DUAL USE OF ULTRASONIC PLATE WAVES: NDE AND ULTRASONIC MOTORS

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BACKGROUND

- Plate waves have been the subject of NDE research and applications for many years.

- The analysis of the wave behavior in isotropic homogeneous materials was made by Lamb followed by many other researchers.

- In the last decade, methods were developed to analyze the wave behavior in anisotropic materials and the results were successfully applied to composites.

- In recent years, traveling flexural waves are increasing being used in actuation mechanisms.
Symmetric and Antisymmetric Mode of Guided Waves

- Symmetric Mode
- Antisymmetric Mode
EXPERIMENTAL SET-UP FOR COMBINED PBS AND LLW

WATER

ROTATABLE AXIS

TRANSMITTER

RECEIVER

GUIDING ARC

TEST PLATE
Figure 1: Schematic description of the Lamb wave phenomenon.
THEORETICAL AND EXPERIMENTAL DISPERSION CURVES FOR GRAPHITE/EPOXY UNIDIRECTIONAL LAMINATE TESTED ALONG THE FIBERS

a. ASSUMED ELASTIC PROPERTIES

b. INVERTED ELASTIC PROPERTIES

PHASE VELOCITY (km/sec)

FREQUENCY X THICKNESS (MHz x mm)
proportional at 45° to the Pictures.

Fig. 2. Influence of the stiffness.
LLW DISPERSION CURVES OF FUNDAMENTAL MODES FOR A UNIDIRECTIONAL GRAPHITE/EPOXY PLATE AND ±10- AND ±20-PERCENT CHANGES IN ELASTIC CONSTANT

**Phase Velocity (km/sec)**

**Frequency x Thickness (MHz x mm)**

**Orient: 0 Deg**

(a) $C_{22}$

(b) $C_{55}$

**Orient: 45 Deg**

(a) $C_{22}$

(b) $C_{22}$

**Orient: 90 Deg**

(a) $C_{22}$

(b) $C_{55}$

SOLID LINES = MATERIAL BEFORE CHANGE
DASHED LINES = AFTER CHANGE IN PROPERTIES
Measured dispersion data for a multilayered Gr/Ep composite before and after heat treatment for wave propagation $45^\circ$ of the fiber.
TECHNOLOGY CONCEPT & DEVELOPMENT APPROACH

- planetary science enablement: sample acquisition, near-field spectroscopy & micro-viewing, micro-instrument emplacement, etc.
- lander (surface platform) based manipulator, coring, drilling and other active devices
- mass, power, size reductions commensurate with MSP and NMP flight objectives
- direct Mars science community participation
Micro-Lander Dexterous Manipulator
FY95 ENABLING TECHNOLOGY ACHIEVEMENTS (Level 2)

Task Highlights

- conception of gas-deployable segmented link structure (graphite epoxy) enabling MSP optimized science payload packaging/mounting (Phase B/C EM spec: arm & actuation: 3.5 kg, 2 meters, 10 liters, 1.5 kg end-arm payload)

- complementary end-effector development based in composite monocoque body and solid state motor actuation (50-70% mass reduction, minimized drive train requirements)

- development of new class of low mass, high torque (low speed), high efficiency and large holding force motor: cooperative with MIT and QMI, Inc. -- 25 in-lb device recently demoed
ULTRASONIC MOTORS - BACKGROUND

Operation principle: Traveling plate/surface waves cause surface particles to move in a circular motion. This motion is used to propel the rotor.

- The motion is the result of accumulated minute displacements.
- Piezoelectric discs, i.e. stator, are used to excite the wave.
- Maximum performance is obtained at the resonance frequency.

- Ultrasonic motors are emerging new technology in consumer products (camera, etc.).
- No space qualified - ultrasonic motor.
ADVANTAGES OF ULTRASONIC MOTORS

Ultrasonic motors offer superior alternative to conventional motors.

- Without gear, average of 10 times higher torque density
- Simpler construction
- Not affected by magnetic field or radiation
- Self-holding force
- Low speed operation allowing direct drive
- Motor is compact with a -pancake shape and easy to miniaturize
- Can be designed annular for electronic packaging
- Lower cost
# Comparison of existing electromagnetic (EM) and ultrasonic (US) motors

<table>
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<th>#</th>
<th>Type</th>
<th>Description</th>
<th>Manuf.</th>
<th>Stall Torque (in. oz)</th>
<th>No-load Speed (rpm)</th>
<th>Mass (g)</th>
<th>Torque Density - without gear (Nm/kg)</th>
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<tr>
<td>1</td>
<td>EM</td>
<td>DC, Brushless</td>
<td>Aeroflex</td>
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<td>4.0K</td>
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<td>EM</td>
<td>DC Brush</td>
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<td>3</td>
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<td>AC/3-phase</td>
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<td>US</td>
<td>Traveling wave - Disc</td>
<td>Panasonic</td>
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<td>5</td>
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<td>Stand. Wave - Rod Torsion</td>
<td>Kumada</td>
<td>189.0</td>
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A Computer Code Developed to Allow Animation of the Motor Operation for Optimized Design
Piezoelectric Motor - Stator Model

a. Stationary

b. At arbitrary actuation position
A Collection of Piezoelectric Motors and Components at JPL
JPL'S ADVANCED ACTUATORS LABORATORY
A Piezoelectric Motor Connected to a Torque Gauge in the JPL Test Chamber (Cryogenic Temperatures and Vacuum)
PORTABLE C-SCAN DEVICE
MACS POTENTIAL TASKS

INSPECTION INSTRUMENTS PAYLOAD
• Visual inspection - video camera, D-Sight

• Tap testing - woodpecker (Mitsui WP631, Tapometer & Impactoscope)

• Eddy-Current - CrackFinder, Magneto Optical Imager

• Ultrasonics - Aircoupled, Ames Smart Bubbler, transducer array

PAINT REMOVING MECHANISM
• Laser induced heat

• Localized heat source such as microwaves

• RF Induced heating
SUMMARY

• The development of NDE methods using plate waves is expanding into field applications and use of dry coupling techniques.

• Improved analytical techniques of evaluating the transfer of friction forces through the USM interface as well as methods of inducing stronger displacements from piezoceramics are expected to improve USM performance.

• Application of USM are expected to grow to many areas which miniature low mass, compact actuators are needed.