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Lead Engineer - Battery Electric Vehicle Energy & Performance
SAE J1634 Draft Leader – SMCT Cycle & DC Discharge Procedure
AGENDA

• Benefits of Shorter Test Method For Determination of Range in the Future

• Introduction to This Shorter Test Method for “Long Range” PEVs

• Comparison of Results from Shorter Test Method and WLTP-STP @ -7°C Ambient
  • Electric Range and Useable Battery Energy (UBE)
  • With and Without Pre-Conditioning

• Comparison of Results from Shorter Test Method and WLTP-STP @ 25°C Ambient
  • Electric Range and Useable Battery Energy (UBE)

• % PER Reduction @ -7°C: Comparison of Methods

• Useable Battery Energy (UBE): Comparison of Methods
Why Shorten BEV Testing in the Future for WLTP?

• WLTP-STP first introduced to reduce test time of PEVs (compare to consecutive cycle method)

• BUT:
  • Electric range of PEVs will increase with time
  • Resulting testing time using WLTP-STP will increase significantly with increasing electric range

• Shortened Method in Content of Low Temp:
  • Can be independently applied to Low Temp (at the moment)
  • In future, can be applied in combination with 23°C temperature condition
    • Would allow for identical setup between -7°C and 23°C temperature conditions

• To Avoid Method Equivalency, Implementation of Shorter Method With Threshold Concept:
  • Similar to WLTP-CCP and WLTP-STP thresholds to determine test type to run
  • Based on range of vehicle:
    • Low Range Vehicle → Medium Range Vehicle (Threshold 1): CCP to STP
    • Medium Range Vehicle → Long Range Vehicle (Threshold 2): STP to Shortened Method (NEW)

• If there is a WLTP Phase 3 → Discuss Shortened Method for both -7°C and 23°C conditions
-7°C Ambient: WLTP-STP With Pre-Conditioning

**WLTP STP: With Battery/Cabin Pre-Condition Prior to Test**

<table>
<thead>
<tr>
<th>Complete Battery Discharging</th>
<th>Soaking, Charging Battery, (Batt Temp Forced to -7°C)</th>
<th>Cabin &amp; Battery Pre-Condition</th>
<th>Drive Schedule (Phase Efficiency, UBE Determination)</th>
</tr>
</thead>
</table>

**Procedure**

- **-7°C** C Start Battery Temp?
- Discharge
- Charge/Soaking
- Duration: min [9h] or fully charged
- Batt/Cabin Pre-Conditioning (If Requested)

**Measurements**

- E_{AC \#1} \cdot -7°C C & t_{\#1} -7°C C*
- E_{AC \#2} \cdot -7°C C & t_{\#2} -7°C C*
- E_{DC \cdot 1\cdot -7°C C}
- E_{DC \cdot 2\cdot -7°C C}

**Pre-Condition:** E_{AC \ FINAL} = E_{AC \ #1} + E_{AC \ #2}

**Move charge measurement equipment from soak to dyno cell**

**Tests**

- Segment 1
- Segment 2
- CSC_{\text{max}} @100 km/h
- UBE_{-7°C} C* C
-7°C Ambient: WLTP Short Test – Detail View

WLTP Short Test with 6-Phase Only: With or Without Battery/Cabin Pre-Condition Prior to Test (Short Dyno Test)

- Discharge
  - Duration: min [9h] or fully charged
  - Batt/Cabin Precondition
    - Move to Dyno, Re-connect AC Monitor
    - If Battery Temp > XX°C, Carry Over 23°C UBE*

- Charge to 100%
  - AC kWh
  - DC kWh

- Test
  - No Soaks
  - Skip for Carry Over UBE, Otherwise Finish UBE Measurement With DC Cycler Within 1 Hr.

