamic data post-processing (PPK) based on synchronous power grid monitoring. The applicability and trajectory accuracy of the scheme are evaluated by combining theory with practical engineering. This provides essential technical support for the mechanism and prevention of cable sloshing. The experimental simulation shows that the monitoring efficiency of the system is high.

Key words: Beidou satellite; Transmission lines; Cable sloshing; Foundation strengthening system

1. Introduction. In recent years, the frequent occurrence of power line swaying events has seriously affected the regular operation of the power system. In January 2020, due to continuous low-temperature rainfall, the power systems of five provinces and cities, Anhui, Hubei, Hunan, and Jiangxi, appeared to have a wide range of swings. Among them, more than 20 high-voltage transmission lines of 220 kV and above appeared to have different degrees of oscillation. The oscillation period is more than 40 hours, and the oscillation amplitude can reach 5 meters. Transmission line oscillation is a kind of mechanical vibration caused by wind force, ice-covered wing lift and wire tension under particular weather conditions. It is determined by three factors: ice covering, wind excitation, line structure and parameters, and the whole process includes starting, maintenance, attenuation and other stages.

The power network monitoring and management system must monitor the transmission lines in the swing area online and measure the swing influence factors in real-time. Currently, there are two kinds of real-time monitoring methods for power line swaying at home and abroad: video image and accelerometer. The existing monitoring method based on video images has some problems, such as limited transmission of transmission lines, low resolution, low accuracy of swing detection, and inability to realize real-time monitoring. The monitoring mode of the acceleration sensor is to measure a single conductor's acceleration and then obtain its oscillation's velocity and displacement through mathematical integration. However, this method can only reflect the swing amplitude locally, and it is easy to produce cumulative errors and cannot reflect the direction characteristics of the swing. Literature [1] uses a novel FBG sensing mode to design a method for measuring the shaking of objects. Literature [2] established a new idea of regional sloshing monitoring and early forecasting based on measured data by combining sloshing sampling with weather data. Literature [3] proposes using independent differential GPS technology to monitor and forecast the swing of transmission lines in real time and dynamics. But the above methods have some defects. Therefore, a method of wide-area transmission line shaking monitoring based on the Beidou foundation strengthening system and Beidou high precision positioning technology is proposed in this paper. A new method of swing detection for a "wide area transmission line" is studied [4], and at the same time, related equipment development is studied. This lays a foundation for the application research of "swing" monitoring and "active early warning" in China's power system.

2. Design a power disaster prevention Beidou system in high-altitude areas.

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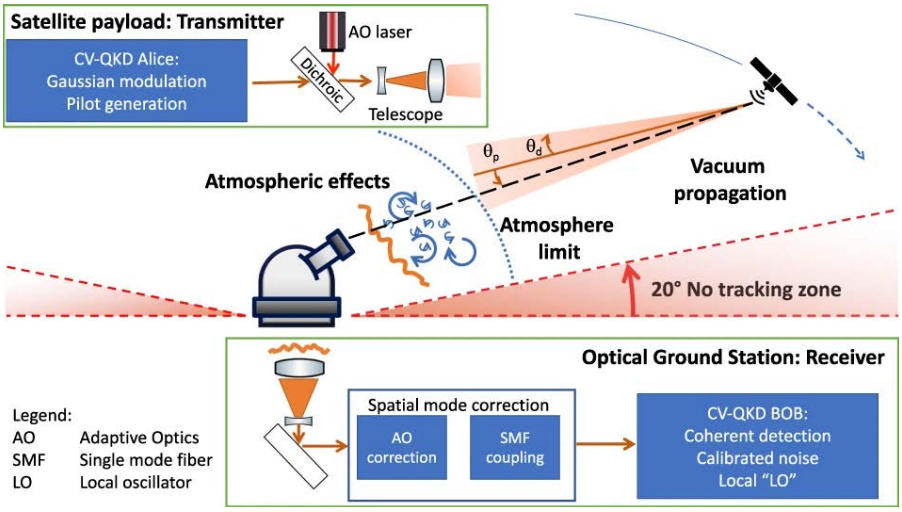

