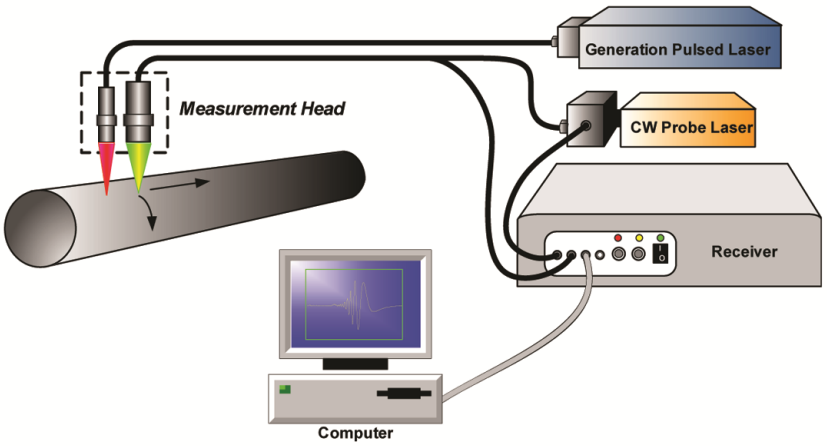
INTELLIGENT OPTICAL SYSTEMS, INC.

LASER ULTRASONIC SOLUTIONS



Schematic layout of a 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.

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.

APPLICATION EXAMPLES:

- Wall thickness measurement
- Weld inspection
- Coating thickness measurement
- Composite flaw detection
- Crack depth measurement
- Bond evaluation

INDUSTRIES SERVED:

- Additive manufacturing
- Automotive
- Semiconductor packaging
- Electronic component
- Steel and cast iron
- Aerospace
- Oil and gas pipeline
- Shipbuilding

Compared with conventional transducer-based UT, laser UT:

- Generates and detects the full complement of ultrasonic waves — bulk (longitudinal, shear), Surface, 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 higher bandwidth than conventional UT, 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.

Solutions Using Laser Ultrasonic Science
2520 W. 237th Street, Torrance, CA 90505-5217
Phone: (424)-263-6361
http://www.intopsys.com/laserultrasonics

Intelligent Optical Systems

Founded in 1998

Business focus areas:

- Physical, chemical, and biomedical optical and electronic sensors
- Advanced light sources
- Signal and image processing
- Laser ultrasonic technology and products (Optech)

>$2.5M in equipment

11,500 sq. ft. facility in Torrance, CA

Several spin-off companies with >$22M in private funding

Laser ultrasonics products commercialized by Optech

Nearing commercialization:

