NON-DESTRUCTIVE INSPECTION FOR INTERNAL GUY CORROSION ON TALL TOWERS

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ABSTRACT

Many of the guys that support the Navy's critical tall antenna towers are developing severe localized corrosion that can lead to progressive antenna collapse. Often hidden within the cross-section of the guy, internal corrosion may have little correlation with the visual condition of the outside of the guy. A non-destructive guy inspection tool has been developed to monitor and assess the corrosive condition of tower guys. This autonomous tool consists of a guy crawler towing a magnetizing sensor head, with a portable computer wirelessly controlling both. The tool measures the loss of cross-sectional metallic area along a guy. This paper introduces the magnetic flux sensing concept, highlights basic prototype development, summarizes test results and establishes a need for validation.

Keywords: guy, tower, structure, strand, wire, rope, galvanized, NDT, magnetic, flux, LMA, crawler

INTRODUCTION

Guyed towers, up to 1500 feet (450 m) tall, structurally support many Naval antennas, including the Very Low Frequency and Low Frequency (VLF/LF) antennas that makeup the worldwide Fixed Submarine Broadcast System (FSBS). In service up to 50 years, a total of about 1000 guys structurally support a total of approximately 50 guyed towers at ten FSBS antenna sites. The guys supporting these antennas are in critical need of reliable corrosion inspection, quantifiable corrosion control, effective structural assessment, and realistic prioritization of guy replacement.

What is a Tower Guy?

Showing external signs of significant corrosion, the guys supporting the FSBS antenna at Harold E. Holt Naval Communications Station in Western Australia (HEH) are the first in need of replacement. Shown in figure 1, the typical guy at HEH is between 250 and 2000 feet (75 to600 m) in length and made principally of structural strand that can be 1 to 4 inches (25 to 100 mm) in diameter. The wires are helically twisted and laid in low-pitch angles around each other. This helical lay tightens the bundle of wires and allows for some curvature along its length. In contrast to structural strand, wire ropes have a high-pitch angle so that they can be bent sharply around running sheaves.

FIGURE 1 - Typical guy supporting slender tower with vibration dampers at lower end

Need for Improved Inspection Methods for Guy Corrosion

Of the few guys replaced at HEH so far, forensic investigations indicate that some were not near failure, while others were very near failure. Figure 2 compares severely corroded cross-section with an uncorroded one on the same guy. Maximum Loss of the cross-sectional Metallic Area (LMA) is about 47%, with an even greater loss of structural strength. Note that the outside surface of this guy shows little if any corrosion in either the corroded or uncorroded sections.

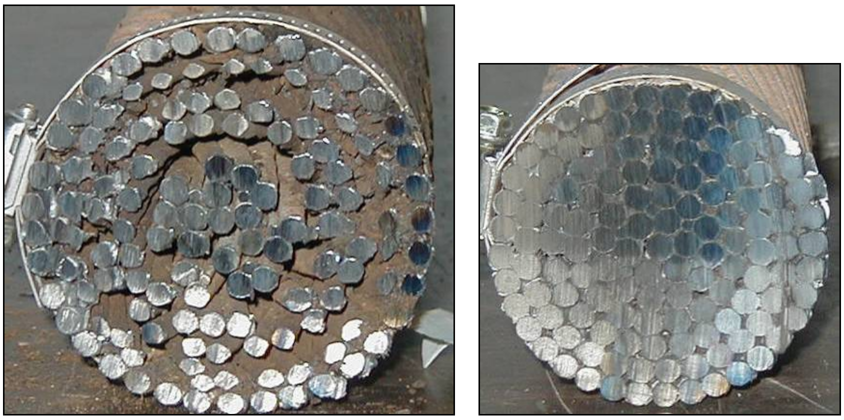

FIGURE 2 - Comparison of internally corroded versus uncorroded sections of same guy

Since structural strand is designed to have little or no movement between wires, individual wires of a structural strand are protected from corrosion by a hot-dipped zinc galvanized coating. Heavier galvanization on the outer layer of wires is protecting outer wires longer, sealing in moisture and promoting corrosion of internal wires, which have thinner galvanized coating. Because internal wires are more active in tension than the outer wires, detection of corrosion on internal wires is critical.

If one corroded guy fails from localized corrosion hidden deep within an otherwise perfectly good guy, the slender tower can easily buckle, collapse, and bring down nearby towers in the multi-tower antenna arrays. Current tower industry protocol calls for a qualitative visual inspection of the external surface of each guy using a high-powered scope. However, quantitative measurements of the interior of the structural strand are essential for prioritizing guy replacements, estimating remaining guy life, developing guy retirement criteria, and reducing risk to mission interruption.