Fig. 2.1: *Schematic diagram of satellite single point positioning.*

2.1. Basic Theory of Satellite GPS. In practical application, the Beidou system (BDS) is complicated to achieve accurate distance measurement because of the uncertainty of inter-satellite and receiver clock differences. Therefore, in measuring the distance between the satellite and the receiver, the Beidou system includes multiple navigation satellites, user receiver equipment and ground measurement and control network [5]. They are both spatial position reference points and communication relay stations. In engineering practice, the receiver synchronously receives signals from multiple satellites and obtains more accurate navigation and position through corresponding algorithms [6]. The receiver then obtains a pseudo-range formula containing the unknowns. Since the unknowns include the user's space coordinates (X, Y, Z) and the receiver's time difference, the pseudo-range positioning is essentially to obtain the receiver's geodetic coordinate system and receiver clock difference by using the pseudo-range measurements of multiple satellites [7]. Figure 2.1 shows the schematic diagram of satellite single point positioning (the picture is quoted in Feasibility of satellite-to-ground continuous-variable quantum key distribution).

Suppose the user's position is (X, Y, Z), the satellite coordinates on BDS are (X_r, Y_r, Z_x), and the distance between the user and the i satellite is S_{ri}.

$$S_{ri} = \sqrt{(X_r - X)^2 + (Y_r - Y)^2 + (Z_r - Z)^2}$$

It is determined that there is an error between the pseudo distance of GPS and the actual distance. The pseudo-distance is represented by Q_{ri},

$$Q_{ri} = S_{ri} + v\Delta t_d$$

v is the speed of light. Δt_d represents the time error of the receiver. There are four unknowns X, Y, Z and Δt_d in equation (2.1) and (2.2). The receiver must receive at least four satellite position signals to find the uncertainty [8]. When more than four satellites are received, the least square method is used to determine the coordinates and clock differences of the receiver. The equation composed of $n(n \geq 4)$ satellite position formulas is shown in formula (2.3):

$$\begin{cases} Q_{r1} = \sqrt{(X_{r1} - X)^2 + (Y_{r1} - Y)^2 + (Z_{r1} - Z)^2} + \sigma W \\ Q_{r2} = \sqrt{(X_{r2} - X)^2 + (Y_{r2} - Y)^2 + (Z_{r2} - Z)^2} + \sigma W \\ Q_m = \sqrt{(X_m - X)^2 + (Y_m - Y)^2 + (Z_{rn} - Z)^2} + \sigma W \end{cases}$$

There is $\sigma W = v\Delta t_d$ in the formula. Because the prerequisite for calculating by the least square method is that the equation is linear, while the satellite navigation is non-linear, the term (2.3) should be linearized [9]. The above expression is malleable using the Taylor series.

$$Q_{rn} = Q_{rn} + \frac{X_m - X}{S_{rn}}\Delta X + \frac{Y_m - Y}{S_m}\Delta Y + \frac{Z_m - Z}{S_m}\Delta Z - \Delta\sigma W$$

Q_{rn} is the approximate distance between the receiver and the second n satellite. $(\hat{X}, \hat{Y}, \hat{Z})$ are the approximate azimuth coordinates of the receiver for each solution. $\Delta X, \Delta Y, \Delta Z, \Delta\sigma W$ is the displacement concerning the four unknowns. Convert all (2.3) to (2.4) and represent it with a matrix table

$$Q_r = \varphi H$$

$Q_r = \left[\begin{array}{llll} Q_{r1} & Q_{r2} & \cdots & Q_m \end{array}\right]^T H = \left[\begin{array}{llll} \Delta X & \Delta Y & \Delta Z & \Delta\sigma W \end{array}\right]^T, \varphi$ is the coefficient matrix, specifically

$$\varphi = \left[\begin{array}{cccc} \frac{X_{r1}-X}{S_{r1}} & \frac{Y_{r1}-Y}{S_{r1}} & \frac{Z_{r1}-Z}{S_{r1}} & -1 \\ \frac{X_{r2}-X}{S_{r2}} & \frac{Y_{r2}-Y}{S_{r2}} & \frac{Z_{r2}-Z}{S_{r2}} & -1 \\ \vdots & \vdots & \vdots & \vdots \\ \frac{X_{mn}-X}{S_m} & \frac{Y_m-Y}{S_{rn}} & \frac{Z_{rn}-Z}{S_m} & -1 \end{array}\right]$$

Due to the interference of atmospheric transmission time delay and multipath effect, the position accuracy of pseudo distance positioning will decrease when the least square algorithm fixes the measured value.

