A Study of Anomaly Detection and Prediction of High-tension Bolts by Strain Measurements on Tower Shell

Yuka Kikuchi, Takeshi Ishihara
The University of Tokyo

PO.290

Introduction

In 2013, the nacelle fell from the tower at Taikoyama wind farm in Japan due to the fatigue failure of high-tension bolts on flange. Axial force reduction lead their drastic short fatigue life. And so, detecting axial force reduction of high-tension bolts is needed to prevent accident recurrence.

Currently, ultrasonic testing once a month and torque-tension test once a three months are performed for bolts with high-labour cost. In this study, anomaly detection and prediction method by using strain data on tower shell was investigated.

Measurement

On-site measurement was conducted on No.1 turbine at Taikoyama wind farm in order to clarify the sensitivity of strain data on bolt’s axial force reduction. The measurement was conducted during Feb. 2nd to 5th in 2015. Five bolts No.21 to No.25 were chosen from 60 bolts, located at the opposite site of dominant west wind direction. Strain gauges were attached at three different layers to clarify its sensitivity on No. 23 bolt’s axial force reduction.

It was found that the measured strain data was sensitive to No. 23’s bolt damage as the following figures showed.

When bolt axial force was zero, the strain changed 100 με in compression side at 20 mm below No. 23 bolts. And the both side bolts showed strain difference in tensile side. The sensitivity of strain became half at 100 mm below bolts.

The strain difference increased as bolt’s axial force decreased and it showed almost same values below 50% reduction of axial force.

Numerical model

The numerical tower model was built up by FEM to evaluate strain data in bolt’s damage condition. Yaw brake, ball bearing and pinion gear were precisely modelled. The predicted strain had a good agreement with measured one.

Anomaly prediction

Axial force prediction equation was derived by using MT method. Predicted axial force had a good agreement with measurements.

Anomaly detection

Two anomaly detection methods were applied. The thresholds were evaluated by using numerical model constructed above. Both methods succeeded in anomaly detection.

- Hotelling’s T2 theory for each strain
  - Anomaly score is evaluated by: \[ a(x') = \frac{(x' - \mu)^T S^{-1} (x' - \mu)}{1 - \alpha} \]
  - Threshold is evaluated by F distribution: \[ 1 - \alpha = \frac{1}{F} \int dx x^2 \cdot p(M,x) \]

- MT method for pattern of strains
  - Strain change distribution of five bolts were represented into two variables: Y1 and Y2. Mahalanobis distances of the two variables were evaluated as anomaly score from health condition. 3σ of anomaly score of normal condition was defined as threshold.

Conclusions

Anomaly detection and prediction method of high-tension bolts were proposed by using strains on tower shell. Conclusions are summarized as follows.

1) Onsite measurement was conducted and it was found that strains on tower shell is sensitive to bolt axial force reduction.
2) Numerical tower top model was developed and validated with measurement data. Thresholds evaluated by numerical model succeeded in anomaly detection of bolts.
3) By using predicted strains by numerical tower top model, axial force prediction equation is evaluated. Predicted axial force agreed well with measured one.

References