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Aspects of a Robust In-Vehicle Lead-Acid Battery Monitoring System (inGEN®)

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ABSTRACT

This paper will primarily focus on automotive lead acid battery performance and the in-vehicle environment that must be monitored to assure battery performance and power for advanced automotive electrical applications. The battery monitoring system serves as an enabling technology for advanced electrical systems that can improve fuel-economy, reduce emission levels, improve safety systems, and provide increased comfort and convenience features.

inGEN, a microprocessor-based lead acid battery state of health (SOH) and state of charge (SOC) vehicle sensor, was recently introduced to the automotive, military, truck and bus and marine vehicle industries. This paper will build upon research presented in SAE papers 2001-01-2715 (Cox and Bertness) and 2002-PSC-29 (Cox, Bertness and Klang)

The battery's environment in the vehicle, especially regarding temperature, plays an important role in the modern world of automotive battery management systems.

INTRODUCTION

Lead-acid battery performance and lifetime are greatly affected by temperature. In warm temperatures, the battery performs well. If the temperature is too warm, however, the chemical reactions in the battery are accelerated, including those that determine the life of the battery. If the battery gets too cold, the chemical reactions are slowed down and its life is extended, but the output of the battery is greatly reduced.

The amount of energy that a lead acid battery can deliver and the ability of a battery to deliver power are both related to temperature. Charge acceptance is also affected by temperature. As the battery is discharged and charged over time, including detrimental over-charging and deep discharging, its reaction to temperature (or lack thereof!) can become more drastic, as anyone who has ever needed a jumpstart on a cold day can attest. There are many other factors such as age, usage, and application; however, temperature remains a key parameter for lead acid batteries.

As the battery ages and declines in health, its ability to deliver its charge becomes diminished. A standard measurement of this state of health is conductance, previously detailed in numerous SAE, IEEE, BCI and other industry technical papers.

inGEN®, a high precision microprocessor-based automotive sensor, is capable of an extremely accurate measure of battery conductance. When a lead acid battery is measured at a known temperature, the monitoring of the battery's state of health (SOH) and state of charge (SOC) is more precise. As the temperature of the battery changes, the measured conductance of the battery will change, and this must be accounted for when determining the state of the battery.

MAIN SECTION

BATTERY MONITORING SYSTEM PARAMETERS

Along with conductance, inGEN continuously measures battery voltage, temperature and charge/discharge current. inGEN utilizes these parameters to calculate the battery's real-time state SOC and SOH[i]. In some vehicle applications, these basic inGEN measurements are also utilized to derive OEM-specific and vehicle-specific battery calculations like State of Life (SOL), Energy Content, Deliverable Energy Units, Discharge Power Capability and others.

SOC and SOH

In simplest terms, the SOC calculation provides a measurement of the available energy in the battery at a given moment in time. The SOC measurement provides a parameter that the vehicle designer can utilize to determine the overall ability of the battery to provide power to various vehicle electrical systems, as well as the battery's ability to accept charge from the charging system, and its resulting recharge level.

For advanced electrical systems that utilize battery power beyond the traditional SLI (starting-lighting-ignition) application, this is critical. If the battery burdened with additional loads, it needs to be monitored to determine if it can meet the mission-critical power requirements so that vehicle operator safety, reliability and/or comfort is not compromised.

To illustrate this point, consider an idle-stop or stop-start system that shuts down the vehicles internal combustion engine when the vehicle decelerates to a stop. The battery is used to power all the electrical systems during the time stopped. The result is that the battery can be considerably discharged during this stop time, depending on the amount of electrical loads enabled. Upon restarting, the battery must crank the engine and is further significantly discharged. The SOC calculation is utilized to ensure that the battery can supply the energy required by the system, and is also utilized by the alternator to provide the appropriate recharging current and voltage to the battery to return its SOC to the appropriate level.