2.2. System Design. This project relies on the national "Beidou" navigation and ground combined navigation technology to carry out high-precision differential positioning of multiple wobbler points in an extensive range (Figure 2.2 quoted in Journal of Revisualization and Spatial Analysis, 2020, 4:1-12.). Grasp the real-time information on wire swaying waveform, swaying amplitude, swaying ellipse Angle, and swaying frequency. The position information of each wobbly satellite is transmitted in real-time [10]. At the same time, combined with the field environment, it is dynamically adjusted in real-time to achieve the purpose of real-time detection and alarm of the security risk of the power grid. The obtained results will be pushed to the monitoring and early warning application center and related monitoring terminals.

The oscillating monitoring equipment based on Beidou is adopted. At the same time, it is integrated with the sensing equipment installed in the equipment to realize the online monitoring of multiple signal sources [11]. Through the public network communication module in the equipment, the obtained information is uploaded to the solution business platform of the "Beidou" ground enhancement system. Using the PPK solution, each observation point's X, Y and Z coordinates in vertical coordinates are dynamically post-processed. The corresponding road map is given, combined with the historical data of each monitoring point [12]. The heave curve's response equations of X, Y and Z coordinates are established, and spectral analysis is carried out.

2.3. System Communication. With the support of the Beidou application terminal, SMS transceiver, mobile communication terminal, emergency communication server and emergency communication service platform software, each component realizes the sending and receiving of Beidou short messages and mobile short messages under the support of the system network of Beidou Communication and mobile communication. The system architecture is shown in Figure 2.3 (image cited in Satellite Navigation, 2020, 1:1-23).

Beidou handheld/vehicle terminal equipment is used for people/vehicles to move in and out of specific areas. The "Beidou" system is used as the command terminal to provide support for communication support in emergencies. The RDSS link is used to realize short message communication between Beidou mobile phone/car users and Beidou command clients. Short message sending and receiving is a communication device with mobile phone short message sending and receiving, which can send and receive short messages to the mobile communication terminal through the communication base station. In an emergency, the mobile phone short message sending and receiving device is configured in the emergency communication support center [13]. The system is mainly used to manage the user terminal and short message-receiving device in the Beidou system and realize the system's data transmission and address transmission.

