

# TECHNICAL BACKGROUND ON MsS

## ***Sensor Principle***

- Guided wave generation—Based on the magnetostrictive (or Joule) effect
- Guided wave detection—Based on the inverse-magnetostrictive (or Villari) effect

The magnetostrictive effect refers to a small change in the physical dimensions of ferromagnetic materials—on the order of several parts per million in carbon steel—caused by externally applied magnetic field.

The inverse-magnetostrictive effect refers to a change in the magnetic induction of ferromagnetic material caused by mechanical stress (or strain).

The above effects exist only in ferromagnetic materials. The magnetostrictive effect was discovered by Joule in 1847 and the inverse effect by Villari in 1864.

## ***Sensor Configurations, Instrumentation, and Technical Features***

The sensor is configured to apply a time-varying magnetic field to the material under testing and to pick up magnetic induction changes in the material caused by the guided wave. For cylindrical objects (such as rod, tube, or pipe), the MsS is ring-shaped to encircle the object. For plate-like objects, the MsS is rectangular-shaped to be placed on the surface of the object.

A schematic diagram of the MsS and associated instruments for generation and detection of guided waves is shown in Figure 1. The MsS instrument is composed of a transmitter section and a receiver section. To allow the directionality control of the generated and detected guided wave signals, the MsS instrument contains two transmitters and two receivers. The output signals of the receiver section are displayed on a digital oscilloscope or on a PC equipped with an A/D card.

To operate the MsS, the material under testing needs to be in a magnetized state. This is achieved by applying a DC bias magnetic field to the material using either permanent magnet, electro-magnet, or residual magnetization induced in the material. The DC bias magnetization is necessary to enhance the transduction efficiency of the sensor (from electrical to mechanical and vice versa) and to make the frequencies of the electrical signals and guided waves the same. The transduction efficiency of the MsS increases initially with increasing DC bias magnetic field level, reaches a maximum, and then decreases with further increase in the DC bias magnetic field level, as illustrated in Figure 2. The optimum DC bias magnetic field is typically the level just below the knee of the magnetization curve of the material under testing.

Technical features of the MsS include:

- Requires no couplant
- Can be operated with a gap to the material under testing
- Is broadband
- Has a good sensitivity in frequencies up to a few hundred kHz

