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Saft's Xcelion 6T® 28V Lithium Ion Batteries

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ABSTRACT

Saft has continued to develop lithium-ion replacement batteries for the traditional lead-acid batteries for use in military vehicles. Saft's 24 volt Xcelion 6T® delivers power at high rate that surpasses the delivered capacity of two lead-acid batteries. The battery design is tailored to support high rates, even at extreme cold temperatures, to support the mission needs for silent watch and starting for military vehicles. An additional design variant is now available, the Xcelion 6T Energy, to provide 30% more energy while still delivering excellent cranking capability. Both products are industrialized and in use in large new vehicle programs. Additionally, development continues on a MIL-PRF-32565 compliant version with release to market expected in 2019.

INTRODUCTION

Most heavy-duty vehicles designed for industrial and military use were originally fitted with batteries that supplied little more power than what was needed for engine starts and ancillary equipment operation. The lead-acid battery has served that purpose extremely well for many years for basic vehicle operations. However, today's modern military assets are equipped with sophisticated electronics and digital packages which often feature an array of mission-critical sensors, jammers, communication and control systems that strain traditional lead-acid batteries. Advanced lithium ion batteries offer the improved performance and life required to meet today's needs for the vehicle.

As a design-compatible, drop-in alternative to traditional NATO 6T lead-acid batteries, the Xcelion 6T® provides increased energy density, measurable life cycle cost benefits and on-board diagnostics that monitor and manage output, performance and protections.[1] The Xcelion 6T® weighs less than its lead-acid counterparts, delivers more power with greater reliability and requires no structural or interface design adaptation. The integral battery management system (BMS) is used for automated balancing and protection, offering Controller Area Network (CAN) communication for advanced vehicles or operation as a standard battery for legacy vehicles. Advanced features of the BMS include real-time battery data monitoring with two-way communication between system and user, reserve protection to support starting at the end of a silent watch, and battle override to allow deep cycles and aggressive use beyond reserve levels.

The advanced lithium-ion (Li-ion) chemistry in the Xcelion 6T® not only provides more power, but reduces life-cycle cost and the total cost of ownership. The battery sustains significantly more deep-discharge cycles compared to legacy lead-acid, as much as 14 times more for shallow cycling and 25 times more for full depth of discharge. Additionally, Saft's proprietary Superphosphate® Li Ion Chemistry is capable of delivering excellent cranking performance and long life while providing a very high level of abuse tolerance.

The purpose of this paper is to introduce Saft's Xcelion® 6T-Energy battery, released to market at the end of 2017. The new design variant provides even more energy in support of longer silent watch missions and energy demanding applications. The battery provides 30% more energy than the baseline while still providing excellent cranking capability, even at cold temperature. The design variant utilizes the same Superphosphate® chemistry for long life and a superior level of safety.[2]

The Superphosphate® chemistry used in the Xcelion® products also provides a high level of safety for the user. The flat profile allows for safe parallel connection of batteries and the iron phosphate based cathode design is highly stable in abuse conditions to minimize the risk of cell to cell propagation.

With the recent release of MIL-PRF-32565 for Li-ion 6T batteries for military vehicles, a new variant to the Xcelion® battery is also in development. [3] Utilizing the same base electrochemistry and design of the Xcelion 6T®, the new version will meet the critical demands and requirements of for US military vehicles. Future upgrades to the Xcelion® 6T-Energy battery will also allow for compliance to MIL-PRF-32565.

As today's systems demand greater power capacity that supersede the capabilities of legacy battery technology, advances in Li-ion technology and the development of new power solutions are pushing beyond outdated technology and chemistry. With greater power density, higher energy storage efficiency, lighter weight, and enhanced performance, plus a reduction of the logistical burdens to store, transport and distribute replacement batteries, the Xcelion 6T® is already transforming industry standards and market dynamics.

ADVANTAGES OVER LEAD-ACID

Batteries that incorporate Li-ion chemistries have demonstrated their ability to provide more power and to operate for significantly more deep discharge cycles. These advantages translate to a lower life-cycle cost compared to lead-acid batteries. The Xcelion 6T® is a Li-ion drop-in replacement for 28V systems that provides the power equivalent of two (2) series lead-acid batteries. Physical dimensions and connections are identical to the standard NATO 6T lead batteries. The Xcelion 6T products can be used in a vehicle with or without the use of active CAN communications. In legacy mode, the batteries will operate like a traditional battery without the need to interface with the communication capabilities.