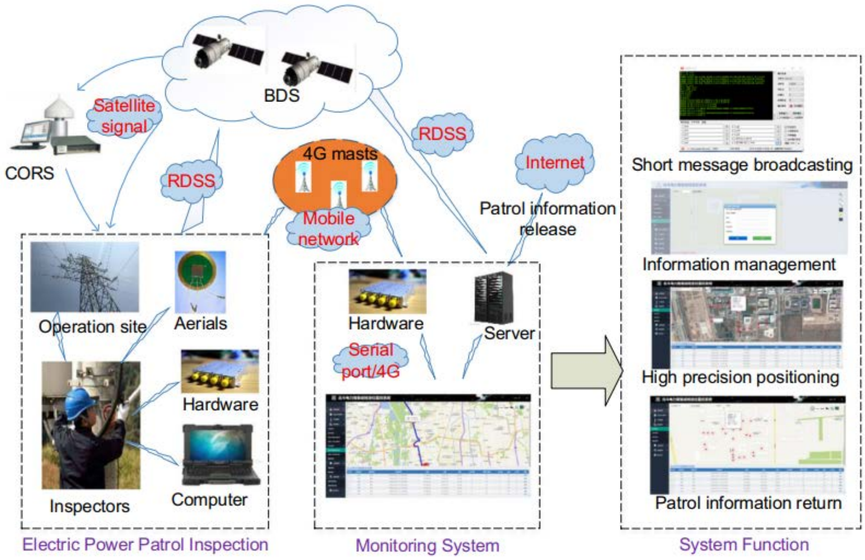

Fig. 2.2: *Structure of BDS swing monitoring system.*

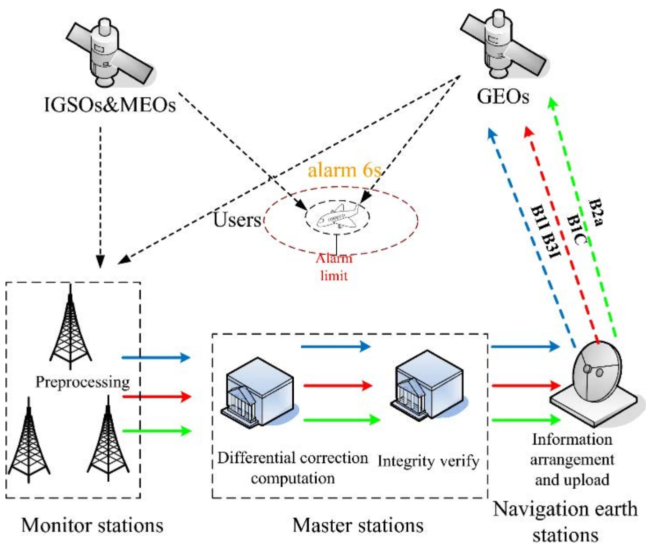

Fig. 2.3: *Structure of the Beidou communication system.*

3. Data processing methods. When the wire is affected by ice or wind force, the wire will have a sizeable self-excited vibration at low frequency. A small swing from the equilibrium position will eventually produce an increasingly sizeable elliptical orbit dominated by lateral and longitudinal orbits. When the wire does not shake the phenomenon, the system will use the position, acceleration and other related data statistics to determine whether the system is balanced. The ”Beidou” system and the sensing system are used to collect the position information of each measuring point in real-time and convert it into discrete values. By comparing the change values of Beidou high-precision coordinates in continuous periods, the change difference values of each observation point on the corresponding axis are obtained [14]. Plot the sway trajectories of the monitoring points. The sloshing rate of the wire can be obtained by differentiating the displacement data by the first

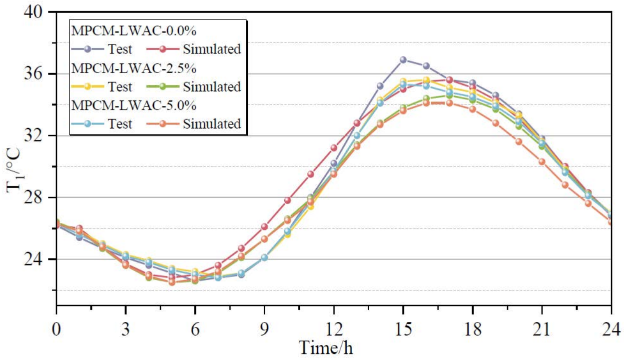

Fig. 4.1: *ENU coordinate change curve of simulation test.*

difference method. Further, the pendulum acceleration of each measuring point is obtained. Set the horizontal movement direction of the wire to the x direction and the vertical movement direction to the y direction [15]. Then, based on the change of the coordinates before and after each direction, the displacement along the direction is obtained, and the calculation method of the velocity and acceleration in each direction is obtained:

$$C_{x(t)} = \frac{s\left(X_t - X_0\right)}{dt}$$
$$\gamma_{x(t)} = \frac{\frac{s(X_t - X_0)}{dt} - C_{x_0}}{dt}$$
$$C_{y(t)} = \frac{s\left(Y_t - Y_0\right)}{dt}$$
$$\gamma_{y(t)} = \frac{\frac{s(Y_t - Y_0)}{dt} - C_{y_0}}{dt}$$

where X_0, Y_0 is the coordinates of each monitoring point in the x direction and Y direction at the previous time. X_t, Y_t is the coordinate of the measuring point in the X and Y coordinates after time t. Where C_{x_0}, C_{y_0} is the velocity of the time before the monitoring point. Under the initial conditions, its speed is zero. $\gamma_{x(t)}, \gamma_{y(t)}$ is the value of the acceleration of the measuring point in both directions X and Y. Then, based on the high-precision differential positioning of the Beidou satellite, this paper obtains parameters such as the trajectory, amplitude, vertical amplitude and horizontal frequency of sway through the simulation analysis of sway.

