

EV Charging Gun Design Guide

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Abstract

The rapid growth of electric vehicles (EVs) has significantly increased the demand for reliable and high-performance charging equipment. As one of the key interfaces between charging systems and electric vehicles, EV charging guns must meet strict requirements regarding:

- Electrical safety
- Mechanical durability
- Environmental protection
- Thermal management
- Long-term reliability

Plastic components play an essential role in EV charging gun design. Materials used for charging gun housings and structural components must provide:

- Excellent impact resistance
- Flame retardancy
- Dimensional stability
- Insulation performance
- Resistance to environmental conditions such as UV exposure, temperature fluctuations, and moisture

This technical guide provides a comprehensive overview of critical design considerations for EV charging guns, including:

- Functional structure and component layout
- Selection of high-performance engineering plastics

- Injection molding process requirements
- Environmental resilience and sealing strategies
- Quality control protocols during manufacturing
- Common production challenges and proven solutions

The information presented is intended for engineering teams, product developers, and manufacturers involved in the development and production of EV charging infrastructure. By adhering to the principles outlined in this document, stakeholders can ensure the delivery of safe, durable, and high-quality charging solutions that meet evolving industry standards and user expectations.

1. Overview of EV Charging Gun Structure

An EV charging gun is a complex electromechanical component that integrates electrical connection, mechanical protection, thermal management, and user operation functions. Its design must ensure reliable performance under repeated use, environmental exposure, and high-power charging conditions.

1.1 Outer Housing

The external housing serves as the primary structural and protective element of the charging gun. It provides:

- Mechanical protection against physical impacts and accidental drops
- Electrical insulation to prevent electric shock hazards
- Environmental protection from dust, moisture, and UV exposure
- User handling comfort through ergonomic shaping and surface texture

Design requirements for the outer housing include:

- Ability to withstand repeated plugging and unplugging cycles
- Resistance to impact from accidental drops (e.g., from vehicle height)
- Long-term durability under outdoor conditions including temperature fluctuations (-30°C to +85°C typical)
- Compatibility with sealing systems to achieve required IP ratings (typically IP65 or higher)

1.2 Internal Structural Components

Internal plastic components provide critical support for electrical and mechanical functionality. These include:

- Terminal supports
- Insulation brackets
- Cable fixing structures
- Locking mechanisms
- Protective covers

Key performance requirements:

- High dimensional accuracy to ensure precise alignment of electrical contacts
- Structural rigidity to maintain position under mechanical load
- Long-term stability under thermal cycling during charge/discharge operations
- Flame retardancy to meet safety standards (e.g., UL94 V-0)

These components are typically made from engineering plastics such as PA66 GF30 or PBT GF, which offer superior strength and heat resistance compared to standard resins.

1.3 Electrical Contact System

The electrical contact system enables power transfer between the charging station and the vehicle. Surrounding plastic components play a vital role in ensuring safe and stable operation.

Critical design aspects include:

- Accurate positioning of terminals to ensure low-resistance connection
- Stable mechanical support to prevent movement during mating/unmating
- Heat resistance to withstand temperatures generated during high-current charging (up to 200A in DC fast charging)
- Electrical insulation protection to prevent arcing or short circuits

Plastic materials used near contacts must maintain structural integrity under continuous thermal loads and resist tracking caused by partial discharges. Proper spacing (creepage and clearance distances) must be maintained according to IEC 62196 and other relevant standards.

2. Material Selection for EV Charging Gun Components

Material selection is one of the most critical factors influencing the long-term reliability, safety, and performance of EV charging guns. The materials used must meet stringent requirements for mechanical strength, thermal stability, electrical insulation, flame retardancy, and environmental resistance.

2.1 PC (Polycarbonate)

Polycarbonate (PC) is a high-performance thermoplastic widely used in applications requiring transparency and impact resistance.

Advantages:

- Excellent impact resistance, even at low temperatures
- High transparency options for indicator windows or status visibility
- Good dimensional stability under varying environmental conditions
- High heat resistance with a typical glass transition temperature around 147°C

Typical applications:

- Transparent indicator covers
- Protective components exposed to physical stress
- High-impact housing parts requiring optical clarity

2.2 PC/ABS Alloy

PC/ABS is a polymer blend that combines the best properties of polycarbonate and acrylonitrile butadiene styrene (ABS), offering a balanced performance profile ideal for exterior components.

