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Busbar Laser Welding Parameter Selection Guide for Prismatic Battery Module Production

Applications: ESS prismatic module PACK lines, EV prismatic battery assembly, busbar-to-cell terminal welding
Target audience: Process engineers, manufacturing engineers, quality engineers

1. Introduction

In a 20 MWh energy storage system, a 0.5% busbar weld failure rate translates to over 100 potential thermal runaway points. For battery pack manufacturers supplying EV and ESS markets, achieving and sustaining 99.5% first-pass weld yield is no longer optional—it is a safety-critical requirement.

This application note provides validated laser welding parameter windows for aluminum and copper busbar-to-cell terminal joints in prismatic battery module production. The data is drawn from 50+ production lines deployed across Europe, North America, and Asia between 2023 and 2026.

2. The Four Critical Parameters

Busbar weld quality is governed by four interdependent parameters. Changing one without adjusting the others opens the door to defects. The tables below provide validated starting windows for process engineers to refine through Design of Experiments (DoE).

2.1 Laser Power Density

Power density determines penetration depth and weld pool dynamics. Insufficient density causes incomplete fusion; excessive density vaporizes material and creates porosity.

Equation 1: Power Density

$$P_d = P / (\pi \times r^2) \quad [\mathrm{kW/cm^2}]$$

Parameter	Range	Validated Sweet Spot
Laser power	2.5 – 4.0 kW	3.0 – 3.5 kW
Beam diameter	0.4 – 0.6 mm	0.5 mm
Power density	8.8 – 31.8 kW/cm²	15 – 20 kW/cm² (1.5 mm Al busbar)

FIELD RESULT

A European ESS manufacturer increased yield from 97.2% to 99.1% by narrowing the power density window from 10–30 kW/cm² to 15–20 kW/cm². No equipment change was required—only parameter discipline.

2.2 Welding Speed

Speed controls heat input per unit length, which directly affects heat-affected zone (HAZ) size, intermetallic compound layer thickness, and solidification microstructure.

Equation 2: Heat Input

$$H = P / v \quad [J/mm] \quad \text{where } P = \text{power (W)},\ v = \text{speed (mm/s)}$$

Busbar Type	Speed Range	Notes
Standard prismatic cells	80 – 150 mm/s	General-purpose window
High-conductivity terminals	60 – 100 mm/s	Slower for thicker busbars (≥2.5 mm)
Thin busbars (< 1.5 mm)	120 – 200 mm/s	Reduce power proportionally

CRITICAL

Speed and power must scale together. A 20% power increase without proportional speed adjustment increases HAZ by 35% and reduces fatigue life by 12%.

2.3 Focus Position

Focus position determines energy distribution geometry. Defocusing changes the weld profile from "nail head" (wide, shallow) to "hourglass" (narrow, deep).

Joint Configuration	Focus Position	Weld Profile
Busbar-to-terminal (overlap)	+0.5 to +1.0 mm	Wide, shallow penetration
Busbar-to-busbar (butt)	0 mm (surface)	Balanced penetration
Thick busbar (> 3 mm)	−1.0 to −2.0 mm	Deep penetration

> **TOLERANCE**
> Focus position deviations of ±0.3 mm reduce yield by 2–4% due to inconsistent penetration depth. Beam alignment must be verified quarterly to ±0.1 mm.

2.4 Shielding Gas Flow

Oxidation is the silent yield killer. Even 0.1% oxygen content in the weld zone increases porosity by 300%.

Parameter	Specification
Gas type	Argon (primary) or Ar-He mix (high-reflectivity materials)
Flow rate	15 – 25 L/min (localized shielding)
Nozzle standoff	8 – 12 mm
Coverage pattern	Laminar flow, no turbulence
Advanced option	Dual-gas system: primary shielding + secondary curtain gas

3. Defect Diagnostic Reference

When yield drops below target, use this table to identify the root cause and apply the corresponding parameter correction.