- Bench Disch**
  - UBE2 -7°C
  - UBE FINAL = UBE1 + UBE2

*Optional: Carry over UBE is recorded from WLTP-STP TA test at 23°C (assuming battery discharge window matches between -7°C and 23°C)

**Leverage DC cycler as alternative to record -7°C UBE to save dynamometer time
### -7°C WLTP Comparison

#### -7°C Ambient: Comparison of Long vs. Short Test Results - Chevrolet Bolt

<table>
<thead>
<tr>
<th>% Difference</th>
<th>No Battery or Cabin Pre-Conditioning Short Test vs. WLTP STP</th>
<th>With Battery + Cabin Pre-Conditioning Short Test vs. WLTP STP</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Diff Electric Consumption [DC kWh / 100 km]</td>
<td>0.2% Less Consumption on Short Method</td>
<td>0.8% More Consumption on Short Method</td>
</tr>
<tr>
<td>% Diff PER [km] Initial Target: &lt; 1% Absolute</td>
<td>0.3% Less Range on Short Method</td>
<td>1.1% Less Range on Short Method</td>
</tr>
<tr>
<td>% Diff - Time on Dyno [Hour] Target: ~50%</td>
<td>60% Less Time on Short Method</td>
<td>40% - 60% Less Time on Short Method</td>
</tr>
<tr>
<td>% Diff - Useable Energy [kWh] Initial Target: &lt; 1% Absolute DC Cycler Rate: ~9 kW</td>
<td>0.51% Less UBE on Short Method</td>
<td>0.37% Less UBE on Short Method</td>
</tr>
</tbody>
</table>

- No pre-conditioning: Short Test is able to meet < 1% PER criteria vs. WLTP-STP using a shorter drive cycle/DC cycler
- With pre-conditioning: Short Test is slightly over 1% PER criteria
  - Not due to UBE measurement which is below 1% criteria
- With better insulated battery, < 1% PER criteria could be achieved with the pre-conditioning method
Baseline (WLTP-STP) – Long Test:

- Duration: Fully charged
- Temperature: 23°C

Shortened WLTP 2x 6-Phase Test (1.6 hr. dyno test) + DC Cycler:

- Charge to 100%
- No Soaks
- Discharge Rate: WLTP-STP (25°C)

Measurements:

- $E_{DC,1,23°C}$
- $E_{DC,2,23°C}$
- $E_{AC,23°C}$
- $t_{23°C}$

Final Calculations:

- $E_{AC\_{FINAL}} = E_{AC\_1}$
- $UBE_{\_FINAL} = UBE_{1} + UBE_{2}$
## 25°C Ambient: Comparison of Long vs. Short Test Results - Chevrolet Bolt

### 25°C WLTP Comparison

<table>
<thead>
<tr>
<th></th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x 6-Phase Only + DC Cycler (Short Test) vs. WLTP-STP (Standard Test)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metric</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Diff Electric Consumption [DC kWh / 100 km]</td>
<td>0.9% Less DC Energy Consumption Using Shortened Method</td>
</tr>
<tr>
<td>% Diff PER [km]</td>
<td>0.3% Improved Range Using Shortened Method</td>
</tr>
<tr>
<td>Initial Target: &lt; 1% Absolute</td>
<td></td>
</tr>
<tr>
<td>% Diff - Time on Dyno [Hour]</td>
<td>68.6% Shorter Test Duration Using Shortened Method</td>
</tr>
<tr>
<td>Target: ~-50%</td>
<td></td>
</tr>
<tr>
<td>% Diff - Average Discharge Rate During Test [kW]</td>
<td>0 (Rate 12.5 kW)</td>
</tr>
<tr>
<td>% Diff - Useable Energy [kWh]</td>
<td>0.68% Less UBE Using Shortened Method</td>
</tr>
<tr>
<td>DC Cycler Rate: WLTP-STP</td>
<td></td>
</tr>
<tr>
<td>Initial Target: &lt; 1% Absolute</td>
<td></td>
</tr>
</tbody>
</table>

- Shorter Test Method is able to meet < 1% PER criteria vs. WLTP-STP using a shorter drive cycle/DC cycler
- DC cycler is capable of meeting < 1% UBE delta to WLTP-STP test
## Chevrolet Bolt WLTP PEV Test Summary

% PER Reduction @ -7°C

<table>
<thead>
<tr>
<th>PER Range Reduction</th>
<th>STP</th>
<th>Short Test (NEW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without Pre-Condition</td>
<td>With Pre-Condition</td>
</tr>
<tr>
<td>% PER has reduced at -7°C Compared to 25°C</td>
<td>41%</td>
<td>37%</td>
</tr>
</tbody>
</table>

