**Laser ultrasonic testing (LUT)** is a remote, noncontact extension of conventional, contact or near-contact ultrasonic testing (UT). A schematic layout of a laser ultrasonic system is shown in the figure.

A laser pulse is directed to the surface of a sample through a fiber or through free space. The laser pulse interacts at the surface to induce an ultrasonic pulse that propagates into the sample. This ultrasonic pulse interrogates a feature of interest and then returns to the surface. A separate laser receiver detects the small displacement that is generated when the pulse reaches the surface.

The electronic signal from the receiver is then processed to provide the measurement of interest.

**Schematic layout of laser ultrasonic inspection system performing tests on a steel tube.** The setup consists of a small, fiber-coupled measurement head that is placed near the part to be evaluated, and a remote base station containing all support equipment.

**Compared with conventional transducer-based UT, laser UT:**
- Generates and detects the full complement of ultrasonic waves — bulk (compressional, shear), surface, and plate
- Uses normal transducer-related geometries: pulse-echo, through transmission, and pitch-catch
- Is remote and non-contact
- Does not load the surface
- Works so that the workpiece or laser beams can be scanned rapidly, thus increasing the rate of inspection
- Offers much higher bandwidth, thus increasing the information available for signal processing.

**BROAD USES OF LASER ULTRASONIC TESTING**

Laser UT is fast and effective on rough surfaces. It functions effectively in a factory environment. It is ideally suited for many applications that are beyond the capabilities of conventional ultrasonic testing. The applications extend over three broad areas:

- **Process monitoring:** measurements early in an industrial process on parts that are hot and/or moving at high speed.
- **Post-process evaluation:** high resolution inspection of small parts; fast areal scans of large components or structures.
- **In-service inspection:** inspection of complex structures (turbine blades); inspection under hazardous conditions (nuclear power plants); fast scanning of safety-critical oil and gas pipelines.
IOS is a leading supplier of innovative noncontact solutions for industrial inspection and process control.

INDUSTRY NEEDS

IN - PROCESS NEEDS
● Post-process evaluation no longer satisfactory
● Monitor/measure earlier in the process: major economic benefits
● Facing higher temperatures, faster process speeds, smaller sample size, more demanding specifications
● Higher quality, lower capital and operating costs.

IN - SERVICE NEEDS
● Extend service life, plan scheduled maintenance
● Respond to stricter safety requirements.

INDUSTRIES SERVED:
● Automotive
● Semiconductor packaging
● Electronic component
● Steel and cast iron
● Aerospace
● Oil and gas pipeline
● Shipbuilding
● Glass bottling

APPLICATION EXAMPLES:
● Wall thickness measurement
● Weld inspection
● Coating thickness measurement
● Composite flaw detection
● Crack depth measurement
● Bond evaluation
● Grain size measurement

LASER ULTRASONIC SOLUTIONS
● Combine noncontact property, and speed and spatial resolution of lasers, with ability to penetrate opaque materials.
● Take advantage of improved performance, and lower price of lasers and adaptive receivers.
● Provides economic benefits to end user via higher throughput, higher yield, reduced down time, and fewer product returns.
WALL THICKNESS MEASUREMENT OF SEAMLESS STEEL TUBES

TYPICAL CONDITIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement spacing</td>
<td>20 cm</td>
</tr>
<tr>
<td>Pipe temperature</td>
<td>Up to 1250°C</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>3 mm to 34 mm</td>
</tr>
<tr>
<td>Pipe diameter</td>
<td>4 cm to 15 cm</td>
</tr>
<tr>
<td>Pipe velocity</td>
<td>Up to 5 m/s</td>
</tr>
<tr>
<td>Measurement position</td>
<td>At exit of mill</td>
</tr>
</tbody>
</table>

SCHEMATIC DRAWING OF MEASUREMENT CONFIGURATION

FACTORY DEMONSTRATION

Photo of pipe exiting mill during measurement

MEASUREMENT DATA

Red dots: laser-based measurement at exit from mill
Triangles: transducer-based hand measurement after cooling

Measurements agree after correction for thermal expansion
TRENDS IN AEROSPACE COMPOSITE MANUFACTURING

- Increased use of large, unitized structures
- Improved designs and processing required
- Large parts are too expensive to be rejected
- Careful evaluation (and possible repair) is required
- Current inspection techniques (water-based, laser-based) are not effective in a lean environment

