High-Rate Performance of Large Format Nickel-Zinc Batteries

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Abstract

This paper presents an overview of the high-rate capability of Nickel-Zinc cells and batteries. New manufacturing techniques and updated electrode design have enabled the manufacturing of cells capable of exceeding 10C continuous rates with relatively high utilization. In addition, large format NiZn batteries are already being manufactured that is capable of delivering 30% more power than a lead-acid battery in an equivalent footprint.

Keywords: Nickel-Zinc; batteries; rechargeable; large format, high power.

Introduction

Nickel-zinc (NiZn) battery technology has advanced considerably in the past several years, both in terms of performance and manufacturability. The historical weakness of poor cycle life has been greatly mitigated to the point where NiZn can readily exceed the cycle performance of lead-acid batteries while offering double the energy density. NiZn is also a potential substitute for lithium-ion batteries in locations and scenarios where safety, cost, and recyclability are of great concern. In addition, recent technical improvements have also been made with regard to high power performance and rechargeability of NiZn. These developments make NiZn batteries a very good fit in high-rate back-up power and standby applications. Suitable areas of use are directed energy, data centers back-up, electric grid augmentation, and EV charging stations.

This paper will discuss some of the developments related to high-rate power performance of NiZn batteries. Specifically, recent efforts to show power characteristics at continuous rates up to 12C in small format cells. Data will also be presented from testing of large format NiZn batteries made for standby and datacenter applications. This will show high wattage voltage profiles conducted while the batteries are on float. Additionally, the paper will discuss advances in manufacturing of NiZn electrodes that has been made by Æsir over the last couple of years.

High-Rate Testing in Small Format Cells

Æsir has in recent years mainly focused on the manufacturing of large format cells and batteries, typically exceeding 120 Ah, for energy and moderate power applications with rate requirement in the continuous 5 to 6C range. There is, however, a large demand for batteries that can perform repeatedly at rates of 10C and higher. In that regard, Æsir has recently made small format cells, ranging in capacity of 6 to 10 Ah, that are designed to perform at continuous 10C rates.

An example of such a cell is shown in Figure 1. The height is 4.09 in, the width is 2.86 in, and the thickness is less than 0.9 in. It is important to note that this prototype is made with a 3D printed case and lid and not truly optimized in terms of volume. The capacity of these cells will vary depending on the different electrode configurations and other design parameters that are being used to achieve the best possible power performance. The key design parameters in the build phase shown in this paper were electrode thicknesses and loadings. The electrodes typically used in larger format NiZn cells are relatively thick and are not optimized for continuous rates up to 10C. Part of the reason for this is the traditional method of manufacturing typically used when making NiZn electrodes. The manufacturing approach has been greatly improved upon, as will be shown later, and it has enabled Æsir to make thinner electrodes with appropriate loading, allowing for a better current distribution in the cell stack and good capacity utilization at 10C rates.

