Testing Battery Systems Designed for Wearable Technologies

The worldwide market for wearable technologies is expected to reach $70 billion (USD) by the year 2025, up from just $20 billion in 2015. This anticipated growth in the wearable technologies market depends on the continuous development of new technologies such as wireless technology, smart electronics and advanced energy storage systems that can provide consistent and reliable power without compromising the overall experience of the user. However, although new battery and energy storage technologies are generally safer than many currently available alternatives, wearable technology devices incorporating them must still be thoroughly evaluated to help identify potential safety and performance concerns.

This UL white paper discusses testing and evaluation considerations for batteries and energy storage systems used in wearable technologies. Beginning with a summary of the historic technical challenges for wearable technologies, the paper highlights the emergence of new approaches to powering wearable technology devices and their advantages over current technologies. The white paper then summarizes potential safety and performance considerations for batteries used in wearable technologies, and details specific tests that can be used to evaluate them for consistency with regulations and customer expectations. The paper concludes with additional recommendations for the assessment of batteries and energy storage systems used in wearable technology devices.

An Overnight Success, Decades in the Making

From smart watches and eyeglasses to health and fitness wristbands and monitors to smart shoes and safety clothes, wearable technologies are enabling users to quickly and easily capture, share and access information in real time regardless of their location. Aside from the convenience and sheer enjoyment that many wearable technology devices and apparel products provide, wearable technologies are also expanding the options for monitoring the personal health and safety of users. And the growing number and types of wearable technologies directly supports the developing “Internet of Everything” (IoE) ecosystem, contributing to its potential, long-term usefulness.

Despite the widespread introduction in recent years of wearable technology devices for consumer use, the idea of wearable technologies is not new. In fact, scientists and engineers have worked for decades to evaluate ways to safely integrate advanced computing technologies into portable devices small enough and comfortable enough to be worn. Some of earliest wearable technology prototypes include a portable telemedical wrist monitor (2002), eyeglasses designed to reflect an image from an LCD panel embedded in the earpiece (1997), and a sensor-embedded jacket that tracked a wearer’s movement (1999).

Making the leap from prototype to commercially available wearable technology devices and apparel products has required developers to address a number of key technical challenges over time. These challenges have included the need to miniaturize critical components, the integration of wireless communications capabilities and smaller, more efficient user interfaces. Meeting these challenges has led to the development of a host of advanced technologies, such as new wireless connectivity protocols, touch screens and voice recognition

software, and durable sensors and body monitors. The widespread acceptance of the current generation of wearable technology devices is due in no small measure to these and other technology developments.

The Limits of Current Battery Systems

Perhaps the biggest ongoing technical challenge facing wearable technologies is the need for small, highly efficient and safe battery systems that are suitable for use in wide variety of applications. The current generation of wearable technologies has greatly benefited from the development of small format batteries that represent significant advances over the bulky battery packs used in earlier prototype devices. In particular, rechargeable lithium-ion (Li-ion) batteries have been the preferred power solution for many devices, due to their relatively high energy/density levels and low weight-to-volume ratios.

But Li-ion battery technology is likely to be inadequate in meeting the power, performance and safety specifications required for future generations of wearable technology devices and apparel products. For example, increases in Li-ion energy density are not keeping pace with performance improvements seen in other mobile technologies. According to one estimate, the energy density of the Li-ion battery used in today's iPhone 5 model smartphone is only about 63 percent greater than the energy density found in comparable devices available in 2003.

In addition, the form factor and construction of Li-ion batteries are likely to impose additional constraints on their use in future wearable technologies. Batteries will need to be smaller and lighter than current Li-ion battery models to meet the size and weight constraints required by new wearable technology devices and apparel products. Meeting both power and energy density requirements in a smaller format may simply represent an insurmountable challenge for Li-ion battery technology.

Finally, Li-ion batteries include active chemicals that can exhibit thermal instability when misused or abused, resulting in overheating and, in some documented cases, explosions. For this reason, Li-ion batteries are typically sealed in a rigid and bulky package to help protect users. Unfortunately, a rigid battery pack is likely to be ill-suited for integration into a wearable technology device where weight, comfort and style are of paramount importance.

Emerging Battery Technologies for Wearables

Clearly, further advances in battery and energy storage technologies will be required to support the development of future generations of wearable technology devices and to encourage broader consumer acceptance of wearable technologies. Fortunately, scientific and engineering developments in a number of key areas have led to the introduction of new battery systems for wearable technologies that are smaller, more powerful and safer to use than Li-ion batteries.