Advantages:

- Higher impact strength than standard ABS
- Better processing performance and flow characteristics than pure PC
- Improved surface appearance and paint adhesion

- Good dimensional stability and warpage control

Applications:

- Charging gun outer shells
- Protective housings subject to handling and environmental exposure
- Control modules requiring both structural integrity and aesthetic finish

2.3 PA66 GF30 (Glass Fiber Reinforced Nylon)

Polyamide 66 reinforced with 30% glass fiber (PA66 GF30) is a preferred material for load-bearing internal components due to its superior mechanical and thermal properties.

Advantages:

- High mechanical strength and stiffness
- Excellent wear and abrasion resistance
- Good heat resistance, maintaining performance at elevated temperatures
- Improved dimensional stability compared to unfilled nylons

Applications:

- Terminal supports requiring precise alignment
- Internal brackets subjected to continuous mechanical load
- Structural components in high-temperature zones near electrical contacts

2.4 PBT GF (Glass Fiber Reinforced Polybutylene Terephthalate)

PBT reinforced with glass fibers offers excellent electrical insulation and chemical resistance, making it suitable for electrical insulation components.

Advantages:

- Outstanding electrical insulation properties
- High resistance to moisture and chemicals
- Good creep resistance under sustained loads
- Inherent flame retardancy potential

Applications:

- Insulation barriers between conductive parts
- Connector housings
- Components requiring long-term dielectric stability

2.5 Flame Retardant Materials

Due to the presence of high-voltage electrical systems, flame retardant materials are essential to ensure user safety and regulatory compliance.

Common requirements include:

- UL94 V-0 or V-1 flammability rating
- Reduced combustion risk and self-extinguishing behavior
- Low smoke emission and halogen-free formulations for indoor use
- Maintained mechanical properties after flame retardant additive incorporation

Materials commonly used:

- Flame retardant PC: For transparent or high-impact enclosures
- Flame retardant PA66: For structural components near heat sources
- Flame retardant PBT: For electrical insulation and terminal blocks

These materials undergo rigorous testing to ensure they do not compromise other key performance attributes while meeting fire safety standards such as IEC 62196, UL 2251, and GB/T 18487.

3. Structural Design Considerations

The structural design of an EV charging gun must ensure long-term mechanical integrity, environmental resilience, and operational safety under diverse usage conditions. Key considerations include impact resistance, ingress protection, and thermal management, each requiring targeted engineering solutions.

3.1 Impact Resistance Design

Charging guns are frequently subjected to mechanical stress from drops, collisions, and repeated handling. A robust structure is essential to prevent cracking, deformation, or internal component displacement.

Design strategies to enhance impact resistance include:

- Rounded corners and fillets to reduce stress concentration at edges
- Reinforced ribs and gussets in high-load areas such as latch mechanisms and cable entry points
- Optimized wall thickness distribution to balance strength and material usage

- Strategic placement of support structures around terminal blocks and locking components

Material selection complements structural design; combining high-impact plastics like PC/ABS with optimized geometry ensures durability across thousands of mating cycles and accidental impacts.

3.2 Waterproof and Dust Protection

Outdoor deployment exposes charging guns to rain, dust, humidity, and temperature fluctuations. Effective sealing is critical to maintain electrical insulation and prevent corrosion.

Key design elements for achieving IP65 or higher protection levels:

- Integrated sealing surfaces with precise tolerances for O-ring or rubber gasket installation
- Double-lip seals at the nozzle interface to block water ingress during connection
- Drainage channels to redirect moisture away from sensitive components
- Controlled assembly tolerances between housing halves to ensure consistent compression of sealing elements

Seal materials must be compatible with UV exposure and wide temperature ranges (-30°C to +85°C), maintaining elasticity over time without hardening or cracking.

3.3 Thermal Management Design

High-power charging (e.g., DC fast charging up to 200A) generates significant heat at contact points and conductors. Plastic components must resist thermal degradation and dimensional changes.

Critical aspects of thermal design:

- Use of high-heat-resistant materials such as PA66 GF30 and PBT GF near electrical contacts
- Adequate creepage and clearance distances maintained per IEC 62196 standards to prevent arcing
- Ventilation paths and air gaps designed into the housing to facilitate passive cooling
- Thermal expansion compensation through flexible mounting features or expansion joints

Proper spacing between heat-generating components and plastic structures minimizes localized softening or warping, ensuring long-term reliability even under continuous high-current operation.