IDEAL SYSTEM

- Agile (robot-mounted)
- High sensitivity
- Effective validation for large structures
- Leads to lower system cost
- Move inspection closer to manufacturing operations
- On tool
- Uncured and cured state

Schematic drawing of agile measurement system

Image of honeycomb panel with artificial disbonds
EVALUATION OF ADHESIVE BONDS

ADHESIVE BONDS HAVE BROAD APPLICATIONS

PERFORMANCE REQUIREMENTS

- High strength
- High thermal conductivity
- High electrical conductivity

MANUFACTURING CHALLENGES

- Stabilize spread of adhesive
- Maintain thickness value
- Insure good adhesion

SOLUTION: LASER ULTRASONICS

- Noncontact
- Fast areal scanning
- Small laser spots yield high spatial resolution
- High bandwidth enables measurement of bond strength
- Replaces slow water-based ultrasonic systems

Image of epoxy underfill beneath flip chip

Image of adhesive distribution underneath sheet metal
LASER WELDING is used in many industrial applications
- High weld speed
- Minimum heat deposition and deformation
- Automotive
- Weld integrity and dimensional control are critical
- In-line quality control required

SPOT WELDING is critical process for auto body assembly
- Weld area and strength are critical
- Inspection techniques are currently unreliable
- Weak bonds are very difficult to detect

FRICTION STIR WELDING is preferred method for aluminum panels
- High weld speed
- Reproducible properties
- Minimal heat deposition

SOLUTION: laser ultrasonics
- Noncontact
- Fast scanning
- High spatial resolution
- Fully automated

Spot weld image

In-line friction stir weld sensor
The receiver and probe laser are mounted in a 19” rack. The remote measurement head is fiber coupled.

The IOS LUKS-532-TWM and LUKS-1550-TWM Laser Ultrasonic Kit for Starters are both designed to provide all the components necessary for establishing a laser ultrasonic inspection capability for laboratory use. The kit includes an innovative Adaptive Interferometric Receiver (AIR), as described on the following pages. The fiber-coupled measurement head is small, reconfigurable and easily focused. The modular design allows simple changes of the detection or generation laser, as well as the fiber head.

<table>
<thead>
<tr>
<th>INDUSTRIES SERVED</th>
<th>MATERIALS STUDIED</th>
<th>MEASUREMENT TYPES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerospace</td>
<td>Steel</td>
<td>Thickness Measurements</td>
</tr>
<tr>
<td>Automotive</td>
<td>Cast iron</td>
<td>Glass containers</td>
</tr>
<tr>
<td>Oil and gas pipeline</td>
<td>Ceramics</td>
<td>Ceramic and metallic coatings</td>
</tr>
<tr>
<td>Steel and cast iron</td>
<td>Glass</td>
<td>Steel tubes and cast iron pipes</td>
</tr>
<tr>
<td>Shipbuilding</td>
<td>Composites</td>
<td>Defect Detection</td>
</tr>
<tr>
<td>Semiconductor</td>
<td>Semiconductors</td>
<td>Laser welds</td>
</tr>
<tr>
<td>Electronic components and packages</td>
<td></td>
<td>Ceramic coatings</td>
</tr>
<tr>
<td>Medical devices</td>
<td></td>
<td>Electronic packages</td>
</tr>
<tr>
<td>Ceramics</td>
<td></td>
<td>Adhesives</td>
</tr>
<tr>
<td>Glass bottling</td>
<td></td>
<td>Small parts</td>
</tr>
</tbody>
</table>

Providing Solutions with Optical Science
Address: 2520 W. 237th Street Torrance, CA 90505-5217
Phone: (424) 263-6300  Fax: (310) 530-7417  www.intopsys.com
# LASER ULTRASONIC KIT FOR STARTERS