The 28V 6T package of the Xcelion 6T® was designed to replace two series state of the art Lead Acid absorbent glass mat (AGM) batteries. The cranking performance of a single battery, even at -40°C, matches the performance of two series lead acid batteries. The Xcelion 6T® also has the capability of high rate discharges while still providing the nameplate capacity from the battery.

Both of the Xcelion 6T® variants weight just 46lbs. The Energy version now provides over 2 kWh of energy at C-rate discharge. Using the Xcelion 6T® rather than the lead-acid 6T option results in a 74% decrease in weight and a two-for-one replacement, or a 50% reduction in volume per system for the same or better performance

Details of the performance of the Xcelion 6T® compared to lead acid batteries are show in the 2017 proceeding of GVSETS [1].

BATTERY MANAGEMENT SYSTEM

The Xcelion 6T® products can be utilized as a drop in replacement for lead-acid batteries without the need to utilize the external communications. In legacy mode, the integral battery management system (BMS) will still properly manage the battery state, cell balancing, and safety without the need to communicate with the battery. Modern vehicles will take advantage of the smart features offered by the BMS with active communication with the battery. Advanced features include real-time battery data monitoring with two-way communication between system and user, reserve protection to support starting at the end of a silent watch, generator control for optimal battery charging to extend battery life, and battle override to allow deep cycles and aggressive use beyond reserve levels.

The built-in BMS provides real-time diagnostic information about the battery's state of charge (SOC), state of health (SOH), and overall condition of the battery. These functions are calibrated within each battery when they are produced. This internal BMS is a much simpler solution compared to a lead acid battery BMS, where a user may have to field calibrate the extremal BMS to the batteries that are in use in the system. The integral BMS is a simpler solution to provide the operator with confidence in the reliability of the information communicated form the BMS.

XCELION 6T ENERGY

To support vehicles with even more silent watch demand, Saft has released a new variant of the Xcelion 6T® battery to provide 30% more delivered energy. The Superphosphate® chemistry is the same as used in the baseline Xcelion 6T® battery, but with a cell design tailored to provide more energy. The new battery has the same proven base design with an update to the cells and firmware to account for the higher capacity.

The Xcelion® 6T-Energy still provides a high level of discharge rate capability while delivering the full capacity of the battery. Figure 1 shows the constant current rate capability of the battery. Even at 240A discharge loads, the battery can still deliver the full rated capacity of about 80Ah, exceeding the capacity requirements of a Type1 battery as defined in MIL-PRF-32565.[3]

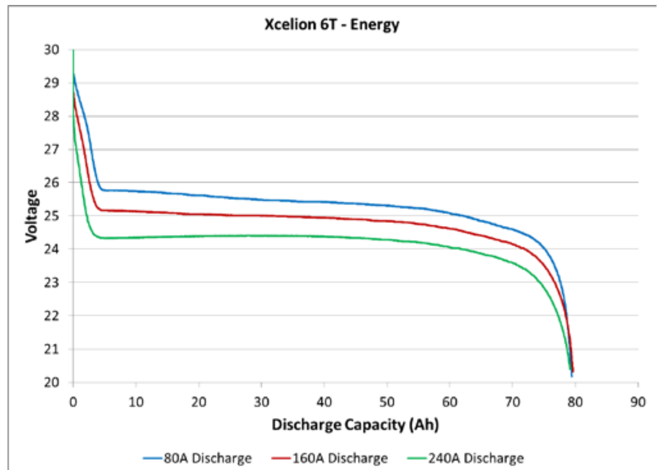

Figure 1: Rate Capability of Xcelion® 6T-Energy at Room Temperature

While providing less power capability than the base Xcelion 6T® battery, the Xcelion® 6T-Energy battery still provides excellent cranking capability, even at cold temperature. Figure 2 shows the cranking behavior of the battery at -18°C. The graphs shows the voltage response of the battery when subjected to three successive 30 second pulses at 600A with 2 minute rest periods between pulses. Prior to testing, the battery was soaked at test temperature for over 24 hours to ensure the temperature. No preheating was used for testing. When tested in the same conditions, the baseline Xcelion® 6T battery can support 1100A. While the Energy variant shows less cranking power, the cranking capability provides the needed starting power for most vehicles, particularly in its intended application with multiple parallel batteries for longer silent watch missions.

