U.S. Department
Of Transportation

**Federal Railroad
Administration**

Research
Results

**RR08-12
July 2008**

Electrochemical Fatigue Sensor Demonstration on the Steel Bridge at the FAST

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) in Pueblo, Colorado. The system demonstrated is called the Electrochemical Fatigue Sensor (EFS) and is part of the AAR's Strategic Research Initiatives Program, with support from the Federal Railroad Administration. The system demonstration was used to detect growth activity in 13 cracks in the bridge.

Observations showed that 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 test bridge, a short-term measurement during a dormant period might miss crack growth that could resume in the future [Ref. 1, 2].

Further development work is progressing on two issues: (1) to calibrate the system to provide a growth rate, rather than simply indicating whether or not there is growth activity and (2) develop long-term monitoring capabilities to determine average growth rates over extended periods of time.

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

Figure 1. Steel Bridge at FAST

BACKGROUND

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

DESCRIPTION OF ELECTROCHEMICAL FATIGUE SENSOR TECHNOLOGY

EFS is a nondestructive fatigue crack inspection 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 electro-chemical 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. Depending upon the structural material, loading conditions, and 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 as to whether a growing crack is present.

The EFS system uses two sensors, one for reference (R) the other as the crack measurement (CM) sensor. Both sensors are 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

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

Figure 2 illustrates the basic parts of the EFS sensor. 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).

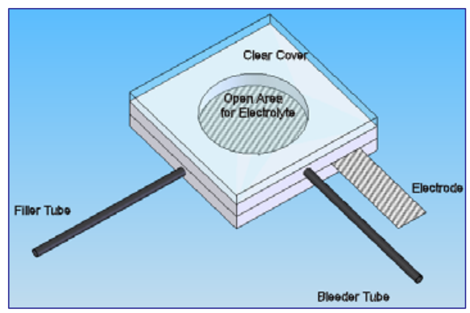

Figure 2. Drawing of an EFS Sensor.

The electrolyte used is a proprietary, water-based solution that has been tested and found to be benign on multiple materials including aluminum, titanium, copper, and steel, causing no premature failure or influence on fatigue life [Ref. 5-8].

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

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

As seen in Table 1, sensors were placed 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 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 showed fluctuations 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 to analyze and parse the data. Multiple datasets from each location were examined to determine specific results.

The EFS data indicated that five of the 15 bridge locations have cracks that are growing (Table 1). Figure 3 shows the inspection locations for the MT 12 and MT 19 locations on the FAST steel bridge with growing cracks.

Table 1. Results from 15 Inspected Locations.

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

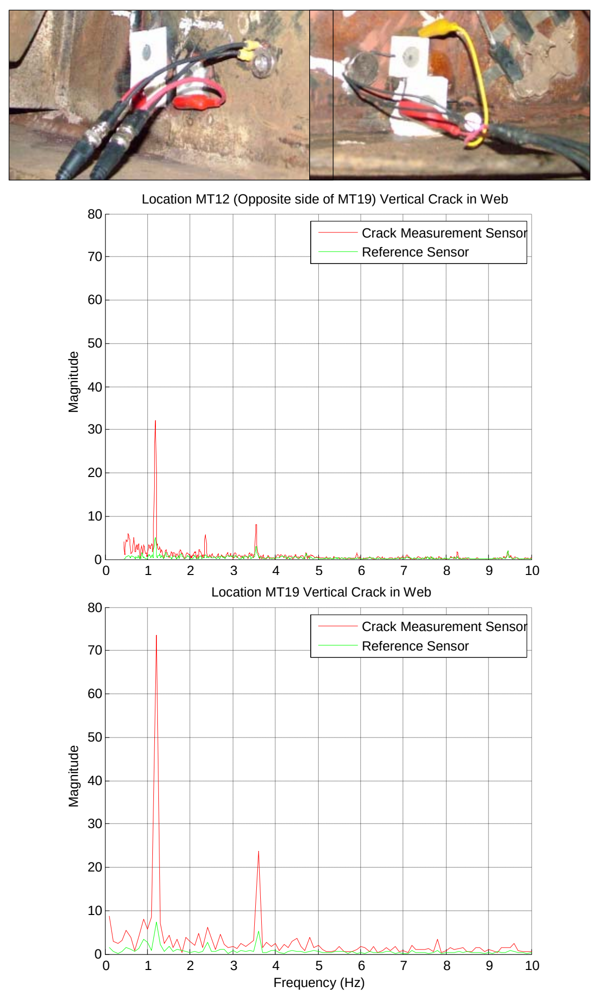

Figure 3. Locations MT 12 (left photo, top graph) and MT 19 (right photo, bottom graph).

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 cracks are growing. One indication of growth is the presence of the higher order harmonics, as Figure 3 shows. The crack at location MT 19 appears to be more active (i.e., the crack at MT 19 is growing faster than the crack at MT 12), 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 to validate the EFS results.

Table 1 summarizes the comparison between the EFS and visual inspection after 800,000 cycles. Note that in four of five 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 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 to 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 [Ref. 1,2]. Development of long-term EFS monitoring equipment would enable the system to capture such changes in crack growth rates.

ACKNOWLEDGEMENTS

Our appreciation to Dr. Magdy El-Sibaie of the Federal Railroad Administration for his support of this study, as well as for his support of the FAST Program.

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KEYWORDS: Steel bridge, crack, fatigue, crack growth, nondestructive evaluation, nondestructive testing, electro chemical fatigue sensor, bridge inspection