In contrast to commercial antennas, FSBS antennas have generally remained unaltered since they were built. Consequently, the guys supporting FSBS towers are now some of the oldest and largest in the telecommunications industry. Therefore not surprisingly, the US Navy is in need of a tool for inspection of large diameter guys long before the broader telecommunications industry needs it.

Traditional Magnetic Flux Sensing for Wire Ropes

Since 1970, Non-Destructive Testing (NDT) devices have been used for quantitative inspection of wire rope, principally for improving the safety of mine hoisting operations. The primary reason for retirement of running wire rope has been wire breaks and other Local Flaws (LF), caused mostly from running and repeatedly bending over sheaves[1]. Shown schematically in figure 3, NDT devices with magnetic flux leakage technology have evolved as the preferred technology for inspection of wire rope and other similar structures.

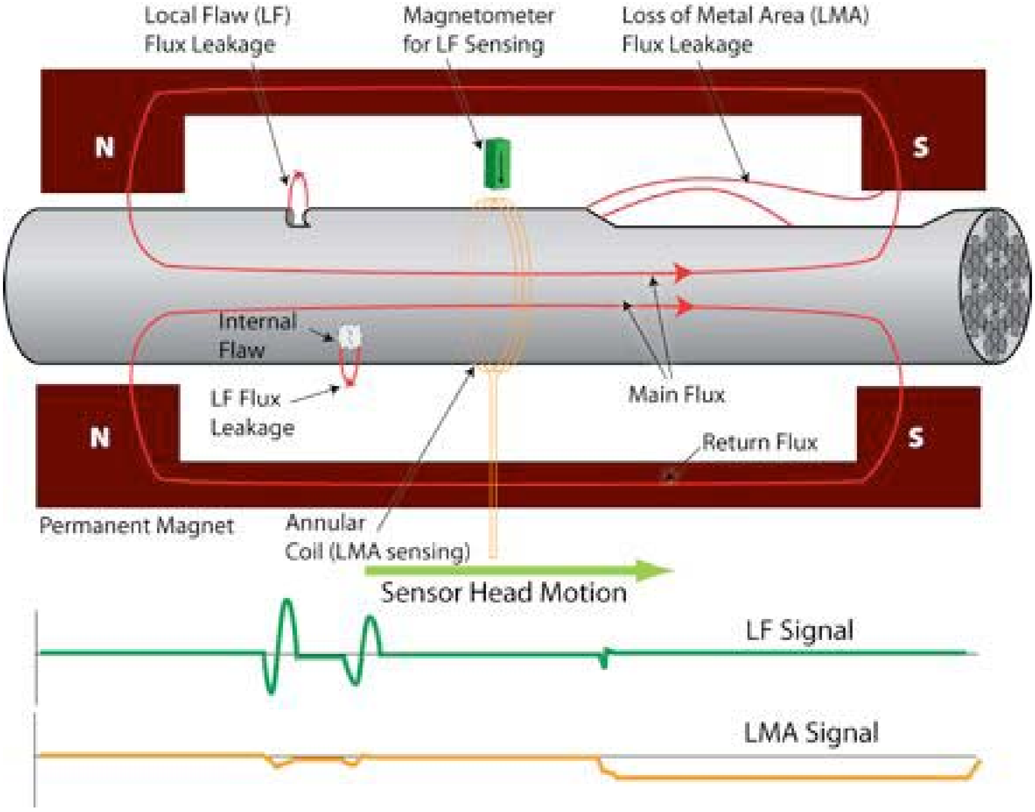

FIGURE 3 - Sectional cut through magnetizing sensor head and idealized measurements representing idealized defects in wire rope [Courtesy of Tethers Unlimited, Inc.]

As shown in the figure, LF produce very localized leakages of magnetic flux over very short distances. These localized flux leakages are difficult to measure even with highly localized magnetometers (often Hall-effect sensors). Interior breaks are almost impossible to detect and thus, the number of wire breaks in any given cross-section are difficult to count without rigorous inspection procedures using high quality magnetic flux devices [2]. Nevertheless, detection of wire breaks has historically been the primary use of magnetic flux devices for wire rope inspection.