Figure 1 displays the current charge and discharge of an idle-stop vehicle application, and the resulting SOC level. From this graph, it is clear that monitoring and utilizing a SOC measurement is essential for such electrical system applications, as the idle-stop system present quite a challenge for discharge and charge performance in an accelerated timeframe.

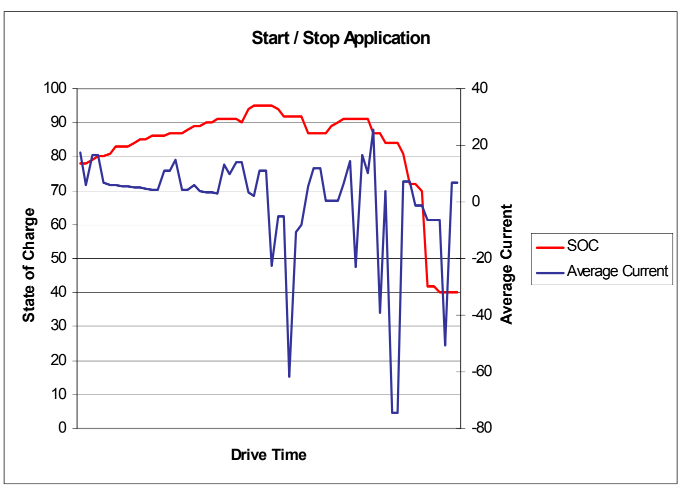


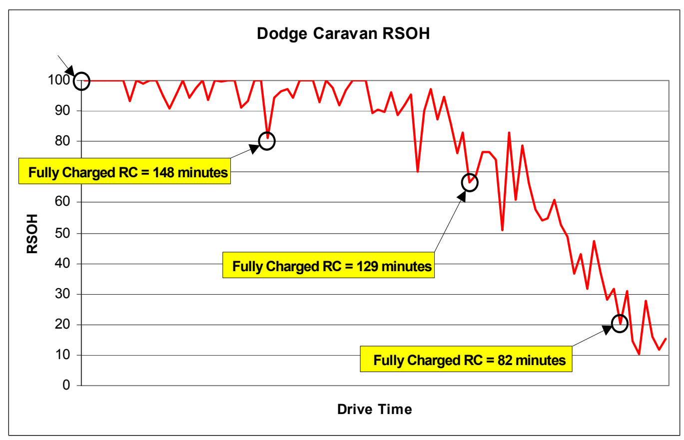
FIGURE 1 – Start / Stop Driving Sequence

This chart shows a simulated loading pattern for a Jeep that was run in a conventional pattern in the first half of the sequence (1 hour) and then run with a heavy stop / start pattern for the remainder (1 hour)

However, SOC by itself may not be sufficient for battery monitoring if the battery is being used to power critical performance or safety systems. As Figure 1 demonstrates, the charge/discharge levels and resulting SOC of the battery is constantly fluctuating across a wide range. As the lead-acid battery ages and its environment varies, especially with temperature, its ability to deliver and accept its charge will change. Thus, the battery will not perform the same after several years, nor will it perform the same when placed into dissimilar temperature environments. For this reason, where a battery is utilized for essential vehicle systems, it is imperative to derive a measurement of the battery's SOH. Understanding the battery's real-time SOH and its decline over time can provide assurance that the battery will perform as designed now and in the immediate future.

State of Health

In Figure 2, conductance measurements are utilized to calculate a SOH measurement equivalent to its CCA (cold cranking amperes) level. inGEN technology measures conductance independently of the battery design, therefore the SOH measurement in percent is indicative of the vehicle's relative power requirement, not the battery design. So, the measurement can be utilized with any battery, including aftermarket replacements.



"Y" axis represents 11 months

FIGURE 2 – SOH Measurements

State of health measurements in Dodge Caravan over 11 months. SOH calculation is not compensated for temperature.