Some recent advances in battery and energy storage technologies include:

- *Solid state batteries*—Manufactured on silicon wafers using semiconductor fabrication techniques, solid state batteries feature high energy density and recharge cycle capacity in a small format, and do not involve the use of hazardous chemicals.
- *Safer battery chemistries*—A number of companies are developing batteries based on safer chemistries and chemistry combinations, such as zinc-polymer, aluminum and lithium carbon fluoride (CFx). These and other combinations are inherently more stable than Li-ion chemistries and less susceptible to safety consequences from misuse.
- *More flexible packaging*—Solid state batteries and safer battery chemistries don't require rigid protective packaging and can more easily be integrated into flexible materials, an especially important consideration for smart apparel garments and shoes.
- *Higher energy densities*—For wearable technologies with minimum power requirements, new high energy density batteries based on CFx chemistries are in development that would potentially power a wearable device for its entire anticipated life without recharging.
- *Wireless charging*—In addition to these advancements, new wireless charging technologies are emerging that enable wearable devices to directly harvest ambient energy by means of a transducer and store it for future use. Radio charging that wirelessly transmits energy via magnetic fields is another recent wireless charging innovation.

Safety and Performance Considerations for Battery Systems

These and similar technical advances in batteries and energy storage systems hold considerable promise for expanding the usefulness and convenience of wireless technologies. At the same time, because they supply or generate electrical energy, these advanced battery systems pose many of the same safety risks to users as Li-ion batteries and other sources of power. Common safety risks associated with all types of batteries for wearable technologies include:

- *Electric shock*—Any energized device poses a risk of electrical shock due to worn or defective circuitry or accidentally exposed components. When any device is designed to be worn or place in close proximity to the human head or body for a prolonged period of time, the risk of electrical shock is increased.
- *Burns*—The temperature of many energized devices often increases during normal use. In addition, battery systems typically integrate microprocessors and other modules in a compact form factor that further contributes to elevated operating temperatures. Again, this is a particular concern for batteries used in devices designed for direct and prolonged body contact.
- *Fire and explosion*—Li-ion batteries can overheat and explode or burst into flames under certain conditions. While batteries based on different chemistries may be inherently more stable, their widespread use in future wearable technologies may expose other, yet unknown vulnerabilities that put wearers at risk.

- *Chemical reactions*—Metals, synthetic fabrics and other materials used in the construction of batteries may contain chemicals that can produce rashes or other allergic skin reactions as a result of prolonged contact. In addition, the electrolytes in some batteries contain lithium salt, which is corrosive and can be toxic.
- *Exposure to electromagnetic energy*—Continuous and prolonged exposure to even low doses of electromagnetic energy may result in adverse health effects.
- *Human factors*—Mechanical design factors in batteries and energy storage systems, such as sharp corners and edges, device housings and straps, may produce cuts, irritate the skin or cause discomfort following extended use.
- *Hazardous environments*—Finally, wearable technologies that rely on wireless recharging may pose specific hazards when worn or operated in potentially explosive environments.

Recommended Testing for Batteries Used in Wearables

Worldwide regulatory requirements generally mandate that manufacturers conduct a range of tests on their products to identify potential safety risks to users. Specific tests applicable to batteries and other energy storage systems are likely to vary from jurisdiction to jurisdiction and will also depend on the type of technology and its anticipated use. However, here are some of specific tests that may be applied to batteries used in wearable technology devices.

Electrical Tests

- *External short circuit test*—The external short circuit test creates a direct connection between the anode and cathode terminals of a battery cell to determine its ability to withstand a maximum current flow condition without causing an explosion or fire.
- *Abnormal charging or overcharging test*—The abnormal charging test applies an over-charging current rate and charging time to determine whether a battery sample can withstand the condition without causing an explosion or fire. The

overcharge test uses various methods to charge a battery to greater than 100 percent state of charge.

- *Forced discharge or overdischarge test*—The forced discharge test determines a battery's behavior when a discharged cell is connected in series with a specified number of charged cells of the same type. The overdischarge test attempts to continue discharging beyond the specified discharge limit.

Mechanical Tests

- *Crush test*—The crush test determines a battery's ability to withstand a specified crushing force applied to a battery by two flat plates.
- *Impact test*—The impact text determines a battery's ability to withstand a specified impact applied by a cylindrical steel rod placed across the battery under test.
- *Shock test*—The shock test is conducted by securing a battery to a testing machine that has been calibrated to apply a specified average and peak acceleration for the specified duration of the test.
- *Free-fall (or drop) test*—The free-fall test subjects each sample of a wearable technology device to a specified number of falls to a hard surface. The sample is examined following each drop for damage.
- *Vibration test*—The vibration test applies a simple harmonic motion at a specified amplitude, with variable frequency and time to each sample.

