AUTOMATED MFL SYSTEM FOR CORROSION DETECTION

Quarterly Progress Report
For the period ending February 28, 2021

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ACCELERATED BRIDGE CONSTRUCTION
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ABC-UTC
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1. Background

The proposed project is aimed at using the methodology that is developed under other projects and supported by other agencies and automates the process for accelerated field application. The scope of the work and budget is kept at minimum budget since the majority of the related work and research have been completed under other projects.

Bridge owners are facing a challenging problem of inspecting steel elements embedded in the concrete. Examples include steel strands in the grouted ducts (plastic or metal ducts) within segmental concrete bridges, prestressing steel in the prestressed concrete girders and post-tensioning tendons in the adjacent concrete box girders. Within the next two decades, it is expected that the condition of embedded steel elements within concrete bridges to pose serious safety problems. The use of prestressed concrete girders in the U.S. dates to about the early 50's. Discussion with State bridge engineers indicates that there is a tremendous interest in developing a methodology that can inspect the condition of embedded steel elements within concrete bridges in ways that is quick, economical and user-friendly for field application.

Over the last 20 years, PI, Dr. Azizinamini has been working on the development of Magnetic Flux Leakage (MFL) method for inspection of steel strands embedded in concrete bridges, such as segmental concrete or post-tensioned bridges. At the same time, Professor Hillemeir, of the Technical University of Berlin, over the last 30 years has been carrying out similar research in Germany. In 2016, an agreement was made between Dr. Azizinamini and Dr. Hiilimier to join forces and develop a version of the MFL method suitable for US application for inspecting steel elements in concrete bridges. Both were successful to obtain a project from FDOT to conduct a joint research, with Dr. Azizinamini as PI and Dr. Hillimier as Co-PI. Since 2016, Dr. Azizinamini has visited Berlin several times, while Dr. Hillimier visiting FIU to exchange research results.

2. Magnetic Flux Leakage Method

MFL method has been used as an NDE technique for a range of applications including bridges, pipelines, rail tracks, etc. The principal components of the MFL are comprised of a magnetic source (permanent or electromagnet) and flux sensors. In the presence of a magnetic field, a ferrous material will allow magnetic flux to pass through the system. However, in the presence of a discontinuity or an anomaly in the ferrous material, the magnetic flux will leak from the system which is then detected by Hall sensors.

The MFL method is a magneto-static measurement technique and is based on the application of an external magnetic field in vicinity of a ferromagnetic (steel) material to create magnetic flux lines to pass through the steel. The application of MFL to concrete structures is possible since concrete medium does not affect the measurements unless ferromagnetic impurities are present in the concrete. MFL method works by magnetizing a strand under an exciting magnetic field and the magnetic flux predominantly remains within the strand. In the presence of a geometric discontinuity such as a part of a corroded strand with loss of cross-section, the magnetic flux is deviated (leakage) and can be detected by magnetic sensors such as hall effect (HE) sensors (Figure 1). Excitation magnetic fields have been produced using a permanent magnet, an electromagnet or a solenoid depending on specific application. The HE sensors are made with semi-conductor crystals which when excited by a passage of current perpendicular to the face of the crystal, responds by developing an output voltage proportional to the magnetic field strength. Analysis of the leakage flux output signals can be used to detect the location and the size of the defect. The extent of metal loss can be identified by the corresponding intensity of the defect leakage flux signals.

