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Mode Converted Reflection of Torsional Guided Waves by a Magnetostirctive Sensor Technique

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1. Introduction

The presence of damage or defects in pipes or tubes is one of the major problems in nuclear power plants. However, in many cases, it is difficult to inspect all of them by the conventional ultrasonic methods, because of their geometrical complexity and inaccessibility. The magnetostrictive guided wave technique has several advantages for practical applications, such as a 100-percent volumetric coverage of a long segment of a structure, a reduced inspection time and its cost effectiveness, as well as its' relatively simple structure.

A dispersion curves for a pipe with diameter of 150 mm and thickness of 11 mm is shown in Fig. 1.

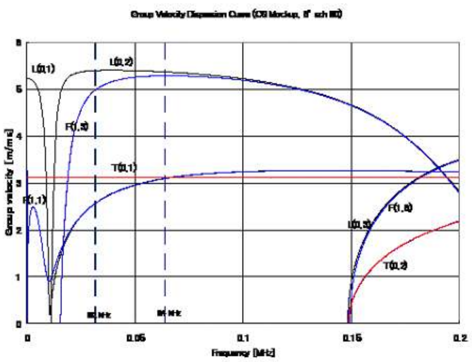

Fig. 1. Group velocity dispersion Curves for a carbon steel piping with a diameter of 150 mm and thichness of 11 mm.

Among various vibration modes, the torsional guided wave T(0,1) mode has many advantages, such as no dispersion, no radial displacement, and low attenuation.

One promising feature of the magnetostrictive transducer is that the wave patterns are relatively clear and simple compared to the conventional piezoelectric ultrasonic transducer. If we can characterize the evolution of the defect signals, it can be a promising tool for a structural health monitoring of pipes for a long period as well as the identification of flaws [1].

In this paper, we report that a mode conversion from torsional vibration mode occurs in a guided wave examination. The guided wave signals were generated and received by a coil and a DC magnetized Fe-Co-V alloy strip. The wave patterns reflected from various ultrasonic reflectors, especially from the end of a pipe were analyzed and indexed. A spurious signals ahead of the main reflection were evaluated as the mode converted F(1,3) vibration mode.

2. Experimental Results

Fig. 2 shows a typical mode converted signal spurious signal marked as "EX' denotes extraneous modes. The pipe is made of SUS 304 stainless steel and the dimensions are diameter of 150 mm, thickness of 11 mm. When a guided wave generated by a magnetostrictive strip glued on the surface of the pipe, the torsional guided wave propagates through the pipe medium. This wave is reflected at the end of pipe and most of the energy returns back to the magnetostrictive strip as a torsional vibration mode, marked as 'EP' in Fig. 2.

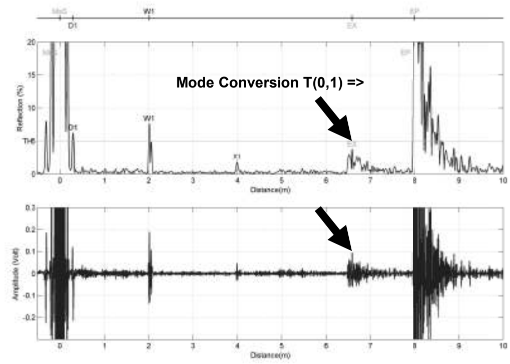

Fig. 2. Mode converted guided wave signal flexural wave F(1,3) from torsional wave T(0,1).(frequency=64 kHz, cycle=1, piping material=SUS304 pipe, diameter=150 mm, thickness = 11 mm, length = 23 m).

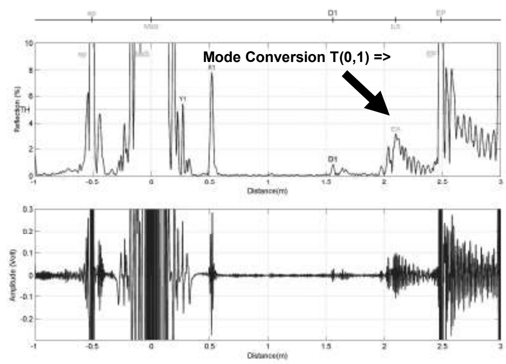

Fig. 3. Mode converted guided wave signal flexural vibration mode F(1,3) from T(0,1) torsional vibration mode.(frequency = 128 kHz, cycle =1, piping material=carbon steel, diameter=65 mm, thickness = 6 mm, length = 3 m).

A small portion of the incident torsional wave (approximately 5% of total amplitude) converted other vibration mode at the pipe end reflection. Spurious signals appear earlier than 'EP' (end of pipe) signal in Fig. 2. Another example of mode conversion of torsional waves at the pipe end is shown in Fig. 3. This piping is made of cabon steel and the dimensions are diameter of 65 mm, and thickness of 6 mm.

These spurious signals can be analyzed as a mode converted flexural wave. Incident wave of torsional vibration mode traveling to the end with a velocity of 3200 m/s as shown in Fig. 1, and the reflected wave converted to a flexural vibration mode F(1,3) and/or longitudinal vibration mode L(0,2) with a velocity of 5200 m/s, illustrated in Fig. 4.

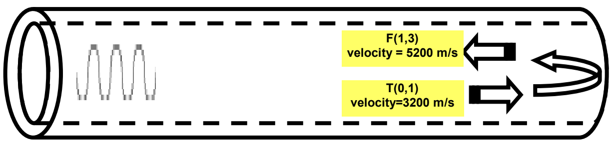

Fig. 4. Schematic drawing on the mode converted reflection at the end of a pipe.

3. Discussions

The torsional vibration mode T(0,1) traveling in a pipe is simply analogous to the case of SH (shear horiziontal) wave in a plate. Because total acoustic energy is reflected at the pipe end, the relations governing the reflection depend on the boundary conditions at pipe. When an acoustic wave traveling in a solid medium encounters a boundary with a vacuum, the boundary conditions may be considered:

(a) The displacements vanish at the pipe end.
(b) The plane of pipe end is free of traction.

The boundary (pipe end) can be clamped end or free end. For the clamped case, the reflected wave undergoes 180° phase shift in the displacement as it is reflected. For a free boundary the reflected T(0,1) wave is in phase with the incident wave. For a normal incidence, the reflected waves represent purely standing waves [2]. In other words, the SH wave has a little possibility of mode conversion at a reflector.

However, our experimental results show some spurious signals and we evaluated it as a mode converted torsional waves. It seems the reflection of torsional guided waves at a boundary is more complex than a relatively simple analytical formulation. [2] More comprehensive study on the propagation of guided waves is required in future.

4. Conclusions

(1) Mode converted reflections from a pipe end were observed various experimental. This observation was analyzed as incident torsional wave T(0,1) and reflected flexural wave F(1,3) or longitudinal wave L(0,2).
(2) It is estimated approximately less than 5% of the total incoming torsional waves are converted to flexural wave at a perfect reflector, such as pipe end.
(3) It seems that the reflection at a boundary is not simple as an analytical expression, even though the torsional modes in a hollow pipe or analogous to SH wave in a plate can be expressed simplest mathematics. A more comprehensive study on the propagation of guided waves.

REFERENCES

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