Environmental Tests

- *Heating test*—The heating test evaluates a battery's ability to withstand a specified application of an elevated temperature for a period of time.
- *Temperature cycling test*—The temperature cycling test subjects each sample to specified temperature excursions above and below room temperature for a specified number of cycles.
- *Low pressure (altitude) test*—The low-pressure test evaluates a battery for its ability to withstand exposure to less than standard atmospheric pressure (such as might be experienced in an aircraft cabin that experiences sudden loss of pressure).

Additional Specialized Tests

In addition to these common abuse tests, certain safety standards and testing protocols for batteries and energy storage systems require additional specialized testing. These specialized tests address specific use applications and/or operating conditions in which wearable technologies might be expected to operate.

- *Electromagnetic compatibility (EMC)*—Regardless of their energy source, electrical devices must not create unintended electromagnetic interference with other electrical devices, and must also be immune to electromagnetic interference from other devices. Due to the environment in which wearable technology devices and apparel products are used, it is recommended that batteries and energy storage systems be tested for both emission and immunity characteristics.
- *Specific absorption rate (SAR)*—Wearable technologies that incorporate wireless technology are often subject to testing to determine the amount of electromagnetic radiation produced by a device under the most extreme use conditions at a given distance from the human head or body.
- *Chemical content and biocompatibility*—The components and materials used in batteries and energy storage systems may include chemicals which can be harmful as a result of prolonged exposure. A chemical content assessment identifies levels of potentially harmful chemicals in these materials.

Recommendations for Manufacturers

The many types of testing noted here are not exhaustive. In some cases, assessing the safety risk associated with a given wearable technology may require a risk assessment that identifies the need for additional or different types of testing. Further, other tests may be required to address application-specific requirements or jurisdictional regulations applicable to batteries and energy storage systems used in wearable technologies. Finally, manufacturers of wearable technology devices and apparel products are still subject to compliance with requirements applicable to equivalent, non-wearable devices and products.

These complexities can result in a seemingly endless array of testing in order to verify the safety of a given wearable technology device or apparel product. Developing a comprehensive testing strategy at the outset of the product development process can reduce overall testing expenditures, save time, and help to avoid unanticipated safety issues that can delay market introduction. At a minimum, the process of developing a comprehensive testing strategy for batteries and energy storage systems intended for use in wearable technologies should include the following steps:

- *Conduct a thorough risk assessment*—A thorough understanding and evaluation of all of the potential safety risks and hazards associated with a given battery is essential. In many cases, a comprehensive risk assessment can result in design changes or modifications that reduce or eliminate potential risks and hazards, thereby easing the testing process. For safety risks and hazards that can't be eliminated, a risk assessment can help to identify up front the complete range of safety testing that may be required.
- *Research current and anticipated regulations in target markets*—The regulatory landscape for wearable technologies is currently a complex patchwork of schemes that separately address distinct aspects of a given product. Unless or until regulators develop a more unified approach to the regulation of wearable technologies, manufacturers should identify and investigate the requirements that apply to each individual aspect or feature of their product. Continued vigilance about proposed regulatory changes in these areas and their potential impact on required testing is also advisable.
- *Evaluate marketplace requirements and customer expectations*—Beyond testing required by regulators, major brand customers may impose additional safety and performance testing requirements on vendors and suppliers of wearable technologies and their components, including batteries. Further testing may also be required to validate product claims that address environmental sustainability or other consumer likes and preferences. Incorporating these additional testing requirements into an overall testing strategy can result in wider product acceptance and greater market penetration.
- *Seek expert advice and counsel*—Finally, establishing an effective working relationship with an independent testing agency can greatly facilitate the effort to develop and execute a comprehensive and cost-effective testing strategy. A suitable testing partner will possess the requisite technical expertise in each and every aspect of a given wearable technology product, as well as a thorough knowledge of the applicable testing requirements in targeted jurisdictions. Worldwide testing capabilities are also a plus, especially for manufacturers that rely on global supply chains.

Summary and Conclusion

Ongoing developments in battery and energy storage technologies will lead to the development of new systems suitable for a variety of wearable technology devices, and are likely to support their broader acceptance by consumers. However, while potentially safer than current battery technologies, new and advanced batteries still pose possible safety risks and hazards to users. A comprehensive testing plan for batteries used in wearable technologies can mitigate these concerns, resulting in safer products with improved performance.

UL offers a complete range of testing services for wearable technologies, including batteries and energy storage systems used in wearable technology devices, and has a comprehensive knowledge of the regulatory approval process in key target markets. In addition, UL provides specialized testing services for energy efficiency, product performance and reliability. UL capabilities also extend to support quality and safety initiatives across global supply chains through product inspections and factory audits.

For additional information about UL's services for wearable technology products, contact Carolyn Arndt, Global Marketing Manager, Consumer Technology Division, at Carolyn.Arndt@UL.com; or Christian Salvans, Business Development Manager, at Christian.Salvans@UL.com.

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