Discrete and distributed chemical sensors
Lateral flow biomedical sensors

Additive Manufacturing Inspection

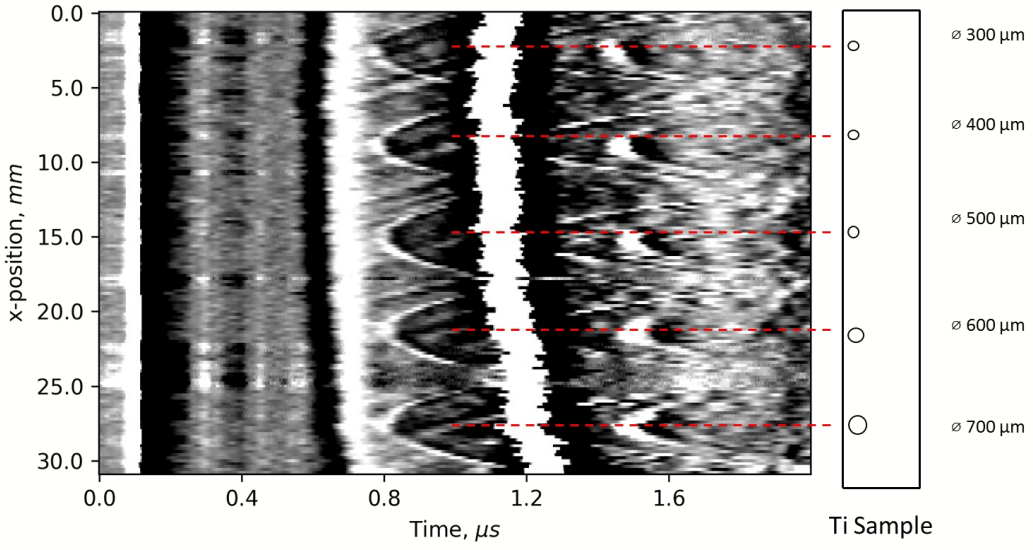
ADDITIVE MANUFACTURING is experiencing

- Additive manufacturing (AM) has great potential for rapid prototyping
- AM enables fabrication of parts with complex geometries

INPECTION CHALLENGES

- In-line inspection is required to detect defects during production
- There is currently a major gap for in-line inspection of AM parts

LUT B-scan image of a Ti-6Al-4V AM sample with five EDM side-drilled holes ranging from 700 µm to 300 µm



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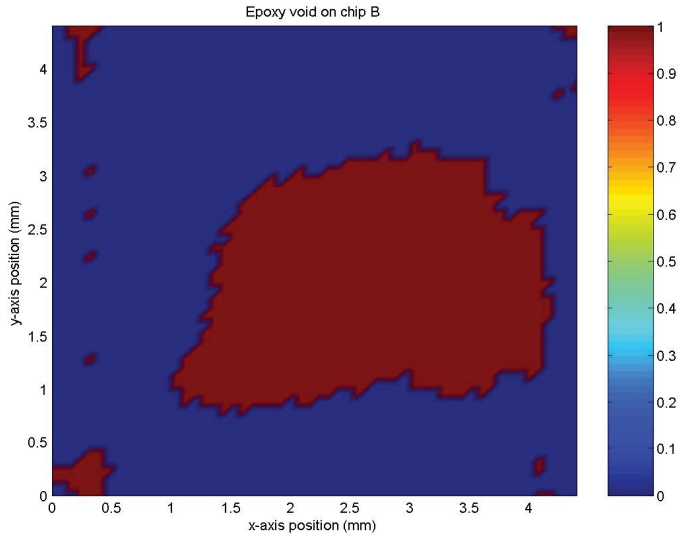
ADHESIVE BOND INSPECTION

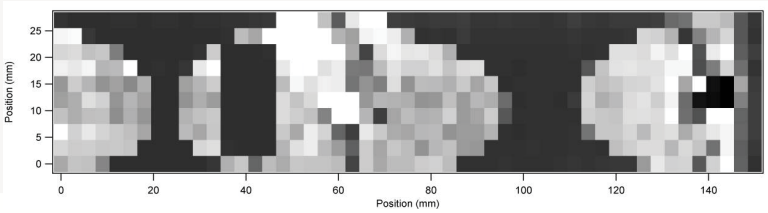
PERFORMANCE REQUIREMENTS
- High strength
- High thermal conductivity
- High electrical conductivity