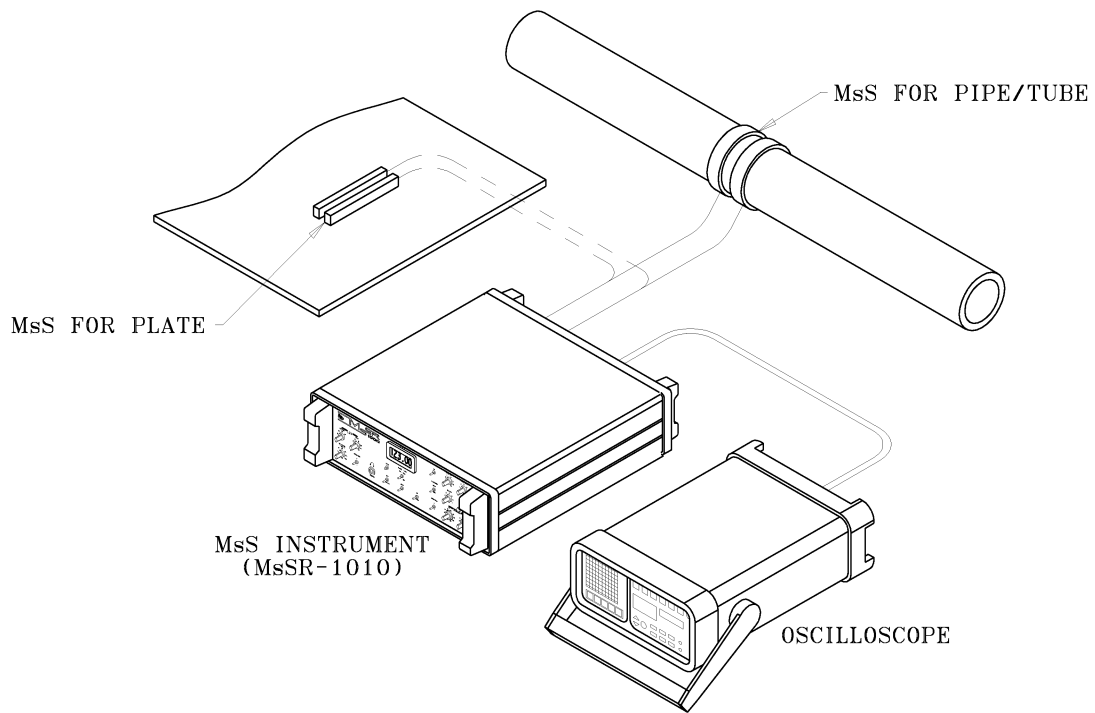


Figure 1. Schematic diagram of the MsS and associated instruments

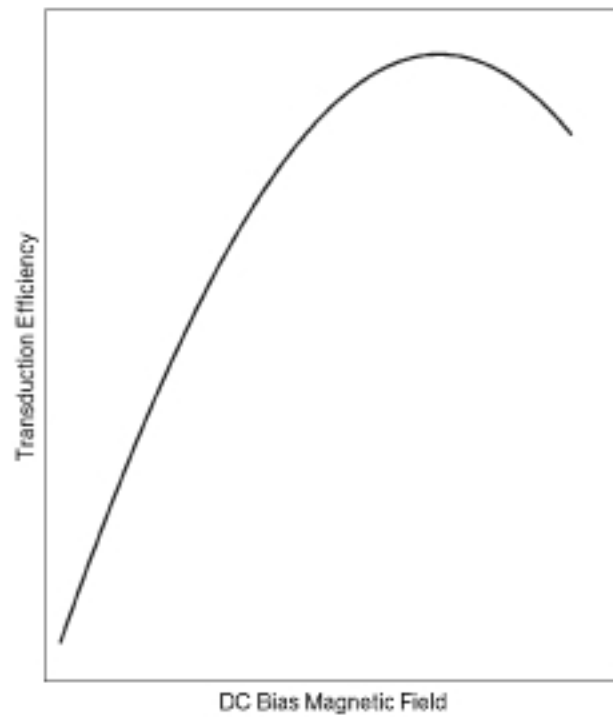


Figure 2. Transduction efficiency versus DC bias magnetic field level

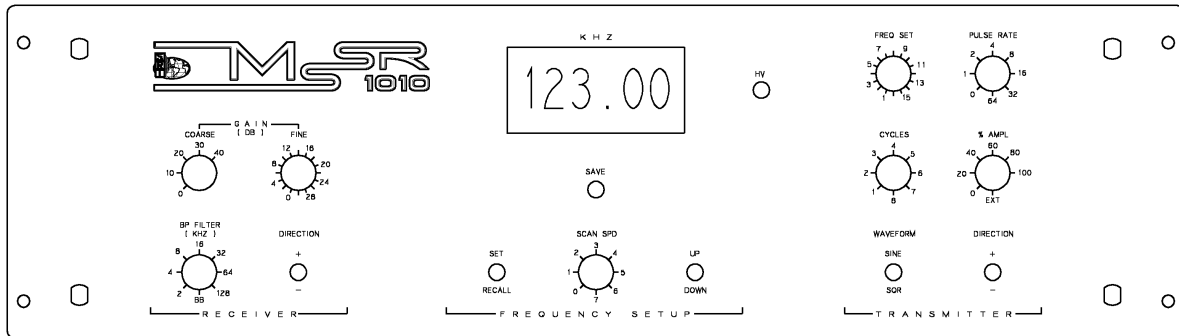
Applicable guided wave modes are:

- Longitudinal, torsional, and flexural wave modes in cylindrical objects
- Symmetric and antisymmetric Lamb wave and shear horizontal wave modes in plates.

