Workshop Report and Overview

This Workshop Report and Overview was prepared by J. L. Sudworth of Beta Research & Development Ltd. for Pacific Northwest Laboratory, Richland, WA 99352, under Contract DE-AC06-76RLO 1830 with the U.S. Department of Energy under Agreement P4423, in February 1986.

1. Introduction

This workshop on battery testing brought together representatives from battery developers, producers, and users in Europe, North America, Australia, and Japan. It provided a unique opportunity for people working on different battery systems to compare their testing procedures and revealed the great variety of test methods used. Perhaps not surprisingly, as this was the first workshop specifically devoted to testing, there was a tendency to emphasize test results rather than test methodology.

2. Performance testing

Most of the performance testing described was conducted on the bench, but for vehicle batteries some dynamometer, track and field testing was also covered.

For prototype batteries some sort of acceptance test is required, and Geilert described the procedures used at BBC for a sodium–sulphur battery. For high temperature batteries it is necessary to check not only that electrical performance is satisfactory but also that the thermal insulation is functioning properly and that the thermal management system operates.

Butler described the baseline tests used at Sandia. These are used on prototype batteries to duplicate developer test conditions and to verify proper battery operation and capacity.

Three types of bench testing were described. The first type, exemplified by the papers of Hornstra, Brilmyer, and Hardin, was to determine fundamental relationships between discharge rate (power) and capacity (time) in the form of Peukert plots (log time *versus* log current) and Ragone plots (log specific power *versus* log specific energy). The Peukert plots provide a good way of comparing batteries of the same type and are therefore useful for comparative testing. Brilmyer described the use of these curves for comparing advanced lead–acid batteries with standard batteries, and Hardin described the use of Peukert plots for comparing the performance of individual cells or modules with that of full battery packs. Hardin also used this technique to study the effect of battery ageing on performance. When prediction of battery performance in specific applications is required, the Peukert plot is not very useful and the methodology described by Hornstra is far more powerful. This was a Ragone plot and a peak power *versus* depth of discharge plot, and allows battery discharge time (and vehicle ranges) to be predicted for any discharge profile. The two plots are relatively simple to obtain and once they have been determined, discharge times can be estimated for any specific application provided the peak and average specific power demands on the battery are known. The agreement between predicted range and actual range was shown to be good for three different driving cycles, one of which included regenerative braking. The methodology was also shown to be applicable to nickel–iron and nickel–zinc batteries. This methodology is also a useful tool for assessing the effect of various peak power and average power demands on discharge time.

The second type of test used was a parametric test in which the effect of several factors was investigated. Butler described parametric testing of zinc–bromide batteries at Sandia, in which the factors studied were temperature, charge rate, discharge rate, and zinc loading. These tests were then used to derive a performance prediction equation for battery efficiency. Parametric testing is especially useful for characterizing complex batteries such as flow batteries.

The third type of performance testing follows on naturally from the two described above. For specific applications where the duty cycle is well established the battery is simply subjected to that profile and its performance is measured. Thus, Grimes described how zinc–bromide batteries have been successfully tested in power pulsing discharge modes, rapid charging by regenerative braking, power feed to utility lines, and the federal urban driving cycle.

Once satisfactory performance has been demonstrated by bench testing of cells or modules, electrical testing of full-size batteries will be required, and dynamometer testing of vehicle batteries is one way of doing this, if a vehicle is available. Grimes described the dynamometer testing of a zinc–bromide battery in the EVI electric car. This is an expensive and labor intensive method of testing, and the bench testing described above should be sufficiently accurate to predict the results of dynamometer testing, which should merely be a confirmatory test to check that a full size battery performs as well as cells or modules.

Track testing of batteries in electric vehicles tests the battery as a system and includes factors which may not be present in bench testing, such as shock and vibration. It does, however, present difficulties in collecting test data. Dowgiallo described a versatile data acquisition system which fits easily into an electric vehicle, acquires data unattended, presents the data in an immediately useful form, and which has a comparatively low cost.

The ultimate test of an electric vehicle battery is the field test, and the system described by Dowgiallo is equally applicable to field testing. He described the results of track tests of lead–acid powered vehicles and compared these with the results predicted by Hornstra's methodology. Reasonably good agreement was obtained. In actual field tests, however, the users allowed a significant margin of safety. Thus the predicted range of a nickel/iron battery powered vehicle was 57 miles (91 km), but actual use varied between 14 and 37 miles (22 and 59 km). When the vehicle was driven in the field until the battery was fully discharged, a range of 53 miles (85 km) was obtained.