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



LUT image of epoxy underfill beneath flip chip

LUT image of adhesive distribution underneath sheet metal

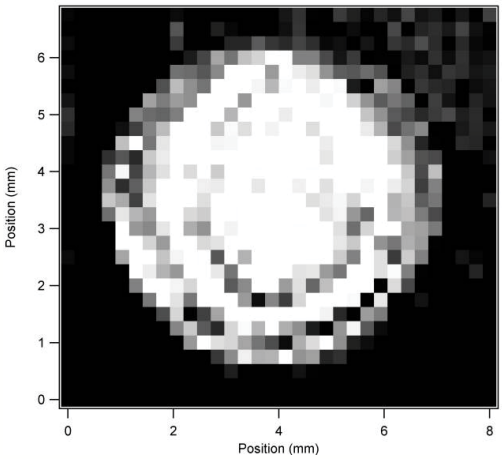


WELD INSPECTION

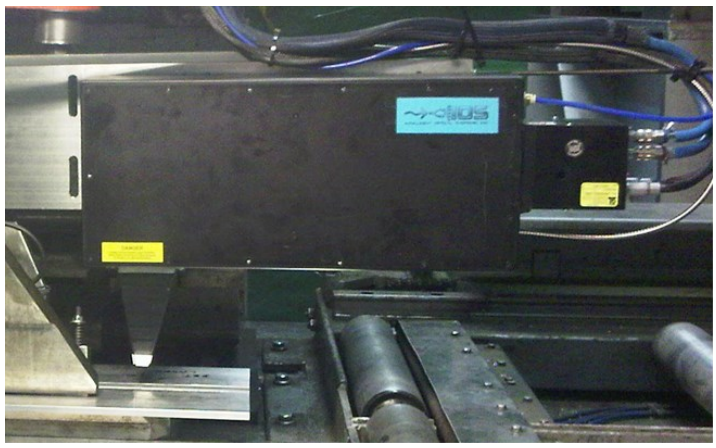
SPOT WELDING is a critical process for auto body assembly
- Weld área and strength are critical
- Inspection techniques are currently unreliable

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

LUT spot weld image



In-line friction stir weld sensor



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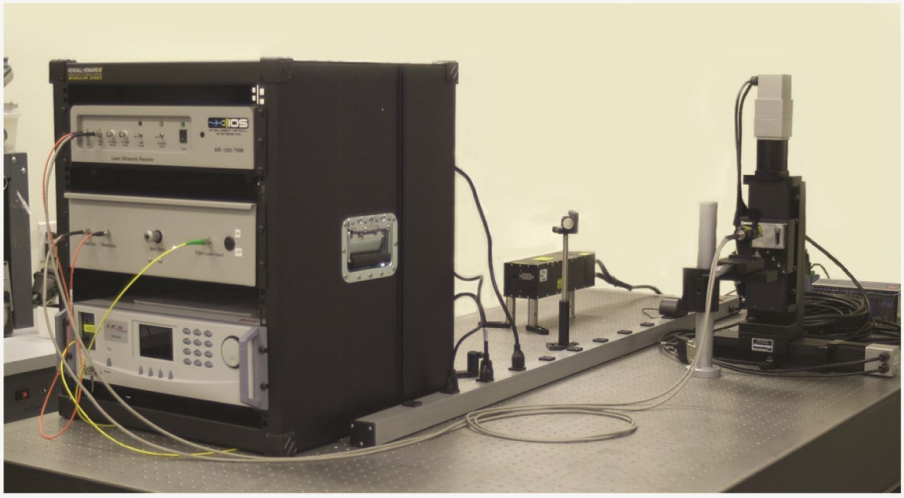
LASER ULTRASONIC KIT FOR STARTERS

LUKS-1550-TWM

State-of-the-Art Reconfigurable Measurement System



The receiver and probe laser are mounted in a 19" rack. The remote measurement head is fiber coupled.

The IOS 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.

INDUSTRIES SERVED

- Aerospace
- Additive manufacturing
- Automotive
- Oil and gas pipeline
- Steel and cast iron
- Shipbuilding
- Semiconductor
- Electronic components and packages
- Medical devices
- Ceramics
- Glass bottling

MATERIALS STUDIED

- Steel
- Titanium
- Inconel
- Cast iron
- Ceramics
- Glass
- Composites
- Semiconductors

MEASUREMENT TYPES

→ **Thickness Measurements**

- Glass containers
- Ceramic and metallic coatings
- Steel tubes and cast iron pipes

→ **Defect Detection**

- Laser welds
- Ceramic coatings
- Electronic packages
- Adhesives
- Small parts
- Gas and oil pipelines

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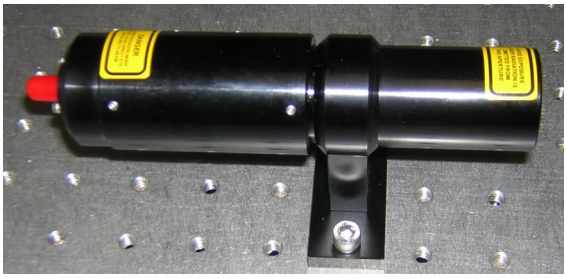
INTELLIGENT OPTICAL SYSTEMS, INC.

