Data Processing Methods for the FAST Active Reflector Health Monitoring System: Research and Application (Postprint)

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Abstract

Based on the multi-sensor measurement points and massive monitoring data from the FAST active reflector health monitoring system, a data processing method is proposed to handle the temperature, stress, wind speed, cable force, and other data collected by the system. Polynomial regression is employed to analyze data correlations and identify the influence of temperature gradient on stress. The proposed data processing method is utilized to analyze the correlations among ring beam structural stress, cable force, and temperature under different working conditions. The analysis results demonstrate that ring beam structural stress is significantly correlated with temperature; during the cable net non-displacement period, ring beam structural stress is primarily influenced by temperature, whereas during the cable net displacement period, it is primarily influenced by cable force. Through data processing, the main factors affecting structural internal forces can be identified, and the effect of temperature variation on stress can be effectively separated, providing data support for subsequent operation and maintenance.

Full Text

Research and Application of Data Processing Methods for the Health Monitoring System of FAST' s Active Reflector

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Abstract

Based on the multi-sensor measurement points and massive monitoring data from the health monitoring system of FAST' s active reflector, this paper proposes a data processing method to handle collected temperature, stress, wind speed, and cable force data. Polynomial regression is employed to analyze data correlation and identify the influence of temperature gradients on stress. The proposed method is applied to analyze correlations among ring beam structural stress, cable force, and temperature under different operating conditions. Results demonstrate that ring beam structural stress is significantly correlated with temperature, being primarily temperature-dependent during periods when the cable net remains unchanged, while mainly influenced by cable force during cable net repositioning. Through data processing, the main factors affecting structural internal forces can be identified, and the effect of temperature variation on stress can be effectively separated, providing data support for subsequent operation and maintenance.

Keywords: FAST engineering; health monitoring; data processing; correlation analysis

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1. Introduction

The Five-hundred-meter Aperture Spherical Radio Telescope (FAST) is a large spherical radio telescope with a 500-meter aperture, representing a major national scientific infrastructure project during China' s Eleventh Five-Year Plan period. Upon completion, it will become the world' s largest single-aperture spherical radio telescope [1]. The telescope' s active reflector system consists of a ring beam, main cable network, ground anchors, and other components. The cable network is installed on a lattice-column-supported ring beam, comprising 4,450 reflector units, with each node connected to a downhaul cable and actuator [2]. The actuators connect to ground anchors, forming a 300-meter illumination aperture instantaneous paraboloid through actuator control for astronomical observations [3]. To ensure operational safety, the reflector system is equipped with sensors and data acquisition equipment at approximately 2,300 cable network nodes for long-term monitoring of ring beam and cable network stress, cable force, and other parameters.

2. Health Monitoring System Composition

The health monitoring content for FAST' s active reflector includes four main components [4]: (1) Structural key member internal force monitoring (lattice column strain, ring beam strain, and main cable force), (2) Structural overall deformation monitoring (ring beam deformation and node spatial position), (3) Environmental monitoring (wind speed, temperature), and (4) Actuator monitoring (actuator oil temperature, position information). Strain measurement points are arranged at the ring beam supports corresponding to the main cable network' s main rib region and the center of each sector, specifically on the four inner horizontal tie rods and four inner column limbs at the base. Ring beam strain measurement points are located at inner and outer supports of ring beam sections corresponding to lattice columns in the main rib region and sector centers, as well as on two lower chord ring members at the supports and two at mid-span. Cable force measurement points are placed on 20 edge main cables with large stress variation amplitudes and significant baseline stresses.

3. Data Processing Methodology

3.1 Data Processing Flow

The raw data collected by the health monitoring system consists of time-distributed data sequences at set sampling frequencies, enabling time-domain analysis. The processing flow includes:

1. **Reliability Verification**: Environmental noise and random interference during data acquisition, conversion, and transmission may cause anomalies. The 3 criterion is applied to identify and eliminate outliers, with Lagrange interpolation used for substitution.
2. **Statistical Analysis**: After preprocessing, time-history curves are plotted for trend statistics and characteristic analysis, comparing data against design thresholds to trigger alerts when exceeded.
3. **Correlation Analysis**: Following statistical analysis, correlation degrees between parameters are analyzed. MATLAB is used to establish regression models for large datasets, quantitatively describing explicit relationships between characteristic quantities [5]. Multiple parameters in FAST' s active reflector system can be analyzed, such as temperature-stress relationships, temperature-cable force relationships, and wind load-ring beam stress relationships.

3.2 Reliability Verification Using 3 Principle

The 3 principle, based on statistical theory, is widely applied in engineering. The criterion is expressed as:

$|x - \bar{x}| > 3$

When data x satisfies this condition, it is identified as an outlier and removed. After elimination, the mean and standard deviation are recalculated, and the process repeats until no outliers remain [6]. This ensures reliable monitoring data for subsequent analysis.

3.3 Statistical Analysis of Monitoring Data

Time-history analysis reveals variation patterns along the temporal axis. Representative temperature measurements from ring beam sections in April (clear skies) and May (cloudy to clear) show temperature differences of 5–6°C across sections. Therefore, temperature effects can be simplified by considering uniform temperature changes without accounting for inter-section temperature differential stresses.