The emphasis in performance testing was on electric vehicle batteries and little time was devoted to load levelling batteries. This is perhaps not surprising as the load levelling requirements are much simpler, but there is still a requirement for testing. Kramer defined the performance factors that are important as: round trip energy efficiency, maximum current, available energy and power availability; and he described the testing of a battery storage test facility for load frequency control and instantaneous reserve.

Pivec described testing of load levelling batteries in the BEST facility. These ranged from simple charge/discharge testing to assessing battery performance through the testing of batteries in a utility environment and eventually in commercial operation.

3. Endurance testing

A multiplicity of life test methods appear to be in use. The most commonly used is a constant current discharge to a set depth of discharge (between 80 and 100%). The situation is compounded by the adoption of different criteria for end of life. Thus, in some tests this might be defined as 50% of the original capacity (Mayer), while in others it may be the inability to meet a certain power level at the end of discharge.

The paper by Klein on the validity of cycle life bench test data in relation to real world in-vehicle testing, discussed the difficulties inherent in endurance testing and compared bench testing with field testing. He concluded that the test cycle should simulate practical operation whenever possible, although some simplification is admissible (*e.g.*, application of a current profile instead of a power profile). He demonstrated that this approach could give good correlation with field tests.

The justification for this kind of endurance testing is that bench testing can be strictly controlled and is less expensive than field testing. The disadvantage, of course, is the length of time required to obtain the results. Chreitzberg has attempted to overcome this by testing lead–acid batteries at elevated temperatures (70 °C). He concluded that accelerated cycle tests at elevated temperatures for long life lead–acid batteries, appear to be a viable alternative to room temperature tests.

The question of whether accelerated tests provide useful information applies equally to advanced batteries. Sudworth used high current densities to increase the number of cycles per day in testing the β-alumina electrolyte in sodium–sulphur cells. For batteries still in the developmental stage, it is unacceptable to have to wait two or more years for the result of the test and, provided the limitations of the test are understood, accelerated testing can be useful. Sudworth concluded that rapid cycling gave useful information on the intrinsic life of the β-alumina solid electrolyte, but that in a real world application the life might be reduced by factors extrinsic to the solid electrolyte, such as deposition of corrosion products from other cell components on to the surface of the electrolyte. Nevertheless, it was seen to be a useful test for ranking electrolytes from different sources.

The effect of corrosion products on the life of β-alumina was observed by Lehnert who found that the life of sodium–sulphur cells at 400 ℃ was less by a factor of 2 - 8 than at 300 - 350 ℃, and that this correlated with corrosion of the cell case. Lehnert also found that increasing the discharge current but not the charge current led to an improvement in life if the temperature was kept in the range 300 - 350 ℃.

The correlation between accelerated testing and normal rate testing is still an open question. For batteries still in the development stage, some kind of accelerated test is probably essential if rapid progress is to be made. When batteries reach the stage of operation in the field, however, bench testing using the profile specific to the application is desirable.

4. Non-electrical testing

The completion of a life test provides useful information on failure rate, but if improvements in life are to be made it is necessary to study the causes of cell failure. Post-test analysis can reveal not only mechanisms of cell degradation but also changes occurring within the cell during normal operation, and thus can provide information on which design improvements may be made.

Thus, Battles showed how deposition of corrosion products on the solid electrolyte, in a sodium–sulphur cell with a chromium-plated container, resulted in a reduction of charge acceptance which would be seen as a loss of capacity. A change in the material used for the cell case would prevent this. The above information was obtained by dismantling the cell, but X-ray examination of whole cells can provide much information.

X-radiographs are often taken from two or more directions before dismantling the cell, and these provide much information. Wada described a more sophisticated use of X-radiography: computed tomography. By using equipment normally used for medical body scanning he produced pictures of cross sections of cells in which fractures in the electrolyte tube and voids in the sulphur electrode were clearly visible.

The range of data acquisition equipment covered the whole spectrum, from simple data logging right through to complete computer control of the testing. There was a division of opinion between those involved in data processing and those testing cells and batteries. Several had the unfortunate experience of having their test ruined due to a computer crashing. Several ways were suggested for preventing this sort of occurrence, from extensive use of fuses, to computer "watchdogs" which could shut the test down safely when the computer malfunctioned. The most commonly adopted method appeared to be to leave operation of the cell or battery to a fairly sophisticated charge/discharge unit and use the computer for data collection and analysis. It was significant that in addition to computerized data collection, many people used analogue recorders.