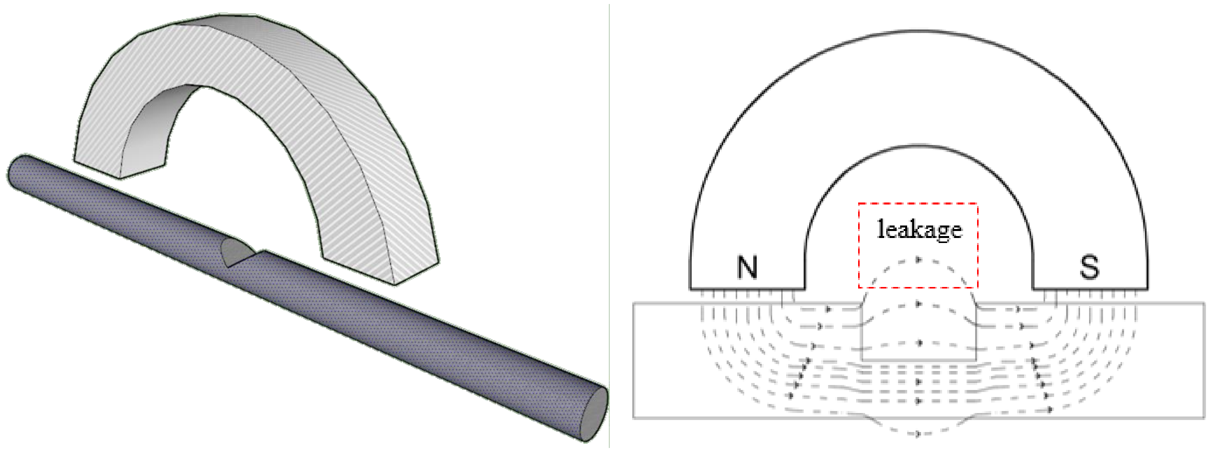


Figure 1: Magnetic flux leakage.

The method first was developed in late 1970s and has been subject to ongoing evaluation as sophistication of electronic instrumentation and data analysis techniques have improved. The two main components of the MFL system are the sensing and magnetizing units. For remnant MFL, a magnetizing unit is traversed over the location of the tendon or post-tensioned rod. After magnetization, the sensing system is used for measurement of MFL signals.

Based on the depth of the tendons from an accessible surface and damage sensitivity requirements, either an electromagnet or permanent magnets may be used. The choice of magnetic source is dependent on many factors including availability of power source, safety requirements and logistical mechanism for supporting the system. A few applications of MFL methods are shown in Figure 2**Error! Reference source not found.** which employs different magnetizing methods and support systems.