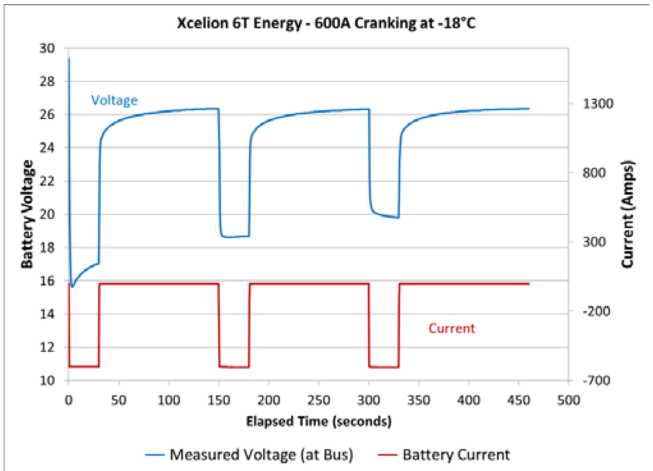

Figure 2: Xcelion® 6T-Energy performance under 600A/30sec load at -18°C without preheating

The Xcelion® 6T-Energy battery still provides excellent cold cranking capability at -30°C without the need for preheating of the cells. Figure 3 shows the cold cranking behavior of the battery under a 300A load at -30°C.

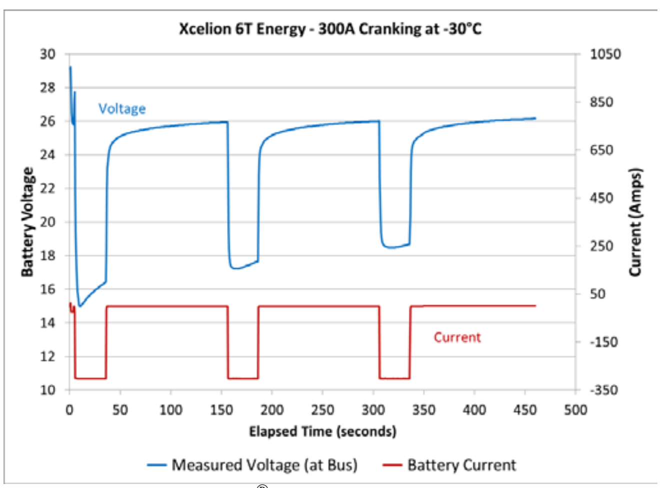

Figure 3: Xcelion® 6T-Energy performance under 300A/s30sec load at -30°C without preheating

The Xcelion® 6T-Energy battery has been demonstrated to provide superior energy to traditional lead acid 6T batteries. In an application where two Xcelion® 6T-Energy batteries are placed in parallel, replacing two lead acid batteries placed in series, the Xcelion® battery will provide over 1200 cold cranking amps (CCA) at -18°C. This is superior to the rated CCA of the lead acid battery. The two parallel Xcelion® 6T-Energy batteries will also provide 160Ah of capacity at high rate, about two times the delivered capacity of the two series lead acid 6T batteries at high discharge rate.

Besides the demonstrated cold cranking rating, the ability to start an actual engine is the real needed performance from the battery. A typical start profile for a vehicle will include a short inrush followed by a lower current load form the starter motor. The ability of the battery to sustain the large inrush and the vehicle cranking is critical to meeting the needs of the application, not just the rated cold cranking amps. Figure 4 shows the response of a single Xcelion® 6T-Energy battery subjected to an engine start at -18°C. A single battery is demonstrated to start the engine. The large initial inrush is supported by the battery without tripping any protection limits. In subsequent testing, a single battery was demonstrated to support the same start profile in a nearly fully discharged state at 5% SOC.

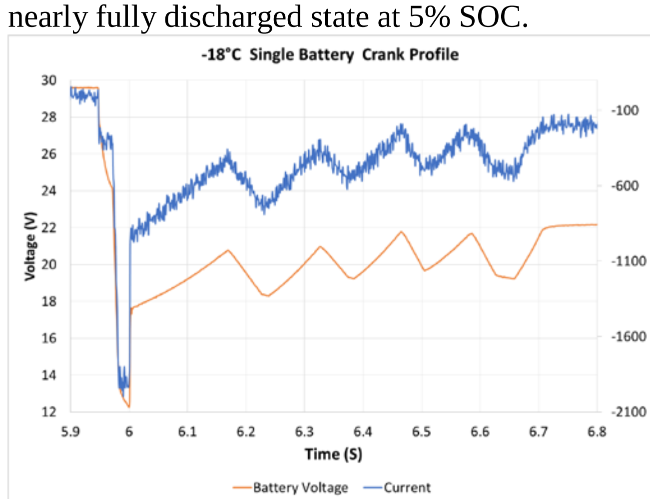

Figure 4: Vehicle cranking supported by a single Xcelion® 6T-Energy battery at -18°C without preheating

