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Milan
2024

High Efficiency lead acid battery formation

- *The lead acid battery formation process is highly inefficient. It accounts for approximately 50% of the total energy usage of battery manufacturers*
- *It also has additional costs of scrap and rework*
- *The present inefficiency increases the process time as well as the energy usage*
- *This presentation shows the R&D and field trials carried out by the collaborators. It demonstrates that an understanding of the chemistry can provide a more efficient process that will save LAB manufacturers hundreds of thousands of USD/annum.*

A report on behalf of:

- UK Powertech Ltd
- Digatron Industrie-Elektronik GmbH
- Energy Storage Publishing Ltd
- Ecotech Energy Solutions Ltd

The personnel and participating companies

- Mark Rigby – UK Powertech, Managing director and electrical connector engineer

- Dr Mike McDonagh – Ecotech Energy Solutions and Energy Storage Publishing,
  Battery consultant and Bestmag technical editor

- Kevin Campbell – Digatron power electronics, Global Strategy and electronics engineer

* Combined experience of over100 years in the battery industry. *

Summary of 6 years R&D and field trials.

- UK Powertech, Digatron and ESPL have carried out 6 years of R&D, and engaged in field trials with 5 international battery manufacturers
- **The first stage of the project was to remove the inefficiency of high resistance formation connections**. This work led to a new connector design, formation rectifier cable modifications, and new maintenance procedures. All of which, drastically reduces process costs
- **This measure alone gave manufacturers a minimum annual saving of between a ½ and almost 1 million USD in formation energy and scrap costs**
- The current project examines the fundamental processes that convert the unformed plate active material into the charged PAM and NAM of the lead acid battery.
- **A new charging methodology is proposed based on laboratory results and collaboration with LAB manufacturers**

Connector formation trials 24 hr process using a 74 Ah 12 volt battery

Results from formation tests for new and used connectors using the Digatron test unit

Connector	Circuit	Connection Resistance (m-ohm)	Phase 1 Wh Input	Phase 2 Ah input	Phase 3 Ah input	Temp rise ^0C	Total Ah input
Used 1	2	390	610	8.07	5.27	19.2	66.91
Used 2	3	300	643	8.95	6.05	18.4	69.58
New 1	2	<1	579	8.55	6.01	19.7	70.08
New 2	3	<1	586	11.11	7.89	19.8	77.07

Voltage rises to set value of 16.5 V

Formation energy losses from used connectors compared with using new connectors

Circuit	% Difference Phase 1 Wh	% Difference Phase 2 Ah	% Difference Phase 3 Ah	Total Ah Difference	%Total Ah Difference
2	5.2	5.95	12	3.17	4.73
3	9.5	24	22	7.49	10.57

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Results of field connector trials

All costs are in USD normalised to 5 million batteries per annum

Formation input is 5 times the Ah capacity (75 Ah), charging voltage is an average of 17.5V/battery

Average manufacturing cost per battery is 21 USD

Energy cost is 0.18 USD/kWh

5% saving = 17.5 x 75 x 5 x 5,000,000 x 0.05 x 0.18 = 295,313 USD

Factory	Energy saving	Incidence of arcing damage	Scrap saving from arcing	Rework saving from arcing	Confirmed cost saving	Potential total cost savings Incl. energy
F1	281,250	None	405,000	250,000	281,250(energy)	**935,250**
F2	180,984(3.25%)	None	405,000	250,000	180,984(energy)	**835,984**
F3	Not monitored	None	270,000	275,000	545,000(arcing)	**840,313**
F4	Not monitored	4 in 180	396,000	244,500	508,500(arcing)	**803,813**
F5	Not monitored	2 in 180	400,545	247,250	514,280(arcing)	**809,593**