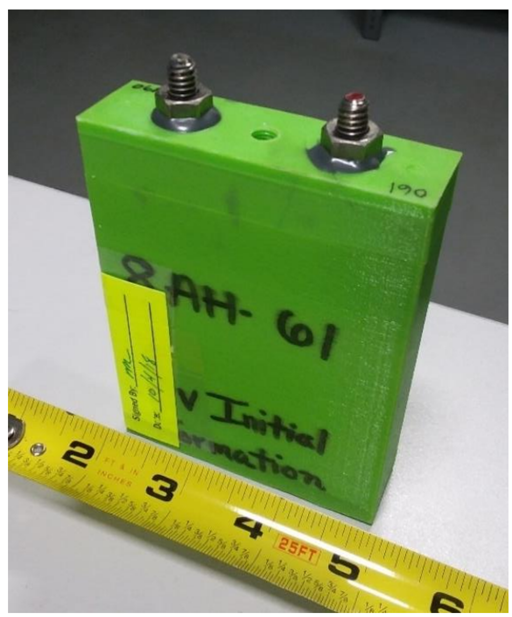


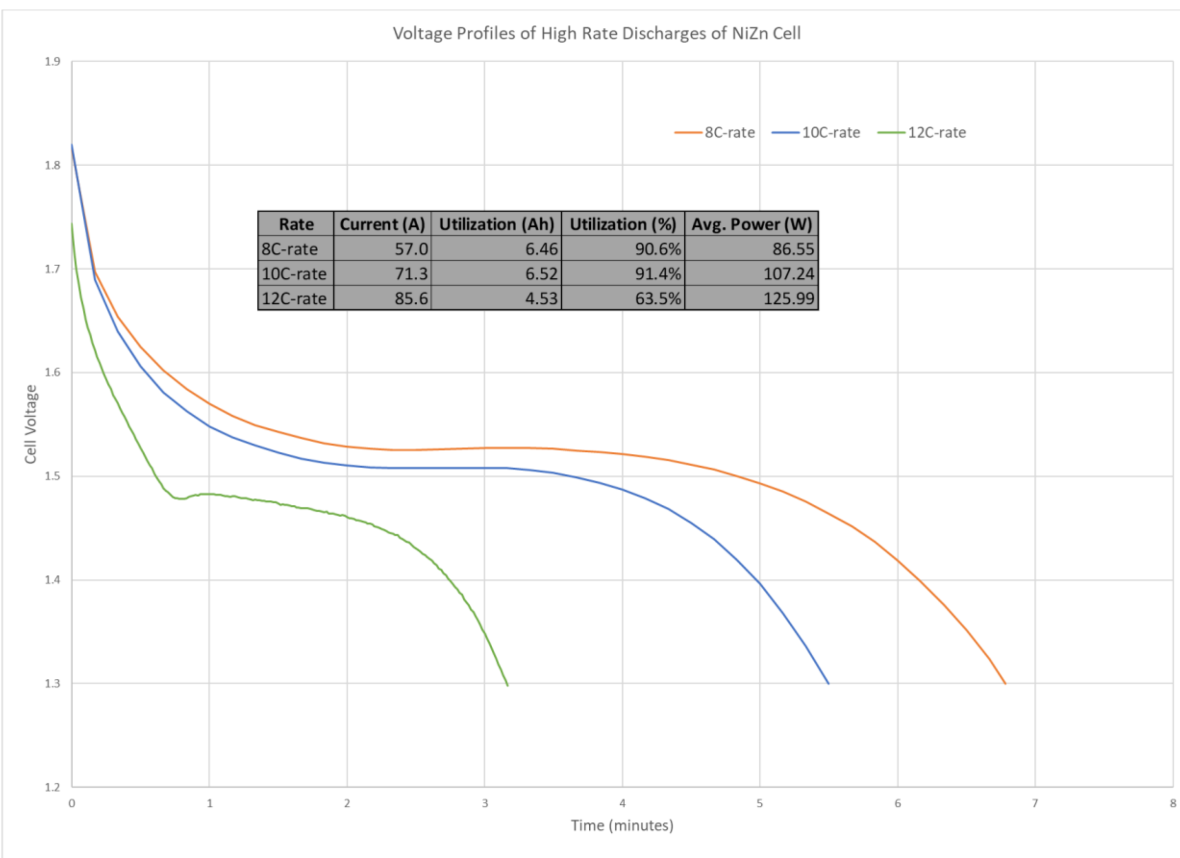
Figure 1: Example of a small prismatic NiZn prototype cell made for high-rate continuous discharge. The case and lid are 3D printed.

Figure 2 shows some of the results from these prototype cell builds. The graph depicts the cell voltage versus time in minutes while the cell is undergoing constant current loads of 8C, 10C, and 12C at a temperature of 21°C. This particular cell design is rated at 7.13Ah. This gives constant current discharge rates of 57A, 71.3A, and 85.6A, respectively. The discharges are cut-off at 1.3V, which is the typical cut-off at lower discharge currents for extracting full capacity. There is insignificant negative impact on NiZn by letting the discharge go down to 1V. Albeit, at some point below 1V there could be gas generation. However, NiZn does not suffer from the same issues as seen with lead-acid and lithium-ion when the cell voltage goes below a certain threshold. In the case shown in Figure 2, it appears to be little benefit letting the voltage go lower. However, this might be worth considering at colder temperatures when the electrolyte impedance will increase, and the overall discharge voltage will decrease.

The voltage curves in Figure 2 show that the cell design is well suited for 8C and 10C continuous loads, running for about 5.5 and 6.8 minutes, respectively. This translates to a capacity of about 6.5Ah, which is about 90% of the nominal nameplate capacity of 7.13Ah at a C/3 rate. The mid-point voltage is above 1.5V and the average power load is 86W and 107W, respectively.

The cell design will also perform reasonably well at the continuous 12C rate of 85.6A. But the duration is just above 3 minutes, and the capacity utilization has dropped to 63.5% with the mid-point voltage below 1.5V. Despite delivering an average power load of 126W, it is clear that this particular design needs further adjustments to deliver a robust 12C run. Æsir believes that this can be accomplished with further electrode design refinement during the ongoing design/build/test phase.

Æsir is also conducting testing with new additives for both electrodes and electrolyte to enhance high power performance. These additives, combined with electrode thickness and loading optimization, will allow for continuous load performance at ranges from 15C to 20C in the near future.