## SPECIFICATIONS

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>LUKS SYSTEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiver</td>
<td>AIR-1550-TWM/AIR-532-TWM</td>
</tr>
<tr>
<td>Probe Laser</td>
<td>2W continuous-wave, single-frequency fiber laser at 1550 nm</td>
</tr>
<tr>
<td></td>
<td>1W continuous-wave, single-frequency DPSS laser at 532 nm</td>
</tr>
<tr>
<td>Generation Laser</td>
<td>Q-switched Nd:YAG at 1064 nm</td>
</tr>
<tr>
<td></td>
<td>Pulse width: 10 ns; pulse energy: 50, 200 or 400 mJ. Includes goggles and</td>
</tr>
<tr>
<td></td>
<td>a selection of mirrors and lenses for directing and focusing the beam</td>
</tr>
<tr>
<td>Scanning System</td>
<td>Two linear stages and controller; range of specifications available</td>
</tr>
<tr>
<td>Data Acquisition</td>
<td>LaserScan™ software: Scanning system motion control, data acquisition,</td>
</tr>
<tr>
<td>and Control</td>
<td>processing and display A-scan, B-scan, C-scan; specialized processing</td>
</tr>
<tr>
<td></td>
<td>Desktop computer with data acquisition card: PC running Windows 7</td>
</tr>
<tr>
<td>Installation</td>
<td>Included with system</td>
</tr>
<tr>
<td>Training</td>
<td>IOS offers a fee-based two-day seminar at IOS (or at a customer site) that</td>
</tr>
<tr>
<td></td>
<td>explains the principles of laser ultrasonics and describes the operation</td>
</tr>
<tr>
<td>Customization</td>
<td>The system components described above can be modified to meet the needs of</td>
</tr>
<tr>
<td></td>
<td>the user</td>
</tr>
<tr>
<td>Pricing</td>
<td>Please contact us for pricing information if you are interested in one of</td>
</tr>
<tr>
<td></td>
<td>our standard systems or a customized solution</td>
</tr>
<tr>
<td>Contact</td>
<td>Dr. Marvin Klein, Manager, Laser Ultrasonics Products Group</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:mklein@intopsys.com">mklein@intopsys.com</a> or +1(424) 263-6361</td>
</tr>
</tbody>
</table>

### Customization Options

- **Miniature (4 cm) detection head**
- **FHG fiber generation head**
- **FHPS detection head**
- **FHY detection head**

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[www.intopsys.com](http://www.intopsys.com)
The AIR-1550-TWM Laser Ultrasonic Receiver represents the state-of-the-art in non-contact laser ultrasonic testing. The AIR-1550-TWM is the first laser ultrasonic receiver operating at the telecom and eye-safe wavelength of 1550 nm. Eye-safe lasers are important for the protection of researchers as well as for workers in production environments.

The operating wavelength also enables the AIR-1550-TWM to work effectively with simple, low-cost laser sources, such as DFB or fiber lasers, thereby reducing system cost and eliminating laser maintenance concerns. Although the 1550 nm wavelength is not visible to the eye, a visible guide beam is provided to visualize the detection beam on the target.

The AIR-1550-TWM includes a compact fiber-coupled measurement head. This sensor head enables remote measurement and is ideal for use with complex configurations or where measurement access is limited.

The non-contact measurement capability of laser ultrasonics and its immunity to test-piece temperature and motion make it ideal for factory use. The AIR-1550-TWM is available configured for factory applications with an optional ruggedized measurement head and fiber optic cables.

When incorporated into a full laser ultrasonic measurement system, the AIR-1550-TWM can measure thickness, sound velocity and grain structure with high precision. In addition, laser ultrasonics can be used effectively to locate sub-surface defects such as inner wall corrosion or delaminations. These inspection systems can be used with real time feedback for process control or in-service system inspection.

**Typical Applications:**
- Thickness measurements
  - Glass containers
  - Ceramic and metallic coatings
  - Steel tubes and cast iron pipes
- Defect Detection
  - Laser welds
  - Ceramic coatings
  - Electronic packages
  - Bonded components
  - Small parts
- Crack sizing
  - Oil and gas pipelines
## AIR-1550-TWM

<table>
<thead>
<tr>
<th>Model</th>
<th>AIR-1550-TWM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Displacement Sensitivity</td>
<td>2 x 10^{-7} nm rms (W/Hz)^{1/2}</td>
</tr>
<tr>
<td>Detector Bandwidth</td>
<td>125 MHz (Optional 1 GHz Bandwidth)</td>
</tr>
<tr>
<td>Measurement Type</td>
<td>High Sensitivity, Fast Response</td>
</tr>
<tr>
<td>Measurement Type</td>
<td>Laboratory and Factory</td>
</tr>
<tr>
<td>External Probe Laser Requirement</td>
<td>60 mW DFB Laser Diode Fiber Lasers up to 10W</td>
</tr>
<tr>
<td>FHY Fiber Measurement Head</td>
<td>Aperture: 25 mm</td>
</tr>
<tr>
<td></td>
<td>Focal Distance: 50-100 mm</td>
</tr>
<tr>
<td></td>
<td>Spot Size: 100-200 µm</td>
</tr>
<tr>
<td>Guide Laser Beam</td>
<td>Diode Laser at 650 nm</td>
</tr>
<tr>
<td>Analog Output</td>
<td>50 Ohm source</td>
</tr>
<tr>
<td>Electrical Requirements</td>
<td>100/220 V, 50/60 Hz</td>
</tr>
<tr>
<td>Alignment Signal</td>
<td>Provided by internal piezo mirror</td>
</tr>
<tr>
<td>Dimensions</td>
<td>325 x 250 x 100 (L x W x H, mm)</td>
</tr>
<tr>
<td></td>
<td>Compatible with 19-inch rack mount cabinets</td>
</tr>
<tr>
<td>Installation and Training</td>
<td>Installation included. Training offered for a fee at IOS or customer site</td>
</tr>
</tbody>
</table>