The statistical analysis of cell failure was discussed by Spindler who advocated Weibull analysis. This is a technique which allows the extraction of useful information from the pattern of cell failures. Thus the slope of the Weibull plot gives the shape factor; a low shape factor (<1) indicates infant mortality type of failure; a shape factor of one is equivalent to constant failure rate indicating random failure mechanism; and a shape factor greater than one indicates wear-out failures. A population of cells may show all three types of failure and this results in the familiar bathtub curve as shown in the paper on maintenance-free, sealed lead–acid batteries by Ebert. More usually, lead–acid batteries show a Weibull distribution with a high shape factor, as shown by the examples in Spindler's paper.

5. Conclusions

The intention of the organizers of this workshop was that it should provide a forum for the discussion of battery testing methodology which might then lead to suggestions for unified approaches and definitions. In the event, the emphasis in many papers was on test results rather than on test methodology. This did, however, reveal the wide variety of methods used in battery testing.

It was clear from several papers, that in performance testing there is good correlation between the results obtained in the laboratory and those obtained in the field. In the area of life testing, good correlation can be obtained if the test regime closely resembles the duty cycle. Unfortunately, this means lengthy testing. Accelerated life testing can give useful information, but the absolute values of life obtained must be treated with caution.

6. Recommendations

There should be a second workshop in twelve months' time and this should emphasize test methodology rather than test results. More users should be represented at the next workshop so that a better understanding of the requirements of the various applications can be obtained. Thus, a description of the requirements for various load levelling applications would allow developers to devise test regimes appropriate to that application. Users should also define new applications which conventional batteries might not be able to meet; this would be useful to developers of advanced batteries.

A clear distinction emerged at the workshop between advanced batteries, where testing procedures are primarily a tool of research and development, and conventional batteries where testing is aimed at the requirements of the user. Consideration should be given to holding parallel sessions at the next workshop for the two types of testing. Testing of advanced batteries, although primarily intended for research and development purposes, will clearly be related to potential applications, and it may be necessary to define test regimes for those applications which conventional batteries cannot meet. Thus, an electric vehicle powered by an advanced battery would accelerate faster and have a higher top speed than a lead–acid powered vehicle and the driving profile would be quite different.

An area which is of concern to all is the relationship between bench tests and field performance. The next workshop could usefully explore in some depth the use of accelerated bench tests to predict real life performance. Most of the testing described at this workshop was electrical testing, but batteries are subjected to a variety of environmental factors in actual applications, and it is suggested that at the next workshop a session be devoted to environmental testing. This could cover shock and vibration testing, safety tests, and the effect of emissions on the environment.

BATTERY TESTING WORKSHOP, HEIDELBERG 1985

Question and Answer Sessions

Rand — *Overview of Australian lead–acid battery test programs*
No questions.

Benninger — *Advanced secondary battery development testing, A Canadian perspective*
Q: Do you use a.c. or d.c. motors in your vehicles?
A: We use d.c. motors with chopper controllers.

Voss — *Testing of batteries in Germany*
Q: What are your recommendations regarding depth of discharge?
A: Difficult to say because depth of discharge doesn't remain constant as the active material degrades.
Q: What is the failure mode at lower temperatures and how does it change as a function of temperature?
A: Above 50 °C the negative electrode becomes the determining factor. The negative active material becomes sulphated. Below 50 °C the positive electrode determines cycle life.
Rand Comment: Failure mode also depends on battery design.
Sudworth Q: Do you use a standard test cycle?
A: For lead–acid we usually use DIN cycles.

Sudworth — *Overview of battery testing in the UK*
No questions.

Hiramatsu — *Overview of rechargable battery testing in Japan* (given by Takahashi)
No questions.

Butler — *Overview of rechargable battery testing in the U.S.A.*
No questions.

Courbière — *Requirements for EV Batteries and consequences for test procedures*

Wouk Q: Is it correct that you have no rest period or period of regenerative braking in your test? Does this represent the worst case?

A: This indeed is a worse case than SAE cycle testing. There is a bonus if the type of testing is harder.

Birnbreier Q: What is the ratio of peak power to constant power?

A: It depends on the electric vehicle and battery design. The conclusion is that you have to give the wanted characteristics of the EV to decide how many cells are required and of which size they should be, before you can give an answer.

Hornstra — *Test programs at the National Battery Test Laboratory*

Q: Do all batteries go through the full program?

A: Generally yes, but it depends on who is asking us to do the testing and what the battery is for. For specific requirements we devise specific tests.