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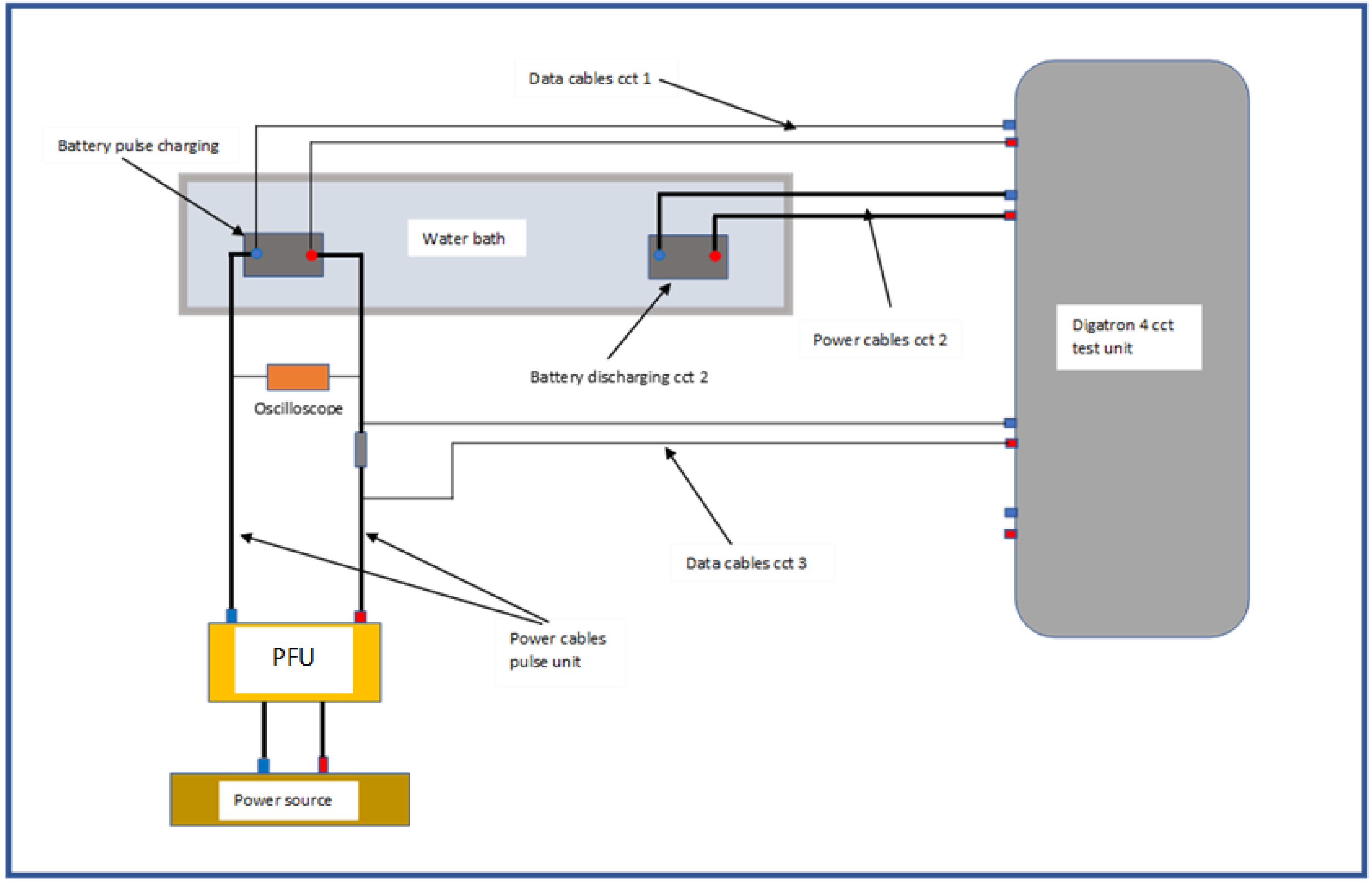
Schematic layout of test equipment including the prototype formation unit (PFU) and the Digatron test unit



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A 105 Ah 12V LAB standard formation programme supplied by a participating battery manufacturer

