Smart Installation and Monitoring System for Large Anchor Bolts of Support Structures for Highway Signs, Luminaries and Traffic Signals (SLTS)

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Iowa State University
Outline

- Backgrounds
- Concept
- Design
- Sensor system testing in laboratory
- Future plans
- Product pay-off potential
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Backgrounds

- Loose nut has been a major problem for all SLTS structures in the past decades
- Currently there are very few techniques that could detect the loose nuts efficiently
- The cost for inspection and maintenance performed by state DOTs is overwhelming, the labor has been stretched thin
Outline

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Concept

- A capacitor-based sensor system connected with wireless data transmission
- The cost of inspection will be significantly reduced
- The inspection crew will no longer have to get off the vehicle to perform inspection
Concept

- The capacitance is calculated by a simple equation

\[ C = \frac{\varepsilon A}{d} = \frac{k\varepsilon_0 A}{d} \]

- Where: C is capacitance, k is the relative permittivity of the dielectric material between two parallel plates, \( \varepsilon_0 \) is the dielectric constant (8.852 \( \times \) \( 10^{-12} \) F/m), A is the area of the plates, and d is the gap distance between the parallel plates
- The relationship between gap distance and capacitance will be the core parameters
- The change of gap distance will reflect on the change of capacitance, thus the movement of nut will be detected
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Design

- The system consists of two major parts:
  - Sensor

- Data acquisition and transmission
Design

- Sensor
  - Top composite washer
    - DTI washer
    - Glass Fiber Reinforced Polymer (GFRP) ring
    - Copper ring
  - Bottom composite washer
    - Middle spacing washer
    - Glass Fiber Reinforced Polymer (GFRP) ring
    - Copper ring
    - Bottom plain washer
  - Dielectric material
    - Neoprene rubber ring
Design

• Sensor
  • As the tightening process goes on, the nut will compress the sensor system, the protrusions at the bottom of the DTI washer will be gradually flattened, causing the decrease of gap distance in the middle and increase of capacitance
Design

- Data acquisition and transmission
  - “Tagboard”
    - Rectifier circuit
    - Voltage regulator circuit
    - Measurement circuit (including microcontroller)
Design

• Data acquisition and transmission
  • The capacitance is measured by measurement circuit, then processed through microcontroller, the output is the frequency, which can be interpreted to capacitance again by using the equation:

\[ C = \frac{f}{10 \times 10^6 \times \ln(9)} \]

  where \( C \) is capacitance and \( f \) is frequency

  • After the data is processed by microcontroller, the signal will be sent out via the antenna, and received by a handheld receiving device (still under development)

  • Comparing with the calibration curves, the inspection crew will learn about the real time status of the anchor bolts
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Sensor System Testing in Laboratory

• The testing consists of two major stages
  • The first stage of the testing is to prove the concept at the component level
    • Compression tests on MTS compression system
    • Tightening tests on Skidmore Wilhelm tension testing system and single anchor bolt
  • The second stage of the testing is to prove the concept at the structure level, and get prepared for the future demonstration and implementation
    • Static tests on sign structure
    • Fatigue tests on sign structure
Sensor System Testing in Laboratory

- Compression tests on MTS compression testing system
  - To simulate the tightening and loosening process, and develop a calibration for testing on single anchor bolt
  - Agilent 4263B LCR meter is used for capacitance measurement to ensure the accuracy for calibration
  - Sensors for 2-1/2” and 2-1/4” anchor bolts are tested
Sensor System Testing in Laboratory

- The testing results on MTS shows that the performance of the sensor meets the expectation.
Sensor System Testing in Laboratory
Sensor System Testing in Laboratory

• The testing results are about 10% off of the calculation, the possible causes are:
  • The limitation during manufacturing of the sensors
  • Fragile connection
  • Temperature

• The results from MTS testing gives part of the reference for the testing on single anchor bolt
Sensor System Testing in Laboratory

- The testing on single anchor bolt
  - For single anchor bolt, the testing is performed on Skidmore Wilhelm tension testing system
Sensor System Testing in Laboratory

- The testing results on single anchor bolt remain consistent with the results from MTS testing
Sensor System Testing in Laboratory

- The curve for single anchor bolt reaches further than MTS is because of the maximum load on MTS is 100 kips
Sensor Testing in Laboratory

- The capacitance trend between MTS results and single anchor bolt results share the same trend, even though the difference exists.

- The MTS testing results could only give reference for single anchor bolts with tension of 100 kips or less, but the calculation and the trend could give an idea of how the capacitor will perform when the load is beyond 100 kips.

- The results from MTS and single anchor bolt have proven the concept of the sensor part of the system.

- When the tension inside the anchor bolts drops (the nut loosens), the change of capacitance will be significant.
Sensor Testing in Laboratory

- When implementing the “Tagboard”, the measurement error comparing with Agilent 4263B is huge, this is due to:
  - Limitation of manufacturing
  - The capacitor is grounded
  - The disturbance from the environment

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</table>
Sensor Testing in Laboratory

- Currently there are two options regarding to the “Tagboard”:
  - Improvement of “Tagboard”
  - Search for a similar product on the market (PCap04) and test its feasibility
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Future Plans

- Static and fatigue testing at structural level
  - Apply sensors on the sign structure specimen that cover at least half of the numbers of anchor bolts
- Improvement on “Tagboard”
- Explore alternative for “Tagboard”
- Development of wireless transmission
- Development of packaging design printing that has better insulation
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Product Pay-off Potential

- Provides an economical way to perform the inspection of loose anchor bolts
- Loose nut can be found in time and prevents the collapse of sign structures
- Easy to install
- With proper modification, it is possible that the system can be applied to any bolted connections
QUESTIONS?
THANK YOU!