Specifications subject to change without notice.

### Broad Uses of Laser Ultrasonics

Laser ultrasonics is ideally suited for many applications that are beyond the capabilities of conventional ultrasonic testing. The applications extend over three broad areas:

- Process monitoring: measurements early in an industrial process on parts that are hot and/or moving at high speed
- Post-process evaluation: high resolution inspection of small parts; fast areal scans of large components or structures
- In-service inspection: inspection of complex structures (turbine blades); inspection under hazardous conditions (nuclear power plants); fast scanning of safety-critical oil and gas pipelines

### Features of Laser Ultrasonics

Laser ultrasonic testing offers many advantages when compared with traditional contact inspection techniques:

- Remote, non-contact, reconfigurable
- Can scan measurement head or sample
- Proven at speeds ≥ 5 m/sec
- Proven at temperatures ≥ 2000°F
- High bandwidth operation
- High spatial resolution
- Micrometer thickness accuracy
- Small contact area on sample
The AIR-532-TWM Laser Ultrasonic Receiver complements the AIR-1550-TWM receiver in representing the state-of-the-art in non-contact laser ultrasonic testing. The AIR-532-TWM is designed for the highest sensitivity for the most demanding laboratory applications.

The operating wavelength enables the AIR-532-TWM to work effectively with simple, low-cost diode-pumped solid-state (DPSS) laser sources, thereby reducing system cost and eliminating laser maintenance concerns.

The AIR-532-TWM includes a compact fiber-coupled measurement head. This sensor head enables remote measurement and is ideal for use with complex configurations or where measurement access is limited.

The non-contact measurement capability, high sensitivity and high bandwidth of the AIR-532-TWM receiver make it ideal for demanding laboratory applications.

When incorporated into a full laser ultrasonic measurement system, the AIR-532-TWM can measure thickness, sound velocity and grain structure with laser precision. In addition, laser ultrasonics can be used effectively to locate subsurface defects such as inner wall corrosion or delaminations. These inspection systems can be used with real time feedback for process control or in-service system inspection.

**Typical Applications:**
- Thickness measurements
- Glass containers
- Ceramic and metallic coatings
- Steel tubes and cast iron pipes
- Laser welds
- Ceramic coatings
- Electronic packages
- Bonded components
- Small parts
- Crack sizing
- Oil and gas pipelines

**Separation B-Scan Taken on 6 mm Steel Sample**
AIR-532-TWM

<table>
<thead>
<tr>
<th>Model</th>
<th>AIR-532-TWM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surface Displacement Sensitivity</strong></td>
<td>$1 \times 10^{-7}$ nm rms (W/Hz)$^{1/2}$</td>
</tr>
<tr>
<td><strong>Detector Bandwidth</strong></td>
<td>125 MHz (optional 1 GHz bandwidth)</td>
</tr>
<tr>
<td><strong>Measurement Type</strong></td>
<td>Highest sensitivity for laboratory use</td>
</tr>
</tbody>
</table>
| **External Probe Laser Requirement** | 1W DPSS laser at 532 nm  
|                               | Higher power lasers available        |
| **FHY Fiber Measurement Head** | Aperture: 25 mm  
|                               | Focal Distance: 50-100 mm  
|                               | Spot Size: 100-200 µm               |
| **Analog Output**              | 50 Ohm source                        |
| **Calibrated Output (Optional)** | Directly calibrated in mV/nm displacement |
| **Electrical Requirements**    | 100/220 V, 50/60 Hz                  |
| **Alignment Signal**           | Provided by internal piezo mirror     |
| **Dimensions**                 | 325 x 250 x 100 (L x W x H, mm)  
|                               | Compatible with 19-inch rack mount cabinets |
| **Installation and Training**  | Installation included. Training offered for a fee at IOS or customer site |