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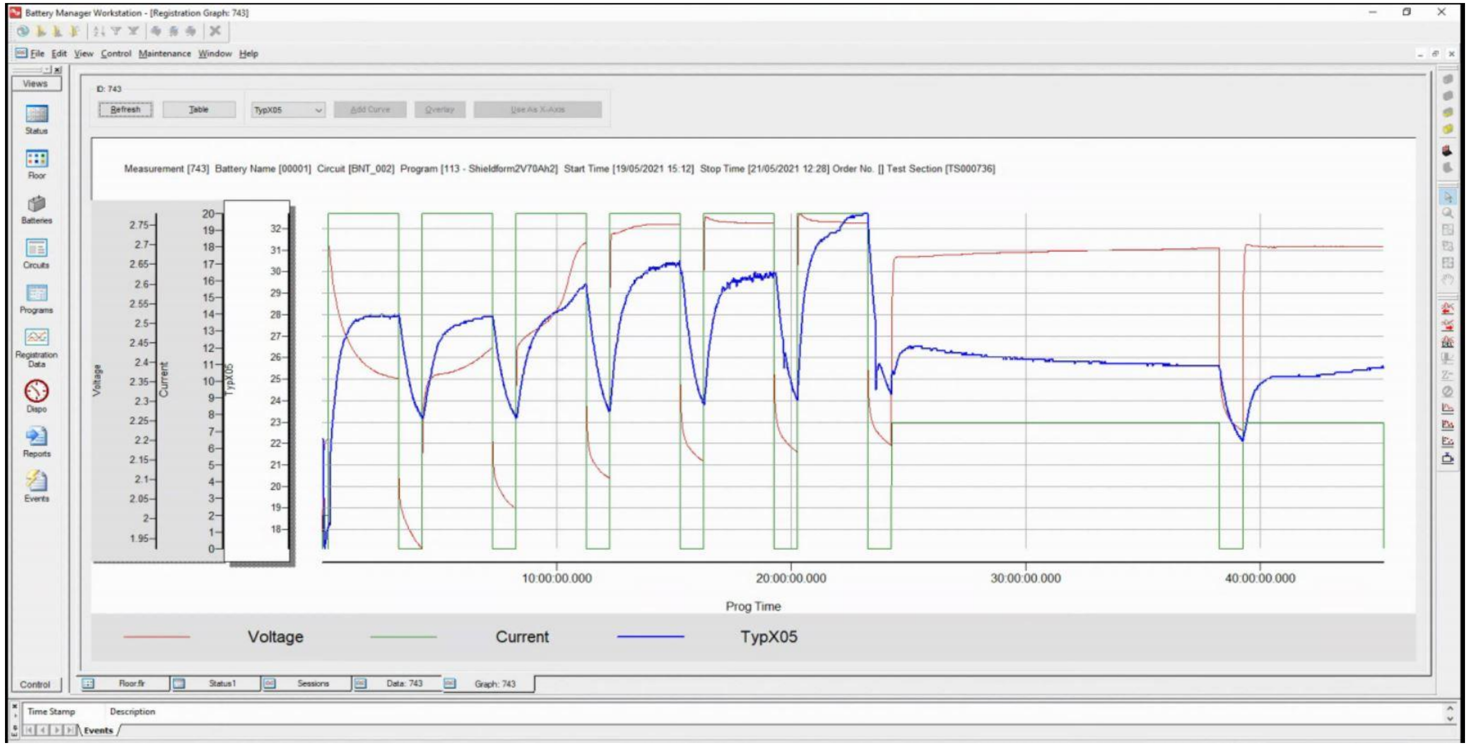
The total formation time, results from a series of CC charge periods and pauses. The pauses and current amplitudes are based on practical experience for controlling the temperature and voltage responses during the programme.

Typical fast charging profile for a low capacity, SLI battery, modified for the Digatron Test Unit



High Efficiency lead acid battery formation

Purpose of battery formation

First time the active materials are formed into the positive and negative plates.

Very low efficiency around 4 - 7 times the Ah capacity is required to completely convert the green active mass into the formed active mass.

The formation reactions can be simplified to:

Positive: $PbSO_4 + H_2O = PbO_2, + H_2SO_4 + 2e^- + 2H^+$

Negative: $PbSO_4 + 2e^- + 2H^+ = Pb + H_2SO_4$

The general overall reaction:

$$2\,PbSO_4 + 2\,H_2O = PbO_2 + Pb + H_2SO_4 \quad \text{(reversible)}$$

It is important to note that sulphuric acid is a by-product which increases in concentration as the formation reaction proceeds.