4. Injection Molding Requirements

EV charging gun components often require high-precision injection molding due to their complex geometries, tight assembly tolerances, and stringent performance requirements. Achieving consistent quality in mass production demands careful consideration of mold design and process control.

4.1 Mold Design

Proper mold design is critical to ensure dimensional accuracy, surface finish, and structural integrity of plastic parts.

Flow Analysis Mold flow simulation plays a key role in optimizing the filling process and identifying potential defects before tooling fabrication.

Key aspects include:

- Gate position optimization to ensure balanced material flow
- Filling balance across multiple cavities for uniform part quality
- Weld line location control to avoid weak zones in high-stress areas
- Warpage prediction based on cooling and shrinkage behavior

Cooling System Design An efficient and balanced cooling system directly impacts cycle time and product consistency.

Benefits of optimized cooling:

- Improved dimensional stability
- Reduced cycle time, increasing production efficiency
- Minimized thermal stresses, lowering warpage risk
- Enhanced part-to-part consistency

Draft Angle Design Appropriate draft angles are essential for successful demolding and surface quality.

Design considerations:

- Typical draft angles range from 1° to 3°, depending on surface texture and material
- Vertical walls should have sufficient taper to reduce friction during ejection
- Proper draft reduces surface scratches and improves mold release

4.2 Common Injection Molding Challenges

Despite advanced simulation tools, several defects commonly occur during production. Understanding root causes enables effective corrective actions.

Challenge	Causes	Solutions
Warpage	Uneven cooling, differential shrinkage, asymmetric wall thickness	Optimize mold temperature distribution, improve cooling channel layout, adjust part geometry for uniform thickness
Sink Marks	Thick ribs or bosses, insufficient holding pressure, poor gate sizing	Reduce rib/ base thickness ratio (ideal: $\leq 60\%$ of main wall), increase holding pressure and time, optimize gate size and location
Short Shot	Inadequate melt temperature, low injection pressure, blocked flow paths	Increase barrel temperature, raise injection speed/ pressure, redesign flow channels or add auxiliary gates

5. Quality Control Requirements

Reliable production of EV charging guns demands a comprehensive and systematic quality control framework. Given the safety-critical nature of these components, rigorous inspection processes must be implemented at multiple stages of manufacturing to ensure compliance with electrical, mechanical, and environmental performance standards.

Dimensional Inspection

Precise dimensional control is essential to guarantee proper assembly, reliable electrical contact engagement, and effective sealing performance.

- Assembly accuracy verification using coordinate measuring machines (CMM) or optical comparators to confirm alignment of mating features
- Terminal positioning checks to maintain required creepage and clearance distances per IEC 62196 specifications
- Structural consistency validation across production batches to prevent fitment issues in automated assembly lines
- Tolerance stack-up analysis for multi-component assemblies to avoid interference or gaps affecting IP rating integrity

Material Inspection

Material properties directly influence long-term reliability, flame retardancy, and thermal stability. Incoming raw materials and finished parts must undergo strict verification.

- Material verification through spectroscopic methods (e.g., FTIR) to confirm resin type and batch consistency
- Flame retardant testing per UL94 standards (e.g., V-0, V-1) to validate self-extinguishing behavior and dripping resistance
- Mechanical performance testing, including tensile strength, impact resistance, and heat deflection temperature (HDT), to ensure compliance with design specifications
- Moisture absorption testing for hygroscopic materials like PA66 to prevent processing defects and property degradation

Functional Testing

Final assembled units must pass a series of functional tests simulating real-world usage conditions to verify operational reliability and safety.

- Assembly testing to confirm ease of mating/unmating, secure locking mechanism function, and cable strain relief effectiveness
- Mechanical strength testing, including drop tests from 1.5 meters and repeated plugging cycles (typically 10,000+ cycles), to assess durability
- Environmental reliability testing, such as thermal cycling (-30°C to +85°C), humidity exposure (85% RH), and salt spray tests, to evaluate long-term resilience
- Dielectric strength testing at high voltage (e.g., 2 kV AC for 1 minute) to ensure insulation integrity under fault conditions

6. Manufacturing Challenges and Solutions

The manufacturing of EV charging guns involves complex processes that must balance precision, durability, and safety. Despite advancements in material science and molding technology, several production challenges can arise during high-volume manufacturing. Addressing these issues proactively ensures consistent product quality and long-term reliability.

