Ultrasound Enhanced Cell Quality Control Selection and Validation

For Long-Life Aerospace Lithium-Ion Batteries

NASA Battery Conference

HONEYWELL

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HONEYWELL PROCESS AUTOMATION IN BATTERY MANUFACTURING

CELL MANUFACTURING PROCESS

BUILDING, PROCESS AND FACILITY INFRASTRUCTURE

ELECTRODE MANUFACTURING

Comprehensive, engineered solution

- Mixing
- Coating and Drying
- Calendaring
- Slitting
- Additional Drying

CELL ASSEMBLY

Comprehensive, engineered solution

- Winding/ Stacking
- Tab Welding
- Packaging
- Electrolyte Filling

FORMATION AND AGING

Comprehensive, engineered solution

- Formation
- Degassing and Final Closing
- Aging
- EOL
- Grading

PRODUCTION ENVIRONMENT

Full smart factory solution

- Clean-room
- Dry-room
- Fire & Gas safety
- Thermal runaway prevention

BUILDING AND UTILITIES

End to end infrastructure solution

- Factory Planning
- Logistics
- Warehouse
- Integrated plant utilities

SOFTWARE

Scalable enterprise software solution

- MES - MOM
- Digital Twin
- Data Warehouse
- Quality
- SPC

FEEDFORWARD/FEEDBACK CONTROL
Data captured in different stages is communicated upstream and downstream

PROCESS MONITORING
Continuously monitor for process deviations and capture all anomalies for resolution

BUILDING/PROCESS/SAFETY SYNERGIES
Environmental conditions influence cell quality
Ensure healthy and safe operating environment

IT/OT INTERCONNECTIVITY
SCADA/MES monitors and orchestrates production while communicating with other systems with complete cybersecurity

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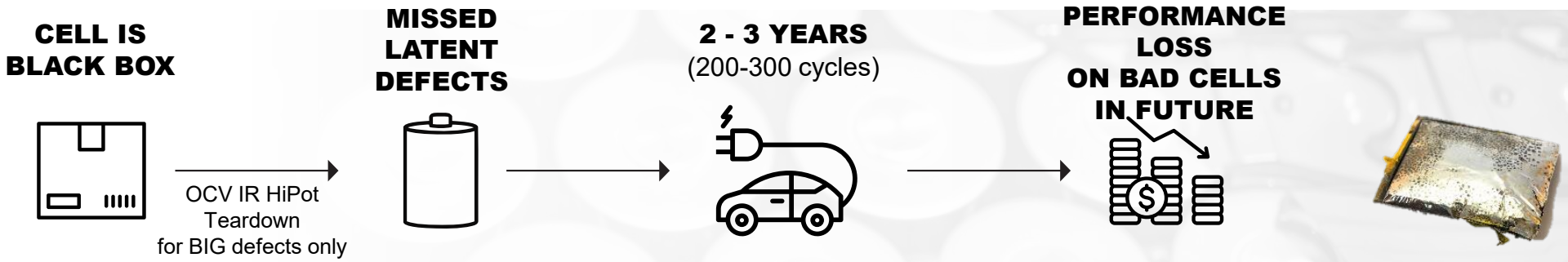
HOW TO ACHIEVE 'ZERO ESCAPES' QUALITY
PROBABILITY AND RISK IN MAKING CELLS

Ultrasound is a faster and more effective quality sensor for latent defects than any other EOL test method



SCENARIO TODAY: Manufacturing output

Latent defects escape EOL tests (OCV.IR/spot CT) .
Start-up Yield: Ramp-up scrap of 10-30% common
Yield reality: Common for yield of 92-97%, **3-8% of good cells are actually bad**

Pack makers receive 3-8% incoming bad cells. Higher risk cells are put into cars unknowingly. US Transport Bureau indicates 1/4000 cells catch fire (10% of bad cells)

PERFORMANCE LOSS IMPACT

A. **$ lost in warranty return of car,** EV packs cost ~15% -20% of the car, GM EV pack replacements cost $7k - $20k

B. **$ lost in full recall**, catastrophic profit loss, GM Bolt recall resulted in **~$1.8B** EV recalls average ~$11k per car, **EV recalls are 70k – 100k vehicles (good and bad). Higher risk cells increase the risk of recall**
In-line ultrasound lowers escapes and scrap **where it's most expensive** to miss

