Main interest of guided waves for NDT applications

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Abstract

Recent guided waves technology’s improvement offers a wide range of possibilities for NDT applications mainly for piping inspection, long-term structural health monitoring, heat exchanger tubes inspection; in general corrosion detection and monitoring. Guided waves are very useful for various industrial applications and their usage is now increasing rapidly.

In the present paper, firstly a brief overview of this NDT Technology is given in terms of actual commercial guided wave inspection systems, what guided waves technology can do exactly at the moment; and finally examples of inspection applications.

In another hand, the second section describes the possibilities to notably improve the efficiency of guided to propagate on a longer distance and detection of smaller defects.

1 Introduction

The implementation of guided waves in particular surface (Rayleigh waves) and Lamb (plate waves) waves mainly using transducers with variable angle or at a fixe angle for a specific configuration is not recent non-destructive testing.

These waves have the advantage to propagate over large distances (several meters) without significant attenuation along the profile parts, which can control quickly structures with complex shape for the detection of surface defects (Rayleigh waves) or in the whole thickness (Lamb waves).

In recent years with advances in modelling of physical phenomena of generation and propagation of ultrasonic waves, in technological developments of EMAT (Electromagnetic Acoustic Transducer) using Lorentz force or the magnetostrictive effect, the enhanced performance of acquisition and signal processing, and use of new magnetic and piezoelectric materials, these techniques are booming.

Electronics surface waves remains a more limited use because of problems of attenuation or the appearance of spurious signals due to deposits of coupling on the control surface; reason why contactless techniques as EMAT / EMAT or laser generation / EMAT reception or dry coupling techniques are prefered.

The use of guided waves in the thickness of the material (Lamb waves and SH: Shear Horizontal waves (horizontally polarized waves)) are of great interest for the control of plates, tubes, bars, round and piping, as it may be possible to control very quickly over large distances usually a hundred meters without having to remove insulation and / or anticorrosion coating, or without having to dig them.
The main interests of guided waves are:

- Ultrasonic guided waves follow the profile of a complex piece.
- The guided waves propagate over long distances up to several hundred meters depending on the configuration of structures to control and frequency transducers used.
- These waves provide easy detection of defects in external and internal skin (corrosion, fatigue cracks) using Lamb waves and horizontally polarized waves.
- The surface waves are well suited for detecting of small surface defects in order to replace in some cases the magnetic particle inspection and / or penetrant testing (sensitivity at least equivalent or even superior in some cases especially in skin defects or cracks having tight lips).

2 Techniques for generating ultrasonic guided waves

There are different techniques to excite ultrasonic guided:

- Piezoelectric Transducers
  - Generation of guided waves (Rayleigh and Lamb waves) by the “corner” of Plexiglas or using variable angle transducer.
  - Generation of guided waves (Rayleigh and Lamb) by interdigital transducer (electrodes printed on a film or sheet type PVDF piézocomposite).
  - Another elegant way to generate Lamb waves or SH is the use of piezoelectric elements in the “form of a comb” still excited in a manner appropriate vibration (longitudinal or transverse).

- EMAT Technique based of the principle of the Lorentz force
- By laser impact
- Magnetostrictive transducers using a tape or a "patch" of magnetostrictive materials (mainly nickel strip) directly bonded to the material and externally excited by a coil of suitable shape and dimensions supplied with a generator delivering a high intensity current (waveform "burst" or train of sine waves)

3 Difficulties in the implementation of guided waves

Ultrasonic Guided waves is a promising technique to inspect and monitor:

- Piping systems in oil, gas, and petrochemical facilities
- Boiler tube, heat exchanger tube
- Anchor rod, bridge cable
- Plate-like structure, stub angle of power transmission line tower...

There are many advantages of using guided waves as:

- Rapid surveying of long lengths of pipe, sheet, cables...
- Detection of corrosion under insulation without removing insulation except the probe location
- Cost reduction in gaining access to the pipes for inspection
- The whole pipe wall (100%) is inspected
- The ability to inspect inaccessible area such as wall penetration pipe, road crossing, and buried pipes.
- High temperature pipeline of up to 300°C is inspected
The main difficulty in the implementation of guided ultrasonic waves is to control the generation of these waves. Indeed, there are an infinite number of vibration modes and dispersion characteristics of guided waves where the propagation speed and changing modes of vibration with frequency and thickness of the material and its nature. A calculation program can be used to make diagrams to represent the phase speed of the different types of waves depending on the product of the frequency, nature and the thickness of the material tested. Broadly speaking, the SH waves and torsion waves as the main advantage of being insensitive to the presence of fluid within a pipe, as well as thermal insulation and anticorrosion coating on the outside thereof. The result is a better acoustic wave propagation with minimal depreciation.

![Example of vibration mode](image)

**Figure 1 - Example of vibration mode**
(Document SRI South Research Institute – NDT Consultants)

4 Existing equipments on the market Mss System and specification

Three guided-wave inspection systems are in commercial used to generate and detect guided waves for piping inspection. As a guided-wave probe, the MsS system uses a thin ferromagnetic strip continuously covering the whole circumference of pipes GUL wavemaker and Teletest use a ring array of piezoelectric transducers discretely covering the pipe circumference. Since only the MsS system satisfies the axial symmetric condition covering the whole circumference continuously. In addition, MsS system can strongly generate torsional and longitudinal wave that are axially symmetric.

