Pipeline Flaw Detection Using Shear EMAT and Wavelet Analysis

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ABSTRACT

This report describes the development of an EMAT based PIG for in-line inspection of flaws in a 30 inch natural gas pipeline. The sensor is capable of detecting physical flaws (e.g., SCC, circumferential and axial flaws, and corrosion) in pipe walls of gas pipelines. Using an in-line non-contact ultrasonic sensor (EMAT) flaws are determined in the wall of the pipe that the current MFL technology has problems detecting. One EMAT is used as a transmitter, exciting an ultrasonic impulse into the pipe wall while a second EMAT located a few inches away from the first, is used as a receiving transducer. Since the discrete wavelet transform of the signal will be non-shift invariant, its coefficients cannot be directly used as a pattern recognition feature. However, comparing composite properties of the signal on different scales is useful, because the mode conversion caused by a flaw changes the composite properties of the signal in wavelet space. For the EMAT data, the useful information projects onto five mutually orthogonal wavelet scales. During the current fiscal year, the project concentrated on obtaining large sets of EMAT signals from defective and good sections of pipes and developing wavelet algorithm to identify the defects.

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1.0 INTRODUCTION

The safety of the Unites States' natural gas supply is of prime importance, since 30 percent of the energy produced in the country is derived from it. Natural gas is supplied through a million miles of vast pipeline network [1]. Pipeline companies have an impressive safety record due to the proactive role of standards and pipeline inspection. Since our pipelines are getting old, there is a great need to identify corrosion, cracks, and other defects that pose potential problems.

Stress corrosion cracks (SCC) can occur in a range of pipeline field conditions including soil type, stress, cathode potential, coating conditions and temperature. This type of defect is usually oriented along the axial length of the pipe. If the defect remains undetected the cracks may grow and/or coalesce and eventually lead to a leak or pipe rupture. Other types of defects can also occur in pipe structures. They are either critical to the safety of the pipeline (e.g., corrosion, welding cracks, and pits) or benign stringer-like internal inclusions. Non-destructive Inspection (NDI) systems are vital to locating the defects early without false alarms from benign inclusions to problematic cracks as well as helping characterize and size the defects for repair or replacement.

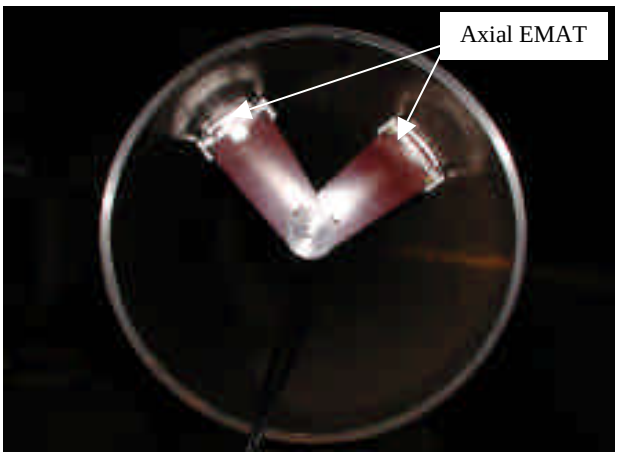
Many technologies have been developed for pipe inspections, but they are limited to detecting certain types of defects. For example, *Axial-field Magnetic Flux leakage (MFL) in-line inspection smart pipe-inspection-gears (PIG),* which is extensively used for pipeline inspection, is good for detecting corrosion damage or circumferentially oriented defects inside a pipe, but have limited success in detecting flaws or cracks in the axial direction.

In this project, ultrasonic guided waves are being studied for the feasibility of detecting many kinds of defects that occur in pipes. One major benefit of guided waves is their rapid global inspection capability, which enables them to inspect a structure line-by-line instead of point-by-point. However, defect classification and sizing by guided waves are still major problems under investigation, due to the complexity of the wave propagation characteristics.