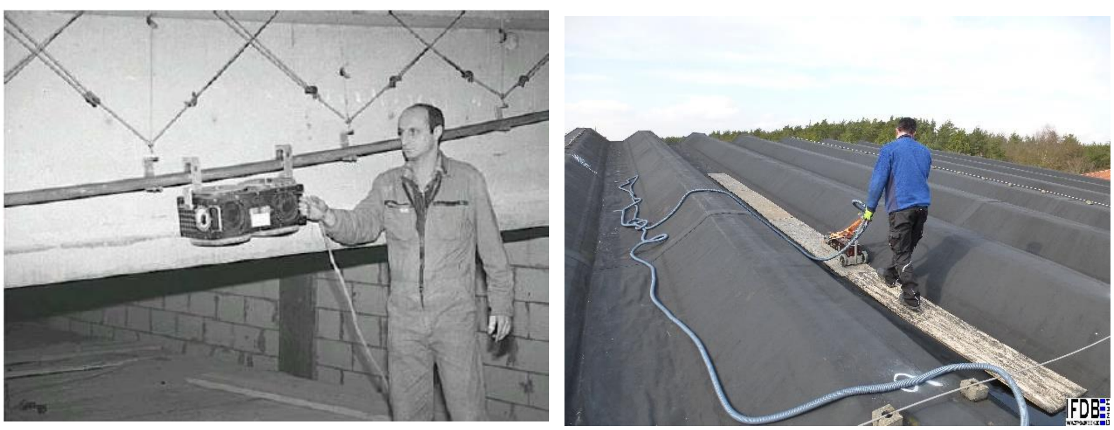


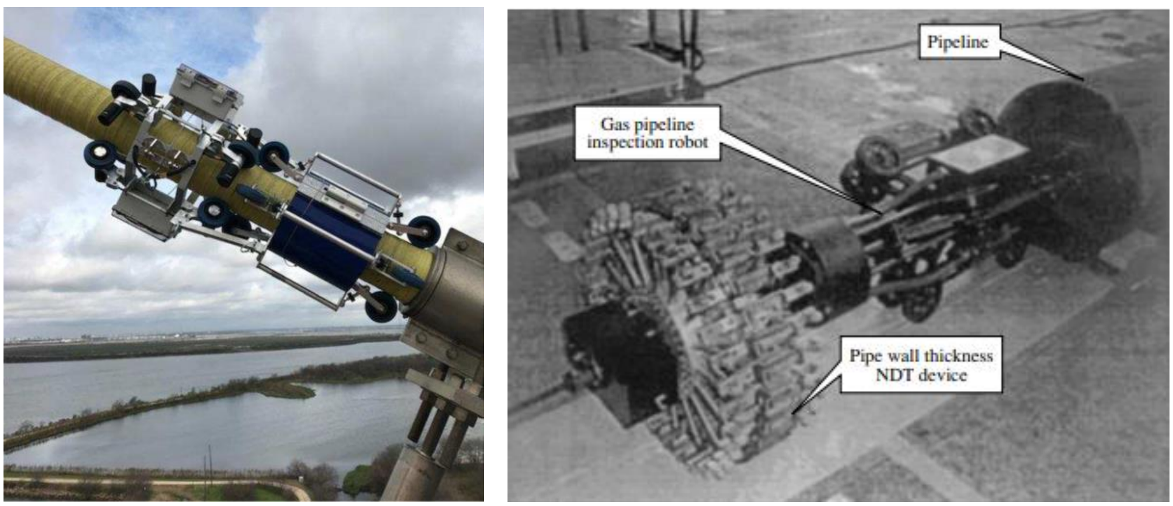
Figure 2. Application of MFL systems (Photo courtesy of Dr. Hillemeier).

3. Problem Statement

The MFL method is not new and has been used by many in the past. However, one major problem has prevented the effective use of MFL. Namely, the presence of other mild steels over and under the ducts or post-tensioning rods or prestressing strands, mask the signals coming out of embedded steel elements of interest. The research team led by Dr. Azizinamini was finally able to solve this challenge and presently the method is fully capable of identifying the areas where corrosion activities are present.

The other shortcomings of present MFL system is the manual operation of the sensing system. For accessible bridge components, the manual operation can be accomplished without the need of any specialized equipment or support mechanisms. However, for majority of the bridges, the components with prestressing systems are difficult to access. Besides these challenges, the safety protocols may require partial or complete closure of traffic during testing.

Due to these challenges, automation in MFL system have been introduced for gas pipes and cable-stay applications. One common example of the use of robotic MFL for external PT system is the clamped module, shown in Figure 3(a), which moves along the external PT tendons or cable stayed bridges. The clamped modules are remotely operated and can move along the cables. Another common robotic system is used for gas pipe which is shown in Figure 3(b).



(a) (b)

Figure 3: Automation of MFL system for (a) cable stays (ref: Infrastructure Preservation Corporation) (b) gas pipe robot [1].

Although few applications of automation in MFL systems can be found for external components but there has been limited research on MFL for internal tendons. An automation of internal tendons requires robotic systems which can be efficiently used for bridges including prestressing tendons in beam and box bridges, slabs, and bent caps, etc.

4. Research Approach and objectives

The main objective of this project is to automate the technology that is developed to inspect the health of steel elements within concrete bridges.

5. Prior Example Results

This section provides a very brief summary of one test that demonstrates the manual application MFL method.

Figure 4 shows four segments of a segmental concrete bridge that were saw cut and brought to FIU Labs for the development of the MFL method.

Figure 4: Segments of segemental concree bridge at FIU.

Surprisingly few ducts within these segments were not grouted, which provided an opportunity for researchers to place steel strands with known damages and check the capabilities of the method.

Figure 5 shows the location of the main strands, the location of secondary strands and the location of rebars with the location of the defect. The strands were magnetized from the bottom side initially with a depth of 7” of the magnet from the bottom surface of the segment and then the strands were again magnetized by keeping the depth of the magnet 3” from the bottom surface of the segment. **Figure 6** shows the MFL system which includes a permanent magnet, magnetic sensors, linear encoder, data acquisition system, and power supply.