On the other hand, magnetic flux devices are theoretically well suited for measuring Loss of cross-sectional Metallic Area (LMA). LMA produces an absolute change in overall magnetic flux throughout the cross-section. As long as the wire rope is saturated with a sufficiently strong magnetic field, LMA is easily and accurately measured by an arrangement of annular coils, semi-annular coils, or magnetometers. Since magnetic flux flows equally throughout the cross-section of the wire rope, LMA within the interior is just as easily measured as that on the exterior of the wire rope. Since corrosion products are non-magnetic, LMA is an ideal measurement for directly quantifying the loss of tensile strength due to corrosion.

Since the mining industry has been concerned almost exclusively with wire breaks, LMA measurements for corrosion quantification remain a rather undeveloped, untested, and unevaluated potential for magnetic flux technology. For wire rope inspection, the rope generally runs through a stationary magnetizing sensor head. For application on a stationary guy, a moving inspection tool must travel along and high up a stationary guy. Therefore, our development and testing of a tool for guy inspection focused principally on moving an autonomous magnetizing sensor head specialized for measurement of LMA up and down large-diameter in-place guys.

NEW GUY INSPECTION TOOL

As part of a larger phased research, developmental, testing and evaluation effort, three small-scale concepts and one small diameter prototype guy inspection tool were built and tested by three different contractors[3]. Afterwards, a prototype large-diameter guy inspection tool was designed and built[4], as shown in figure 4. This tool consisted of a magnetizing sensor head hitched to a powered guy crawler, with a portable computer wirelessly controlling both.

FIGURE 4 - Guy Crawler towing magnetizing sensor head on tower guy

Development of Prototype Magnetizing Sensor Head for Tower Guys

Hinged and clamped around a guy, the magnetizing sensor head was built to accommodate a variety of magnetic sensing options. The key to accuracy of the tool is sufficient magnetic saturation of the guy cross-section with respect to the chosen type of magnetic sensor. Better magnetic sensing requires less magnetic saturation, which leads to a smaller assemblage of rare earth magnets, which leads to a lighter tool that is more easily handled and hauled up and down a guy.

Various simulations and experiments were used to size an optimal magnetizing head and to select an optimal magnetic sensor arrangement. The current prototype head uses an arrangement of Hall-effect sensors, but can also accept an annular coil. Attached to the head, different sized plastic inserts and different sized wheels help make one tool work for inspection of different diameter guys.

The accuracy of the head is evaluated or calibrated on the bench per standard rod reference tests [1]. As shown in Figure 5, these tests involve removing individual rods from a bundle of rods inserted into the head. The drop in LMA is recorded for each rod removed. For the test, a plastic pipe was used to hold all of the rods in a circular pattern.

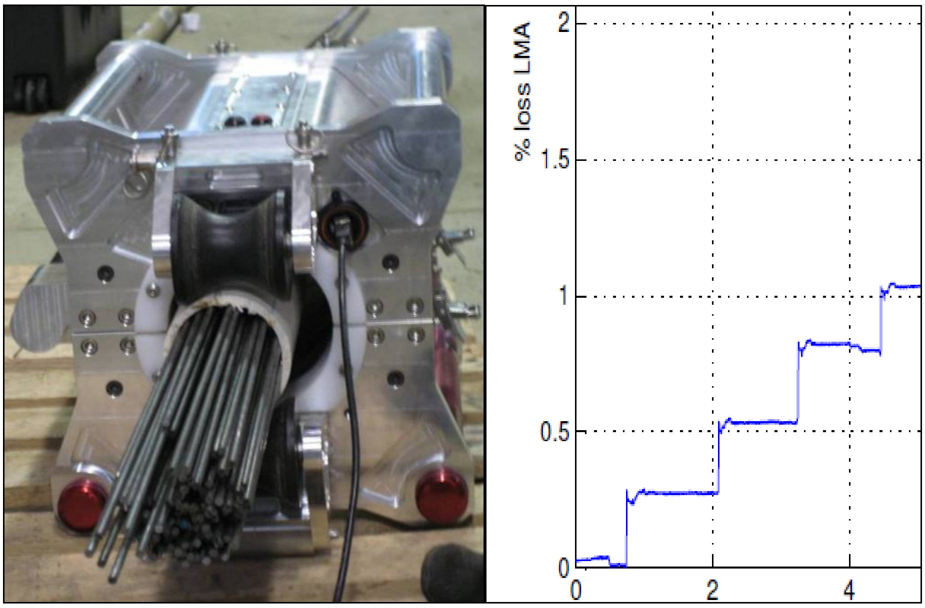

FIGURE 5 - Magnetizing sensor head undergoing standard rod reference test

Figure 5 also shows the LMA signal versus time that was generated as individual wire rods (each representing 0.25 percent of total cross-sectional area) were pulled from the throat of the magnetizing sensor head. The test verified that LMA is more accurately measured for rods pulled from the interior rather than from the surface of the bundle of rods.