Cells per year	Cars per year (400 cell pack)	% bad cells (slow)	Probable # bad cells in 1 car (400 cell pack)	Probably # pack failures per year (warranty loss)	Cost of pack replacement (warranty loss)	Probable # car TRP per year (10% fire)	Cost of EV recall 100k – 250k EVs (recall loss)
100,000,000	250,000 cars	0.25%	1 / 400	625	$4.4M - $12.5M	62.5	$1.1B - $2.75B
		3%	12 / 400	7,500	$52.5M - $150M	75	$1.1B - $2.75B
		8%	32 / 400	20,000	$140M - $400M	2,000	$1.1B - $2.75B
		10-15%	40-60 / 400	25k – 36k	$175M - $720M	2.5k – 3.6k	$1.1B - $2.75B

https://www.bts.gov/content/gasoline-hybrid-and-electric-vehicle-sales
https://www.autoinsuranceez.com/gas-vs-electric-car-fires/

CHALLENGES FOR LI-ION BATTERIES IN SPACE

SPACE BATTERIES

Space batteries require greater reliability while being exposed to extreme conditions. Li-ion batteries are the predominant batteries in space, flight, satellites, ISS, and Mars Rovers due to their high energy density, light weight and long cycle life.

Latent defects come from (1) manufacturing or (2) evolve during the cell cycle life while expose to the extreme space environment. Manufacturing defects are the same across industry and can be detected with high accuracy with ultrasound. Defect evolution can be monitored during cycling.

KEY RISKS IN SPACE

Batteries require reliable performance in extreme conditions. Space exacerbates battery issues, making li-ion batteries more sensitive to standard defects and have higher risks:

- thermal cycling (-100°C to +100°C);
- high radiation causes material damage, electrolyte degradation (radicals) and impedance increase;
- thousands of cycles over 15-20+ years (30,000+ cycles);
- vacuum causes outgassing for cell dry-out and vapors cause corrosion to spacecraft; vacuum ruptures can alter trajectories;
- launch vibrations create micro-cracks in electrodes;
- EMI electromagnetic interference and extreme cold require insulation.

Satellites have orbital eclipses 16x/day in LEO and experience rapid temperature swings (e.g., -100°C to +100°C) for thousands of cycles per year, while exposed to high radiation and vacuum in space.

SPACE EXACERBATED ISSUES CONTRIBUTE TO 4-14% OF SATELLITE FAILURES, NO IN-FLIGHT REPAIR POSSIBLE

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https://www.theverge.com/2018/8/17/17681422/nasa-lithium-ion-batteries-thermal-runaway-human-spaceflight

HONEYWELL ULTRASOUND DETECTS LATENT DEFECTS

HIGH RESOLUTION ULTRASOUND NON-DESTRUCTIVE ACOUSTIC IMAGING FOR AUTOMATIC DEFECT DETECTION AT HIGH SPEED

ULTRASOUND IMPROVES QUALITY CONTROL AND CYCLE LIFE PREDICTION MODELS

Ultrasound identifies physical defects from manufacturing and usage that cause cell failure, like defects caused by vibration/thermal stress during launch.

- Non-destructive Ultrasound acoustic imaging will detect physical defects not directly visible via CT x-ray or electrochemical methods, including low z materials like anode carbons, separators, gases, and electrolytes
- Ultrasound improves cell degradation models and cycle-life prediction by tracking defects and structural changes that cause capacity fade.

