Battery Performance in Sub-Zero Conditions Report

Polar Dynamics Robotics, Inc.

Technical Report TR-2023-114

December 15, 2023

1. Executive Summary

This report documents comprehensive testing and analysis of the PDR-8000 Series lithium iron phosphate (LiFePO4) battery systems deployed in Polar Dynamics Robotics' autonomous mobile robots (AMRs) operating in sub-zero environments. Testing was conducted between September 2023 and December 2023 at our Milwaukee Technical Center under controlled conditions ranging from 0 C to -40 C.

2. Test Methodology

2.1 Testing Environment

- Primary testing chamber: Thermotron SM-32-15000 Environmental Chamber
- Secondary validation: Tenney T30C-2 Walk-In Environmental Room
- Temperature monitoring: Fluke 1523 Reference Thermometer (calibrated 08/2023)
- Humidity control: 15% 2% relative humidity

2.2 Test Battery Specifications

- Model: PDR-8000-CR Series (Cold-Rated)
- Chemistry: LiFePO4 with proprietary electrolyte formulation
- Nominal capacity: 280Ah
- Nominal voltage: 51.2V
- BMS: PDR ColdSense(TM) v4.2
- Quantity tested: 12 production units

3. Performance Results

3.1 Capacity Retention

Temperature | Capacity Retention | Cycle Count

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0 C | 97.2% | 500

-10 C | 92.8% | 500

-20 C | 88.5% | 500

-30 C | 82.3% | 500

-40 C | 75.1% | 500

3.2 Discharge Performance

- Sustained discharge rate at -30 C: 0.5C (140A)
- Peak discharge capability at -30 C: 1C (280A) for 30 seconds
- Voltage sag under peak load: 12% maximum
- Recovery time to nominal voltage: <45 seconds

4. Thermal Management System Analysis

4.1 Heating System Performance

- Preconditioning time from -40 C to optimal operating temperature: 22 minutes
- Power consumption during preconditioning: 780W peak, 420W average
- Temperature differential across cell array: 3.2 C maximum
- Thermal runaway prevention validation: Passed UL 2580 requirements

4.2 Insulation Efficiency

- Heat retention coefficient: 0.92
- Passive thermal protection duration: 4.8 hours at -30 C
- Thermal imaging analysis: No significant cold spots detected
- Condensation control: No internal moisture accumulation observed

5. Safety and Compliance

5.1 Safety Testing Results

- Short circuit protection: Validated at all test temperatures
- Overcharge protection: Functional to -40 C
- Cell balancing: Maintained within 0.01V at all temperatures
- Emergency shutdown: Functional within 50ms at all temperatures

5.2 Compliance Verification

- UN 38.3 Transportation Testing: Passed
- IEC 62133-2:2017: Compliant
- UL 2580: Certified
- IP67 Rating: Validated at all test temperatures

6. Operational Recommendations

6.1 Operating Parameters

- Recommended operating temperature range: -35 C to +45 C
- Maximum continuous discharge rate: 0.5C below -20 C
- Minimum preconditioning time: 25 minutes
- Maximum storage duration at -40 C: 72 hours

6.2 Maintenance Requirements

- Monthly cell balancing recommended
- Quarterly thermal system inspection
- Semi-annual BMS firmware validation
- Annual full capacity testing

7. Conclusions and Certifications

The PDR-8000 Series battery system demonstrates industry-leading performance in sub-zero conditions, maintaining operational capability to -40 C with appropriate preconditioning. The system meets or exceeds all relevant safety standards and operational requirements for cold-chain logistics applications.

8. Authentication

This report represents the findings of Polar Dynamics Robotics' Engineering Division and has been verified by our Quality Assurance Department.

Prepared by:

Dr. Marcus Chen

Chief Technology Officer

Polar Dynamics Robotics, Inc.

Reviewed by:

Katherine Wells

Chief Financial Officer

Polar Dynamics Robotics, Inc.

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