The MsS System is a device that electromagnetically generates and receives lowfrequency ultrasonic guided waves. It is used for rapidly surveying a long length of pipeline from a single test location. The corrosion wall loss and cracks in aboveground, buried, and insulated pipe can be detected, and their locations and sizes can be estimated by analyzing the data with user-friendly software. The MsS system is also useful for inspecting and monitoring areas that are difficult to access, such as those at high elevations, behind walls, or under insulation, from a remote accessible location. This saves the time and money that would otherwise be used for scaffolding, insulation removal, or excavation.
The MsS System is composed of the MsSR3030 instrument, MsS probes, and a laptop computer, as shown in a schematic diagram. The operating software in the laptop computer controls operating parameters of the MsSR3030 and acquires data through a USB port. The MsSR3030 instrument generates tone-burst electric pulses to the MsS probes and detects induced voltage in the MsS probe that is generated when the ultrasonic guided wave passes through the probe. The signal received from both directions of pipe are analyzed and reported with data analysis and reporting software.

The MsS System was developed at Southwest Research Institute® (SwRI®) and is manufactured at SwRI® located San Antonio, Texas by SwRI personnel to ensure high quality instrumentation.

**Technical feature of MsSR 3030 or Ruggedized MsSR 3030**

- Two channel transmitters and receivers for controlling direction of wave propagation
- 120 V or 240 V AC, 50/60 Hz, power or battery operated
- Inspection range in straight above ground pipeline is typically 50 meters on either side of the MsS probes and can be up to 150 meters in ideal conditions.
- Only a 25-mm clearance is needed around the pipe in dry coupling; the clearance is 12 mm in permanent monitoring.
- Operates on pipes from ¾ to 60 inches in diameter. In monitoring mode MsS probe is made and installed at onsite. Probe is very light (less than 1 kg for 24-inch pipe testing probe).
- Wide frequency range operation of MsS probe and instrument: 4 kHz to 250 kHz
Mss Probe

There are a number of magnetostrictive effects, which are described in detail in the literature. Two of those are important in the context of generation of guided waves. The first effect refers to the change in dimension in the direction of the applied magnetic field. For example, a magnetostrictive cylindrical rod changes its length when subjected to an axial magnetic field. This longitudinal effect is called the Joule Effect. The second effect refers to a twisting motion due to combination of circular and axial magnetic fields. This is called the Wiedemann effect. These effects can be exploited for the excitation of longitudinal and torsional waveguide modes in cylindrical waveguides.

The magnetostrictive sensor (Mss) probe uses the magnetostrictive effect to generate and detect guided wave in pipe. The Mss probe applies a time-varying magnetic field to the ferromagnetic material for guided wave generation and picks up magnetic induction changes in the material caused by the propagating guided wave for guided wave receiving.

The most common application of Mss technology uses a nickel strip material. The guided wave is generated in the ferromagnetic strip (nicked strip) and coupled to the structure through epoxy bonding (in monitoring application) and dry coupling by pressure (in inspection application). Examples are longitudinal and torsional mode probes in pipe and tube inspection, symmetric and asymmetric Lamb wave probe and shear-horizontal mode probes in plate or sheet, and longitudinal mode probe in nonferrous anchor rod.

5 Some applications of ultrasonic guided waves

There are also many other applications we can mention as:

- Boiler tube inspection
- Heat exchanger tube inspection
- Plate structure inspection and monitoring: ships, airplanes, underground storage tanks, steel columns...
The guided waves system can be used to inspect and monitor following pipeline structures:

- Piping systems in oil, gas, and petrochemical facilities
- Offshore piping systems/risers
- Power generation piping systems
- Road crossings/levee penetrations
- Elevated or complex piping systems with limited clearance
- Buried pipelines

6 Conclusions

We can summarize the capabilities of MsS system has been:

- The total cross-sectional wall of the pipe is inspected.
- Ability to detect corrosion wall loss and cracks in aboveground, buried, and insulated pipe.
- Sensitivity can be as good as 2% loss of cross-section in ideal conditions (but is set at 5% or 10 % for...
buried pipeline or at long distance).

- Signal-to-noise ratio of better than 50 dB is obtained with epoxy-bonded MsS probe on site. The generated signal with MsS probe is 50 dB (300 times) higher than the coherent noise of unwanted modes.
- Inspection range about 50m, but can be up to 150m in ideal conditions.

We think guided waves is promising technology for which technical performances will grow up thank to the development of more accurate simulation tools and the use of novel magnetostrictive material.

In addition, phased array tuning to generate all sorts of guided waves will offer the possibility to significantly enhance the performance of the existing technologies (i.e. E. Kannan of the Center for NDE Department of Mechanical Engineering has demonstrated [4] that low cost magnetic oxyde based MsS material significantly enhance the transduction efficiency).

Software development constitutes another route for automated defect detection and location analysis because this technology is somewhere very difficult to be interpreted without be a NDE Expert.

References

[3] Magnetostrictive sensor (MsS) system for long range guided wave inspection and structural health monitoring – Technical documentation of guided waves analysis LLC company