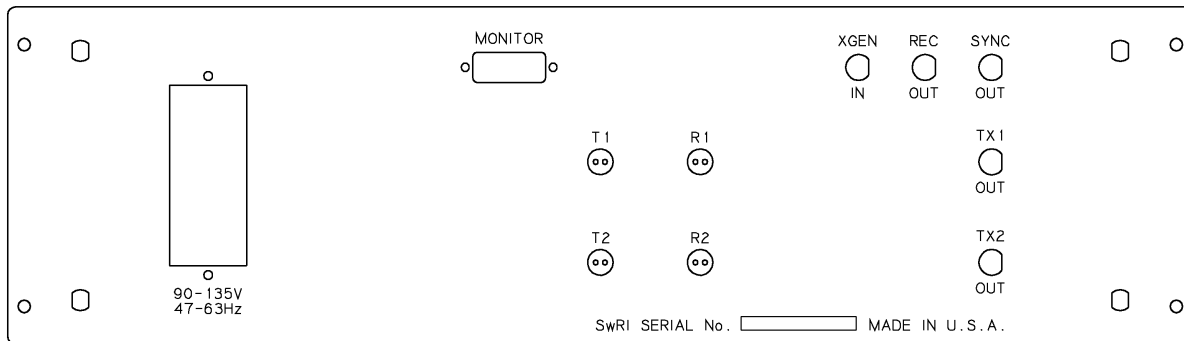
The operating wave mode of the MsS is controlled by the relative alignment between the DC bias magnetic field and the time-varying magnetic field produced by the MsS. For longitudinal wave modes in cylindrical objects and Lamb wave modes in plates, a parallel alignment is used. For torsional wave modes in cylindrical objects and shear horizontal wave modes in plates, a perpendicular alignment is used.

# MsS INSTRUMENT (Model MsSR 1010) AND SPECIFICATIONS

## Front View



## Rear View



## Specifications

### Transmitter:

Outputs:	Two HV differentially driven synchronous burst type outputs. May be operated in-phase or with $\pm 90$ -degree phase displacement (for directionality control)
Waveforms:	Sine or square
No. of Cycles:	1-8 selectable
Output Voltage:	300 Vpp max.
Output Current:	40 App max.
Output attenuation:	0 to 100% in 20% steps
Frequency:	1 to 25 kHz with 50-Hz resolution 1 to 250 kHz with 500-Hz resolution
PRF rate:	1 to 64 pps in binary increments
Ext. Sync:	TTL compatible, neg. edge justified
Setup monitor:	Switch settings readable by PC

### Receiver:

Inputs: Two HV protected differential inputs summed together. Prior to summation, the signals may be electronically phase shifted  $\pm 90$  degrees (unidirectional capability).

Gain: 110 dB max. overall  
40 dB fixed gain standard (internally adjustable)  
0–40 dB coarse gain (10-dB steps)  
0–30 dB fine gain (2-dB steps)

Filters: 8 individual 4-pole active bandpass filter modules  
Standard designs span frequency range.  
(Other LP, HP, or BP designs can be provided for special applications.)

Signal Output: Analog waveform,  $\pm 3V$  max. into 50 ohms

Output Impedance: 50 ohms

Setup monitor: Switch settings readable by PC

**Power:**

MsS Unit: 90–264V, 50/60 Hz

**Environmental Conditions:**

Temperature: +5 to +122 deg. F (operating)  
-15 to +50 deg. C  
-4 to +140 deg. F (storage)  
-20 to +60 deg. C

Humidity: 10 to 80 % rel. hum. (operating)  
5 to 95 % rel. hum. (storage)  
Noncondensing

**Enclosure:**

Dimensions: 18.2" (46.3 cm) d x 18.5" (47.1 cm) w x 5.8" (14.7 cm) h  
without end covers  
Add 3.5" (8.9 cm) to depth with end covers installed.  
Tip-up handle also included.