Rate	Current (A)	Utilization (Ah)	Utilization (%)	Avg. Power (W)
8C-rate	57.0	6.46	90.6%	86.55
10C-rate	71.3	6.52	91.4%	107.24
12C-rate	85.6	4.53	63.5%	125.99

Figure 2: *Voltage versus time characteristics for a 7.31Ah NiZn prototype cell undergoing continuous discharges at 8C, 10C and 12C rates at 21°C.*

Large Format Battery for Standby Applications

On the large format side, Æsir has developed a battery with characteristics that makes it very suitable for standby and backup applications. This is a 12V battery with a capacity of about 150Ah at a C/3-rate. It has eight NiZn cells in series, giving it a nominal voltage of 13.2V. The battery has a length of 23 inches, a width of 4.74 inches, and a height of 12.74 inches. Figure 3 depicts three of these assembled batteries. The geometry is deliberately designed to fit into commercially available battery cabinets used in datacenters. The battery weighs about 105 lbs., which is about 70% of a lead-acid battery in the same volumetric footprint. The cells are designed to be discharged continuously at 5C-rates, or at currents of about 750A. At the battery level this translates to a power load of 8400W for more than 5 minutes when sitting on float charge. This is about 30% more power than a lead-acid battery in similar format.

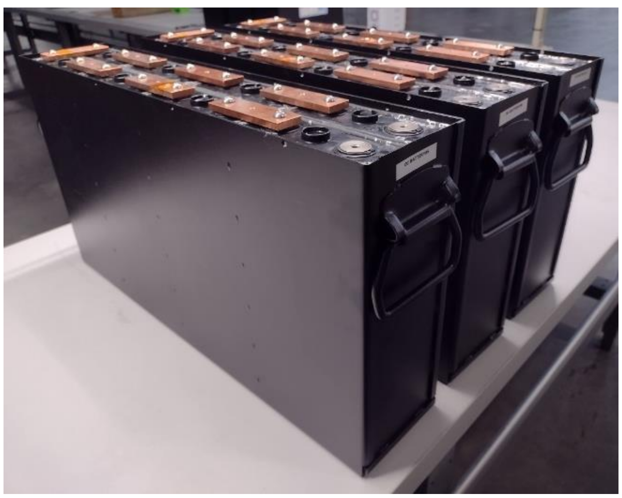


Figure 3: Three 12V NiZn prototype batteries made for high-rate standby applications. Each battery contains 8 NiZn cells.

Large Format Battery Test Results

An example of the high-power characteristics of this battery is shown in Figure 4, showing the voltage profiles of repeated 8400W constant power discharges performed on a 150Ah 12V battery during an extended float stand. This testing is designed to reflect an accelerated full load event scenario of what would be expected in a datacenter cabinet. For the purpose of testing, it is assumed that a cabinet will house 38 of these 12V batteries in series. The test profile consists of letting the battery sit on float charge at a voltage of 14.72V. This is the equivalent of float charging at 559.4V in a full cabinet. At intervals of about one week, the battery is subjected to a continuous 8400W load until the battery reaches a voltage cut-off of about 10.53V. This voltage cut-off is equivalent to 400.5V in a 38-battery cabinet and a single battery load of 8400W is equivalent to 319.2kW at the cabinet level. Once the battery reaches the cut-off load, it is placed on rest for about 1 hour before it is recharged. The preferred charge profile, after a full discharge, is a constant current – constant voltage (CCCV) profile. For this specific test, Æsir used a constant current of 57A and charged the battery to either 15.52V for about 2.5 hours, or 15.2V for about 24 hours. These battery voltages are equivalent to 589.7V and 577.6V at the cabinet level, respectively. What voltage to be used in the field would be based on a combination of the need to be back to a full state-of-charge in a specific time and the limitations of the charging electronics in the cabinet. It is important to note that this load scenario is very conservative. Typical usage profiles in US based datacenters will run at derated loads and durations of less than 3 minutes.

A sample set of the 8400W load results are shown in Figure 4. The graph shows the battery voltage versus the discharge time in minutes. There are ten discharge curves shown, each representing a weekly load over the span of 2.5 months. Each load is discharged from a float or trickle charge state. Prior to the loads shown in Figure 2, the battery was subjected to seven loads conducted in the same manner and showing a similar outcome. The duration of each load typically lasts for about 7 minutes before reaching the 10.54V cut-off voltage. As the battery ages, this duration will gradually decrease until it no longer can reach the 5-minute mark. Notice that load number 13, shown with the blue line, comes up slightly shorter than the other loads. This is because there was a power outage during recharge and the battery went into this load not fully charged. The battery recovered by the next load.

