

Design and Performance of The GM Sunrayer Battery

Introduction

The silver oxide-zinc battery system was selected for the GM Sunrayer after considering several systems because it had the highest specific energy and power of any system available. A schedule of tasks was established to design, test, ^{and} manufacture the batteries in time to support prerace tests and the actual race.

Various tests were run on prototype cells to evaluate specific design parameters such as separator system, electrolyte concentration additives and charge/discharge efficiencies. When the final cell design was available cells were tested to provide polarization performance data that could be used in the computer modeling program for tactical simulation (TACSIM) on how to most efficiently use the available energy.

The battery was primarily sized based on the predicted energy available from the ~~silicon~~ solar panels and the race rules that allowed for charging from sunrise until 8:00 a.m. and 5:00 p.m. until sundown. The battery was oversized based on the premise that the battery would operate most efficiently between 20% and 80% state of charge. Basically, the battery would be used as a "load leveler." In the morning and afternoon energy would be drawn from the battery when solar energy was low to keep the car at near a constant speed. During midday some of the solar panel energy (if it was great enough) could be used to charge the batteries.

Another reason to oversize the battery was that the highest charging current was available at 8:00 a.m. when the battery would be reaching full charge. This is the time when the battery is least efficient or has the highest polarization voltage. Press stops, driver change stops, tire changes or car breakdown would also afford times to charge the batteries. Fortunately, there were no stops for mechanical or electrical problems. Tire changes and driver stops were so short, one to three minutes, that they were insignificant. Press stops were scheduled 10 minutes stops which allowed time to return about one ampere hour to the battery.

Battery Selection

An initial consideration for the battery requirements was the schedule. The decision to enter the race was made April 1, 1987 and batteries were required to support testing of the Sunrayers August 1, 1987. This allowed only four months to procure cells, design the battery and manufacture the battery. This short time span required that the electrochemical system would have to be essentially an "off-the-shelf" system and ruled out the possibility of using any of the new systems such as sodium sulfur or lithium cells. Preliminary system design studies based on using a silicon solar panel assumed a charge voltage of 145 Volts and that a 2.5 kWh would be required.

Temperature predictions were made based on maximum highs and lows measured in Australia over the past several years and the fact the battery would be under the "hood" or solar panel. The operating temperature established was from 10° to 60° C. The ^{required} power output was estimated to be about 1KW nominal with short term requirements of 4KW for acceleration and hills. These power requirements translated to ^{Early estimates were that the race could take ten days} currents of 10 to 40 amperes. ^{10 deep cycles for the battery which would only require about 100 kWh.} Three electrochemical systems were considered. They were Ni-Zn, Ni-Cd and Ag-Zn. Table 1 summarizes the initial design criteria and the estimated specific energy provided by the three systems. It is noted that the specific energy for the Ni-Zn and Ni-Cd systems are

lower than usually shown in the literature. This is because of the estimated low charge efficiency of the nickel electrode at the predicted high operating temperatures. Information on the Ni-Zn cell was obtained from Delco Remy (1). Based on this analysis, it was obvious that the Ag-Zn system was the obvious selection.

Battery Design Criteria

The battery design considerations encompassed many facets such as sizing, safety, instrumentation, operational requirements mounting in car and race rules.

Battery Sizing

~~An additional power systems design information became available the cell size and numbers of cells in series were fixed. As noted above, initial~~

The race rules played an important part in the design consideration for the battery. The rules stipulated that the battery had to be charged from the sun on the solar panels, but regenerative braking was OK. The race day was from 8:00 am to 5:00 pm. Battery charging was allowed from sunset to 8:00 am and from 5:00 PM to sundown. Of course battery charging was allowed any time during the race day, but in most instances, except during mid day, it was more efficient to use the solar panel energy to propel the car ^{rather} than to charge the battery. Basically the race strategy was to use the battery to augment the solar panel energy in the morning and evening hours when the sun was low. A computer program, ^{call TACSIM} was developed to tactically simulate most of the parameters of

of the race. It was used to assist in the decision on how to the battery energy would be used and if it was more efficient to charge the battery than to propel the car which was dependent wind velocity, car velocity, friction and drag.

The race rules required that the organizers seal the battery installation and no battery replacement was allowed without a time penalty based on a given formula. It was estimated from the formula that if the sunrayer battery was replaced it would amount to a time penalty of one day. Replacement of any other item in the car was allowed without a penalty. Since battery replacement could cause one to lose the race, battery reliability was considered a major design factor. We did

not plan to replace the battery.