2.0 EMAT SENSOR DEVELOPMENT

EMAT sensors were designed for 10 inch and 12 inch pipe geometry with hardware fabricated for attaching them onto the inside walls of the pipe. The anchoring mechanism had provisions to vary the gap between the pipe wall and the EMAT. With wheels or ball rollers, the EMATs could be positioned anywhere inside the pipe. Figure 1 shows the circumferential and axial EMATs developed for pipeline inspection. A separation of 6 inches between the transmitter and receiver was used for both configurations.

Cuts of 0.125, 0.25, and 0.006 inch wide and varying depths were fabricated on the pipe walls to determine whether the EMATs were able to detect these flaws. Most tests were performed using horizontal n_1 mode SH wave. By utilizing the through-transmission mode whereby the distance between the EMATs is fixed, better correlation was obtained for the effect of flaws. A sample of the windowed receiver pulse signal for the cases of *flaws* and *no-flaws* on the pipe walls is given in Figure 2.



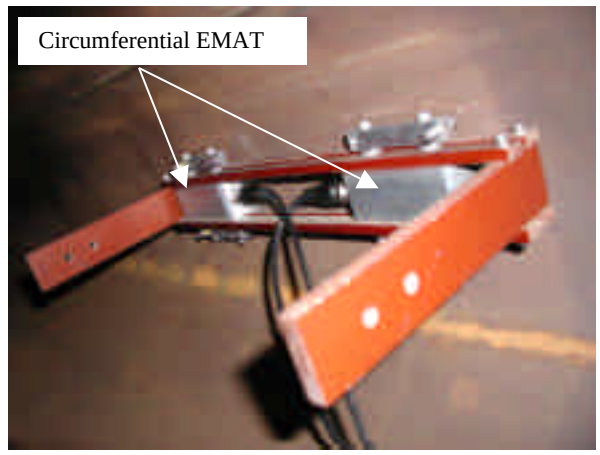


Fig. 1. Axial and Circumferential EMATs.

The multiple pulses in SCC flaw data are due to the smaller section of the pipe used for this case ¾ 18 inches instead of 6 feet. These pulses correspond to the reflections from the pipe ends and are separated by larger time intervals when the pipe section used is long. The number of EMATs required to characterize the entire diameter of the pipe was determined by assessing the propagation angle that does not adversely affect the quality of the signal for preset EMAT separation. For axial EMAT configuration, the axial separation could be 2 inches without large degradation of the receiver signal while, in case of the circumferential EMAT, the angular separation could be $\pm 30^{\circ}$.

Attenuation or changes in amplitude in the time domain data (see Figure 2) are not a useful feature for identifying flaws. Despite the fact that such changes are obvious in laboratory data, which are collected under carefully controlled conditions, their reliability does not hold up for data collected in less controlled field conditions. Too many other mechanisms besides a flaw in the medium of propagation can lead to attenuation in field data. The only reliable features for flaw detection are those that depend on the change imposed by the flaw on the shape rather than the amplitude of the signature.