Muller Q: Who was the manufacturer of the car you tested and did he allow any regenerative braking in the test program?

A: The ETV-1 was designed and built by GE/Chrysler for U.S. DOE. It used an efficient drive train. A large amount of regenerative braking energy was available. Because of the high charging currents involved, many battery manufacturers at one time discouraged the use of regenerative braking. Our analysis has shown that all the batteries we tested can take the full regenerated current. Dynamic effects in the battery allow it to absorb these currents efficiently.

Muller Q: If you allow regenerative braking on only one axle you must reduce the braking to one third of maximum power. Is this correct?

A: We don't actually test EVs. The batteries will take the current but the vehicle must be safe so that it may be necessary to reduce the available braking effort.

Kunisch — *Utility requirements for battery energy storage and their effects on battery test programs*
No questions.

Pivec — *Application testing of batteries for utility load leveling and customer applications at the BEST facility*

Wouk Q: In the high voltage strings how do you protect against accidental short circuits?

A: The 1.8 MW h battery has d.c. ground detection bars and a d.c. circuit breaker within the converter. Additionally there are fuses in each of the four strings.

The zinc–chlorine battery has no fuses within the battery but fuses in the converter d.c. port. In the event of overcurrent due to a short, the control system stops the pumps to de-energize the battery. Additionally a shorting switch removes residual charge.

d.c. circuit breakers are expensive and a commercial system would probably only use fuses. As a general protection against ground faults, neither the positive nor the negative bus is grounded.

Spindler Q: Is it true that the 1.8 MW h lead–acid battery has only done seventy cycles in six years?

A: It needs to be noted that this particular battery was only purchased as a "facility shakedown battery". As such its cycle life and performance is not important. The test program for load levelling and peak shaving batteries has only been running for eighteen months. It is true that the 1.8 MW h battery was sitting around for a long time before the test program started.

Spindler Q: Are there any operating differences between the parallel strings?

A: We anticipated circulating currents between parallel strings so we installed thyristors gated to deliver energy only to or from the converter but preventing any string discharging into another string. We then tried the system without the thyristors and found only trivial circulating currents. We concluded that the thyristors were not needed.

Winsel — *Measurements with a pilot cell*

Q: Do you relate the temperature of the recombinator to the recombination rate?

A: Yes.

Q: Is it possible to measure the recombination rate in sealed batteries?

A: We haven't done it, but yes.

Q: Are these devices commercially available?

A: I could provide you with some names.

Hardin — *Rationale and methodology for group testing of EV batteries*

Q: What is the cause of the variability?

A: We only have experience on lead–acid batteries and we believe that pasting and construction are the chief causes.

Comment: I think you are correct. It is possible to avoid variability by careful quality control.

Comment: I think that the user is now asking for more arduous and critical requirements. Therefore it is necessary to build better batteries and use them in more controlled ways. We must also ensure that all modules of a battery see the same conditions in service, especially temperature, for lead–acid batteries.

Grimes The user is not prepared to pay for heavy duty batteries. He expects EV performance for S.L.I. price.

Hornstra — *Autonormalization of battery test data to reduce impact of battery ageing on test results*

Q: Your calculations are based on the capacity obtained from a 3 h rate discharge immediately after the test discharge. What about memory effects? Should you not wait many cycles before obtaining the prevailing capacity.

A: Yes, depending on the accuracy required.

Nowak — *A test and data reduction algorithm for the evaluation of lead–acid battery packs*

No questions.

Lundsgaard — *Qualification of lead–acid batteries for traction applications*

No questions.

Butler — *Flowing electrolyte batteries — test methods and results*

Q: Did you investigate the effect of zinc loading on specific energy?

A: No.

Q: What debit have you allowed for auxiliaries. How much do they change battery efficiency?

A: 5 to 10% decrease in energy efficiency on small (1 kW h) batteries. Hornstra is working on a larger battery which will provide better data regarding this issue.

Grimes — *Circulating electrolyte zinc–bromide battery test program and procedures*

Birnbreier Q: What is your cell management system and what performance do you obtain at low temperatures?

A: A coolant is circulated through a heat exchanger in the anolyte and then passed to an external heat exchanger which has a high surface area and is capable of dissipating the heat generated in the battery. We have used an automotive type radiator and fan and found good results.
We have added additives to the electrolyte to improve performance at low temperatures. Exploratory testing has covered a range to −20 °C. Energy efficiency is not appreciably affected by temperature change. Coulombic efficiency increases and voltaic efficiency decreases as the temperature is lowered.