Safety Consideration and Battery Mounting

Safety hazards to personnel and electronics were of prime importance. Generation of hydrogen on overcharge or overdischarge could possibly cause an explosion. Spewing of potassium hydroxide electrolyte could be hazardous to personnel and electrical equipment. The safety concerns and the fact that we wanted to keep the battery as cool as possible led to the concept of mounting the battery in a closed container with its own air circulation as seen in Figure 1. which shows the location of the battery in the car.

The four battery packs were mounted in a battery box, two side by side on the bottom and two on an upper shelf. They were mounted on stand-offs to allow for air circulation on all four sides. The air entered from a duct in the bottom of the sunracer chassis and circulated thru the box and back out a duct to a second opening in the chassis. A small fan was also in the duct to provide circulation when the car stopped.

In addition a battery safety handling and operating procedure was developed.

Battery Instrumentation

Early in the program it was pointed out that ~~proper~~ battery instrumentation would be required for safety, battery management and to properly diagnose impending problems. The battery was instrumented to measure temperature, battery and cell voltages and charge and discharge current. All of these functions were connected to a telemetry unit which telemetered the data to a computer system in a command vehicle trailing behind the Sunracer. The computer contained a subroutine which could calculate the ampere hours in and out of the battery based on the charge or discharge current. If there were glitches in the data, this method of keeping track of the state of charge of the battery would not be accurate; therefore, a current integrator was used. It was part of the instrumentation

mounted in the car for the driver to observe. Radio contact was maintained between the driver and the command vehicle.

An auxiliary battery box was built to also monitor cell voltages primarily during charge in the mornings and evenings ^{when the car was stopped}. It was a manual switch box that could be plugged directly to the battery packs to monitor voltages with a hand-held V.M. It proved quite useful as the telemetry unit failed during one of the morning charges and it was initially thought to be a battery problem.

Battery Sizing

Preliminary system design data was noted previously in the discussions concerning the selection of the battery system. As design study information evolved battery sizing, capacity and number of cells was modified. Initial data indicated we could use about a 2.4kWh battery with 72 cells in series. As the solar panel and power electronics designs firmed up, the battery sizing was firmed up. Solar panel nominal output voltage was predicted to be a nominal 150 volts. The voltage differential between the power electronics (charger) and the panel was estimated to be 4.0 volts. From this it was decided to use a 68 cell battery which would allow for an end of charge voltage of about 2.1 volts per cell with some margin.

The battery cell capacity was initially determined based on the predicted solar panel power output using silicon K7 cells. The panel power output curves versus time of day at the start of the race in Darwin and at the finish of the race in Adelaide are shown in figures 2 and 3. The figures also show the power outputs of a gallium arsenide and a "hybrid" panel. The hybrid panel contained about 20% silicon cells on the front sides of the panel. Figure 4 shows a photograph of the car and panel and it is seen that the sides of the front portion of the panel have a steep slope and do not contribute much to the total power.

The power prediction curves show discontinuities in the curves at 8:00 AM and 5:00 PM because it was planned to tilt the panel to be normal to the sun when charging the battery. The panel was

hinged on both sides of the car with a piano hinge.

Also shown in the figures is the total estimated energy output of the panels for the two charge periods. It is seen that maximum charge energy is 1840 Wh at Adelaide. The battery charge efficiency was estimated to be approximately 75% (the nominal discharge voltage, 1.50V, divided by the nominal charge voltage, 2.0V). Coulombic efficiency was assumed to be 100% over most of the charges. Therefore $1840 \text{ Wh} \times 0.75 = 1380 \text{ Wh}$ is the maximum energy that could be stored in the battery in the allotted charge time. The writer did not want to use the battery at 100% depth of discharge, DOD, because reliability and battery performance characteristics. It

was concluded that it would be more efficient to operate the battery between 20% and 80% state of charge. This would help prevent overcharge and overdischarge of the cells and allow for cell capacity mismatch and provide for more efficient battery usage. So $1380 \text{ Wh} \times 1.4 = 1932 \text{ Wh}$ and the nominal discharge voltage was assumed to be about 100 volts which would require a 20 Ah cell for the silicon panel.

About a month after the program was initiated it was decided to use the hybrid panel which required a battery of higher capacity. Based on a panel output of 2355 Wh and going thru the same calculations, one calculates a battery capacity of 25 Ah.

INTERNAL CELL ASSEMBLY

HUGHES