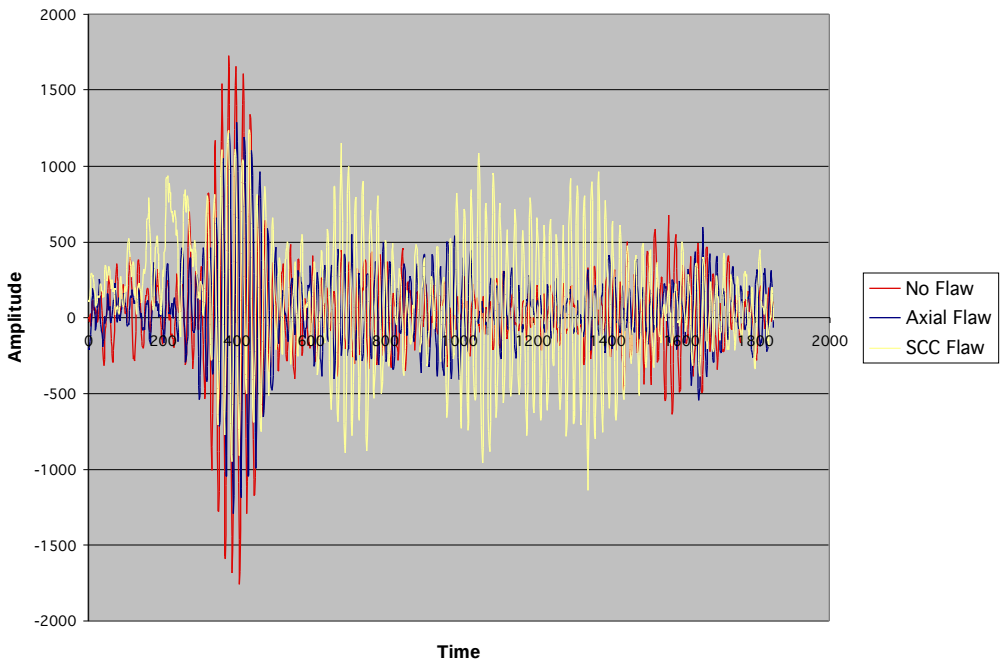


Fig. 2. Amplitude versus time for *flaw* and *no-flaw* receiver EMAT signal.

After the initial development of the EMAT sensors for the 10 inch and 12 inch pipes, sensors were developed to inspect a 30 inch pipe with the PIG traveling along the length of the pipe (see Figures 3 & 4). An industrial computer, EMATs, resolver, and control box were all mounted on a frame that could travel along the inside of a 30 inch pipeline and characterize the wall defects. The schematic of the experimental PIG developed at ORNL is shown in Figure 8. The EMATs are mounted on linear springs that ensure that the distance between the pipe inside wall and the EMAT surface is maintained as tightly as possible. The receiver and the transmitter radial positions are controlled independently to account for the geometric variation of the pipe diameter. The separation distance between the transmitter and the receiver can be adjusted and, the current setting of 10 inch circumferential separation ensures that the excitation signal does not overlap with the transmitted chirp signal.

A windowed SH wave generated every 12 milliseconds is sampled at 5 MHz frequency by the data acquisition system. When the PIG is traveling at 2 miles per hour a sample is taken every 0.42 inches of travel. A LabView program is used to gather the data from the data acquisition board and write it to a disk file. The data collected is being evaluated offline to detect flaws in the pipeline using wavelet analysis.

