Design and Implementation of Active Thermal Insulation to Improve Run-Time in Thermal Reserve Batteries

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Abstract

In this paper, the development of a novel thermal management method is presented that can be used to significantly increase the run-time of thermal reserve batteries. In this method, the thermal battery core is packaged with a layer of heating "fuse-strips". The relatively thin and slow burning pyrotechnic heating fuse-strips are wrapped between insulation layers around the thermal battery core. The heating fuse-strips burn at a tunable rate, providing a continuous source of heat to the battery core extending the run-time of the battery. Depending on the thermal requirements, the heating fuse-strip geometry, burn time, initiation delay, and initiation location can be varied. The development of the heating fuse components and their incorporation into prototype batteries and results of their testing are presented. The test results, which directly compare the performance of prototypes with active thermal insulation vs. standard thermal batteries, show that the inclusion of heating fuse-strips in small and thermally limited batteries more than doubled their effective run-time. Current research and development efforts and future work are discussed.

Keywords

Thermal Reserve Battery; Molten Salt Battery; Thermal Battery Run-Time; Thermal Battery Thermal Management; Slow-Burning Heating Fuse; Heating Fuse Strips for Reserve Batteries

Introduction

Thermal reserve batteries have many advantages over other reserve power systems. Since all internal components are immobilized solids at ambient temperatures, the units are inherently rugged. They can withstand severe environments of shock, vibration, linear and spin accelerations, high spin rates, and a very wide range of temperatures. Thermal batteries are maintenance free, and can withstand long term storage, retaining the ability to provide immediate power upon activation for well over 20 years. They have been used in production applications for over 70 years and have a proven history of safe operation and high reliability.

Following activation upon ignition of its pyrotechnic heat source and melting of the solid electrolyte, a thermal battery can provide power to an external load so long as its electrolyte is molten. The relatively large surface area to volume ratio in a small thermal battery causes its run-time to be short. To increase the thermal battery run-time, the amount of available heat energy needs to be increased. The initial heat energy that can be provided is limited by the maximum activation temperature that the battery can tolerate without causing a significant performance degradation.

In this paper, a novel thermal management method[1] is presented that can be used to significantly increase the run-time of thermal reserve batteries. The thermal battery core is packaged with a layer of heating "fuse-strips". The relatively thin and slow burning pyrotechnic heating fuse-strips are wrapped between insulation layers around the thermal battery core. The heating fuse-strips burn at a tunable rate, providing a continuous source of heat to the battery core extending the run-time of the battery. Depending on the thermal requirements, the heating fuse-strip geometry, burn time, initiation delay, and initiation location can be varied.

The present technology was developed by Omnitek Partners, LLC, of Ronkonkoma, New York, under a U.S. Navy SBIR project and in collaboration with Advanced Thermal Batteries, Inc. (ATB) of Westminster, MD and Hanley Industries, Inc. of Alton, IL. In this novel thermal

[1] U. S. Patent Number 10,186,713 and 11,031,607 and other pending.

reserve battery technology, the battery core is packaged inside a layer of slow burning and heat generating fuse strip, which is ignited following battery activation to maintain the battery core temperature above the melting point of its electrolyte. The battery run-time is thereby significantly increased. This is particularly the case for smaller batteries used in gun-fired munitions, rockets, and missiles.

The schematic of a typical thermal battery with the integrated slow burning heating fuse strips is shown in Figure 1. The thermal battery may be initiated using inertial igniters or electrical initiators.

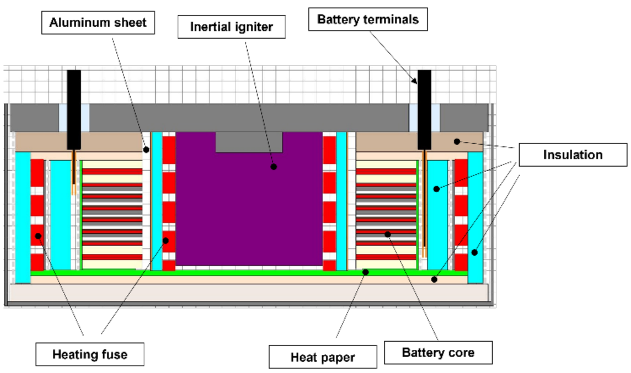

Figure 1: Schematic of a long run-time thermal battery.

Thermal energy at the end of life is often a limiting factor for thermal batteries. The heating fuse is meant to slowly release thermal energy into the battery throughout its life in addition to the heat pellets present in the battery cell stack. This slow release of heat aims to provide the crucial heat needed at the end of life, as the heat pellets begin to lose thermal energy. The purpose of providing slow burning heating fuse coils that are wrapped around the battery core is to keep its electrolyte temperature above its melting point to allow for longer battery life (run-time).