Electrode Manufacturing and High-Rate Battery Performance

A key aspect of being able to produce good high-rate batteries is to be able to manufacture the electrodes in such a way that they deliver on the intent of the design. Traditionally, NiZn had a very laborious and manual manufacturing method. Not only did this drive cost up and impact reliability of the product, but it also limited some features of the electrode design that is desired for high-rate performance, most notably the thickness and loading. Æsir has made significant improvements to the cathode manufacturing in recent years. The cathode used to be made using a manual tape casting approach that was tedious and it limited what range of slurry density that could be targeted. The implementation of a high-volume automated coater has also enabled Æsir to manufacture better high-rate electrodes when building cells. This new coater can be seen in Figure 5 and compared to the older manual tape caster. Currently an effort is ongoing to improve the anode manufacturing, not just for the benefit of production volume and cost, but also for high-rate performance.

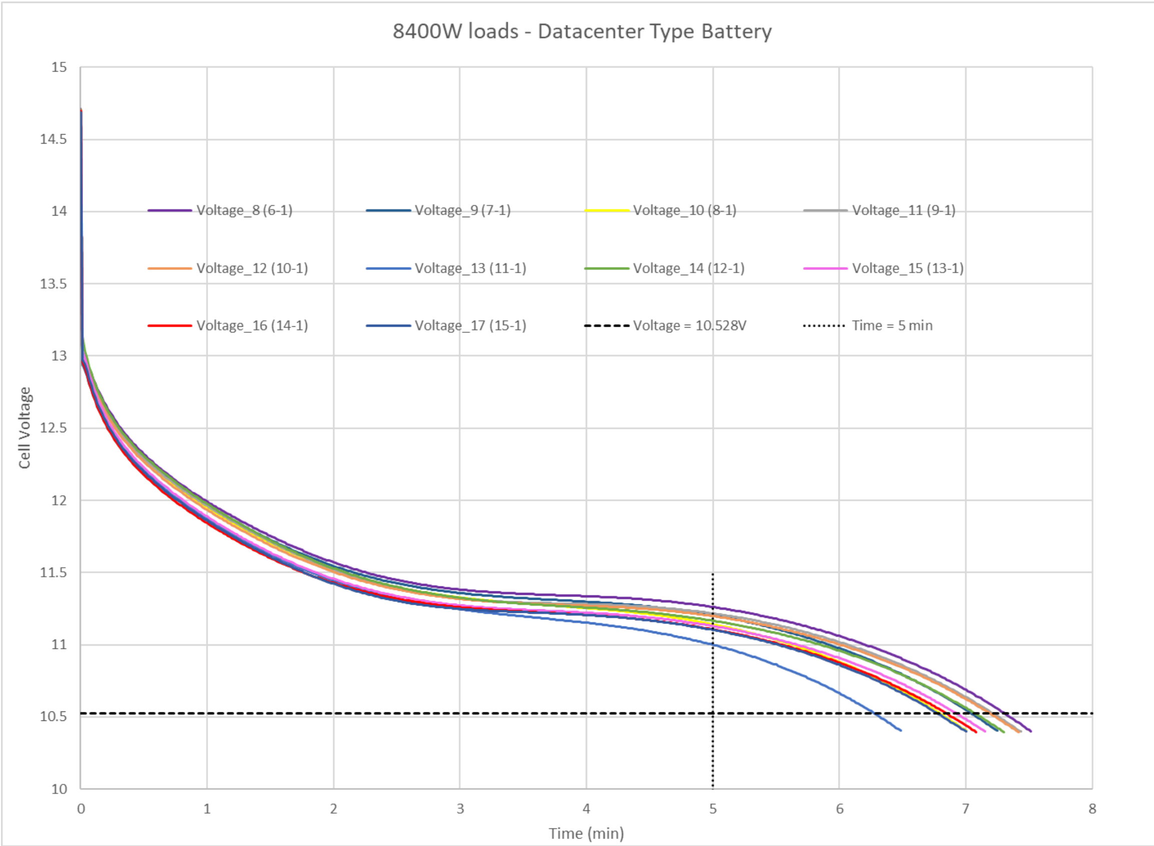


Figure 4: Repeated 8400W continuous power discharge profiles of a 150 Ah 12V Ni-Zn battery while on float charge.

Figure 5: Advancement in the manufacturing process of NiZn cathodes: From manual tape caster to automated coater.

Conclusion

Advancements has been made in producing NiZn cells that can perform at continuous current loads of up to 12C. This phase focused on using thinner electrodes, previously limited my manufacturing, and electrode loading. Future build phases will include evaluation of additives and separator enhancement to raise the power capability. Æsir believe that rates of 15 to 20C are achievable in the near future.

This paper also presented some recent NiZn developments related to high-rate power performance in large format batteries. It was shown that NiZn is capable of delivering about 30% more power than lead-acid batteries in the same geometric footprint with 2/3 of the weight.