Gross Q: What is the corrosion rate of the plastic and the shelf life of the battery?

A: We have not done much testing on this. Normally most of the bromine complex is held outside the stack. If the battery is stored properly with the bromine complex drained from the stack then shelf life could be long. Only that bromine complex contained within the stack will self discharge and correspondingly reduce capacity.

Q: What effects have you found of cell reversal?

A: Performance improves. We have done up to 17 hours of continuous cell reversal in a test. Two cycles later the battery capacity was back to normal condition prior to the reversal. Reversal seems to act like a purge and rejuvenates the battery.

Mennicke Q: Have you done any vibration and shock testing?

A: Not extensively. What testing we have done shows little effect.

Geilert — *Start up test for Na/S traction batteries*

Q: Does the energy density figure include the case, etc.

A: Yes.

Q: When charging, how do you determine end of charge?

A: The voltage rises.

Q: What is the battery size?

A: 40 cm cross-section and 1.4 m long.

Jones — *Cell and battery test methods* (given by Molyneux)

Q: How many kinds of cell do you have?

A: Four kinds (i) 600 A h for load leveling; (ii) 150 A h old EV cell; (iii) 20 - 30 A h for technology demonstration; (iv) 10 A h P.B. cell eventually for EVs.

Q: What is happening in the first hundred cycles?

A: We believe that some of the reactants are becoming inaccessible — corrosion, absorption, etc. We don't think these are recoverable. Capacity falls to about 89% of original.

Hornstra Q: Have you tried recovery with C.V. charging?

A: Yes, for 3 months at 5 V. Very little was recovered and we don't think the effort is worth it.

Hornstra Q: What would you do in an EV to detect end of discharge? Is the O.C.V. of 1.76 V universal for sodium–sulphur cells?

A: In practice we can monitor the voltage down to the four cell strings. We measure the O.C.V. allowing a tolerance for cell capacity variation. If no O.C.V. is available, *i.e.* continuous load, we would have to calculate end of discharge.

Gross Q: Are there differences between cell types under freeze–thaw conditions?

A: Yes, the small cells are better.

Q: Can you indicate the statistical scatter of the capacity decline.

A: I don't have the figures but of 20 curves, I remember the lowest loss was to 89% and the highest to 74%.

Fischer Q: What is the calculated energy density for the EV battery and what is the thickness of the insulation?

A: Normally 20 mm thick. We use a range of thickness in our batteries from 16 to 25 mm.

The battery figures are 180 W kg^{-1} and 120 W h kg^{-1} at the 3 h discharge rate. The cells at the same rate are 250 W h kg^{-1}.

Sudworth Q: Do you use preforming cycles as BBC do?

A: We do use running-in cycles but we don't use pulse discharge.

Brilmyer — *Performance testing of advanced lead–acid batteries for EVs*

No questions.

Mayer — *BCI cycle life testing procedures for deep cycle lead–acid batteries*

No questions.

Brandt — *Testing methods for lithium–molybdenum disulphide intercalation batteries*

Q: What determines end of life?

A: Determined by the anode. Stripping of plated lithium. We use excess Li and lose approx. 1/2% per cycle.

Eberts — *Quality test of lead accumulators especially of maintenance-free, sealed lead batteries with immobilized electrolyte*

Q: At which cycle in the last curve does the lowest failure rate start?

A: This is a trend curve only but is valid for most batteries. At about two to three cycles.

Hodgson — *Battery data for use in expert systems*

No questions.

GENERAL DISCUSSION

Q: Have you included any value for d.c. ripple?

Mayer A: This is not specified in any procedure. So, no.

Eberts A: Ripple of less than 3% has no influence but, again, this is not part of the official specification.

Q: Do you have an upper voltage limit?

Mayer A: This is subject to controversy but, in practice, yes.

Q: What formation conditions do you use for your large battery?

Brilmyer A: This is a trade secret. Briefly we aim to keep the battery cool during formation even to the extent of standing it in ice. We use a low gravity acid then alternate high and low rate charging with rest periods. I cannot give specific figures.

Q: How would you know in practice if a beta battery was discharged?

Molyneux A: We normally use an intelligent controller.

Sudworth A: In an electric vehicle we use a simple method of monitoring chain currents on a recorder. Any imbalances become immediately obvious. This could be easily automated.

Chreitzberg — *Accelerated life cycle testing in advanced lead–acid cells at elevated temperatures* (given by Hornstra)

Sudworth — *Rapid testing of β-alumina ceramics*

Lehnert — *Accelerated life testing of Na/S cells*
All questions were left to the general discussion.