**Result:**
- No Pre-Condition: Equivalent range reduction WLTP-STP compared to Shortened Method
- With Pre-Condition: Within 1% range reduction WLTP-STP compared to Shortened Method
- 40 – 60% less time on dyno to achieve results with short test @ -7°C
- 70% less time on dyno to achieve results with short test @ 25°C
### Chevrolet Bolt – Carry Over UBE 25°C vs. -7°C

<table>
<thead>
<tr>
<th></th>
<th>WLTP-STP Method (UBE kWh)</th>
<th>Short Cycle + DC Cycler Method (UBE kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25°C UBE</td>
<td>Baseline For This Column, WLTP-STP Discharge Rate (12.5 kW)</td>
<td>Baseline For This Column, WLTP-STP Discharge Rate (12.5 kW)</td>
</tr>
<tr>
<td>-7°C UBE</td>
<td>2.8% Loss in UBE</td>
<td>2.8% Loss in UBE</td>
</tr>
<tr>
<td>With Pre-Conditioned Battery</td>
<td></td>
<td>WLTP Short Test Discharge Rate, 8.8 kW</td>
</tr>
<tr>
<td>-7°C UBE</td>
<td>6.7% Loss in UBE</td>
<td>6.6% Loss in UBE</td>
</tr>
<tr>
<td>Without Pre-Conditioned Battery</td>
<td></td>
<td>WLTP Short Test Discharge Rate, 8.8 kW</td>
</tr>
</tbody>
</table>

- **Meets** 5% UBE rule from SAE J1634 draft for pre-conditioned battery at or below 20°C.
- **Did Not Meet** 5% UBE rule from SAE J1634 draft for non pre-conditioned battery at -7°C

- DC Cycler methods show that a full discharge is not needed to achieve final UBE @ -7°C, can piece together from WLTP DC energy and remaining from DC cycler, which saves test time.
BACKUP
Vehicle: Chevrolet Bolt EV

- Facility: Milford Proving Grounds Emissions Lab (Milford, MI)
- Engineering development vehicle
- Instrumented Controllers
  - Allow more data capture
  - Pre-conditioning programming via calibration change
- Add: 7.4 kW Mobile Vehicle Charger & Energy Measurement Station
  - 25°C tests
- Add: ABC 150 or ABC 170 can be used for discharging HV battery to measure Useable Battery Energy (UBE)*
  - Many different publicly available brands to choose from
- 4.4 kW Mobile Vehicle Charger & Energy Measurement Station
  - for vehicle charging and dyno pre-conditioning (-7°C tests only)

*GM does not endorse a specific hardware set for this procedure
### -7°C Ambient: WLTP-STP vs. WLTP Short – Chevrolet Bolt Comparison

<table>
<thead>
<tr>
<th></th>
<th>WLTP-STP</th>
<th>WLTP Short + DC Cycler (No Steady State)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dynamometer Test Duration</strong></td>
<td>3.9 hr.</td>
<td>1.6 - 2.4 hr.</td>
</tr>
<tr>
<td><strong>Energy Measurement Equipment</strong></td>
<td>DC Monitor (Driving) AC Monitor (Charging)</td>
<td>DC Monitor (Driving) DC Cycler (Discharging)* AC Monitor (Charging)</td>
</tr>
<tr>
<td><strong>Pre-Conditioning Equipment</strong></td>
<td>AC Monitor (Charging)</td>
<td>AC Monitor (Charging)</td>
</tr>
</tbody>
</table>

*Approximate payoff period with dyno session cost savings: 2-4 months

<table>
<thead>
<tr>
<th></th>
<th>No Pre-Conditioning</th>
<th>Pre-Conditioning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HV Battery Temperature During Soak</strong></td>
<td>~1°C per hour loss</td>
<td>Stable</td>
</tr>
<tr>
<td><strong>Start of Test HV Battery Temperature</strong></td>
<td>Variable</td>
<td>Stable</td>
</tr>
<tr>
<td><strong>Range Test Repeatability With Variable Soak Time</strong></td>
<td><strong>Up to 4% Variation</strong></td>
<td>Less Than 1% Variation</td>
</tr>
</tbody>
</table>