Intrinsic Safety of BLUESHAPE Li-Ion battery packs

Potential dangers

Since its introduction in the industrial market, li-ion technology has fascinated scientists with its fast development of increased energy density within a modest volume and weight , especially when compared with existing nickel based rechargeable chemistry.
These features made it the ideal solution for wireless applications and video cameras that demanded lighter weights, more compact volumes and longer battery runtimes.
Moreover, lithium-ion chemistry offered other interesting advantages over its counterparts due to its freedom from memory effects, unneeded special precautions for extending service life (like frequent deep-discharge cycles) and relatively longer shelf life due to very low self-discharge rates.

However, and mostly because of its infancy, lithium-ion technology has clearly shown some drawbacks. To some extent, it can be considered as “fragile” or even “unsafe”. It cannot be abused of, or mishandled and does not tolerate extreme temperatures.

Excessive charging, even if just a little over its nominal threshold of voltage and time, will cause plating of metallic lithium on the anode, with the cathode material becoming an oxidising agent, thus losing stability and releasing oxygen in the process. Prolonged overcharging can cause the cells to heat up, with a serious risk of venting and flaming. Even if not prolonged, an overcharge above the cell safety voltage threshold will pose a potential risk to the pack life, since the material deteriorates with increased risk of potential dangers. If the cells are of poor manufacturing quality (with possible contamination of moisture and other external agents during cell manufacture), the negative effects of overcharging will bring cells and packs to a dangerous risk of instability (possibly explosion, when the mechanical safety devices do not work properly in releasing the internal pressure build-up)

Excessive pack discharge lowers the cells to extreme low voltages that must also be prevented. At low voltage levels, formation of copper shunts may occur inside Li-Ion cells leading to a partial or total electrical short, eventually rendering the pack unserviceable.

Excessive current, both in charge and discharge directions affect the efficiency and stability of Li-Ion cell electrode structures, with the unwanted side effects of potential temperature build-up, venting and flaming.

Extreme temperature also plays a negative role in pack performance, safety and service life. Low temperatures decrease the energy released by the battery during discharge due to a severely reduced ionic conductivity in the electrolyte. Charging at low temperature decreases the charging acceptance of the cells and stresses the electrodes with the risk of some lithium to be deposited as metallic lithium on the surface of carbon electrodes. Both charging and discharging at extremely high temperature create the risk of further overheating and internal pressure build-up with risk of venting and flaming, and in any case, with severe cell degradation and reduction of cycle life.

Implementation of safety in BLUESHAPE batteries

In order to offer the best service to the user and in line with the technical guidelines outlined above, lithium-ion packs need to be designed, manufactured, tested, and monitored during their lifetime, in order to avoid any severe stress conditions and possible abuses.

Cells

Primarily, BLUESHAPE batteries are made using only first quality A-grade cells from the world’s best renowned lithium-ion cell manufacturers. This is the first step towards a professional high performing and safe lithium-ion pack. Large lithium-ion battery packs require an elevated level of consistency and uniformity between each of the cells to guarantee safety and performance over the pack life cycle. If poor quality cells are assembled together into a large pack where the balance in the critical cell parameters is poor or non-existent, the degradation of performance can be quite rapid and there is also an increased risk of potential problems or hazards.

Design

In the world of professional broadcasting, the users dictate their requirements and designers have to design around these requirements. When we were in the development stage of our battery range, we issued a questionnaire to users in order to find out their main priorities and even any problems or complaints with their current batteries. In general, all agreed that there was no more scope for the older Ni-Cd packs and that the V-mount type batteries were the most practical and hence the most demanded.
Some users showed disappointment because their Li-ion batteries were not living up to their expectations. It is a fact that not so many people are knowledgeable in battery technology. Some are not aware at all, of properties like cycle-life, ageing, cell-balancing,

energy density, etc. Not everyone knows that a Li-ion battery must have incorporated safety electronic controls. Few are fully aware of the potential dangers of Li-ion batteries and how important it is to treat them with respect.

All users agreed that their batteries should demonstrate:
- Long runtime in daily use
- Long cycle life and reliability
- Straightforward charging without any special precautions
- Balanced weight - or rather high capacity to weight ratio
- Accurate onboard capacity monitoring (gas gauge) complementary to any capacity information displayed in the camera's viewfinder
- Solid feel and robustness
- No overheating or strange behaviours that compromises safety

For a BLUESHAPE battery design project, we attempt to cover all aspects demanded by users together with the best possible safety precautions. Below, we shall illustrate how this has been achieved with our new 'GRANITE' battery series which is the 3rd generation of V-lock batteries emerging from BLUESHAPE.