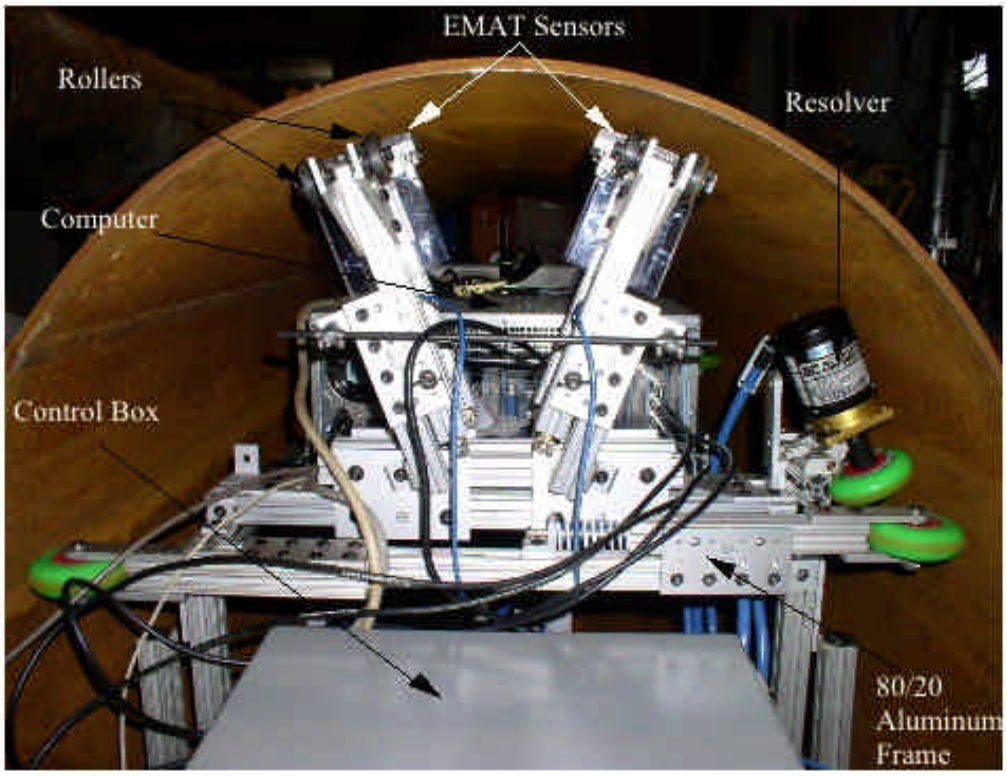


Fig. 3. ORNL PIG with EMAT sensors and resolver mounted inside a 30 inch pipe.

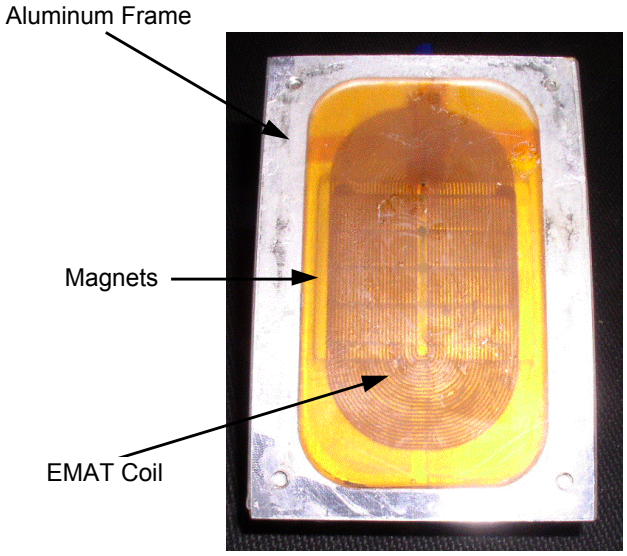


Fig. 4. EMAT used for the 30 inch pipe defect characterization.

The current set-up is used to evaluate the defects that exist in the 30 inch circumferential distance between the transmitter and the receiver EMATs. The receiver EMAT on the 30 inch pipe wall will also obtain the signal that is traveling the 84.25 inch circumferential path, but the signal would be too weak to be used for flaw classification. Hence, for a field-deployable flaw classification and characterization PIG, multiple pairs of EMATs will be installed.

3.0 DISCUSSION OF CURRENT ACTIVITIES

Most of this year's research was focused on the developing the wavelet analysis and acquiring EMAT signatures over larger sections of pipe to add statistical significance to the analysis.

To obtain the data, the EMAT data acquisition system was taken to Battelle pipeline test facility in Columbus, Ohio. Battelle has extensive inventory of pipes with known defect sets to help calibrate the EMAT sensor. The 30" pipes with SCC defects provided by Battelle had a tape covering on it. There were places on the pipe were the tape was removed to expose the defects and quantify them. The EMAT system developed by ORNL, worked very well in areas were there was no tape covering, but was completely attenuated in areas were there was tape present. The tape used by Battelle was a thin white tape.

To overcome this problem it was decided that the problem associated with tape be simulated at ORNL and methods developed to obtain signals under the presence of tape. Battelle personnel provided a green tape that they were currently using with Royston resin coating. When the tape was applied on good sections of the pipe at ORNL, the EMAT signals did not vanish completely although there was some attenuation. Realizing that this may be due to the fact that the tape applied was fresh and not subjected to heat variation and pressure associated with deployment in the field, pipe sections with tape, taken out of commission were obtained.

