High-precision Ultrasonic Metal Welding of Lithium-ion Battery Cell through Laser Vibration Sensor Technology

Ultrasonic welding is an industrial process whereby high frequency ultrasonic acoustic vibrations are locally applied to workpieces being held together under pressure to create a uniform bond. It is commonly used for plastics and metals for joining dissimilar materials. Ultrasonic welding has several advantages: 1) No connective soldering materials or adhesives are required to bind the materials together, the process is much faster than conventional epoxy bonding. 2) The welding makes clean and precise joints, rarely requires any rework, making it suitable for automation. 3) When applied to metals, the temperature stays well below the melting point of the involved materials thus preventing any unwanted properties which may arise from high temperature exposure of the materials. The low thermal impact on the materials involved enables a greater number of materials to be welded together. With these advantages, the applications of ultrasonic welding are extensive and are found in nearly every industry.

Ultrasonic welding is dependent on composition and dimensions of the materials being joined. It is a particularly important consideration in the application of welding with dissimilar metals. Wires, microcircuit connections, sheet metal, foils, ribbons and meshes are often joined using ultrasonic welding. One essential application is the wielding of battery cell for hybrid and electric vehicles. The demand for hybrid and electric vehicles with low carbon emissions has increased rapidly in recent years along with the environmental regulations. The useable power and the performance of the vehicles depend on the density and capacity of the batteries. Battery manufacturing technology that connects numerous cells is required to provide high-capacity batteries for electric vehicles. The batteries for electric vehicles are typically manufactured by connecting several cells and a bus-bar to form a single module and dozens of modules are assembled into a battery pack. Stable electrical conductivity and mechanical strength are essential for welding the battery cells and the modules reliably. The Battery cells are connected to multilayered foils and tabs. Materials such as Cu and Al, which are the most commonly used are joined using resistance spot welding, laser welding, and the ultrasonic metal welding (UMW). It has been proven that the Ultrasonic Metal Welding process is simpler and it allows wider welds in a short period and minimizes the formation of the intermetallic compounds and energy loss at the contact surface. This process has gained widespread interest as a suitable technology for battery cell welding.

Lithium-ion battery production demonstrates the UMW process has some limitations, mainly due to the thickness and the multilayer structure of the battery cell. Fundamentally, the UMW quality is determined by the combination of the welding time, amplitude and pressure. Though the wielding time and pressure is adjustable, it’s hard to measure the amplitude which is determined in part by the transducer and booster components (See Fig 1). When the total energy applied on the welding metal foils are too extreme, it contributes to “over welds” which causes the deformation of the metal foils. If the total energy is too low, it produces “under welds” and the corresponding bond is weak. In addition, the UMW processing quality is also affected by the alignment of the Horn and Anvil. Misalignment can cause uneven pressure producing underwelds. When welding thicker and harder metal materials, the required welding energy grows exponentially. Since the high-density Lithium-ion battery cells can contain up to 100 layers of Cu foils and a Ni-plated Cu strips, it is necessary to carefully monitor the ultrasonic power and its effective output. Considering the variations of each part and process related stress distribution, an PID system is normally implemented in the ultrasonic driver to lock the output power at a controlled level. Even with this type of output power control, the weldability of these multi-layer Lithium-ion battery cells varies considerably and can produce latent quality issues and potential failures in Lithium-ion battery assemblies.

Targeting on this industry challenge, OmniSensing Photonics has partnered with a leading UMW processing company and developed a weldability monitoring scheme through our compact laser vibrometer sensor. In this study a 8μm thick 99.99% pure Cu foils and a 0.2 mm thick nickel-plated copper strip were used and applied to the cathode cell of an electric vehiclebattery. A UMW machine with a 3kW maximum output power, operating at a frequencyof 20 kHz, was used to perform the welds. A schematic and photo of the UMW machine are shown in Figure 1. When an alternating current (AC) power of 50 Hz is applied to the power supply/controller, it converts the AC power into high-frequency electrical energy and then creates high-frequency mechanical vibration energy. The mechanical vibration signal is amplified by the booster and then transmitted to the welding material through a tool called a horn. The transferred welding materials are welded using the frictional heat generated by 20 kHzultrasonic vibration energy. With an installed compact laser vibrometer capable of non-contact measurements, the vibration at a given location on the Anvil adjacent to the target material can monitor how well the target material has absorbed the energy during the welding process by analyzing the anvil's featured vibration frequency in time.