Mechanical stress precautions and design considerations
In the design of our BLUESHAPE 'GRANITE' range, we endeavoured to apply all our assembly know-how accumulated through years of experience in this sector. A great deal of attention has been paid to detail and aspects of importance to the end-users. Safety was our main concern and priority but we also emphasised on no-compromise assembly quality, performance, longevity and overall reliability
Our final solution entailed the design of a special "cradle" in order to assemble the cell groups neatly and create a solid pack, resistant to mechanical shock and electrically, very carefully insulated. A cell group may consist of 2, 4 and 6 cells depending on the battery model. Large and thick high quality nickel tabs have been employed in interconnecting the cells together. The cell terminals have multiple welds in order to ensure an unobstructed current flow and the lowest possible impedance. The whole cell assembly, together with its electronics were then enclosed in a strong case made from special and flame-retardant plastics. This case is appreciably thicker than enclosures used by competitors and can resist very heavy impacts and multiple drops without breaking. The top and bottom shells were firmly secured by 8 screws. Moreover, this case had been specially designed for water resistivity and incorporated a special rubber gasket between the upper and bottom parts in order to prevent moisture seepage. The LED gas gauge array and push-switch were also protected by a rubber gasket.

BLUESHAPE batteries have been water-resistant certified to IP54 standards.

Manufacturing processes
All cells used in our production are amongst the best available on the market in terms of quality and performance. In our quality incoming, we make sure that all cells are homogeneous in their state of charge (SOC) and internal impedance. At the time of cell assembly, all cells employed are matched within 30mV. We consider this a vital starting point that will continue to assume importance throughout the lifetime of a battery. Moreover in our electronics, we incorporate an efficient cell-balancing circuit to monitor and control this feature. In this way, the cells will remain perfectly uniform at all levels of SOC and there will not be any that become overcharged or over discharged during normal operation. It is proven that cell balancing extends cycle-life and helps in ensuring trouble free battery operation. (see application note: AN-BVCellBal)

We have been assembling battery packs for over 20 years and our workforce is fully trained, certified and experienced in the various operations that make up a battery pack. We have been entrusted with complete design and realisation of several OEM projects and each of these has helped us accumulate increased know-how – ready to apply in our next project upon commission.
Our ISO9001 certification is in the area of 'Design and assembly of OEM battery packs'.

Testing
However good an assembly is, the final assurance of a product is always obtained by thoroughly testing that product. We have worked hard in order to conceive and apply a rich testing process that not only controls all aspects of the battery operation but also readily presents us with all the useful data for monitoring and assessing our processes with the intention of continuously improving our products.
In devising our test system we set as an objective, the need to control and measure every possible parameter. We saw that through the sophisticated electronics implemented inside our batteries this was possible. What was needed was just a clever means of creating a system that would simulate certain conditions and test those conditions. It is not our scope here to describe in detail how this has eventually been achieved but we are pleased to declare that we know exactly in which state each BLUESHAPE battery leaves the factory. We have each battery's parameters logged in our data system and this can be accessed at any time from

anywhere. The idea of issuing a battery certificate for every battery is a continuation of this, since we thought the user would be pleased to know that we have put every effort in order to guarantee his battery's safety and performance.

Pack Management and enhanced safety

In battery packs consisting of multiple Li-ion cells, every measure has to be taken to ensure safety throughout the entire battery lifetime. This safety has to present and operational whether the battery is in use on a camera or whether it is idle or being transported.

What can go wrong in a battery pack?

We will now go through the causes that may compromise the battery safety and how we planned and implemented safety features to encounter and resolve these.

a) ***External short-circuit*** - possible due to user misuse or defective equipment including chargers.

We have built in, 3 redundant methods of limiting the current in the event of an external short circuit. Each battery cell is internally equipped with the classic PTC (positive temperature coefficient resistor) of optimum rating and integrated in series with the battery cells in order to limit the current in the case of an accidental short circuit. This device will reset to its original state once the short circuit is removed. In a similar fashion, a thermal breaker will stop current flow once a certain temperature/current ratio has been exceeded, possibly because of an over-current flow. This device again resets to normal once the temperature/current ratio returns to normal. Before these devices intervene however, there is also an electronic protection that comes in to completely disconnect the output and therefore the current flow in the event of an external short circuit. Each battery has been programmed to deliver a certain maximum amount of current, after which it simply shuts off if this maximum is exceeded. The maximum programmed current is an excellent compromise that allows all the user applications to power up with ease but will not tolerate current abuse or short circuit. The electronics will automatically reset to normal after a while once the short circuit has been removed. In the 'GRANITE' series, we have used a generous over-rating of the discharge MOSFETs in order to ensure excellent high current discharge performance without overstressing the electronics.

b) ***Overheating*** - Battery current abuse aggravated by high ambient temperatures

Overheating precautions work in both charge and discharge. Being devices that are able to deliver large amounts of current on demand, this safety measure is very important in order to prevent the battery from running hotter than normal. This also ensures the lifetime of the battery cells and electronics. The pack will automatically disconnect if the temperature rises above a certain threshold during discharge (the packs have an internal temperature-measuring device). The same happens if the temperature rises above the charge temperature limit. Charge and discharge temperature thresholds may not necessarily have the same values and are carefully chosen to optimise the battery operation. We have set both charge and discharge temperature limit thresholds at 60°C. (note however that charging is inhibited if a battery is already at 45 °C or more at start of charge)

Similar to the over-current protection, if the electronic protection fails then the thermal breaker and cell PTCs will intervene.