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**Broad Uses of Laser Ultrasonics**

Laser ultrasonics is ideally suited for many applications that are beyond the capabilities of conventional ultrasonic testing. The applications extend over three broad areas:

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**Features of Laser Ultrasonics**

Laser ultrasonic testing offers many advantages when compared with traditional contact inspection techniques:

- Remote, non-contact, reconfigurable
- Can scan measurement head or sample
- Proven at speeds $\geq 5$ m/sec
- Proven at temperatures $\geq 2000^\circ$F
- High bandwidth operation
- High spatial resolution
- Micrometer thickness accuracy
- Small contact area on sample
LaserScan™ is an IOS-developed software program specifically tailored for laser ultrasonic experiments. It is a fully integrated package for data acquisition, motion control, signal processing, A-scan, B-scan and C-scan display, as well as storage of raw data, images and text files for graphic displays. A large number of filters may be applied in sequence to the temporal signals.

LaserScan™ will drive mechanical stages from Newport, Velmex and Aerotech. It will also communicate with controllers for Quantel lasers. Scanning of the stages can be set for stepped or continuous.

Two features of LaserScan™ are unique to this program. The C-slice is a graphical display of the C-scan data, taken as a slice along the X or Y axis of the C-scan. Both an amplitude vs. X (Y-slice) and amplitude vs. Y (X-slice) are plotted, as set by the C-Scan’s cursors.

The plate echo simulation is an aid to identifying bulk and surface wave arrivals when performing experiments in a rectangular plate. For selected values of the plate thickness, beam separation and wave velocities, the wave arrivals are overlaid onto B-scan data. The waves that are calculated are the Rayleigh wave, the surface-skimming longitudinal wave, bulk longitudinal waves, bulk shear waves and mode converted waves. Longitudinal wave arrivals up to 10L (i.e. 10 single passes through the plate) are calculated.

Data Analysis Screen
<table>
<thead>
<tr>
<th>Attribute</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supported positioning systems</td>
<td>Newport, Velmex, Aerotech</td>
</tr>
<tr>
<td>Supported pulsed laser controllers</td>
<td>Quantel</td>
</tr>
<tr>
<td>Input channels</td>
<td>2 channels, plus trigger input</td>
</tr>
<tr>
<td>Data acquisition</td>
<td>250 MS/s, 125 MHz, 8 bit, 8 MB memory standard</td>
</tr>
<tr>
<td>Scanning modes</td>
<td>Stepped, continuous; X and Y stages</td>
</tr>
<tr>
<td>Raw data file format</td>
<td>Raw files are acquired and saved as a 3D (X, Y, t) data cube</td>
</tr>
<tr>
<td>Graphic image displays</td>
<td>A-scan, B-scan, C-scan, C-slice, histogram</td>
</tr>
<tr>
<td>B-scan display options</td>
<td>AC data, DC data; X-t (fixed Y), Y-t (fixed X)</td>
</tr>
<tr>
<td>C-scan grayscale for set time window</td>
<td>Max amplitude, min amplitude, time of maximum, time of minimum, max–min amplitude, average amplitude</td>
</tr>
<tr>
<td>A-scan, B-scan, C-scan save formats</td>
<td>Graphic (bitmap), numeric text</td>
</tr>
<tr>
<td>Macro temporal signal filters executed sequentially</td>
<td>Low pass, high pass, d/dt, d/dx, d/dy, FFT, square, subtract mean X, subtract mean Y, outlier removal, X axis averaging, Y axis averaging, Y axis smoothing, AC/DC. Macro sequential filters can be saved.</td>
</tr>
<tr>
<td>X axis or Y-axis smoothing algorithms</td>
<td>Moving average, Savitsky-Golay</td>
</tr>
<tr>
<td>C-Slice</td>
<td>Plots signal amplitude vs X (or Y) for given Y (or X)</td>
</tr>
<tr>
<td>Plate Echo Simulation for identifying signal arrivals in B-scan</td>
<td>Vertical cursors overlaid onto B-scan, representing Rayleigh, surface-skimming, longitudinal, shear and mode-converted arrivals. Thickness and beam separation entered by operator. Rayleigh, longitudinal and shear velocities for metals available in lookup table.</td>
</tr>
</tbody>
</table>