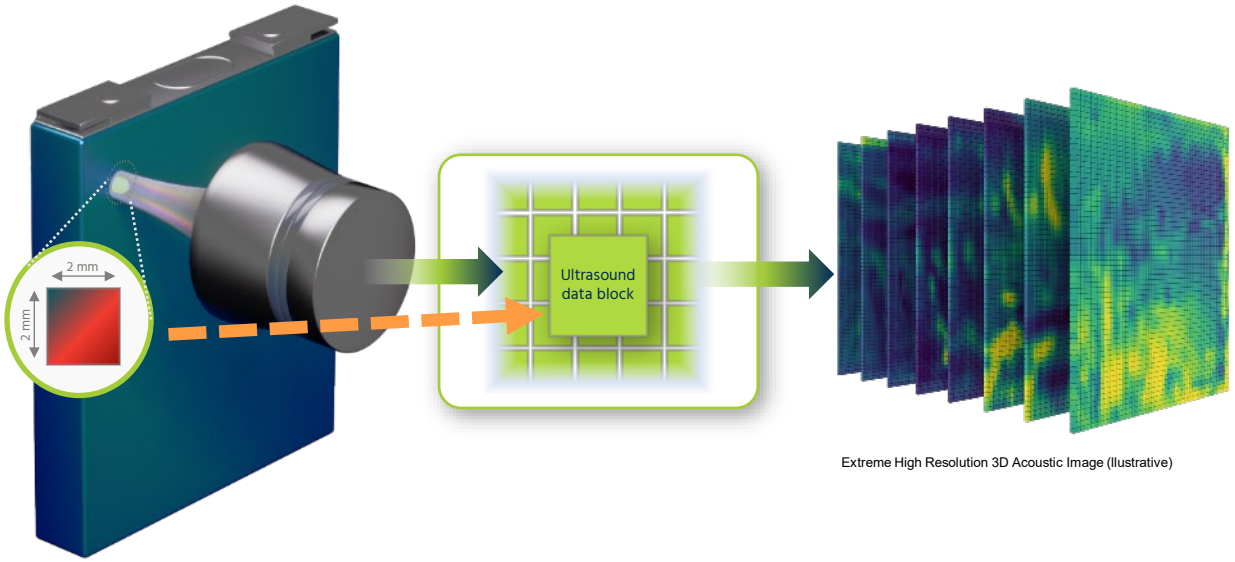
100% AUTOMATIC DETECTION AT 1 CELL/SEC

Factory machines operate at high speed (~1cell/sec) without human supervision at the highest resolution in the market, 70,000 voxels per mm². Pictures here are for human illustration only. R&D machines available.

Machine learning algorithms perform pattern detection using large data sets from (nearly) every global battery manufacturer. Algorithms use physics-based mathematics to transform acoustic patterns into 3D defect maps, identified and classified by type, location, and severity, with >99% accuracy. Algorithms written by physicists previously from NASA and Shell oil deep sea mining industry

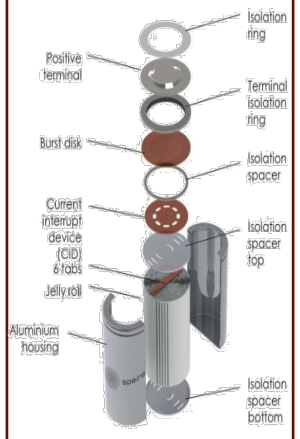
100% SCREENING STRATEGY

Screen ALL cells for specific defects. Monitor cells during cycle for degradation mechanisms and model improvement. Complimentary test methods improve accuracy. Large sample sets improve accuracy for individual customers



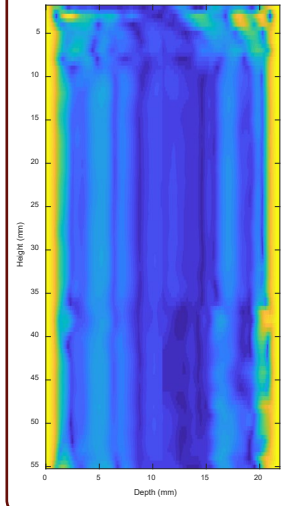
Extreme High Resolution 3D Acoustic Image (Illustrative)

Typical design of 21700 cell

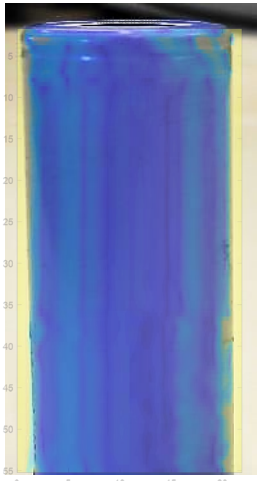


Source: https://www.batterydesign.net/battery-cell/formats/cylindrical-cells/

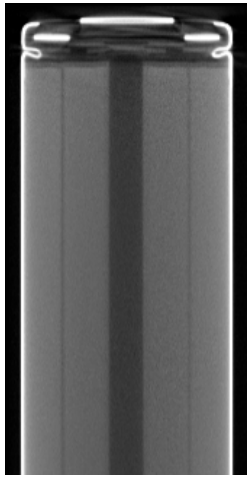
Mid-slice of Ultrasound Volume (partial)



Ultrasound scan overlayed on cell image



CT scan of the same cell (the scanning took 1 hour)