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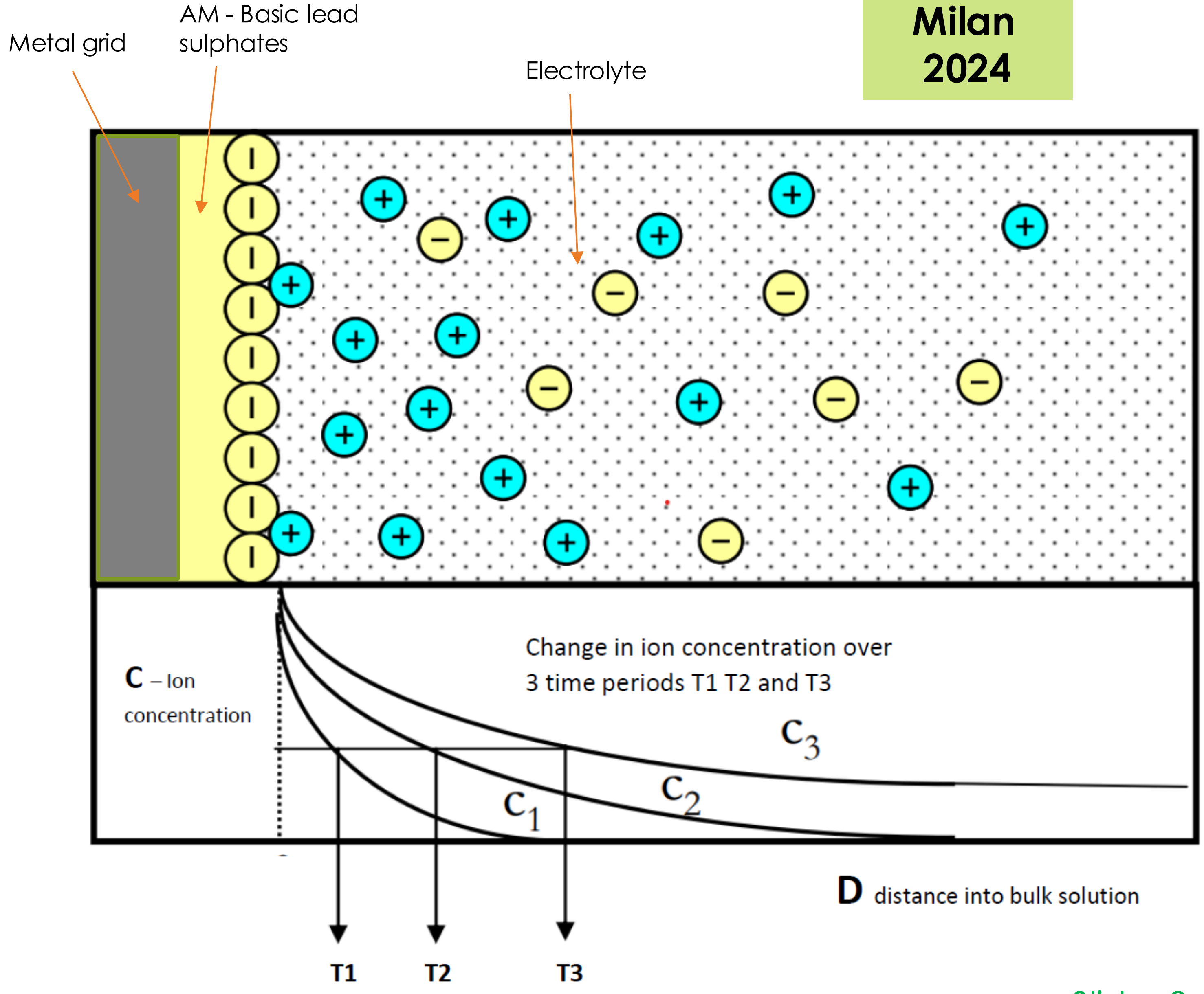
Ion polarisation on battery electrode.