In Figure 2, note the fluctuation in measurements; one would not expect SOH to be highly variable over a short time frame. These fluctuations represent temperature effects, in which the battery state has changed as a result of temperature rather than actual decay in performance. Battery conductance varies due to ionic and electronic changes that are reversible with temperature. In particular, ionic mobility and conductance is severely degraded with low temperatures. Therefore, if we are to look at an in-vehicle SOH measurement based on conductance, this must be corrected to a standard temperature. Then, the SOH will actually represent the health state of the battery that will meet the needs of the vehicle under a wide range of operating conditions.

Figure 3 represents SOH data similar to Figure 2 that has been corrected for temperature. Conductance has been recalculated to a common temperature (0 deg F – its definition temperature) and compared continuously with a minimum requirement to determine a percentage SOH. **Note the linear relationship with the removal of the severe swings due to temperature aberrations**.

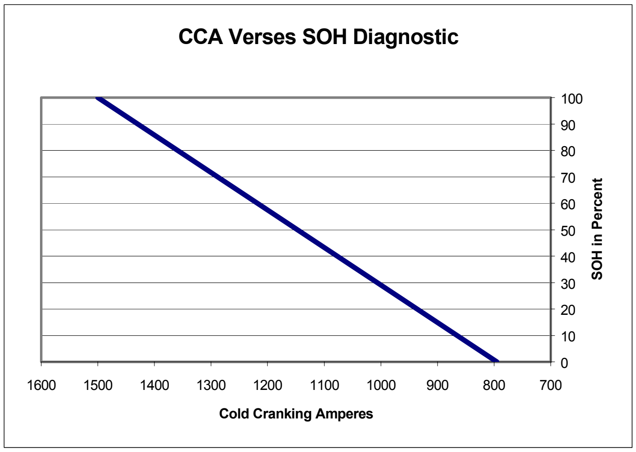


FIGURE 3 Temperature-compensated SOH

Comparison of temperature compensated CCA/SOH measurements, where SOH is relative percentage from 100% equal to new, healthy battery at 100% of its rated capacity

However, when we need specific performance data, especially at low temperatures, we can use the basic input data to generate specific power predictions. For instance, if we knew that the battery was very cold and that the starter would need a specific current to crank the vehicle, we can also predict a voltage that the battery could produce at that current. Comparing this with the minimum requirement will determine whether the battery is capable of starting the vehicle reliably under those conditions.

A chart showing the instantaneous voltages of various lead-acid batteries under load at multiple temperatures versus those generated by a predictive algorithm is displayed in Figure 4. It is obvious that this data is specific to the needs of the vehicle and correlates well with actual performance.

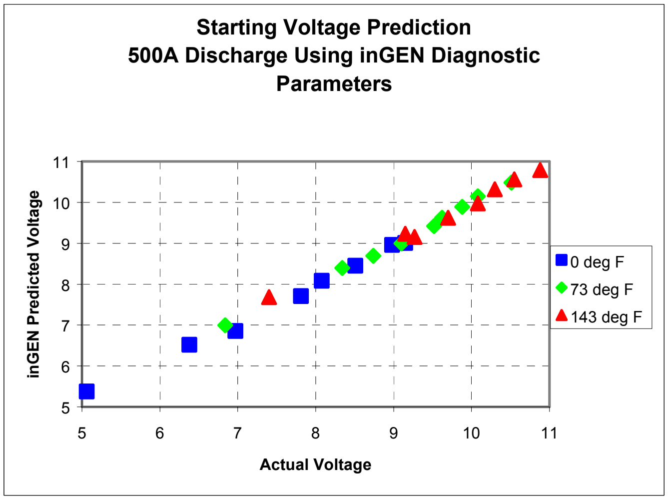


FIGURE 4 – Starting/Cranking Voltage Prediction

Using inGEN Parameters versus Actual Voltage at a 500A discharge. Various size and age lead-acid batteries at three different temperatures

Figure 5 shows the results for the same starting voltage prediction at different temperatures, where the SOC of the batteries has also been varied. This indicates the ability of the system to predict the cranking ability of the battery, even if the battery has been discharged, or has self-discharged by sitting in storage or a parking lot for an extended time.