Weight: 31.5 lbs (14.3 kg)

## MsS TYPES

**Ring MsS** (Figure 5) – For cylinders with outer diameter (OD) of 3 inches or less

Part Number	A (inch)	Cylinder Diameter (inch)	Center Frequency Wavelength (inch)
<u>_R_</u> _05	0.52	0.1 – 0.5	1, 2, 4
<u>_R_</u> _10	1.02	0.6 – 1.0	1, 2, 4
<u>_R_</u> _15	1.52	1.1 – 1.5	1, 2, 4
<u>_R_</u> _20	2.02	1.6 – 2.0	1, 2, 4
<u>_R_</u> _30	3.02	2.1 – 3.0	1, 2, 4

\_R\_\_05: The first underline indicates dual(D)- or single(S)- ring MsS, the second one indicates transmitter (T) or receiver (R), and the third one indicates the wavelength in units of 1 inch at the center frequency of the sensor.

Example: DRT215 --- Dual-ring transmitter with the center frequency wavelength of 2 inches for use on 1.1- to 1.5-inch-diameter cylinder.

### EXAMPLE OF WAVELENGTH AND CORRESPONDING CENTER FREQUENCY OF GUIDED WAVE

Wavelength (inch)	Nominal Center Frequency (kHz) in 2.875-Inch-OD, 0.203-Inch-Wall Steel Tube			Nominal Center Frequency (kHz) in 1-Inch-Diameter Steel Rod		
	L(0,1)	L(0,2)	T(0,1)	L(0,1)	L(0,2)	T(0,1)
1	119	206	128	107	130	128
2	-	107	64	55	-	64
4	-	53	32	42	-	32

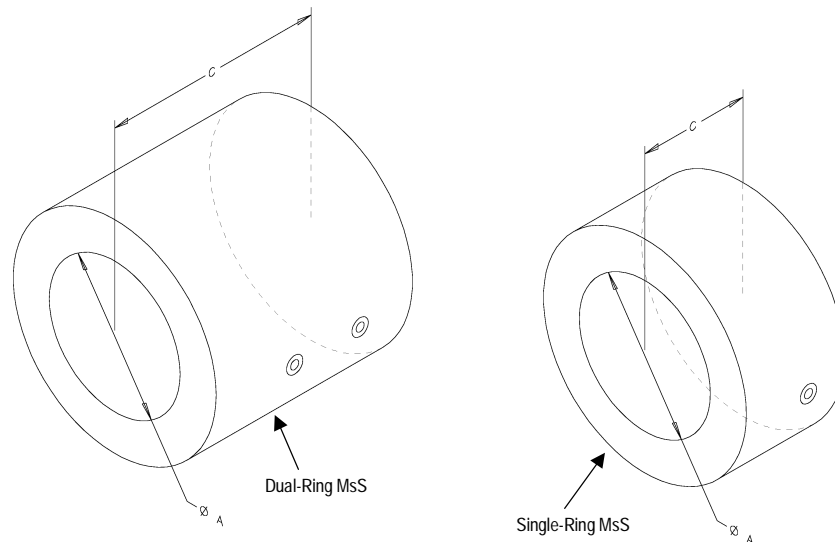


Figure 5. Ring MsS

**MsS Adapter and Ribbon Coil** (Figure 6) – For cylinders with OD larger than 3 inches

Part Number	Center Frequency Wavelengths (inch)
_A_ _	1.64, 3.34, 6.65

\_A\_ \_: The first underline indicates dual (D)- or single (S)-adaptor, the second one indicates transmitter (T) or receiver (R), and the third one indicates the wavelength in units of 1/100 inch at the center frequency of the sensor.

Example: SAT164 --- Single-adaptor transmitter with the center frequency wavelength of 1.64 inches.