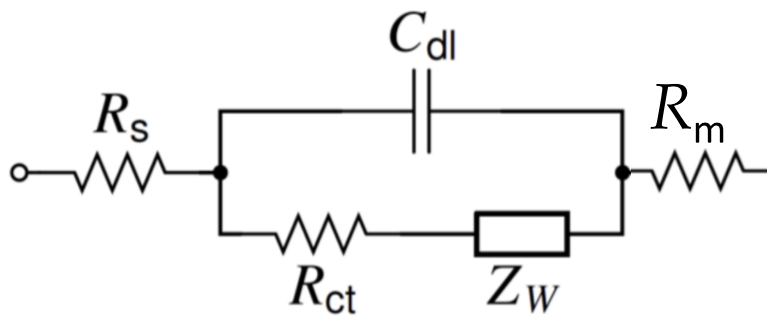
As formation progresses the concentration of sulphate ions in the electrolyte increases.

This raises the total voltage of the electrolytic cell and increases the energy required for the conversion of $PbSO_4$ to Pb and PbO



Origin of battery resistance and composition of on-charge voltage

- The resistance of the circuit is comprised of metallic and reactive components.



Total resistance = $R_s + R_{ct} + Z_w + C_{dl} + R_m + Z_W$ (Warburg element) = $A_W/(j\omega)^{0.5}$

R_s is the electrolyte resistance

R_m is the resistance of the metallic components

C_{dl} is the double-layer capacitance at the electrode/electrolyte interface

R_{ct} is the faradaic (charge transfer) resistance at the electrode/electrolyte interface, and

Z_w is the Warburg impedance

When an AC signal $I = I_0 \sin(\omega t)$ is applied to the cell under study, the response is given by $V = V_0 \sin(\omega t - \varphi)$, where I_0 and V_0 are signal amplitude, $\omega = 2\pi f$ (f is frequency, Hz), and ϕ is the phase angle.

- Voltage = current x resistance, $V = I \times (R_s + R_{ct} + Z_w + R_m + C_{dl})$
- The relative contribution of each of these components to the battery voltage will change with time during the formation process. The metallic components will alter very little but the reactive elements of Cdl and Zw are related to the electrolyte density and the ion concentration at the double layer/plate interface on charge

Parasitic reactions that reduce the AM conversion efficiency

positive electrode: $H_2O \longrightarrow \frac{1}{2} O_2 (g) + 2 H^+ + 2 e^-$ V > 2.4 V/cell

negative electrode: $2H^+ + 2 e^- \longrightarrow H2(g)$ V > 2.4 V/cell

Overall cell: $H_2O \longrightarrow \frac{1}{2} O_2 (g) + H_2(g)$

Heat $= I^2R$

Battery manufacturers' formation priorities :

1. Maximise throughput
2. Control battery temperature by cooling or recirculating electrolyte to reduce damage
3. Put in thicker cable to offset the higher charging currents

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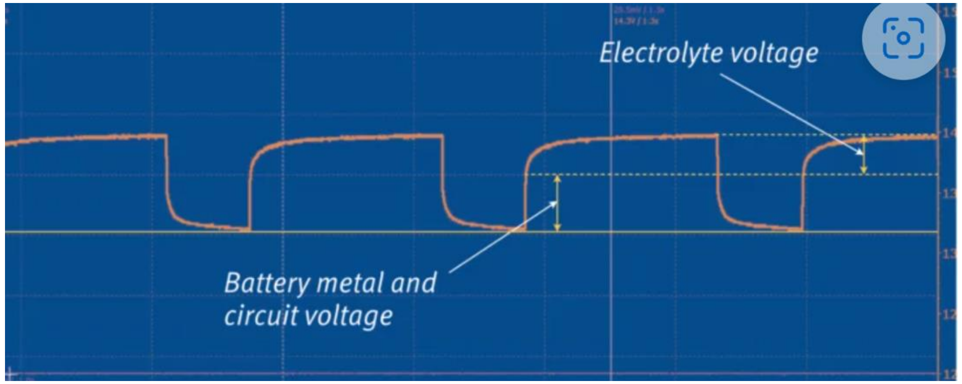
Increase in resistance of a battery indicates electrolyte based reactions