GENERAL DISCUSSION

Q: With testing batteries at 70 °C and 2 cycles per day what was the water consumption and how much paste shedding occurred? How was maintenance carried out?

Hornstra A: Every five to six weeks the batteries were cooled to 25 °C for maintenance. Shedding was no problem. We did have cell jar problems at 70 °C, hence the temperature reduction to 66 °C. The heaters interacted with the case and fractures occurred.

Q: Why didn't you try more than 2 cycles per day?

Hornstra A: The lead–acid battery is more rate limited. The current density used was within design parameters. Discharge was possible at the one hour rate but really needed a different battery design.

Q: Did you notice different failure modes under fast cycling rather than standard cycling?

Lehnert A: No.

Fischer A: Our experimental cell life improved at high current densities on discharge. Did you observe this?

Sudworth A: Yes.

Kramer — *Data acquisition and control instrumentation of BEWAG battery test facility*

Alber — *Battery monitoring and integrity testing of large lead–acid storage batteries*

Altmejd — *Use of computer networking to achieve testing flexibility*

Kiessling — *Multiple constant power discharge tester*

Dowgiallo — *Innovative on-board instrumentation for EV battery characterization*
All questions deferred to panel discussion.

PANEL DISCUSSION

Q: What method of control do you use for your electrolyte flow system?

Kramer A: An air lift pump.

Hornstra Q: You said you needed an S.G. measuring device. Have you considered Winsel's device?

Kramer A: It is not suitable as the relaxation time is too long (30 - 45 min). We completely discharge in 16 min.

Comment: You could try an ultrasonic device.

Comment: There is a commercial unit available in Austria.

Kramer A: I know this system. It uses resonance determination. The measuring chamber is very small and needs much water flushing. It is very difficult to operate.

Handel Comment: We found problems measuring between adjacent cells. Also temperature problems if the acid is hot.

Kramer A: At very high discharge rates the acid sampled by any instrument is nothing like the acid actually in the cell because diffusion has not taken place.

Comment: You could try impedance or double layer capacitance measurement.

Klein Contribution: Showed an 8 mm sensor for measuring acid between the plates. A pump and density meter made up the liquid flow system. Measurement by acoustic resonance. Flow rate 2 cm^3/10 min.

Q: What pump did you use and what was its life?

Klein A: A standard hospital/chemical lab. peristaltic pump. We have operated continuously for over 18 months with the same pump and density meter. Only the tubes in the pump need replacing every month.

Wouk Q: What is the effect of agitation on lead–acid battery performance? I can predict the range of an E.V. under normal conditions empirically. The range at a constant speed of 50 kmph in real life is about half the theoretical figure. A paper to be given in Sorrento suggests this might be improved to 60 - 65% using agitation.

Sims A: There are dangers in generalization. Tubular batteries may give different results.

Hornstra Comment: A paper to be given tomorrow gives a generalized range prediction.

Sims Q: Did you use measured battery results?

Hornstra A: Yes.

Brilmyer Q: Using your *IR* drop sensor, what happens in a battery with lots of leads very close together?

Kramer A: We have had no problems but there have been some at the BEST facility.

Pivec A: The result is fireworks. You must watch insulation. We have found relative humidity to have a profound influence on data acquisition systems. Very high R.H. (>98%) for a long time can play havoc with instrumentation.

Alber A: Just normal switching in switchyards can induce high transients.

Altmejd Comment: There are many unseen problems with static.

Sims Comment: Our experience of computer reliability is an unhappy one.

Grimes Comment: I agree. Crashes occur frequently and at the most inconvenient time. Everything must be fused.

Sims Comment: We need more failsafe engineering.

Loponen Comment: We have an H.P. 9860 computer and data logger. We have to be very careful to avoid hidden programming errors.

Alber Comment: It is useful to use watchdogs.

Comment: Most faults are power line faults. Optical isolation is preferable.

Dowgiallo Comment: My grey hairs come from putting computers in cars.

Battles — *Post-test analysis of Na/S cells and aqueous batteries*

Q: Did you find a correlation between electrical data and examination results?

Battles A: The sodium–sulphur cells supplied by FACC were provided with limited performance data. None examined showed a resistance rise greater than 15%.

Q: How many cycles had the cells achieved?

Battles A: Three standard Mark II D cells were voluntarily terminated after four cycles. Other cells were operated up to 1600 cycles over two and one-half years. We are now examining one with 2500 cycles over five years.