The heating fuses are currently fabricated by Hanley Industries, Inc. of Alton, Illinois, by filling 12 inch long and 0.133" and 0.093" diameter and 0.028" wall thickness annealed stainless-steel tubes with slow burning (5-15 second per inch) pyrotechnic material and compacting the filling, adding a secondary pyrotechnic material to one end, and inserting a flexible fuse element to facilitate its ignition before crimping both ends of the tube. The tubes are annealed prior to filling to assist their crimping, and their coiling and consolidation at Omnitek.

The stainless-steel tubes filled with slow burning pyrotechnic material are then cut to the required length at Omnitek Partners and coiled with extended spiral cap section and flattened to consolidate the pyrotechnic material and to minimize the occupied battery space as can be seen in Figure 2 and fit the intended battery size. In general, two such heating fuse elements are used on a cylindrical battery to also cover its top and bottom section. A thin (around 0.010") layer of aluminum sheet is provided between the heating fuse strips and the battery core to distribute heat and prevent local hot spots. The flexible ignition fuses seen at the bottom end of the heating fuse strip of Figure 2 are thereby positioned at mid-section of the battery for ignition at the time of battery activation.

Figure 2: A coiled and consolidated heating fuse section with integral helical cap section.

Figures 3-7 show the process of fabricating batteries with the slow burning heating fuse strips. Figure 3 shows the battery core as covered with a 0.001" thick aluminum sheet over an insulation layer during the battery assembly. Figures 4 and 5 show the process of assembling the heating fuse strips over thin aluminum foil. Figure 6 shows the process of providing the final insulation layer over the heating fuse strips. Figure 7 shows two assembled thermal battery prototypes, one with (right) and one without (left) heating fuse strips, but with identical battery cores. Figure 8 is an x-ray picture of the two batteries that is commonly made to ensure that the batteries are assembled properly.

Figure 3

Figure 4

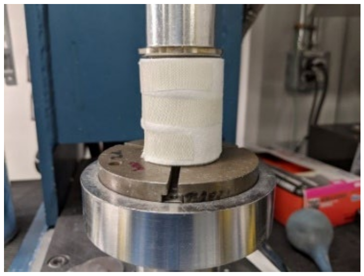

Figure 5 **Figure 6**

Figure 7

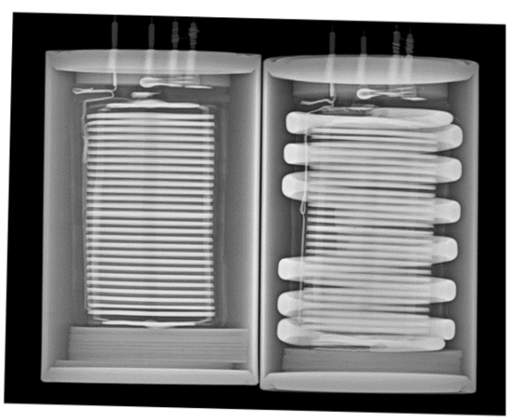

Figure 8

The batteries shown in Figure 7 have a diameter of 1.75" and are 2.9" long and were sized so that a current production battery core could be used for the tests. The run-time of one of the sets of fabricated two prototypes (shown in Figure 7) were tested at -30°C under identical loads. The measured battery run-times are shown in the plots of Figure 9, showing the output voltage of the battery with standard insulation as are commonly manufactured and used in munitions applications and the output voltage of the battery with the heating fuse strip under an identical load as a function of time.

A test of the above size batteries and with the same battery cores with standard insulation material; with Aerogel insulation (best - but costly - available insulation material); and with the heating fuse strips was also performed at -43°C under identical loads. The test results are shown in the plots of Figure 10. As can be seen in Figure 10, at 20.7 Volts, the best available insulation material (Aerogel) increased the battery run time by only 15%, while the heating fuse strips increased the battery run time by around 285%.

Discussion And Conclusions

The developed novel thermal management method is shown to have the potential of significantly increasing the run-time of thermal reserve batteries. The method, as described in this paper, is more effective for use in smaller thermal batteries due to their higher ratio of the battery core surface area to its volume. However, other modifications of the technology, such as the use of multiple heating fuse layers with delayed ignition capability, and/or the provision of generated heat storage capability, should make it possible to achieve similar performances for significantly larger thermal reserve batteries. Furthermore, minimizing the heating fuse volume and finding alternate nonconductive packaging material would be a significant enhancement.