LASER ULTRASONIC KIT FOR STARTERS
SPECIFICATIONS

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

Miniature (4 cm) detection head

FHG fiber generation head



FHPS detection head

FHY detection head

INTELLIGENT OPTICAL SYSTEMS, INC.

LASER ULTRASONIC RECEIVER

AIR-1550-TWM

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 insensitivity 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.

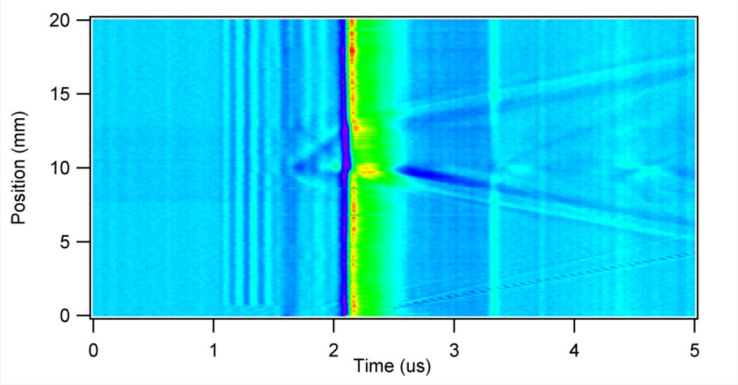
AIR-1550-TWM Receiver and Measurement Head

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
- AM builds

Crack sizing
- Oil and gas pipelines



B-scan across blind hole under Ti 6-4 laser-clad surface.

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.

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INTELLIGENT OPTICAL SYSTEMS, INC.

LASER ULTRASONIC RECEIVER
Technical Specifications

AIR-1550-TWM

Model	AIR-1550-TWM
Surface Displacement Sensitivity	2 x 10^{-7} nm rms $(W/Hz)^{1/2}$
Detector Bandwidth	125 MHz (Optional 1 GHz Bandwidth)
Measurement Type	High Sensitivity, Fast Response Laboratory and Factory
External Probe Laser Requirement	60 mW DFB Laser Diode Fiber Lasers up to 10W
FHY Fiber Measurement Head	Aperture: 25 mm Focal Distance: 50/100/200 mm Spot Size: 100/200/400 μm
Guide Laser Beam	Diode Laser at 650 nm
Analog Output	50 Ohm source
Electrical Requirements	100/220 V, 50/60 Hz
Alignment/Calibration 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/training offered for a fee at IOS or customer site