Q: In how many batteries did you see a coralloidal structure?

Battles A: We examined batteries from two manufacturers: Johnson control and Exide but I have no other details on how many or if all showed a coralloid structure.

Eck — *Design of the thermal management system for Na/S traction batteries by using battery models*

Q: What influence did you find between temperature difference and cell lifetime?

A: Very dependent. Large temperature differences lead to battery imbalance. You need close control.

Q: What was the rate of heat loss when idling?

A: 200 W overall.

Wada — *In-test and post-test analysis of Na/S cells*

Hornstra Q: Figures 4 and 5 show a voltage fluctuation of 2 mV but the expanded one shows 20 mV. Are these consistent?

A: The actual fluctuation is 10 - 100 microvolts but we have an amplifier before the recorder. We have used different ranges for these graphs.

Q: Data shown for crack formation over 9 cycles. Is this slow crack growth rather than rapid propagation? The voltage fluctuation may be due to the acoustic noise of the growing crack affecting the double layer capacitance like a microphone thus producing these voltages.

A: I am not sure.

Lehnert Q: From your measurements, are you seeing sodium leaking into the sulphur compartment or vice versa on failure. This would depend on the pressure difference between the electrodes and the state of charge.

A: We have observed sodium into sulphur. I am not sure however if we can see the difference.

Klein — *The validity of life cycle bench test data in relation to real world in-vehicle testing*

Sims Q: Can you indicate the gravimetric energy density in the M.A.N. bus?

A: No. For the "CitySTROMer" battery it is 32 W h kg^{-1} at the 5 h rate and 24 - 25 W h kg^{-1} at the 1.5 h rate for the battery as an assembly.

Spindler — *Extra paper on zinc–chlorine testing*

No questions.

Dowgiallo — *Examination of battery related EV track and field measurements*

No questions.

Wagner — *Design, EV simulation program and duty cycle for a computer-controlled bench test of lead–acid batteries*

Q: What differences were there between the two vehicles?

A: The estimation was made on the electric van with a 33 kW motor maximum power. For the Golf the motor maximum power was set to 25 kW.

Q: What are the power levels on the last slide?

A: The same number as speed. Mean value 5.8 kW.

Kramer — *A battery storage test facility for load frequency control operation*

Q: What is the float voltage per cell?

A: 2.7 V equalization.

Q: Where does the shedding come from?
A: Some from the positive but most from the negative plates.
Q: I suggest that the deep cycling and only partial daily charging is causing the excessive sedimentation?
A: The effect was previously unknown. The mechanism is not known.
Q: Are there safety devices between the batteries and the busbars?
A: Two fuses for each battery string. d.c. circuit breaker between the converters and the battery.

Spindler — *How handy is Weibull...?*
No questions.

Loponen — *Comparison of laboratory, dynamometer & road test of EV*
No questions.

Hornstra — *A simple methodology for obtaining battery discharge times...*
Q: Are you suggesting we forget testing batteries by cycling and do it all using constant current?
A: I am not advocating eliminating profile testing. We need much basic information on the battery to start with. This method saves time and money on other profile testing since it gives a good estimate of range without actually having to apply the profile.
Q: How do you define peak power?
A: The classical maximum power point of the battery except we use two-thirds of battery voltage, rather than half, and we use a 30 s pulse.
Q: What effect does temperature have on this method?
A: We haven't done any work on this. The method should still be valid.
Q: Have you applied the method to advanced batteries?
A: We are going to apply it to Beta batteries. We have applied it to lead–acid, nickel–zinc and nickel–iron.

Nakamura — *Fundamental studies...*
No questions.

7. Discussion

In opening the panel discussion P. Butler (U.S.A.), the panel chairman, said that he felt that the workshop had provided a forum for people working in different countries, and on different battery systems, in which they could see how other groups tested batteries. It was clear from the papers at the workshop that many different testing regimes were in use and, consequently, there was scope for some standardization. He announced that the next workshop would be held in Chicago in 12 months' time.

D. A. J. Rand (Australia) made a number of suggestions for the next workshop. He thought that the participants in this workshop should be canvassed for their views on the format of the next workshop. He felt that each session should consist of an overview on a controversial subject to stimulate discussion, then the workshop should break up into small groups to discuss specific topics which, he suggested, might include: standardization of terminology, test procedures and charge regime (specifically for lead–acid batteries); identification of the important parameters to be measured in a test; methods for the determination of state of charge; availability of testing equipment. He proposed that a gazeteer of techniques be published and, possibly, a quarterly report devoted to battery testing.