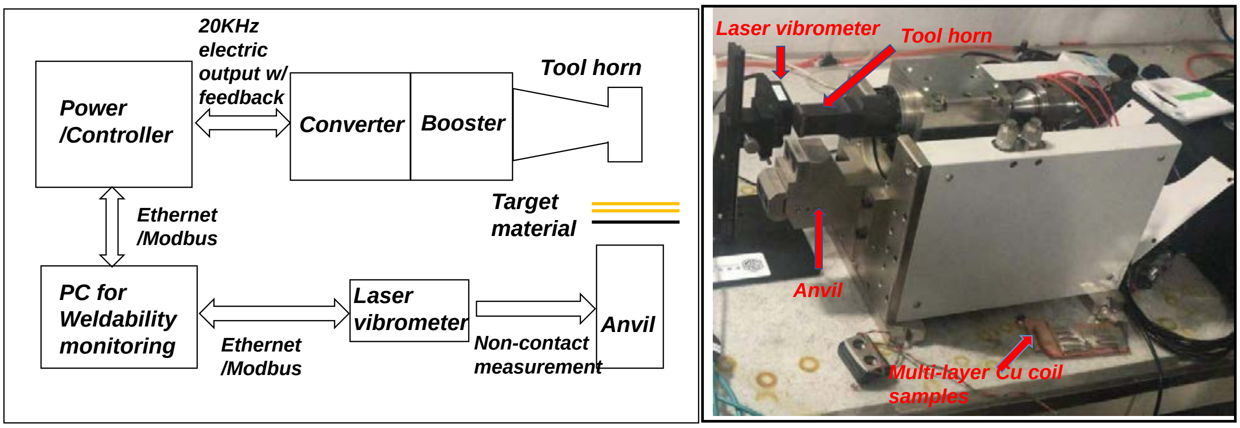

Figure 1: Schematic diagrams and experiments setup

A test setup has been constructed to validate this solution. Three typical weldability cases,"Under Weld", "Over Weld" and "Good Weld", were replicated. During each case testing, the vibration signal on Anvil was captured through the laser vibrometer sensorand its spectrum was analyzed for further correlation. Fig. 2, 3 and 4 shows the three typical results.

Under this collaboration test, a total of 105 samples were measured. After removing several NA data points, Fig. 5 displays the correlation distribution of the three pre-screened sample points by applying machine learning algorithms where we can clearly see the separation of these data points for under weld data. This scheme can extract most of the over weld samplesas well. In our analysis, some of the over weld samples were caused by the operator error during the screening stage which further demonstrates the importance of quantifying the processes and product quality monitoring through active sensors and machine learning technology.