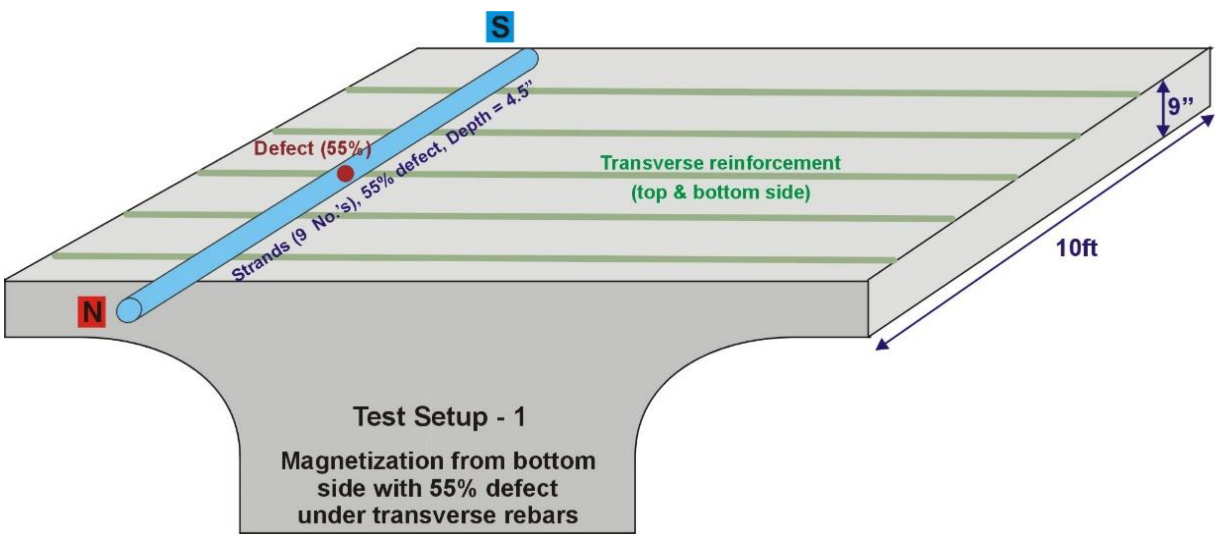


Figure 5: Location of defects in post-tensioning strands with transverse reinforcment.

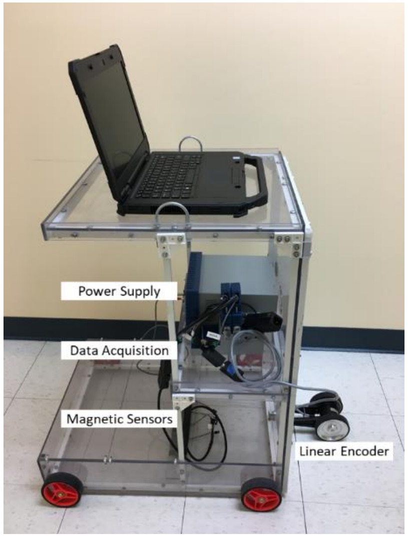


Figure 6: MFL measuring system (left), permanent magnet (right).

Results of MFL with signal of 55% defect under transverse reinforcement

The first test was performed by keeping the location of the defect in such a way that the transverse reinforcement is passing just above and below the defect. As the tendon contains nine strands and the defect was introduced in five strands which makes it 55%. The MFL signal is shown in **Figure 7**. The signal shows clearly the location of the defect and the transverse rebars present above and below the defect are not affecting the signal.

This methodology is effective when active corrosion is caused by 20% steel cross-sectional losses.