**EXAMPLE OF WAVELENGTH AND CORRESPONDING CENTER FREQUENCY OF GUIDED WAVE**

Wavelength (inch)	Nominal Center Frequency (kHz) in 18-Inch-OD, 0.25-Inch-Wall Steel Pipe	
	L(0,2)	T(0,1)
1.64	128	78
3.34	64	38
6.65	32	19

**Ribbon Coils for Adaptor**

RC\_\_ \_\_: The first underline indicates the outer diameter of cylinder to be tested, and the second one indicates for use with single (S) or dual (D) adaptor.

Example: RC08D --- Ribbon coil for 8-inch-OD and for dual adaptor.

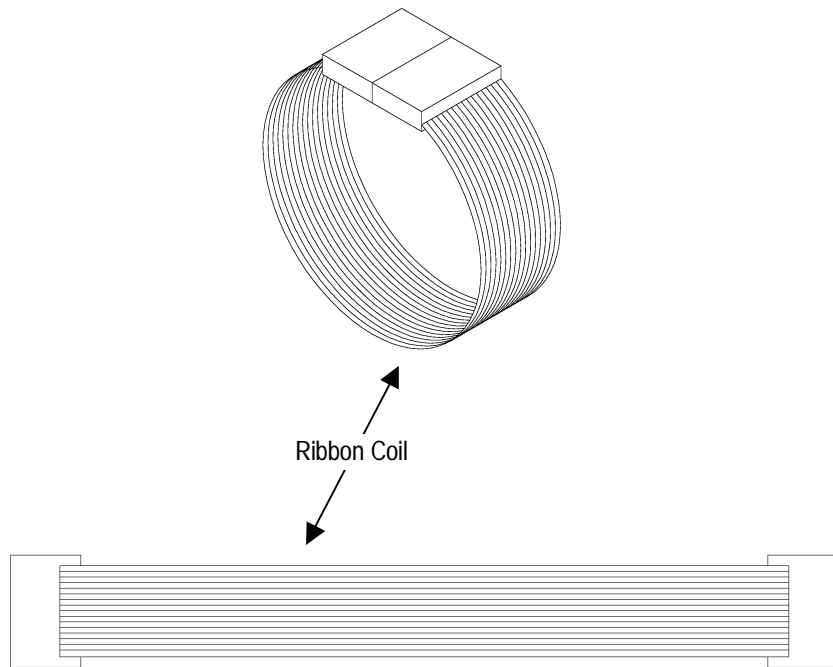
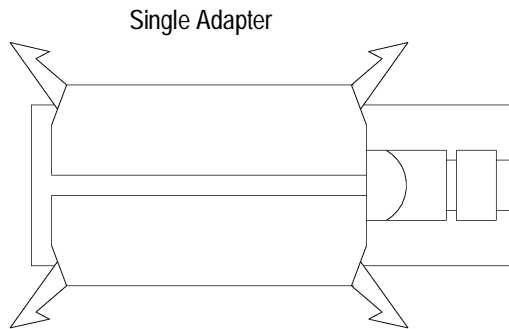
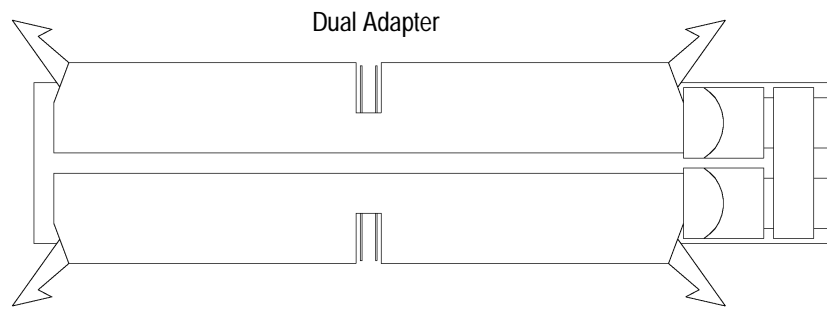