Battery voltage response to a single constant current pulse at different stages into the formation process

The contribution of the different components of the Randle model to the total voltage is clearly shown in these two measurements

30 mins into programme (700ms on 300ms off)



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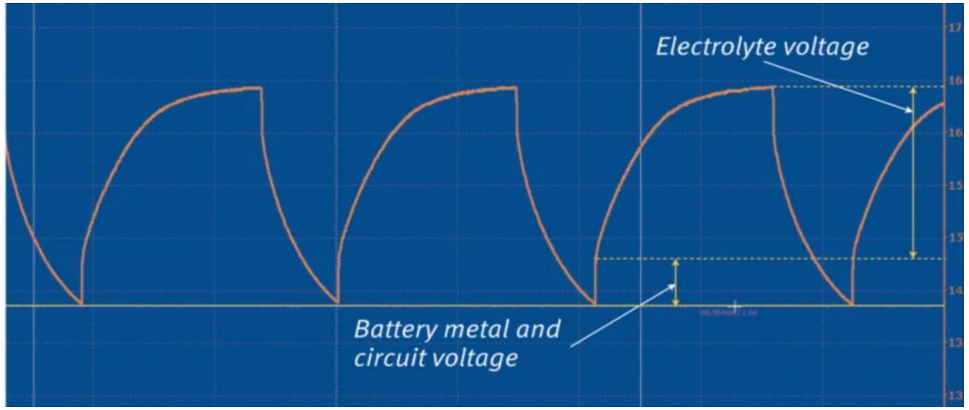
3 hours into programme (700ms on 300ms off)



High Efficiency lead acid battery formation

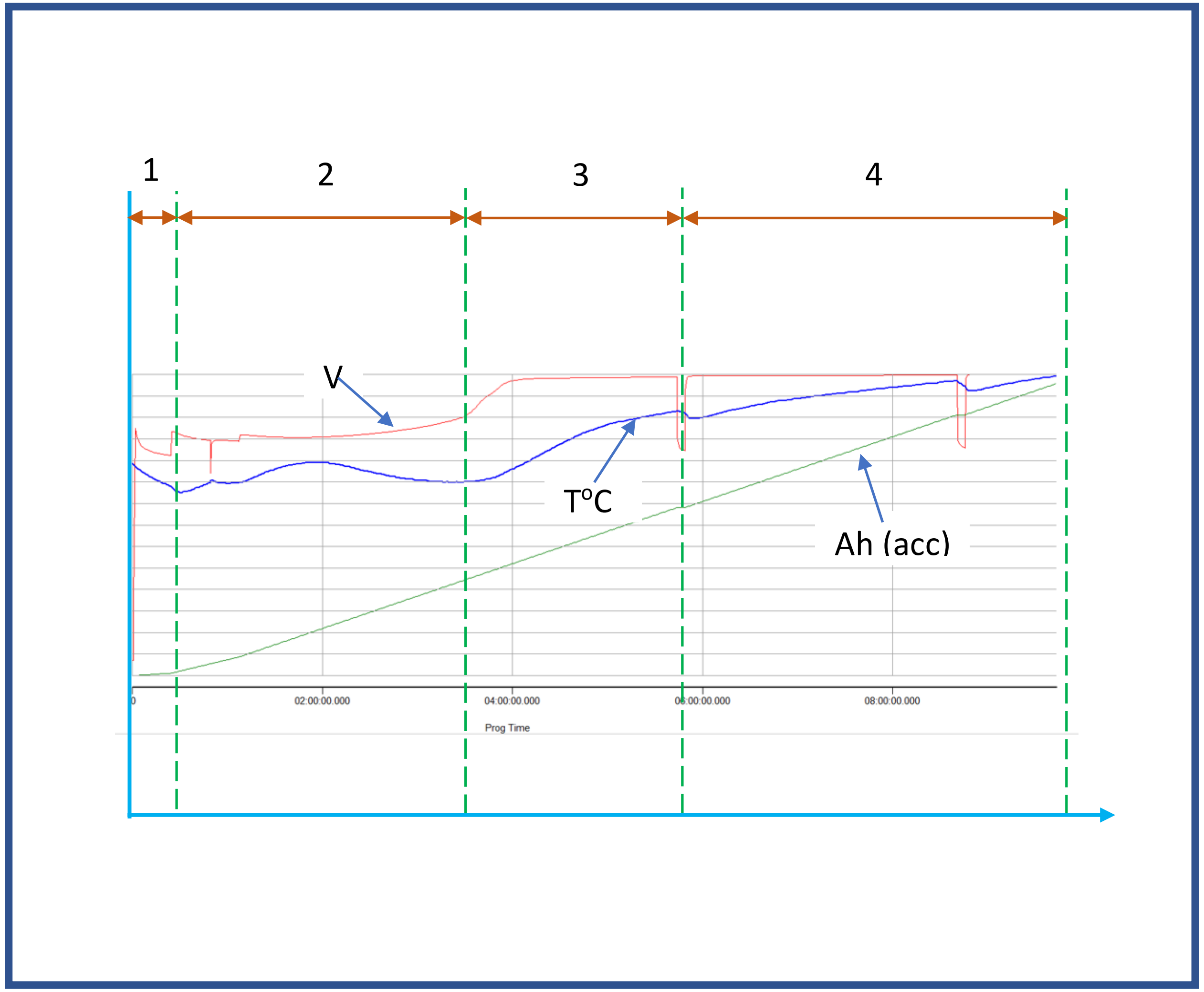
This is a reproduction of a standard programme divided into 4 simplified sections