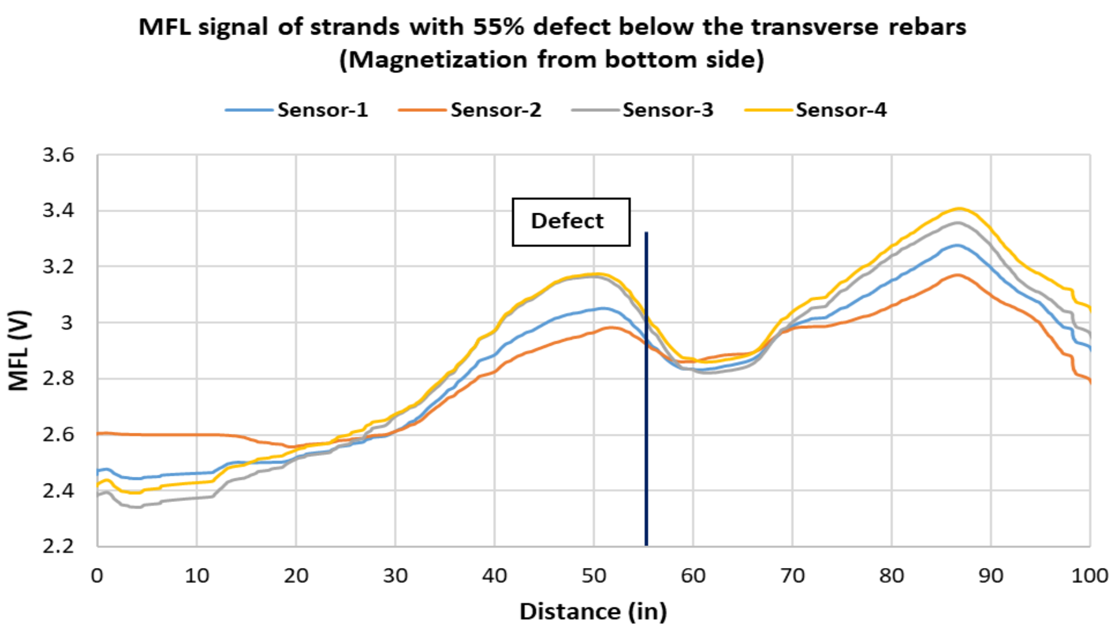


Figure 7: MFL results for 55% defect under transverse reinforcement.

6. Description of Research Project Tasks

The following is a description of tasks carried out to date.

Task 1- Development of an automated approach for MFL

The use of various small robots in conjunction with wireless data acquisition with robots controlled from a distance is the solution for automating the procedure. Under this task, the elements of the current MFL system will be modified to make use of wireless sensors in conjunction with the use of small robots.

> *Progress: A small robot as shown in Figure 8 has been utilized as first prototype and the MFL system with wireless data acquisition was mounted on it. A second robot with an integrated MFL system will be developed next.*

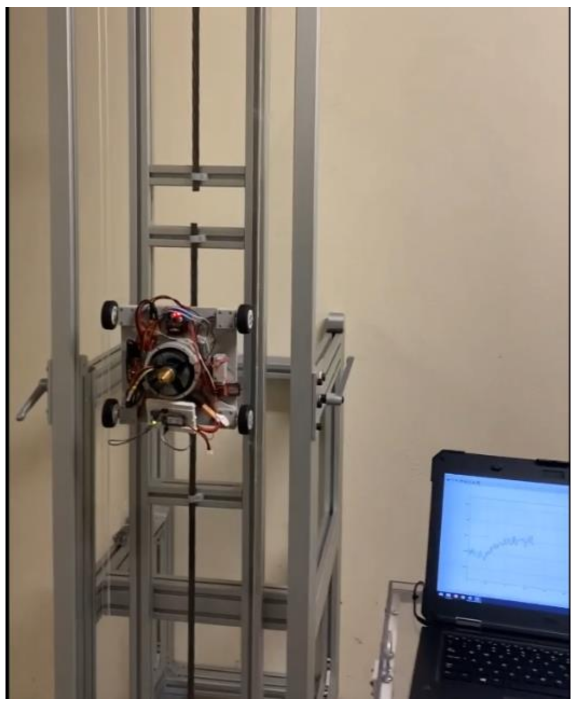


Figure 8: Prototype of automated MFL system

Task 2- Laboratory validation of the new automated system for MFL

In this task, laboratory validation of the efficacy of the automated system utilizing small robots and wireless data acquisition system. The laboratory test will be conducted on the bridge segments at FIU as shown in **Figure 4**.

> *Progress: Several laboratory tests were performed using the wireless automated system to check the efficiency of the robot and its behavior to move on horizontal and vertical surfaces. The results of the system were satisfactory but need further testing on the bridge segment available in the lab as shown in Figure 4.*

Task 3– Field validation of the new automated system for MFL

In this task, field validation of the efficacy of the automated system utilizing small robots and wireless data acquisition system. The PI will work closely with FDOT to identify a bridge candidate for the deployment of the new system for field validation.