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

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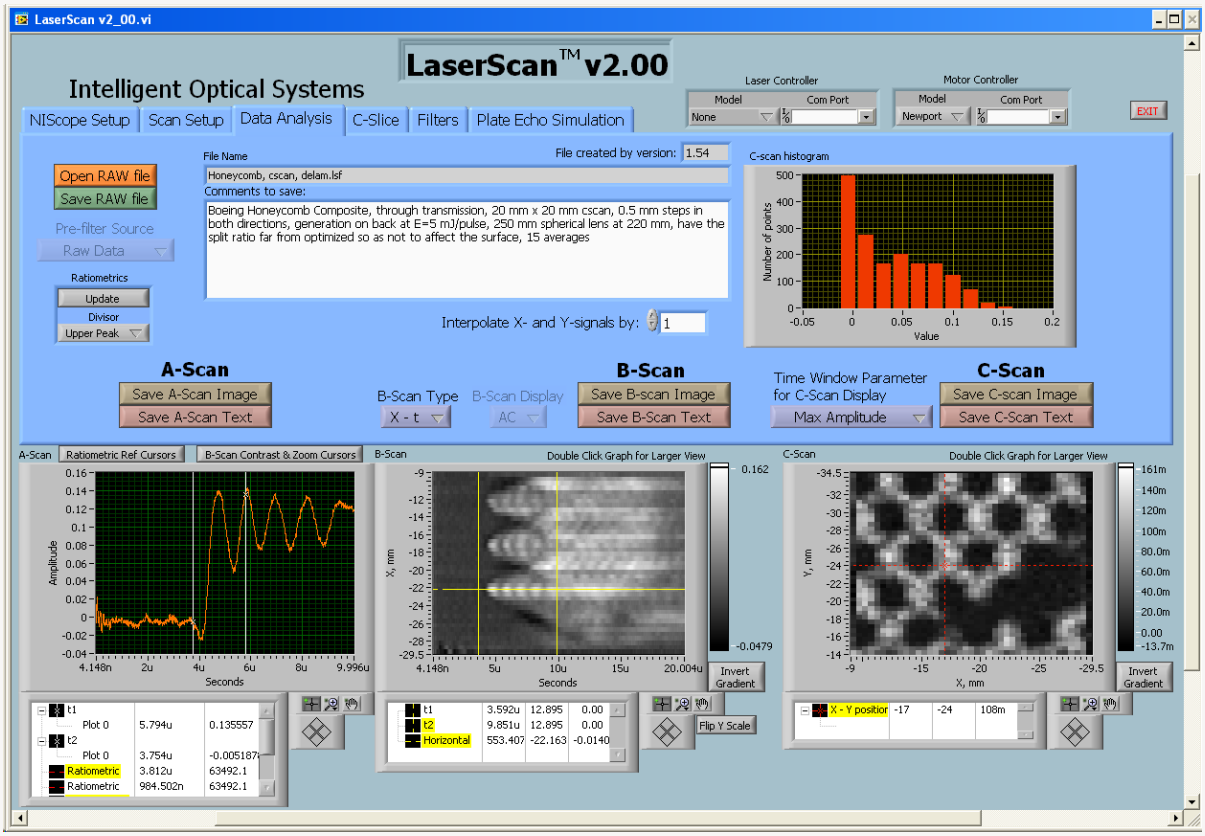
LaserScan™

LaserScan™ is an Optech-developed, user-friendly 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

LASERSCAN™ SOFTWARE
Technical Specifications

Attribute	Feature
Supported positioning systems	Newport, Velmex, Aerotech
Supported pulsed laser controllers	Quantel
Input channels	2 channels, plus trigger input
Data acquisition	250 MS/s, 125 MHz, 8 bit, 8 MB memory standard
Scanning modes	Stepped, continuous; X and Y stages
Raw data file format	Raw files are acquired and saved as a 3D (X, Y, t) data cube
Graphic image displays	A-scan, B-scan, C-scan, C-slice
B-scan display options	AC data, DC data; X-t (fixed Y), Y-t (fixed X)
C-scan temporal window	Max amplitude, min amplitude, time of maximum, time of minimum, max–min amplitude, average amplitude
A-scan, B-scan, C-scan output formats	Graphic (bitmap), numeric text
Macro temporal signal filters executed sequentially	Low pass, high pass, d/dt, d/dx, d/dy, FFT, square, subtract mean X, subtract mean Y, outlier removal, X axis averaging, X axis smoothing, Y axis averaging, Y axis smoothing, AC/DC, wavelet denoising. Macro sequential filters can be saved.
X axis or Y-axis smoothing algorithms	Moving average, Savitsky-Golay
C-Slice	Plots signal amplitude vs X (or Y) for given Y (or X)
Plate Echo Simulation for identifying signal arrivals in B-scan	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.
Plate thickness measurement	Uses 2L, 4L, 6L… echoes. Requires beam separation and wave velocity.