Defect	Visual Indicator	Primary Cause	Parameter Fix
Incomplete fusion	Thin, discontinuous weld bead	Insufficient power density	Increase power 10–15% or reduce speed 20%
Porosity	Surface pits, X-ray voids	Contamination or oxidation	Increase gas flow 25%, check nozzle alignment
Cracking	Centerline or transverse cracks	Solidification shrinkage	Pre-heat to 80–120 °C, reduce cooling rate
Undercut	Groove along weld edge	Excessive power-to-speed ratio	Reduce power 10% or increase speed 15%

Defect	Visual Indicator	Primary Cause	Parameter Fix
Spatter	Metal droplets around weld zone	Unstable keyhole	Optimize focus position, reduce power density

4. Design Example: 2 GWh ESS Line Ramp

Background: A North American ESS manufacturer commissioned a new 2 GWh prismatic module line targeting 99.5% first-pass yield on busbar-to-cell terminal welds.

Initial state: First-pass yield at 96.8%, primarily due to inconsistent weld penetration and porosity on aluminum busbar-to-cell terminal joints.

Parameter adjustments applied:

Parameter	Before	After
Power density window	12 – 28 kW/cm²	18 – 22 kW/cm²
Plasma monitoring	None	15% deviation → auto rework
Pre-weld Argon purge	None	3 seconds before weld start
Nozzle cleaning SOP	Weekly	Daily

Results after 4 weeks of production:

Metric	Result
First-pass yield	**99.6%**
Rework rate	0.3%
Scrap rate	0.1%
Throughput increase	+12%

KEY TAKEAWAY

No equipment replacement was needed. The yield improvement was achieved entirely through parameter window narrowing, real-time monitoring, and maintenance discipline.

5. Production Implementation Checklist

Before Production Start

- ☐ DoE completed with 15–20 parameter combinations
- ☐ Cross-section samples approved by quality engineering
- ☐ Micro-ohm testing protocol established (target: < 0.05 mΩ)
- ☐ Plasma monitoring system calibrated
- ☐ Operator training on parameter adjustment authority
- ☐ Cpk > 1.67 validated for selected parameter set

Daily Production

- ☐ First-article inspection with full cross-section
- ☐ Hourly visual inspection of 5 random samples
- ☐ Plasma signal trend monitoring (no drift > 10%)
- ☐ Protective lens transmission check
- ☐ Gas flow verification

Weekly Maintenance

- ☐ Protective lens replacement (or as needed)
- ☐ Beam alignment verification (±0.1 mm)

- ☐ Weld sample archival for traceability
- ☐ Parameter log review for drift patterns

6. Preventive Maintenance Schedule

Component	Interval	Action
Protective lens	Weekly	Inspect for spatter; replace if transmission < 95%
Nozzle tip	Daily	Clean spatter buildup
Gas flow meter	Monthly	Calibrate flow meters
Beam alignment	Quarterly	Verify focus position accuracy ±0.1 mm

About Huiyao Laser

Huiyao Laser Technology (Luoyang) Co., Ltd. is a manufacturer of battery module and PACK assembly lines, laser welding systems, and EOL testing equipment for EV and energy storage manufacturing. Our application engineering team provides on-site parameter validation support for customer-specific cell and busbar combinations.

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DOCUMENT VERSION HISTORY

Rev.	Date	Author	Changes
A	2026-04-22	Application Engineering Team	Initial release. Validated parameter windows from 50+ production lines (2023–2026).
B	2026-08-08	Application Engineering Team	Added company logo to document header. Added version history and production log sections. Reformatted as standard downloadable template.

Production Log: Source: HTML → PDF via Playwright (Chromium headless). Template: HY-AN-001 Rev. B. Content derived from blog article *busbar-laser-welding-parameter-control-99-yield* (2026-W17). Reviewed by: Application Engineering Team. Next scheduled review: 2027-04 or upon new production line data.