H. J. Kunisch (Germany) thought that a second workshop would be worthwhile, but felt that more users should be represented to provide an opportunity for discussions between researchers and users. He thought that the workshop should encourage discussion to agree test procedures between users and suppliers, and that it would be helpful to split the workshop into two sections. One section should deal with research and development and performance testing, and the other section with testing and test methods for batteries in operation. The next workshop should also discuss the problem of getting up to date information on batteries.

M. Loponen (Finland) suggested that, for lead–acid batteries, charging methods were equally as important as discharge methods. He thought that the next workshop should produce recommendations for charging methods, but warned against standardization on one charge regime.

F. Hornstra (U.S.A.) pointed out that much of the emphasis at this meeting had been on results rather than on test methods and that the next workshop should emphasize testing methodology, which he thought should transcend applications such as electric vehicles and load leveling.

P. Butler (U.S.A.) agreed that the next workshop should focus on methodology of testing.

The discussion was then thrown open to the floor.

A speaker from the floor asked for a journal of battery testing as he felt that most papers published on batteries concentrated on the results and not on the test procedures. He felt that one problem was that there was no common terminology and that the battery users did not know what the battery manufacturers were doing in the area of testing.

F. Gross (Brown Boveri) felt that there were two groups of people at the meeting. One group was advocating testing peak power and average power only while the other group felt it necessary to do detailed tests. The first group consisted of people working with battery systems, and the second group of people developing batteries. One of the things highlighted by this meeting was the lack of contact between developers, users, and producers. Dr Gross also made the point that, although there had been information available on computers and instrumentation, there was also a need for information on sensors.

One participant described how a small group had been established within the ISE to work on fundamental test procedures. They had recently concluded that they needed a greater input of information to establish a framework for test procedures. He thought that the ISE group would like an input from this workshop.

Another speaker disclosed that in Europe the AVERE technical committee was trying to define test procedures. There were two EEC subgroups, 302 for electric cars and vans and 303 for electric buses. There was a need for recommendations on a standard test cycle. F. Hornstra (Argonne National Laboratory) thought that there was no one test that would characterize a battery and there was a need to know the minimum number of tests required to predict battery life and performance.

G. E. Mayer (Mellon Institute) pointed out that vehicles, etc., did not run at constant current, but nevertheless testing done at constant current could still provide useful information. The Battery Council International (BCI) was attempting to establish a starting point for battery testing procedures. The present methods use constant current and there appears to be good correlation between laboratory results and field trials. BCI talks to users and manufacturers to try and make the tests as realistic as possible. There is no BCI test for electric vehicle batteries and they would like to get a world consensus before establishing one. E. Dowgiallo (U.S. Department of Energy) pointed to the need for well-defined, application targeted R&D goals, and the need to look at the whole test picture, *i.e.*, laboratory, dynamometer, track and field testing, with more stress on relatively inexpensive dynamometer testing, which is usually skipped or overlooked. This lack can cause premature fielding of batteries, not fully integrated as refined systems, into vehicles which are generally not instrumented for gathering engineering data.

L. Pearce (U.K. ARE) warned against the danger of standardization being imposed on advanced batteries still under development. He felt that what was really needed was a framework for testing rather than standard tests. W. Spindler (EPRI) hoped that at the next workshop there would be discussion of data reduction methods as well as data acquisition. A. Pivec (PSE & G) pointed out that batteries used in utilities will be subject to licensing, and therefore testing should include environmental effects such as emissions and contaminations. P. Grimes (Exxon) thought there was a need for a bibliography of all documents relevant to battery testing. The criteria for a good test procedure should be that it provides useful information and is the lowest cost way of obtaining that information. He thought that many tests were used simply because other people used them, and are of little value.

G. Lehnert (BBC) asked that quality testing methods should be included in the next workshop, *i.e.*, information should be given on failures. Participants should not just concentrate on the best results. Dr Gross (BBC) proposed that the interface between the battery and the system be given more attention at the next workshop.

A. R. Landgrebe (U.S. Department of Energy) felt that it would be necessary to form subcommittees to define terms used in battery testing and to devise tests for available batteries. Regarding new technologies such as sodium–sulphur, the user was not so much interested in the type of battery but wanted to know if it would meet his application. It would be helpful to battery developers if the users would define new applications.

F. Hornstra in his concluding remarks said that it had been a successful workshop which had shown that there could be good correlation between laboratory and field tests. One of the targets for the next workshop should be to exchange ideas on applications of tests.