Figure 6. MsS adapter and ribbon coil

**Plate MsS** (Figure 7)

Part Number	Length (inch)	Center Frequency Wavelengths (inch)	
		Single-Plate MsS	Dual-Plate MsS (inch)
_P__02	2	1.36, 2.47, 4	1, 2, 4
_P__04	4	1.36, 2.47, 4	1, 2, 4
_P__06	6	1.36, 2.47, 4	1, 2, 4
_P__08	8	1.36, 2.47, 4	1, 2, 4
_P__10	10	1.36, 2.47, 4	1, 2, 4

\_P\_\_02: The first underline indicates dual (D)- or single (S)- plate MsS, the second one indicates transmitter (T) or receiver (R), and the third one indicates the center frequency wavelength in units of 1/100 inch.

Example: DPR15204 --- Dual-plate receiver with the center frequency wavelength of 1.52 inches and the sensor length of 4 inches.

Application of center frequency wavelength: The nominal center frequencies for wavelength of 1mm in 1-mm-thick steel plate are as follows:

**EXAMPLE OF WAVELENGTH AND CORRESPONDING CENTER FREQUENCY OF GUIDED WAVE**

Wavelength (inch)	Nominal Center Frequency (kHz) in 0.25-Inch-Thick Steel Plate		
	S0	A0	SH0
1	201	126	128
1.36	153	88	94
2	106	54	64
2.47	85	40	52
4	54	19	32