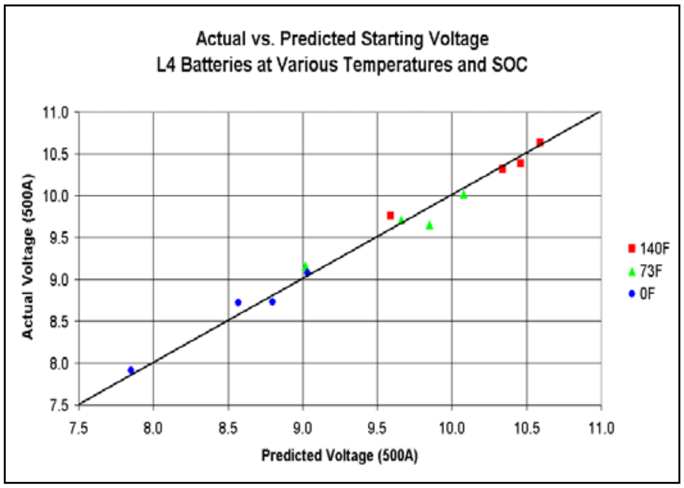


FIGURE 5 – Starting/Cranking Voltage Prediction

Using inGEN Parameters versus Actual Voltage at a 500A discharge. OEM flooded lead-acid batteries at various SOC levels and three different temperatures

The above performance criteria can further be used to recognize when a battery will not be able to support a high rate discharge due to low temperature. The charging system can then be adjusted to maintain the battery at a higher charge condition during operation in cold temperatures to compensate. This will also prevent a deep discharge even in warm temperatures. Increased voltage and load shedding could be used to compensate for added loads in an interactive means with the charge control system. Additionally, a vehicle could warn its operator or operating system in advance that the battery will fail to meet its requirements at a specified temperature.

Overcharging

As mentioned, temperature plays a major role in the life expectancy of the lead-acid battery. Corrosion of the grids and separators are greatly by high temperatures. Overcharge, or a sustained charge when the battery is already charged, also causes severe corrosion and further increases battery temperature. Water contained in the electrolyte can be driven from the battery further reducing the life of the battery, even those considered maintenance free. The electrolyte is concentrated enhancing corrosion and sulfation of the negative active mass.

Knowing the charge state of the battery accurately gives the inGEN the ability to interact with the electrical system so as to drastically decrease the charge as the battery approaches a full charge state. By so doing, the life of the battery is extended as well as reducing the energy needed to supply the electrical system. This translates into fuel savings as well as extended operating life of the battery and electrical system.

CONCLUSION

Advanced automotive electrical systems are creating a new need to continuously monitor the battery for energy supply to these systems. In addition to measuring the available energy during operation, it is imperative to calculate the state of health of the battery so that all applications for fuel economy, emissions, safety, comfort and convenience and drive operation are ensured whenever and wherever required.

inGEN®, a microprocessor-based lead acid battery state of health and state of charge measurement instrument was recently introduced to the automotive, military, truck, bus and automotive market place. An inGEN system will be utilized in a 2005 model year passenger vehicle in Europe to derive battery SOC and SOH measurements for load management and alternator control for SOC-adjusted, or optimized, battery charging. Systems are also deployed in various North American and European military applications and heavy-duty truck systems.

Measurements obtained from the inGEN battery monitoring system, and SOC, SOH and other diagnostics are calculated from these measurements by algorithms within the inGEN system. Comparison and verification of these measurements obtained through laboratory testing and examination of the batteries according to battery testing methods established by the battery manufacturers and Battery Council International (BCI).

REFERENCES

i. SAE Paper 2001-01-2175

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