1. This is the initial phase where the AM/grid interface is formed and the battery resistance drops

2. Is the 2nd phase marking the onset of the conversion of lead sulphates into the formed AM of both plates

3. This third phase is the increasing SG of the electrolyte

4. The last phase is the final conversion of the remaining sulphate with an increasing contribution from parasitic reactions



Efficient version of standard formation programme

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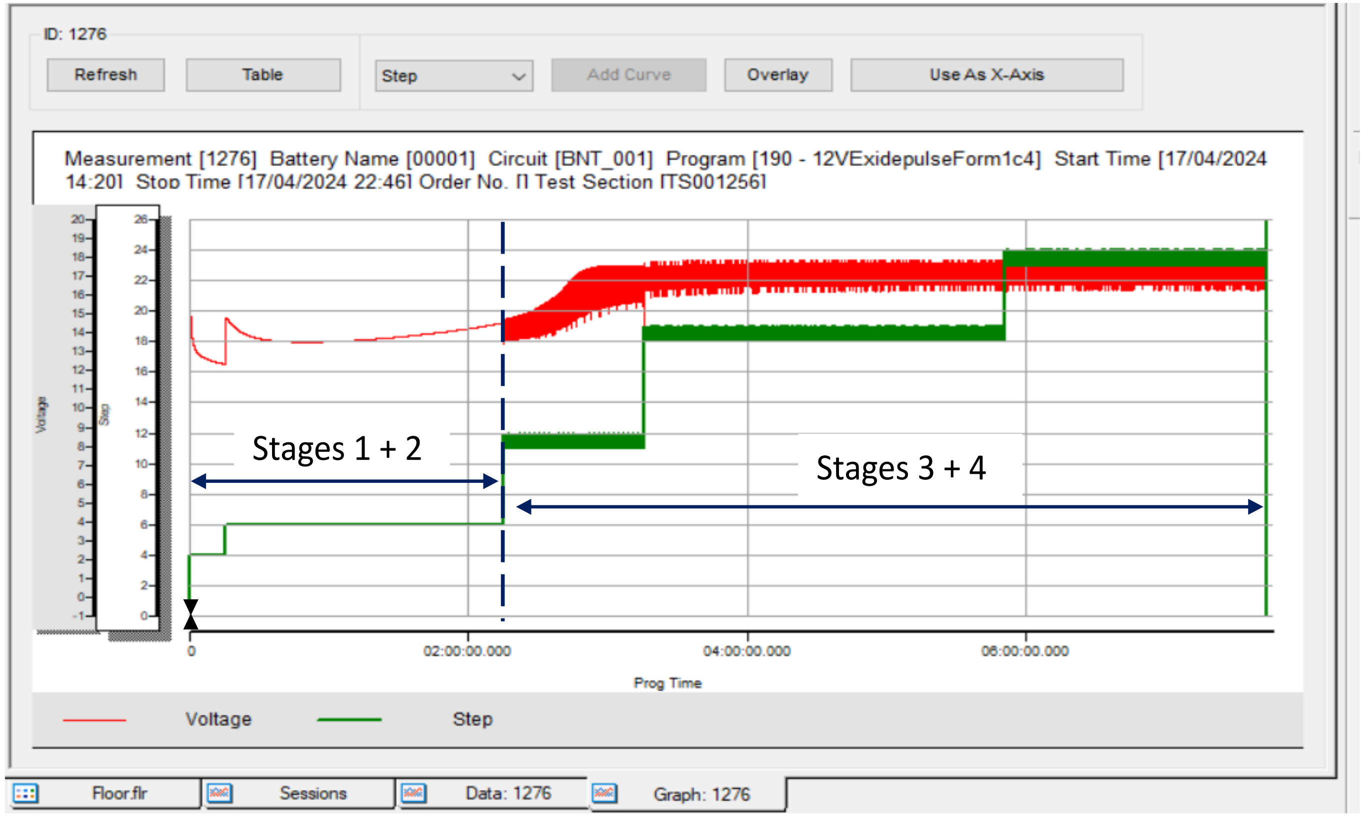
Digatron recording of the result from one of the improved efficiency programmes