> *Progress: A new system for large scale measurement is under development. The wire diagram and the bread board wiring to be mounted on the robot has already been completed as shown in Figure 9 and Figure 10. A linear encoder will be added in the system to measure the linear distance and then whole sensor package will be assembled on the robot to take MFL signal of the bridges.*

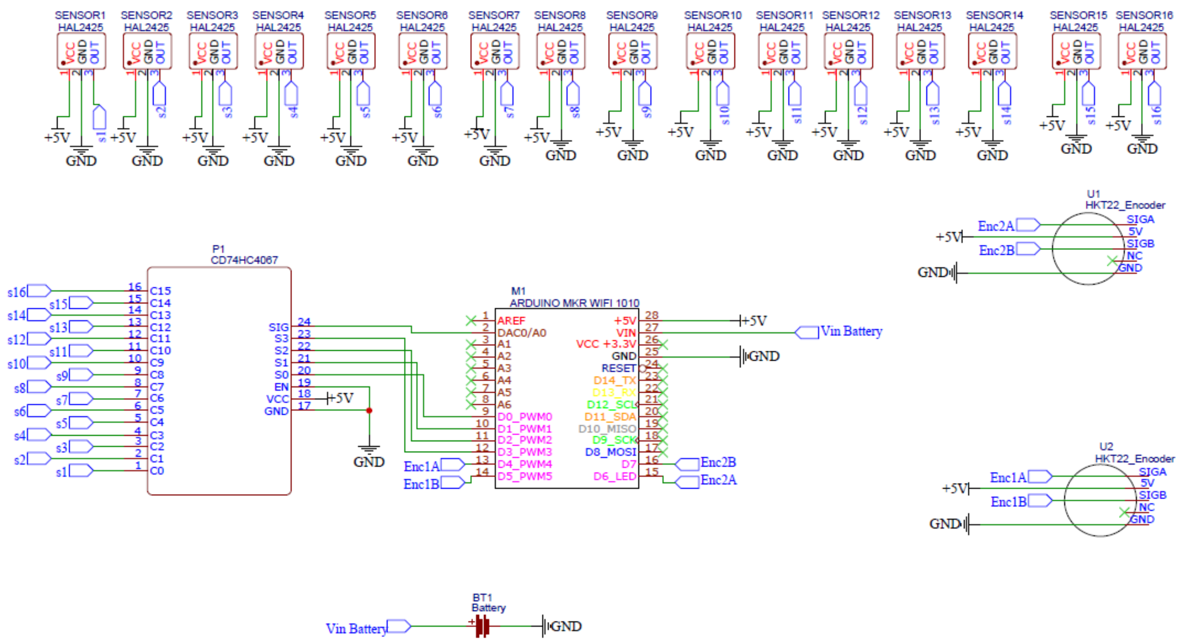


Figure 9: Wire diagram of the prototype sensor package

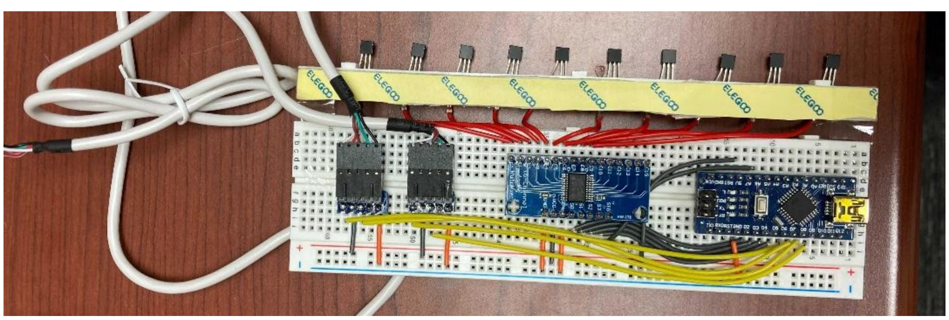


Figure 10: Prototype of sensor package

Task 4- Final Report

A final report will summarize the findings of this proposed research.

> *Progress: Not started.*

7. Expected Deliverables

The main deliverables will be a final report for the new proposed automated system for MFL.

8. Reference

1. Zhang, Yunwei, and Guozheng Yan. "Detection of gas pipe wall thickness based on electromagnetic flux leakage." Russian Journal of Nondestructive Testing 43, no. 2 (2007): 123-132.

9. Schedule

Item	**% Completed**
Percentage of Completion of this project to Date	55%