Stress and temperature diurnal variation curves for the ring beam section corresponding to the #36 lattice column demonstrate similar trends. From 0:00–6:00, decreasing temperatures cause ring beam chord stress reduction; from 6:00–12:00, rising temperatures increase stress; afternoon temperature recovery further increases stress. Statistical analysis confirms that ring beam stress is significantly temperature-affected, though other factors also contribute.

3.4 Correlation Analysis

3.4.1 Correlation Coefficient Definition To monitor how different factors affect structural stress, the system employs various sensors. Correlation analysis determines influence degrees. For sensor data sequences X = [X , X , X , ···, X] and Y = [Y , Y , Y , ···, Y], each sampled n times, the correlation coefficient is defined as [7]:

$$r = \Sigma(x\ \ - \bar{x})(y\ \ - \bar{y}) \ / \ \sqrt{}[\Sigma(x\ \ - \bar{x})^2\ \Sigma(y\ \ - \bar{y})^2]$$

where $\bar{x}$ and $\bar{y}$ are the means of sequences X and Y. For nonlinear correlation, the Spearman rank correlation coefficient can be used [8], with -1 r 1.

3.4.2 Regression Model Establishment Statistical analysis shows ring beam stress is significantly temperature-dependent. To further quantify this relationship, scatter plots of temperature versus stress data reveal strong correlation with an approximately quadratic relationship. A quadratic polynomial regression model is established:

$$y = \ \ + \ \ x + \ \ x^2 +$$

where x represents temperature, y represents stress,   are coefficients, and   is error. Using data from monitoring point 36#-1, the regression model yields:

$y = 0.078x^2 - 2.89x - 12.56$, with $R^2 = 0.9124$, confirming model validity.

3.4.3 Temperature Stress Separation Ring beam structural stress comprises: (1) dead load stress (_D) from reflector unit and cable net self-weight, (2) temperature stress (_T), (3) working load stress (_W) during cable net repositioning, and (4) random load stress. Total stress at any point is:

 = _D + _T + _W

Given significant temperature effects, separating temperature stress prevents masking stress changes during cable net repositioning, enabling accurate live load safety assessment. Assuming a linear temperature-stress relationship based on steel arch rib material properties:

_T = a (T - T)

where T is measured temperature, T = 20°C is design temperature, and a are fitting coefficients determined by least squares regression. Temperature stress _T is calculated and subtracted from total stress , then moving averaging is applied to the remaining data to eliminate random load effects and obtain _D + _W. During periods without reflector repositioning (_W = 0), _D is obtained directly.

For monitoring point 36#-1, temperature stress shows strong correlation with total stress (correlation coefficient = 0.8120). After separation, moving averaging (n = total measurement count) effectively isolates dead load stress.

4. Engineering Application

4.1 Correlation Analysis in Cable Net Tensioned State

Using ring beam stress as the research object, correlation analysis is performed during cable net tensioning (April 16). For monitoring point 36#-1, correlation coefficients with adjacent sensors are calculated. The highest correlation (0.73525) occurs with cable force sensor 221-E379-E501, indicating cable force is the primary factor affecting ring beam stress during tensioning, with temperature having secondary influence.

4.2 Correlation Analysis in Cable Net Untensioned State

During the untensioned spherical state (May 14), analysis of the same monitoring point shows correlation coefficients of 0.914 with temperature sensor 70-36#-1, 0.821 with cable force sensor 221-E379-E501, and 0.196 with other sensors. This demonstrates temperature is the dominant factor affecting ring beam stress when the cable net is not repositioned.

4.3 Wind Load Analysis

Beyond temperature and working loads, environmental factors like wind can affect large structures. Field wind measurement provides effective wind characteristic data. At the ring beam elevation plane in the #36 lattice column region, wind speed was measured and statistically analyzed using 5-minute average values from 11:00–17:50. The average wind speed was 2.27 m/s, with a maximum 5-minute average of 4.4 m/s.

Scatter plot analysis of wind speed versus stress shows weak correlation (R^2 = 0.1024), indicating wind load has minimal effect on ring beam structural stress at the FAST site.

5. Conclusions

Based on multi-sensor measurement points and massive monitoring data from FAST' s active reflector health monitoring system, this paper proposes a data processing flow and method that:

1. Effectively processes temperature, wind, and cable force data using polynomial regression for correlation analysis, establishing explicit temperature-stress relationships.
2. Separates temperature effects from total stress using least squares regression and moving averaging, providing a foundation for strain statistical analysis.
3. Demonstrates through engineering application that:
    - Ring beam structural stress is significantly correlated with temperature
    - During cable net repositioning, cable force substantially influences ring beam stress and requires focused monitoring
    - During static periods, temperature is the primary factor affecting ring beam stress
    - Wind load has minimal impact on ring beam structural stress

The data processing method provides valuable reference for operation and maintenance of FAST' s active reflector system and offers insights for similar structural health monitoring systems.

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Note: Figure translations are in progress. See original paper for figures.