Development of Prototype Crawler for Tower Guys

To measure LMA along an in-place guy, the magnetizing sensor head must be pulled up and down the guy against gravity, magnetic drag, and rolling resistance. This would normally require specialized tall tower rigging support, whereby riggers or technicians would have to climb the tower and install specialized rigging for pulling the sensor head up and down each guy. In contrast, an autonomous tool would bring important time and safety benefits. With all workers remaining safely on the ground, normal operations of the tower can continue (for example, antenna can continue to broadcast), while guy inspections are underway. Furthermore, the inspection of each guy takes only as long as it takes the crawler to travel up and down that guy.

A commercial-off-the-shelf two-stroke gasoline engine was found to be sufficient to lift the total 210 lb (95 kg) weight of the crawler plus magnetizing sensor head. The crawler is designed to accommodate either a two- or four-stroke engine. Critical system components for the guy crawler include a clutch, transmission, brake, replaceable wheel assemblies, odometer/bulge sensor, optical end-of-guy (or obstruction) sensor, and digital wireless control.

Shown in figure 6, a clamping leaf spring developed the required friction force in the wheels. Power is required to overcome rolling resistance and travel both up and down the guy. After some initial adjustments, the crawler was able to repeatedly travel up and down one of the largest diameter and longest guys supporting the FSBS antenna at Cutler, ME.

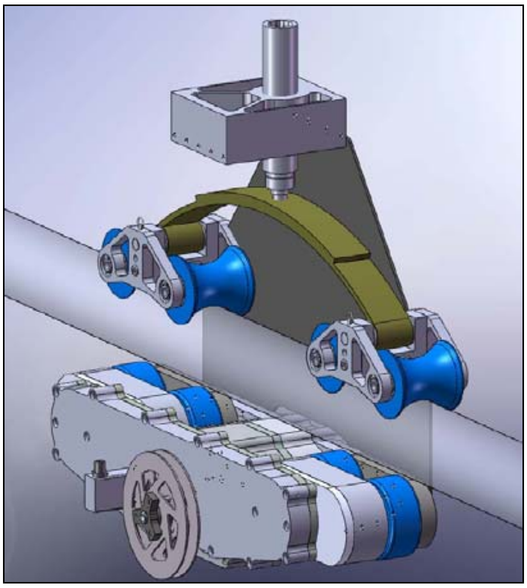

FIGURE 6 - Cutaway schematic view of guy crawler

Figure 7 shows a view from the rear of the crawler looking below the towed magnetizing sensor head at a corkscrew deformation on one of the and longest length guys at Cutler. Corrosion of internal wires is only one of many possible causes for such a structural deformation.

FIGURE 7 - View from the rear of the robotic crawler about half way up the guy

RESULTS

The guy inspection tool exceeded all tested performance goals. During nine days of field trials, the tool traversed some 18,000 feet (5500 m) of guys at an average speed of 2.3 ft/s (0.7 m/s). Maximum ascent speed was 3.6 ft/s (1.1 m/s) at full power. The crawler easily climbed and descended even the longest guys in less than a half hour, much faster than any other means of ascending the tower. The crawler traction is sensitive to any significant grease or rain on the surface of the guy. The tool appears unaffected by any stray electromagnetic radiation from the atmosphere and/or induced from the adjacent operating FSBS antenna.

The weight of the tool was sufficiently low to allow for human-only handling of the tool. A temporary scaffold that is normally used for re-tensioning guys was used to provide safe working access above the anchorage hardware. Battery power, data storage capacity and wireless communication range were found to be adequate for all-day continuous guy inspections.

Since guy corrosion is not yet an issue at Cutler, the measured signal showed no obvious signs of corrosion along the large diameter guy used for testing. In order to check that the tool was correctly measuring LMA, artificial defects were added to the guy. As shown in figure 8, a short and long artificial defect was added in two different locations by wrapping rebar tie wire around the guy. Measuring the gain of cross-sectional metallic area from the added defects is essentially equivalent to measuring a similar level of LMA, while remaining non-destructive to the guy.

FIGURE 8 - Artificial defects added to the guy for testing tool sensitivity

Figure 9 shows the raw measured LMA signal versus travel along the guy over the artificial defects. Noise in the LMA signal is mostly due to helical rotation and radial shifting of the individual wires that make up the structural strand of the guy. The magnetic averaging length of the magnetizing sensor head tends to lengthen defects that are much shorter than the head length. With proper filtering, these detracting measurements can generally be minimized or eliminated.

