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Electrochemical Fatigue Sensor Demonstration on the Steel Bridge at FAST

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Summary

Engineers from Transportation Technology Center, Inc. (TTCI) and Material Technologies, Inc. (MATECH) recently demonstrated a new nondestructive evaluation technology on the steel bridge at the Facility for Accelerated Service Testing (FAST). The Electrochemical Fatigue Sensor (EFS) system was used to detect growth activity in 13 cracks in the bridge.

The EFS system indicated crack growth in several existing cracks in the steel bridge. Long-term visual and ultrasonic monitoring of these cracks over 800,000 additional load cycles showed that:

- Of eight cracks indicated by the EFS not to be growing, only one has shown growth in 800,000 cycles. That crack did not show growth in the first 600,000 cycles after EFS testing.
- Of five cracks indicated by the EFS to be growing, four have shown visible growth. The other is a large crack that shows some variability in size based on frequent measurements using ultrasonic testing.

Other observations include:

- The EFS system can be readily set up for testing on a railroad bridge.
- At this point, the EFS system simply indicates the presence or absence of crack growth activity.
- Due to the step-like character of crack growth in this bridge,[1,2] a short-term measurement during a dormant period might miss crack growth that could resume in the future.

Further development work is progressing on two issues:

- Calibration of the system to provide a growth rate, rather than simply indicating growth activity
- Development of long-term monitoring capabilities in order to determine average growth rates over extended periods of time

With these further developments, the EFS could become a viable tool for use in railroad applications to help prioritize and verify the success of maintenance and replacement work.

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INTRODUCTION

MATECH and TTCI recently demonstrated the EFS system on the steel bridge at FAST. At 15 locations on the bridge, the EFS system was installed at visually identifiable cracks or at control locations without cracks. Previous testing of cracks in the steel bridge included using acoustic emission (AE) and ultrasonic testing (UT) technologies.[1-4] The EFS system indicated that at 5 of the 15 locations tested cracks were continuing to actively grow.

DESCRIPTION OF ELECTROCHEMICAL FATIGUE SENSOR TECHNOLOGY

EFS is a nondestructive fatigue crack inspection system. Specifically, EFS is a method used to indicate if fatigue cracks are actively growing. During an EFS inspection, a sensor is applied to each location of interest. Crack activity detection occurs for areas under the sensor. Because the EFS system is designed to detect crack growth activity while it is occurring, data collection is done while a train is passing over a bridge.

The EFS system consists of an electrolyte filled sensor, a potentiostat that applies a constant polarizing voltage between the structure and the sensor, and data collection and analysis software.

The EFS system works on fundamental electrochemical principles. During testing, the inspection area is electrically polarized to create a protective, passive film on the area of interest. When the structure being inspected undergoes a cyclic stress, the current flowing within the cell fluctuates in a complex relation to the variation of the mechanical stress. Dependent upon the structural material, the loading conditions, as well as the state of the fatigue damage in the structure, the transient current within the cell provides information on the status of the fatigue damage.

As fatigue damage develops, cracks induce localized plasticity during different times in the fatigue cycle, and in locations where cracks have not yet formed. Crack-induced plasticity introduces higher harmonic components into the transient EFS current. It is the analysis and calibration of these various current components that allows determination of whether a growing crack is present.

The EFS system uses two sensors, one as the reference (R) and one as the crack measurement (CM) sensor. The two sensors are both installed near the location of interest. The CM sensor is specifically located over the area to be inspected, whereas the R sensor is located a short distance away from the CM sensor where a crack is not probable. Using signal processing, the two signals are compared to determine if a crack is present.

HARDWARE

The EFS hardware system consists of three major components: the sensor, the electrolyte, and the potentiostat data link (PDL).

As Figure 1 shows, the basic EFS system consists of several parts. Each sensor has a contact adhesive on one side for attachment to the structure. The open area in the middle of the sensor holds an electrolyte. The sensor is filled with electrolyte through the lower filler tube while air escapes out of the upper bleeder tube. The sensor electrode is sandwiched between the upper and lower sensor sections. When the sensor is filled with electrolyte, the electrode is completely covered. Depending on the area to be tested, sensors can be custom-made to fit virtually any 3-dimensional geometric requirements (including size, shape, and orientation).