By contacting El Paso Gas, a 5 ft. section of 30" pipe with black tape was obtained. When EMAT was used on the pipe internal diameter, although there was attenuation of the signal, it was not anything experienced at the Battelle test facility with the white tape. Since Battelle did not have pipe sections to spare and it was difficult to replicate the attenuation experienced with white tape, NETL Program manager was contacted for further directions. Since the scope of the project was to detect SCC cracks on pipes and not to address the tape problem, it was decided that further testing be conducted using only bare pipe sections with no tapes on the outside.

ORNL EMAT pipe inspection jig was again taken to Battelle and data obtained on bare 30" pipes with SCC flaws (see Figure 5). Numerous test runs were performed and are currently being analyzed using the wavelet analysis.

Presently, most of the preprocessing routines are complete and the wavelet analysis routines are being developed. By mid July, 2004 most of the processing routines and preliminary analysis of all data collected will be complete. Refinement of the routines will be completed by early August. The final testing of the system for DOE sponsors is set for the week of September 13th, 2004.

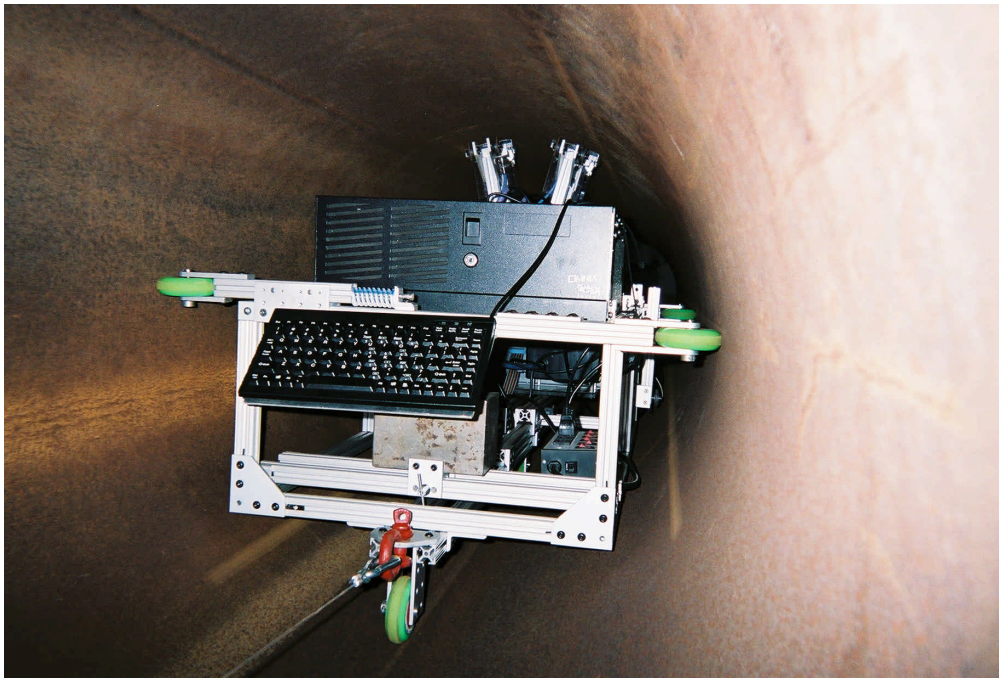


Figure.5. ORNL Inspection Jig inside a 30" pipe at Battelle

4.0 CONCLUSION

An EMAT sensor to classify flaws in pipelines has been successfully developed. Corrosion, SCC, and gauges were the flaw types used for this study. EMATs were developed for exciting the SH_1 mode in pipes and were integrated into a PIG with data acquisition and data representation algorithms in place. Flaw classification algorithms are in their final stage of development and will be ready by the middle of August, 2004. Characterization of the flaws will require further study and will be attempted during the FY 2005.

References

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