It is important here to notice that the battery can heat up both during charge and discharge. The higher the currents in use, the more heat developed inside the battery. Internally, the battery is compact and there is no room for convection cooling apart from the fact that it is fully enclosed. It is also important to realise that if a battery has been delivering an appreciable amount of current during discharge (especially if it has been powering lamps during shooting) it may well reach the charge temperature threshold early.

It is good practice to rest the battery between charge and discharge.

c) ***Overcharging*** - Inadvertently reducing cell lifetime

The charge algorithm required by a Li-ion battery is very precise. Deviation from the correct algorithm is bound to cause problems. For a single Li-ion cell, the cell voltage must never be allowed to exceed 4.2V (+0.05V). This means that the charger must have very precise detection means in order to keep this parameter under control. In packs where multiple cells in series are present, the problem is more complex. During charge and discharge, cells tend to depart from their uniformity and become unbalanced. There may therefore be instances where one cell is below 4.2V and another one above. This is where the cell-balancing feature plays a vital role. Moreover, our battery electronics continually monitors individual cell voltages and will not allow any cell group to go into overcharge. If a cell reaches the overcharge threshold, charge activity is suspended. A maximum voltage of 4.25V per cell group has been imposed in the battery programming.

d) ***Overdischarge*** - Continue demanding current from a totally empty battery

Our system will automatically suspend discharge current at a pre-set value in order to protect itself from overdischarge. The harms of overdischarge are described above and are to be avoided. After a full discharge, the internally remaining capacity is sufficient to continue powering the safety electronics (electronic load). Complete internal shutdown (shutdown mode) occurs in stages as the cell capacities continue to drop due to internal power consumption leaving the vital safety features operative till the very end. At this point, the LED display will also be disabled. Charging fully restores normal operation.

e) ***Overcurrent*** - Exceeding the current safe limit

The pack electronics have powerful, very low RDSon MOSFETs in order to be able to deliver large amounts of current with maximum efficiency and minimum heat losses. Nevertheless, our batteries have programmed safety thresholds that if exceeded, will shutdown the current flow in both charge and discharge directions to prevent possible damage. These safety thresholds will not hinder normal operation in any way and indeed, our batteries are able to deliver currents comparable to or higher than those of the competition. A cunning feature is the 'surge control' whereby the batteries allow a temporary high current transient to flow for a certain time. The magnitude and duration of this transient are also parameters programmed inside the battery. This feature comes in very handy in the usage of light bulbs, where the current surge produced on start-up of these devices is far greater than their normal running current.

As a secondary protection there are again the cell PTCs and the thermal breaker.

f) ***Precharge*** - Treating the battery gently

The precharge feature is both a charger and a battery feature. For precharge, the battery has additional circuitry for limiting the charge current to only a fraction of the normal charge current. The precharge feature primarily comes into operation if the individual cell voltages drop to a value less than a programmed threshold. The battery will remain in a state of precharge until the cells reach the programmed voltage setting at which the main charge FETs open.. The other instance where precharge is activated is when the battery temperature is too low or rather when it lies between the precharge threshold temperature and the temperature at which no charging current flows at all. The introduction of charging current in a gentle manner protects the battery from sudden shock due to current surge and is beneficial in extending its lifetime and performance. The precharge stage lasts only a few seconds or minutes at most since healthy batteries recovered very quickly from a very low voltage status.

From the charger point of view, this has to be able to detect if a battery is in precharge state and continue to operate without thinking that that battery is unserviceable.

Unfortunately, not all batteries on the market possess the precharge feature. Therefore not all chargers can comply to this requirement. Some chargers go straight to the constant current portion of the algorithm and thus declare a battery failure as soon as they detect that the current they expect to apply is not the actual current flowing.

All BLUESHAPE batteries and chargers are precharge compliant.

g) Dual D-TAP feature and additional safeties

All the new 'GRANITE' series batteries each have twin D-TAPs (one on each side). These D-TAPs were included because of the increased demands of today's users to power additional devices during shoots. BLUESHAPE provided a generous 80W output from these D-TAPs but also incorporated an independent overload protection circuit separate from the battery's other overload and safety protections. The D-TAP protection is engaged once the 80W limit is reached or exceeded and returns back to normal operation once the overload is released.

Conclusion

BLUESHAPE batteries are built to guarantee unparalleled performances and runtimes without compromising user safety. Their quality has been measured and certified through international standards laboratories. For airline transportability, the whole 'GRANITE' range of batteries has been subjected and successfully passed the UN 38.3 tests as defined by IATA.