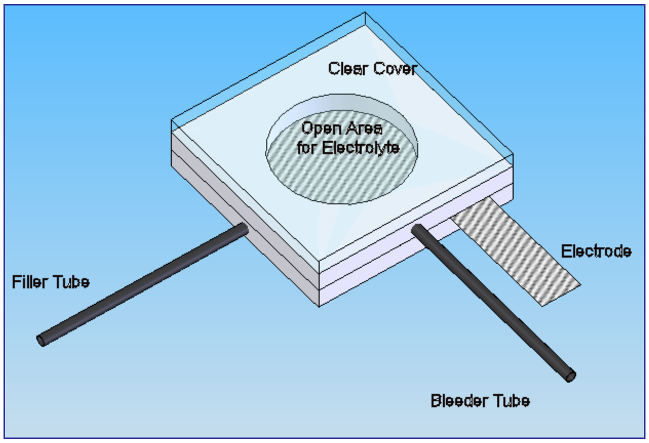

Figure 1. Drawing of an EFS System

The EFS electrolyte is a proprietary, water-based solution that has been tested on multiple materials including aluminum, titanium, copper, and steel. The EFS electrolyte has been tested and found to be benign to metals and did not cause premature failure or influence the fatigue life.[5-8]

The EFS PDL controls the voltage and measures the current flow between the working and reference electrodes. The PDL, shown in Figure 2, provides all of the features necessary to collect data in the field and to interface with a data collection computer.

Figure 2. PDL and Sensors Installed at Location MT 16

TEST DETAILS

The bridge at FAST consists of two open deck, all welded steel deck plate girder spans. Over 35 cracks of various sizes, locations, and configurations currently exist in the bridge. Testing was conducted during normal train operation, with a 65-car loaded unit train operating at approximately 40 mph. Testing did not impact normal train operation.

Sensor Locations

Sensors were located at several locations on both spans of the bridge. The inspection locations are designated as MT 1 through MT 19. MT 6, MT 9, MT 10, MT 11 and MT 17 were not tested. Thirteen of the locations had known visible cracks. The remaining inspection locations were in areas where cracks were not known or visibly present, but corresponded to locations of known cracks in similar geometric details elsewhere on the bridge. At all locations, the two sensors (i.e., the CM and R sensors) were installed close to one another (see Figure 3) with the CM sensor located directly over the specific area of interest.

Two, essentially side-by-side, locations (MT 16 and MT 16R) on the bottom flange of girder 1 near the midspan were inspected. The CM sensor at MT 16 was located directly over a large crack within the bottom flange that was approximately perpendicular to the longitudinal bridge axis. Location MT 16R was directly beside location MT 16 but was not located over a crack. The data for MT 16R was collected to compare a growing crack with a nongrowing crack (once the growing crack had been initially identified). The CM sensor at location MT 16 has the characteristics of a growing crack when compared to the R sensor (both with the multiple harmonics and general magnitude). In comparison, at location MT 16R, the magnitudes of the CM sensor data and the R sensor data are very similar both in the time domain and frequency domain, indicating that no growing crack is present.

Follow-up EFS testing in March 2007 indicated that this crack was no longer growing. The previous test was conducted in May 2006. Ultrasonic testing of this crack over several years has shown fluctuations in size on the order of 10 percent. This may be due to temperature effects as well as measurement error.

RESULTS

After data collection, the data was examined and analyzed using the custom EFS system software to determine crack growth activity. The software consists of frequency and time domain based algorithms used to analyze and parse the data. Multiple datasets from each location were examined to determine specific results.