This programme uses the information from the standard method to minimise the temperature rises and maximise the current input

The same formation process stages are being followed but the efficiency of the current input is improved

TypX09 is the temperature channel



Efficient version of standard formation programme

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Battery number	Formation schedule	Acc Wh	Acc Wh % standard	Acc Ah	Acc Ah %standard	Total process time (mins)	Total process time % standard	Discharge test results	Discharge Ah	Discharge Ah %standard
1	Standard	4071	100.00	251	100.00	638	100.00	5h:35m	62.5	100.00
2	Efficient 1a	4158	102.14	251	100.00	589	92.32	5h:31m	61.8	98.88
3	Aborted	Aborted	Aborted	Aborted	Aborted	Aborted	Aborted	Aborted	Aborted	Aborted
4	Efficient 1b1	3302	81.11	204	81.27	505	79.15	5h:07m	57.4	91.84
5	Efficient 1b2	3261	80.10	205	81.67	505	79.15	5h:15m	58.8	94.08
6	Efficient 1c	3403	83.59	212	84.46	494	77.43	5h:25m	60.7	97.12
7	**Efficient 1c4**	**3373**	**82.85**	**211**	**84.06**	**463**	**72.57**	**5h:28m**	**61.33**	**98.13**

Efficient version of standard formation programme

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Battery number	Formation schedule	Acc Wh	Acc Wh % standard	Total process time	Total process time % standard	Annual energy cost saving (USD)* per 5M batteries**	% productivity increase
1	Standard	4071	100.00	638	100.00	0.00	0.00
2	Efficient 1a	4158	102.14	589	92.32	-78,300	7.68
3	Aborted	Aborted		Aborted		Aborted	
4	Efficient 1b1	3302	81.11	505	79.15	692,100	20.85
5	Efficient 1b2	3261	80.10	505	79.15	729,000	20.85
6	Efficient 1c	3403	83.59	494	77.43	601,200	22.57
7	Efficient 1c4	3373	82.85	463	72.57	628,200	27.43

= Low capacity

Contact details

If you would like to discuss how your formation costs can be reduced, or if you wish to participate in field trials, please contact:

Mark Rigby or

Mike McDonagh or

visit the UK Powertech stand at this conference

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