PARALLEL CONNECTION CAPABILITY

The high rate capability of the cells combined with the flat discharge voltage of the chemistry allows for direct parallel connection of multiple parallel Xcelion® batteries in a system. In such a system with multiple batteries to support a long silent watch missions, it is critical to ensure the ability to start the engine at the end of silent watch. The ability to connect batteries at different SOC allows for reserving a single battery for starting while using the other batteries in the system for a full discharge. The Xcelion® 6T batteries have been demonstrated to be capable of being directly connected in parallel even with large differences in SOC and voltage. Connecting batteries in parallel at different SOC can be a problem for other lithium ion solutions, as the current sharing between batteries as they equalize in voltage can be sustained over a long period of time and the excess current can damage internal protections or at a minimum force the batteries to go into a protected state. The Superphosphate® cells used in the Xcelion® 6T provide a superior solution to the user, allowing the user to more fully utilize the batteries in a multi battery system.

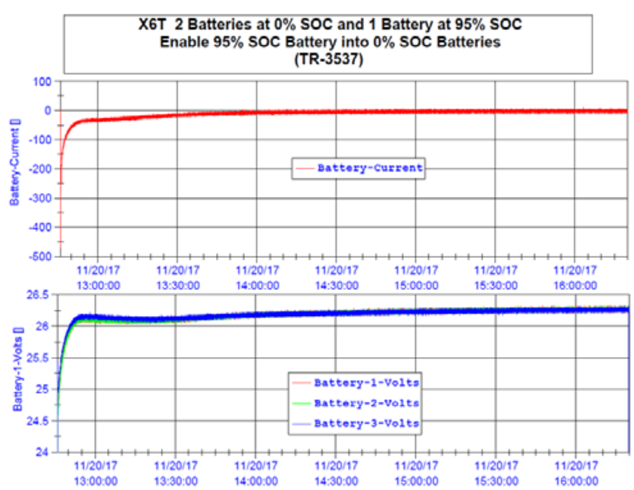

Figure 5: Parallel connection testing of fully charged Xcelion® 6T-Energy with two fully discharged batteries. Battery current displayed in Amps.

Figure 5 shows the connection of a single Xcelion® 6T Energy battery into two fully discharged batteries. As the batteries are brought online together, there is a large current spike that peaks at 470A as the higher SOC battery discharges some of its energy into the lower SOC batteries. As the voltage of the high SOC battery drops and the voltage of the low SOC batteries rise, the current quickly diminishes and reaches essentially zero as the battery reach the voltage plateau.

No protection limits are tripped during this testing, demonstrating the ability of connecting batteries at different SOC at the end of a silent watch.

Similar testing was conducted on the Xcelion 6T® with 6 parallel batteries at different SOC and temperatures. Figure 6 shows the results of testing conducted at 60°C. Five of the batteries were set to 90% SOC and one battery was set to 10% SOC. As the batteries are brought online together in parallel, the five higher SOC batteries charge the single lower SOC battery. An initial charge spike of about 300A is observed that quickly diminishes. The upper portion of the figure shows the current vs. time for all batteries and the lower potions shows a zoom of the initial current spike.

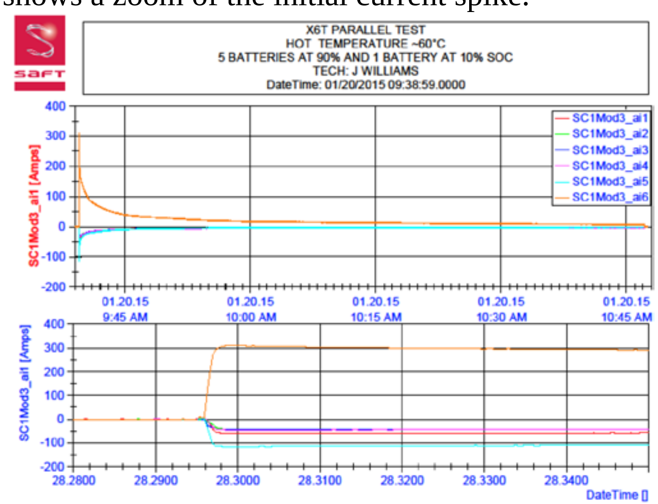

Figure 6: Parallel connection testing of five charged Xcelion 6T® batteries with one discharge battery

A HIGH LEVEL OF SAFETY

The Superphosphate® cell chemistry in the Xcelion® products provides a high level of abuse tolerance and inherent resistance to cell to cell propagation. The iron phosphate base cathode material is essentially non-reactive in abuse. This results in substantially less heat output from an abused cell compared to a layered oxide type lithium ion cell such as Nickel-Cobalt-Aluminum (NCA) or Nickel-Manganese-Cobalt (NMC). With a layered oxide cathode, the cathode material will decompose in a highly exothermic reaction, in many cases involving a thermite reaction with the aluminum foil substrate. Additionally, a layered oxide type lithium ion chemistry will exhaust oxygen as the cathode material decomposes, providing an oxygen source for additional combustion reaction. In phosphate type cells, the anode material and electrolyte can still contribute to a thermal event in a cell, but with much less heat produced. The lower heat output and lower abuse temperatures substantially reduce the risk of cell to cell propagation within the battery.