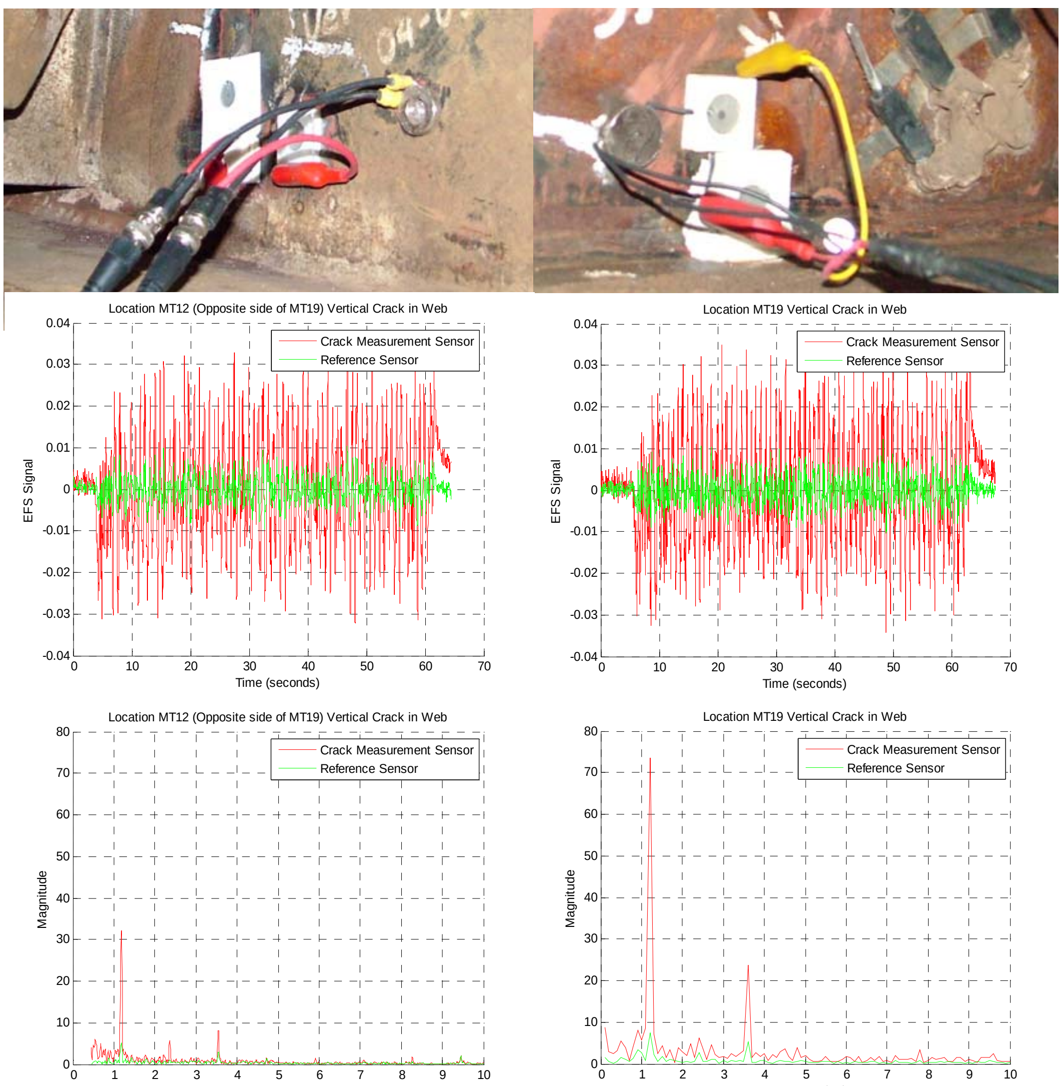

Figure 3. Results from Locations MT 12 and MT 19

The EFS data indicated that five of the fifteen bridge locations have cracks that are growing (see Table 1). Figure 3 shows the specific data with associated photographs of the inspection locations for two locations on the FAST steel bridge with growing cracks.

Table 1. Tabulated Results from 15 Inspected Locations

Inspection Location	Visible Crack	EFS Crack Status	Visual Inspection After 800,000 Cycles
MT 1	Yes	Not Growing	Not Growing
MT 2	Yes	Not Growing	Not Growing
MT 3	Yes	Not Growing	Not Growing
MT 4	Yes	Not Growing	Not Growing
MT 5	Yes	Not Growing	Not Growing
MT 7	Yes	Growing	Growing
MT 8	Yes	Not Growing	Recent Growth
MT 12	Yes	Growing	Growing
MT 13	Yes	Not Growing	Not Growing
MT 14	Yes	Not Growing	Not Growing
MT 15	No	No growing crack	No growing crack
MT 16	Yes	Growing	No Visible Growth
MT 16R	No	No growing crack	No growing crack
MT 18	Yes	Growing	Growing
MT 19	Yes	Growing	Growing

Cracks at locations MT 12 and MT 19 are back-to-back sides of a through crack growing vertically from the bottom flange of girder 1 in the short span of the steel bridge near the center pier. The EFS data for these two locations indicate that both of these cracks are growing. One indication that the cracks are growing is the presence of the higher order harmonics shown in Figure 3. The crack at location MT 19 appears to be much more active (i.e., the crack at MT19 is growing faster than the crack at MT12), as shown by the relative magnitudes of the higher order harmonics

LONG-TERM MONITORING

The crack locations tested with the EFS were monitored for a period of over 125 MGT (over 800,000 load cycles) to measure crack growth over a longer period of time. The long-term crack measurements were compared to the EFS measurements in an effort to validate the EFS results.

Table 1 summarizes the comparison between the EFS and visual inspection after 800,000 cycles. Note that in 4 of 5 cases where crack growth was measured visually, it was also noted by the EFS. The one case missed by the EFS showed no visible growth through inspections up to 600,000 cycles after the EFS reading. Only within the most recent 200,000 cycles did the crack grow visibly.

Note also that at one crack location, the EFS indicated the presence of crack growth activity, but no crack growth has been measured visibly or using ultrasonic testing. This may be due to the high sensitivity of the EFS (10^{-9} inches per cycle), as claimed by the manufacturer. Even with 800,000 cycles accumulated, the crack growth could be less than 0.001 inch. Depth of crack MT 16 can only be measured with ultrasonic equipment, which is not sensitive enough to detect such a small change in crack size. Also note that previous studies showed crack growth occurred in a step-wise fashion.[1,2] Development of long-term EFS monitoring equipment would enable the system to capture such changes in crack growth rates.

Acknowledgement

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