HEH is the only FSBS antenna where guys are actively being replaced and forensically being investigated for internal corrosion. We plan to use the prototype guy inspection tool to make baseline LMA readings on several of the guys at HEH, particularly those guys scheduled for replacement in the near future. We then plan to compare these NDT measurements with destructively obtained forensic results and evaluate the overall fidelity of the device for measuring actual internal guy corrosion. This baseline inspection data and its comparison to forensic information will permit us to develop a reliable process for assessing the remaining life and/or risk of failure for each guy, based on a reliable quantifiable measure of maximum corrosion along each guy.

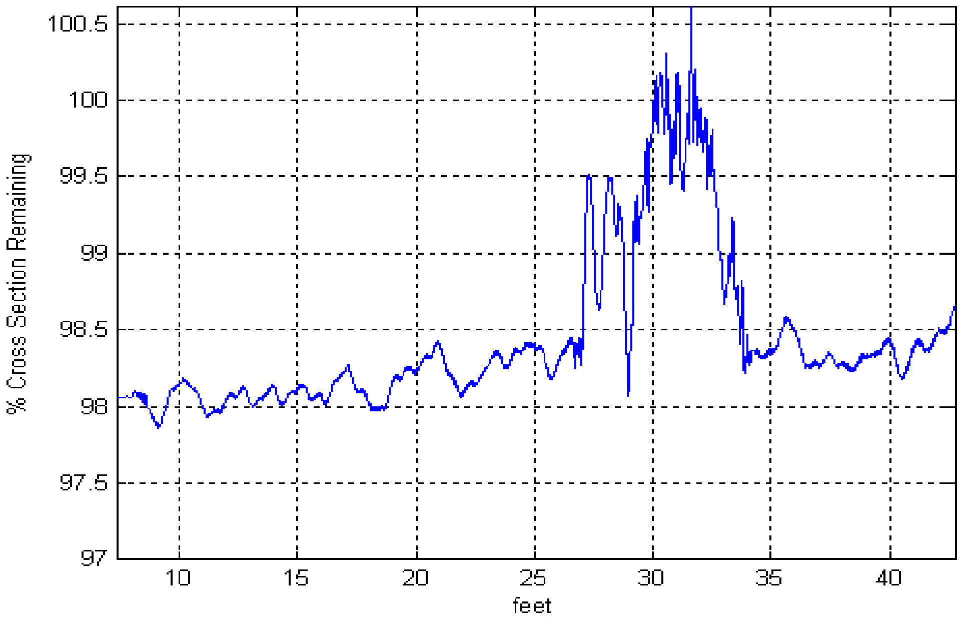

FIGURE 9 - Measured gain in cross-sectional metallic area across artificial defects

CONCLUSIONS

Magnetic flux sensing technology is an excellent development choice for measuring the loss of metallic cross-sectional area in the structural strand of tower guys. After several small-scale research efforts, an autonomous tool consisting of a magnetizing sensor head hitched to a powered guy crawler, with a portable computer wirelessly controlling both, was developed to inspect the Navy's largest diameter guys supporting its most critical antenna system.

The guy inspection tool exceeded all tested performance goals. Based on standardized rod reference tests and field tests on artificially added defects, the tool exceeded the desired performance goals for detecting remaining metallic area well within the goal of 5% of the cross-sectional area. Differing significantly from traditional non-destructive testing for wire breaks in running wire ropes, the tool performs best when measuring interior LMA.

Additional validation work remains to gauge the performance of the tool against forensic data from actual corroded guys at HEH. The key to accuracy of the tool is sufficient magnetic saturation of the guy cross-section. The key to smaller tool size and cost is better magnetic sensing, which leads to a lighter tool that is more easily handled and hauled up and down a guy. The final guy inspection service will include a process for assessing the remaining life and/or risk of failure of guys with varying levels of internal corrosion.

The magnetizing sensor head is of sufficient size to be used for inspection of all guys on all naval guyed towers. Appurtenances along the wire rope, such as insulators, can make complete inspection of certain guys on some towers a bit challenging. Fortunately, the three largest FSBS antennas, containing the majority of potentially corroding guys, have clear guys with no appurtenances. In addition to guyed towers, the tool is also useful for inspection of large diameter wire rope, structural strand, and bridge strand supporting other types of government and commercial structures or substructures.

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