4. Application testing. A 500 kV power line tower simulation test system is established. The research results show that using Beidou navigation technology for transmission line sway detection has high accuracy and practicability. Install the swing monitoring device on the top of the tower. The observation data of Beidou have been accepted by the shaking detector in the field test site, and the condition is good. In this project, the initial observation data of the wobbly monitoring equipment were established on board, 1-second sampling was adopted, and Beidou B1 was used as the receiver frequency. In this way, the measured data at every moment are transmitted in real-time to the fixed platform of the Beidou ground-enhanced positioning system. Through the data exchange with the ground data server, the "Beidou" observation data near the reference station of the swing monitoring network are verified. The Beidou satellite navigation positioning and solving platform monitors the real-time ground sway. After dynamic post-processing under the PPK model, each measurement's X, Y and Z coordinates are obtained. The velocity and acceleration curves of each measuring point are obtained after testing. Figures 4.1, 4.2, and 4.3 show the values of the coordinates, velocity, and acceleration differences over different periods.

A total of 357 pieces were tested. After systematic processing, the definite number of dynamic post-processing was obtained for 355 pieces, and the ratio of the definite number of dynamic post-processing to the

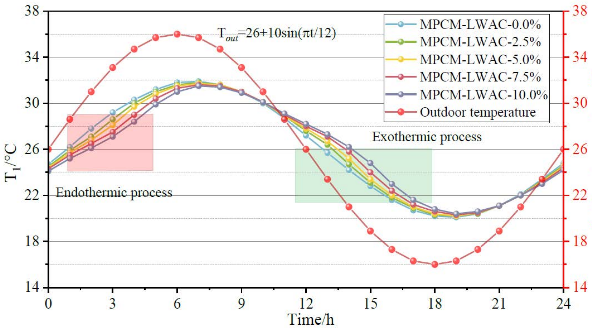

Fig. 4.2: *Speed change curve of simulation test.*

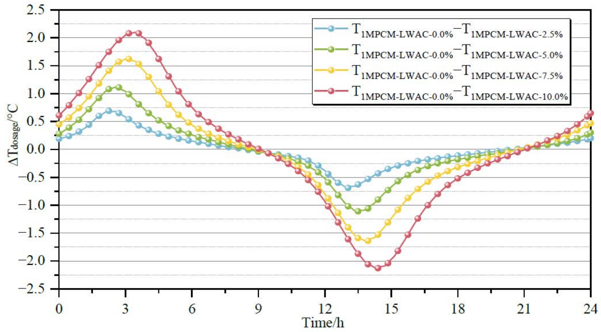

Fig. 4.3: *Acceleration change rule in simulation test.*

number of outputs was 99.44%. The internal consistency accuracy error (Table 4.1) is calculated for data with coordinate change values, velocity and acceleration i $\sigma_i = \sqrt{\frac{\sum \Delta_i^2}{n-1}}$. Where σ_i is the internal consistency of each component, and Δ_i is the calculated value and average difference of each component. n is the actual observed quantity of each component.

At the same time, the system can also quickly obtain high-precision motion speed, acceleration and other parameters to meet the needs of transmission line sloshing detection. The calendar has a total of 2511 elements. By analyzing the system, 2511 definite solution values were obtained after dynamic post-processing, among which the ratio of the number of definite solutions after dynamic post-processing to the total number of iterations reached 99.47%. Several monitoring points were sampled. The MATLAB software was used to analyze the horizontal and vertical displacement data of each measuring point measured at each time, and the corresponding dance traces were fitted. The fitting results show that the vibration amplitude is 0.66 meters.

5. Conclusion. This paper introduces a new idea of real-time monitoring of power line swing by using Beidou satellite positioning technology. This method can improve swing detection and monitoring of transmission lines. The research results of this project will lay the foundation for the realization of real-time monitoring and intelligent analysis of big data of the whole network under space reference. The threshold of the power cable is adjusted individually using the existing history data. The research scheme proposed in this project can adapt to the safety monitoring requirements of power systems for transmission lines. This system has a high reference significance.

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Table 4.1: *Results of accuracy calculation following.*

Precision value	Accurate in the X direction	Match accuracy in the Y direction	Accurate in the Z direction
Coordinate accuracy /m	0.0093	0.0078	0.0188
Velocity accuracy $/(\mathrm{m} \cdot \mathrm{s}^{-1})$	0.0049	0.0053	0.0079
Acceleration accuracy $/(\mathrm{m} \cdot \mathrm{s}^{-2})$	0.0066	0.0056	0.0072

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