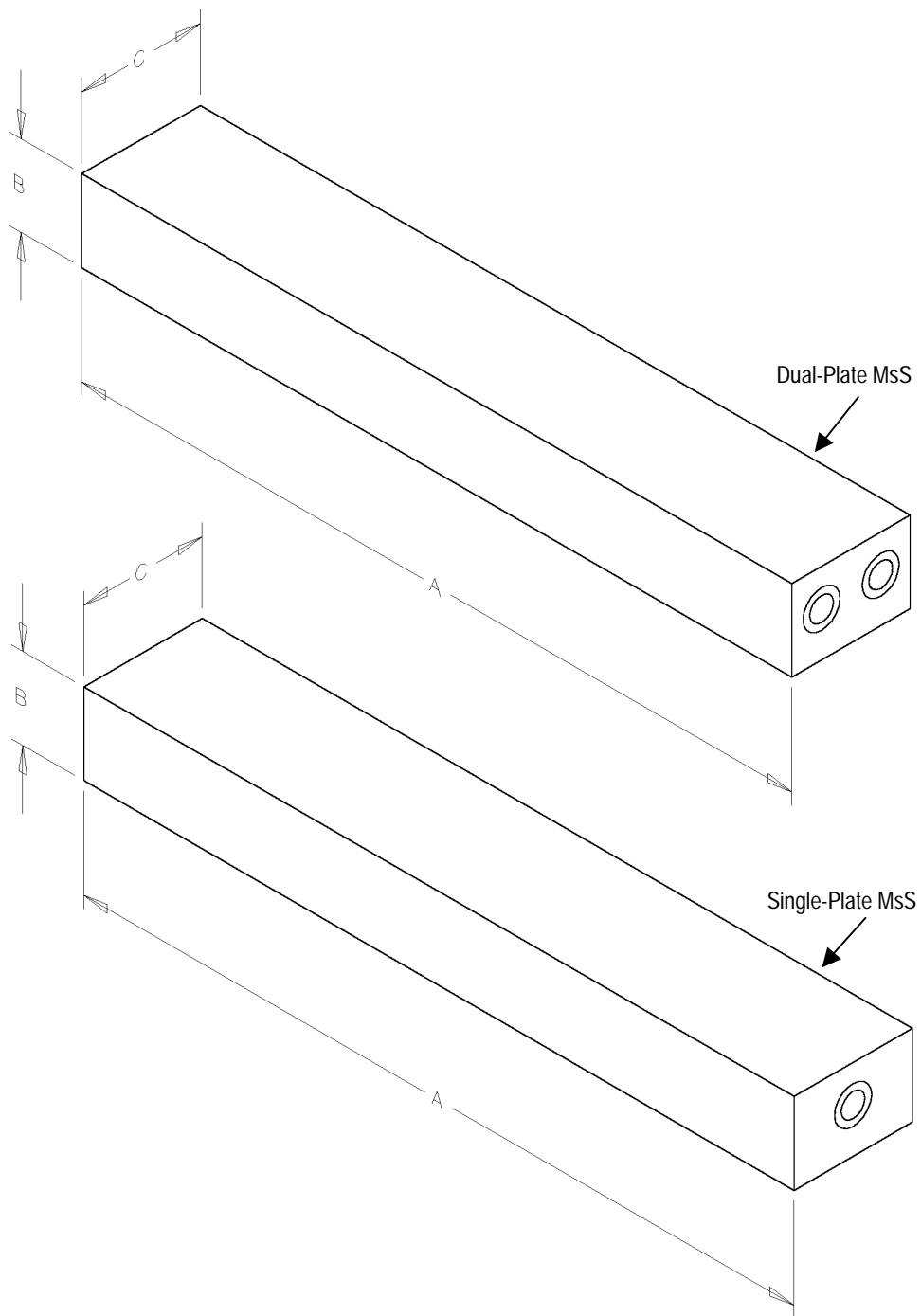


Figure 7. Plate MsS

## EXAMPLE OF GUIDED WAVE MODE DISPERSION CURVES

1. Dispersion curve for pipes and tubes
  - (a) Longitudinal mode–icon
  - (b) Torsional mode–icon
2. Dispersion curve for rods
  - (a) Longitudinal mode–icon
  - (b) Torsional mode–icon
3. Dispersion curve for plates
  - (a) Symmetric and asymmetric Lamb wave and shear-horizontal wave–icon

## APPLICATION REFERENCES

Pipes and tubes [1], [2], [3], [4]

Plates and sheets [5], [6], [7], [8], [9]

Rods and cables

Industrial measurement applications [2], [10], [11], [12]

- [1] H. Kwun, K. A. Bartels, and C. P. Dynes, “Dispersion of Longitudinal Waves Propagating in Liquid-Filled Cylindrical Shells,” *J. Acoust. Soc. Am.* **105** (1999) 2601–2611.
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- [3] H. Kwun and C. P. Dynes, “Long-Range Guided Wave Inspection of Pipe Using the Magnetostrictive Sensor Technology—Feasibility of Defect Characterization,” *SPIE* Vol. 3398 (1998) 28–34.
- [4] H. Kwun, J. J. Hanley, and A. E. Holt, “Detection of Corrosion in Pipe Using the Magnetostrictive Sensor Technique, *SPIE* Vol. 2459 (1995) 140–148
- [5] H. Kwun and S. Y. Kim, “Magnetostrictive Sensor for Generating and Detecting Plate Guided Waves,” submitted to the *J. Acoust. Soc. Am.* (2000).
- [6] H. Kwun and S. Y. Kim, “Long-Range Guided-Wave Inspection of Steel Plates Using Magnetostrictive Sensors,” to be published in the *Proceedings of the 2nd International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components*, to be held in New Orleans, Louisiana, May 24–26, 2000.

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- [11] H. Kwun and K. A. Bartels, "Experimental Observation of Elastic-Wave Dispersion in Bounded Solids of Various Configurations," *J. Acoust. Soc. Am.* **99** (1996) 962–968.
- [12] L. C. Lynnworth, "Industrial Applications of Ultrasound—A Review, II. Measurements, Tests, and Process Control Using Low-Intensity Ultrasound," *IEEE Transactions on Sonics and Ultrasonics* (1975) 71–101.