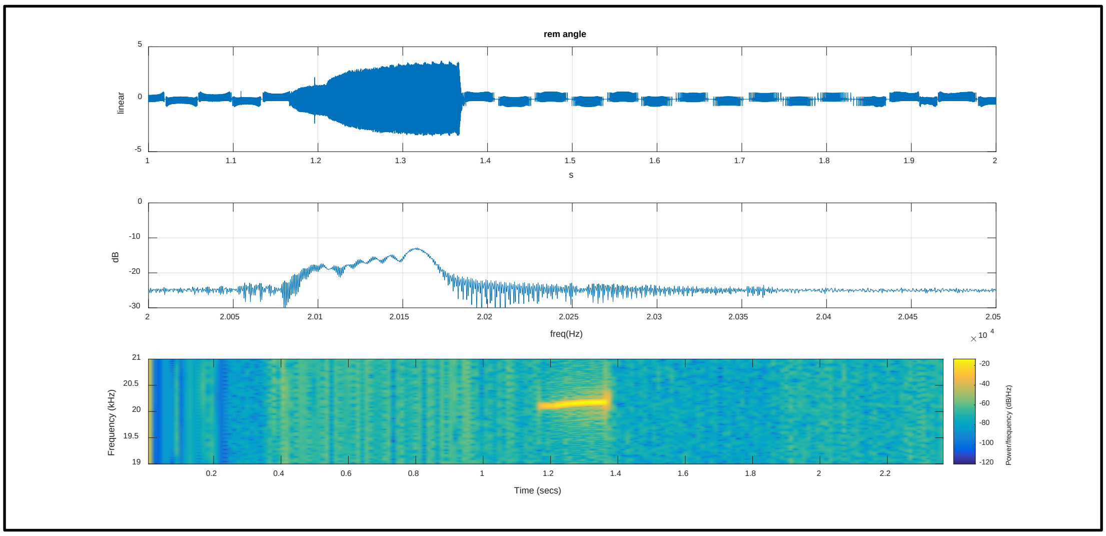

Figure 2：Real-time vibration monitoring-Under Weld Case

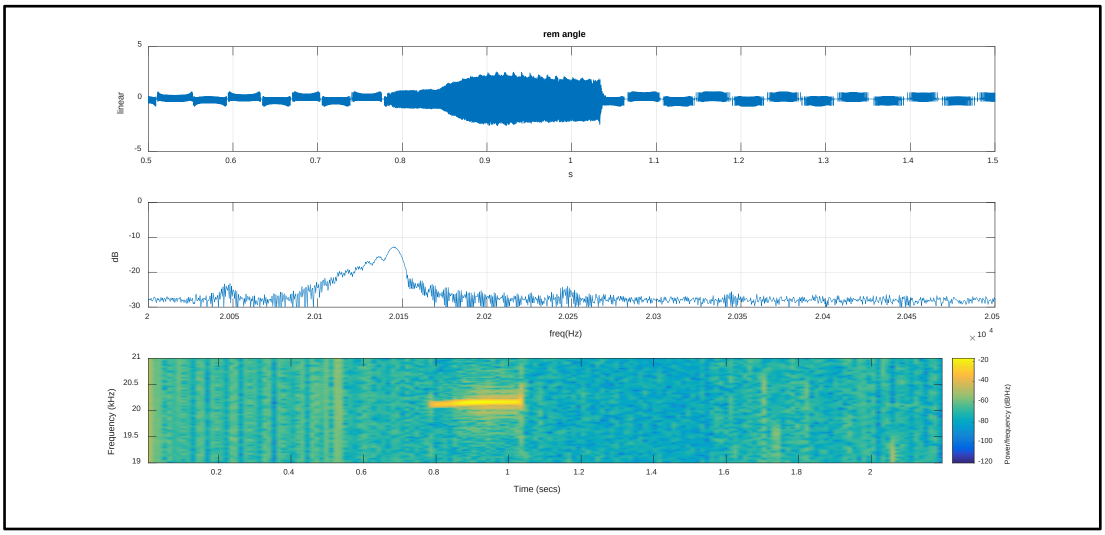

Figure 3：Real-time vibration monitoring-Over Weld Case

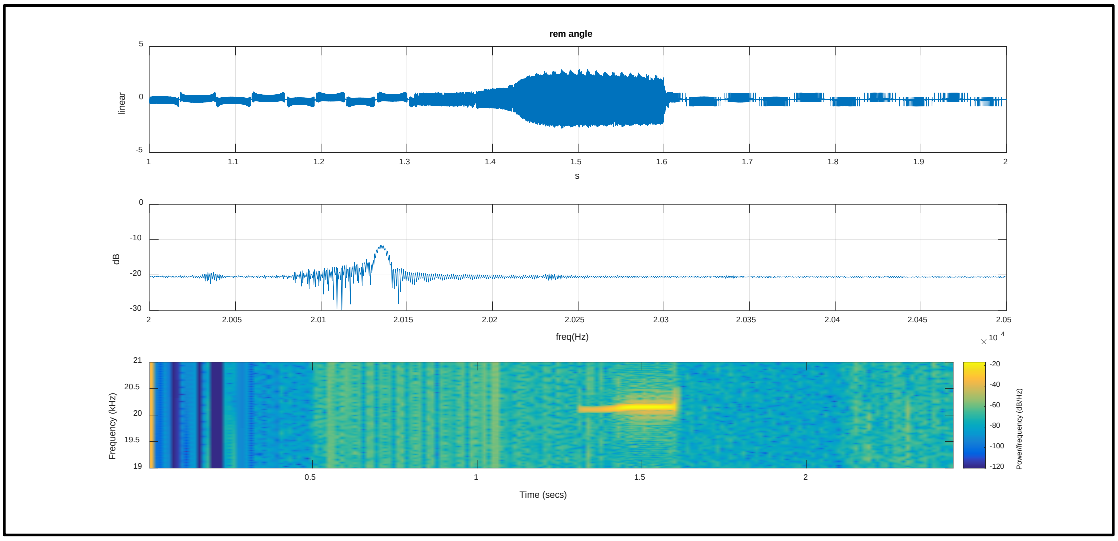

Figure 4：Real-time vibration monitoring-Good Weld Case

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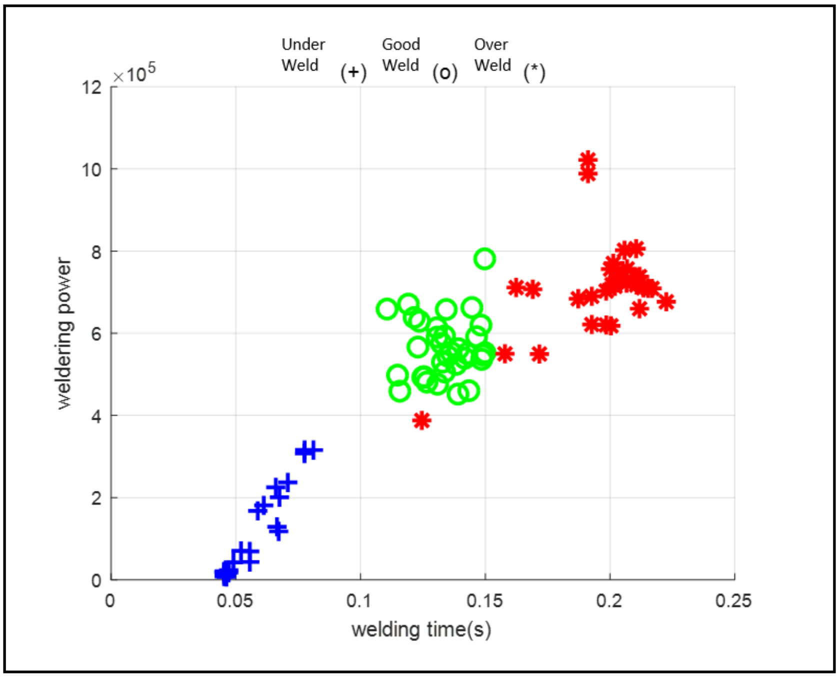

Figure 5: Testing results grouping after machine learning processing

Through our industry collaboration with UMW partners, OmniSensing Photonics has proposed an in-line weldability monitoring scheme for high-precision UMW processes. It utilizes the compact laser vibrometer sensor developed by OmniSensing Photonics for vibration signal collectionand advanced machine learning algorithms for correlation analysis.

The key component for this implementation is the MV-H series compact laser vibration sensor developed by OmniSensing Photonics (See Fig. 6). The MV-H series compact laser vibrometer sensor has superior performance with a small footprint and very competitive pricing. Using non-contact measuring techniques, we have demonstrated an alternative test methodology than can provide a better solution for monitoring and controlling Ultrasonic metal welding processes. Using these modules, our applications engineers can assist in developing a test platform that is unique to your testing needs and quick and easy to implement. For further information please contact us at: info@OmniSensingTech.com.

Figure 6: Compact laser vibrometer sensor made by OmniSensing Photonics LLC

Specs	OSP MV-H

Max. frequency	2.5MHz
Velocity full scale	±1.5 m/s (regular mode) ±5 m/s (extended mode)
Decoder range	Single range continuous
Typical resolution	0.015 $m/s^{-1}/\sqrt{Hz}$ (@5KHz)
Analog output	No (contact for custom model)
Time trigger	Trigger in & out
Size	~80x50x22 (mm^3)
Weight	175 g
Operating temperature	0-50°C
Power supply	12-24V, 3W max
Protection class	IP65
Laser class	Class 1, <5mW output (H1)
Laser wavelength	1310 nm (invisible near infrared, detector card included)
Measurement distance	0.075-4m (fixed lenses, pre-adjusted, contact for adjustable lenses)
Data connection	Ethernet
Control Software	GUI & DLL (for system integration)

Table 1: MV-H laser vibrometer sensor spec