It is noted that the primary goal of the designed and fabricated prototypes and their testing was to demonstrate the potential of the developed technology in significantly increasing thermal reserve battery run-time. To this end, little effort was made for their optimal design to maximize their run-time. It is appreciated that the process of optimally designing thermal reserve batteries with properly sized and distributed heating fuse strips for a prescribed application and its requirements are generally complex and require further efforts.

In addition, the process of fabricating the flattened coiled sections with the spiral caps, Figure 2, such that it would achieve reliable ignition and complete burning along the entire length of the fuse strip requires further development and automation.

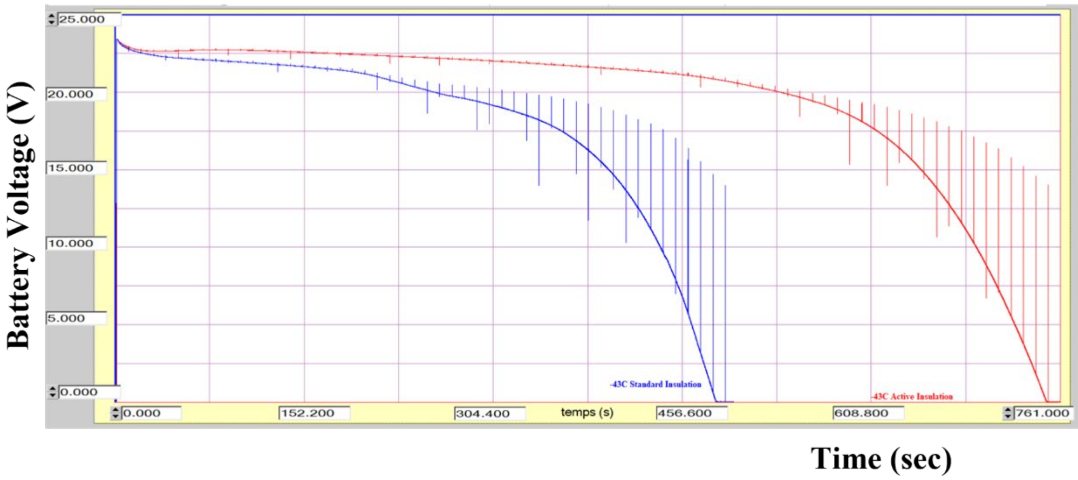

Figure 9: The run-time of the prototype thermal battery with standard insulation and with heating fuse strips demonstrating the increase in the run-time that can be achieved.

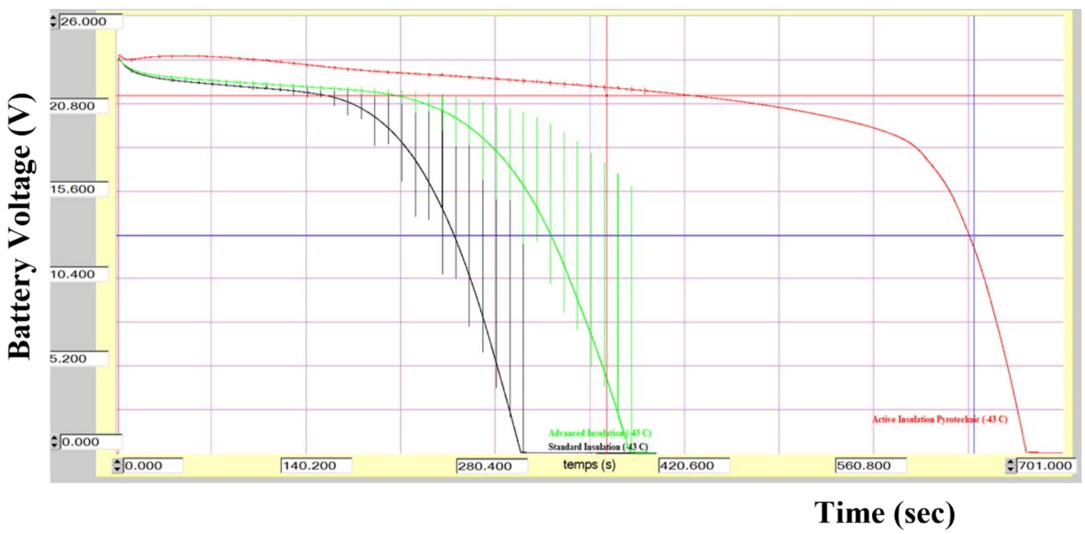

Figure 10: The run-time of the prototype thermal battery with standard insulation (black), Aerogel insulation (green), and with heating fuse strips (red) demonstrating the increase in the run-time that can be achieved.