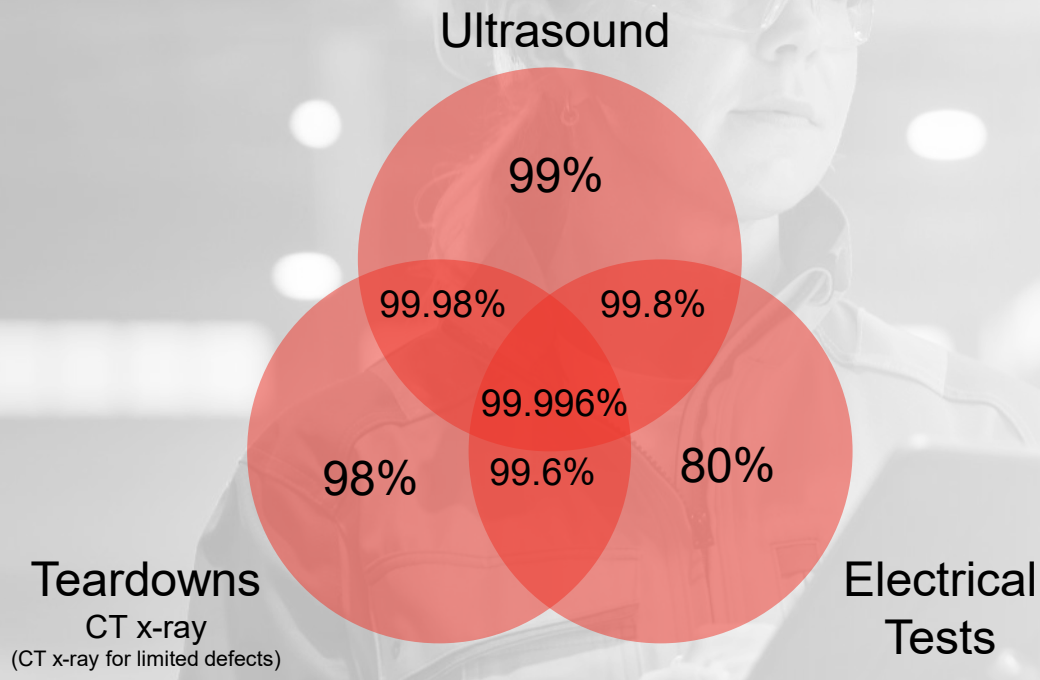
HONEYWELL CAN SCAN POUCH, PRISMATIC & CYLINDRICAL CELLS

Image courtesy: Titan IonSight™

ULTRASOUND CAN SEE LATENT DEFECTS

ULTRASOUND DETECTS MORE PHYSICAL DEFECTS THAN ANY OTHER TEST METHOD

Diagnose defects with multiple test types for high confidence



See the whole cell, both soft and hard materials.

- Ultrasound can directly image low z and high z materials.
- CT scan can directly image high z (hard) materials. CT cannot directly image low z (soft) materials like anode carbons, separators, gas, nor electrolytes.
- Teardowns have limited use because electrolyte is drained and jellyrolls can squish.
- Electrical tests give an average behavior for the whole cell or interface behaviors.

CT x-ray
(CT x-ray for limited defects)

Ultrasound with Electrical Tests
(possible for almost all defects)

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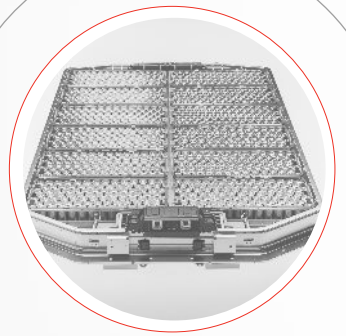
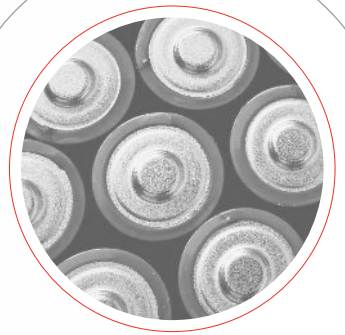
THANK YOU

BENEFITS OF HONEYWELL
100% INLINE QUALITY TESTING



Detects multiple defects to prevent QC escapes & optimize cell sorting:

Label multiple defects rapidly, including type, location, and severity. Improve cell quality, sorting, & process control. Informs QC process control with fast feedback



Rapidly identify quality issues:

100% cell testing, identify failure quickly. Test inline at ~1 cell/sec. Measure defects and capacity with < 1% error. Rapid Root cause analysis and corrective action CAPA implementation.

Enhanced Performance & Longevity:

Test and predict cell cycle-life degradation modeling. Prevent premature failures. In-Situ early detection of thermal runaway risks or cells with abnormal leakage currents or subtle defects.

Improved Safety Assurance, Compliance with UN38.3, IEC62133:

Encourage consumer confidence and reduce warranty loses. Reduces warranty replacement costs. Inform risk of failure over lifetime of cell & pack.

Increase Yield, Improve OPEX, Reduce CAPEX

Improves overall yield. Reduces aging inventory, time (3-7 days), & space. Reduce cost of quality COQ. Improve cell quality, capacity tests and grading for pack longevity.

DEFECT FREE BATTERY PACKS WITH HONEYWELL AUTONOMOUS CELL TESTING

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