Many types of abuse tests are conducted on cells and batteries in order to force a cell into thermal runaway. One main emphasis on battery level abuse testing is to ensure that a single cell event does not propagate and cause thermal runaway of adjacent cells. IEC 62619 [4] and NAVSEA S9310 outline methods for conducting such testing.

The Xcelion 6T® was subjected to such propagation testing by Saft using a method outlined in NAVEA S9310. In this test, a single cell in the Xcelion® battery was outfitted with an external heater during the battery build. The battery was fully charged and the heater was heated to 500°C in order to trigger a thermal runaway of the cell. During this testing, the temperature of the heater was taken to a temperature in excess of 600°C before the subject cell went into thermal runway. Figure 7 shows the results of this testing.

Figure 7: Abuse testing results of the Xcelion 6T Battery – yellow circle indicates abused/overheated cell

The high temperature of the heater caused some heat damage to the exterior case. Inspection of the interior of the battery revealed that the cell with the heater vented and went into thermal runaway, but with no other cells involved in the event. The abused cell did not evolve enough heat to cause propagation to neighboring cells.

The safety advantage of the Superphosphate® chemistry is clear. Besides providing excelling cranking performance, high impedance stability over the life of the battery, the safety and abuse tolerance is a real need for crewed vehicles. The abuse tolerance and non-propagating behavior make the Xcelion® batteries an ideal solution for military vehicles.

US MILITARY VEHICLE REQUIREMENTS

With the recent release of MIL-PRF-32565 for Lithium Ion 6T batteries for military vehicles, a new variant to the Xcelion® battery is also in development. Utilizing the same base electrochemistry and design of the Xcelion 6T®, the new version will meet the critical demands and requirements for US military vehicles. In continuing work with US Army Tank Automotive Research Development and Engineering Center (TARDEC), Saft anticipates the availability of a MIL-PRF-32565 compliant version of the Xcelion® product line early in 2019. The design is expected to be compliant with the Type I battery requirements, offering the highest level of required safety within the spec. While the cells and performance of the battery are identical to the baseline Xcelion 6T®, the BMS is updated to include the specified CAN protocol and I/O functions. Additionally, the power terminal and communication connector are updated to the required interfaces.

CONCLUSIONS

The Xcelion 6T® and Xcelion® 6T-Energy batteries are the result of several generations of battery design for military vehicles. The design has been industrialized with a substantial value engineering effort. The resulting design is competitive with existing lead-acid battery pricing over the life of the vehicle. The cell design is tailored specifically for the application to guarantee performance for power, life, and overall performance. While the cells are customized for the application, they are produced in high volume at Saft's industrial cell manufacturing facilities. This allows for low cost cell manufacturing that is competitive with the commercial lithium ion market while also maintaining design control and guaranteed source of cells from the United States and Europe.

Lead-acid batteries have served as the energy storage backbone of military fleets for decades. However, as the power and energy demands on these vehicles continue to increase in response to dynamic global mission needs, advanced-chemistry batteries, particularly cost-effective, ruggedized options such as Saft's Xcelion 6T® emerge as reliable power system options that weigh less than their lead-acid counterparts, do not require vehicle / interface design rework, yet extend the system life cycle.

REFERENCES

[1] Ferguson, Hensley, et al., Saft's Xcelion 6T® 28V Lithium Ion Battery for Military Vehicles, GVSETS, 2017

[2] Ferguson, Hensley; Saft's Xcelion 6T® 28V Lithium Ion Battery for Military Vehicles, Power Sources, 2018

[3] MIL-PRF-32565 Rev A Amendment 1, Battery, Rechargeable, Sealed, 6T Lithium-ion, 14-Nov-2018

[4] IEC 62619:2017, Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for secondary lithium cells and batteries, for use in industrial applications

[5] NAVSEA S9310-AQ-SAF-010, Navy Lithium Battery Safety Program Responsibilities and Procedures