The following table outlines common manufacturing challenges and their corresponding engineering solutions:

Challenge	Solution
Housing cracking	Use impact-resistant materials such as PC/ABS or reinforced polycarbonate; optimize structural design with rounded corners, uniform wall thickness, and stress-relief ribs to minimize crack initiation under mechanical load

Dimensional deviation	Improve mold precision through high-accuracy CNC machining; implement strict process control including temperature regulation, injection pressure monitoring, and real-time dimensional inspection using coordinate measuring machines (CMM)
Heat deformation	Select high-temperature engineering plastics with high heat deflection temperature (HDT), such as PA66 GF30 or PBT GF; incorporate thermal expansion gaps and ventilation paths in the design to accommodate thermal cycling
Flame safety requirements	Utilize certified flame retardant materials meeting UL94 V-0 or equivalent standards; ensure complete material traceability and conduct regular flammability testing on incoming resins and finished components
Assembly inconsistency	Enhance tolerance control in both part design and mold fabrication; employ automated assembly verification systems to detect misalignment or improper locking during production

7. Future Trends in EV Charging Gun Design

The evolution of electric vehicle charging infrastructure is driving significant advancements in charging gun design. As market demands shift toward

faster charging, enhanced user experience, and smarter grid integration, next-generation charging guns must incorporate innovative materials, structural concepts, and electronic functionalities.

Key future trends include:

- Higher Charging Power
 - Next-generation high-power charging (HPC) systems are targeting 350 kW and beyond, necessitating major improvements in thermal management.
 - Plastic components will require superior heat resistance to withstand prolonged exposure to elevated temperatures generated at contact points.
 - Structural materials must maintain mechanical integrity under increased thermal cycling stress, reducing the risk of warpage or cracking.
 - Enhanced safety designs will be critical, including improved arc resistance, optimized creepage/clearance distances, and real-time temperature monitoring capabilities.
- Lightweight Design
 - To improve user handling and reduce cable strain, manufacturers are actively pursuing weight reduction strategies without compromising durability.
 - Adoption of advanced engineering plastics with higher strength-to-weight ratios, such as long-fiber reinforced thermoplastics, enables thinner yet stronger structures.
 - Integrated structural designs minimize part count and assembly complexity, contributing to overall mass reduction.
 - Material optimization through topology analysis allows for strategic material placement, removing excess resin from non-critical zones while reinforcing load-bearing areas.

- Intelligent Charging Systems
 - Future charging equipment will integrate embedded sensors, wireless communication modules, and smart control electronics directly into the charging gun assembly.
 - These intelligent features enable:
 - * Real-time monitoring of contact temperature, current load, and connection status
 - * Predictive maintenance alerts based on usage patterns and component health
 - * Secure authentication and encrypted data exchange between vehicle and charger
 - * Over-the-air (OTA) firmware updates for performance optimization and security patches
 - The integration of electronics requires more complex plastic housings with dedicated compartments, EMI shielding, and precision-molded features for sensor mounting and signal integrity.

8. Summary

EV charging guns are mission-critical components in the electric vehicle ecosystem, serving as the primary interface between power infrastructure and vehicles. Their design must integrate multiple engineering disciplines to ensure safe, reliable, and durable performance under demanding operational conditions.

Key success factors include:

- Electrical safety through proper insulation, creepage/clearance distance control, and arc-resistant materials
- Mechanical reliability achieved via impact-resistant structures, robust locking mechanisms, and fatigue-resistant cable strain relief

- Environmental resilience enabled by effective sealing (IP65 or higher), UV-stable materials, and thermal management strategies
- Manufacturing precision ensured by high-accuracy molds, strict process controls, and comprehensive quality inspection protocols

The performance of plastic components is central to meeting these requirements. High-performance engineering plastics—such as PC, PC/ABS, PA66 GF30, and PBT GF—provide the necessary combination of strength, heat resistance, dimensional stability, and flame retardancy.

Advanced injection molding technologies further enable the production of complex, high-integrity parts with tight tolerances. When combined with rigorous material verification, dimensional inspection, and functional testing, manufacturers can consistently produce charging guns that meet international standards including IEC 62196, UL 2251, and GB/T 18487.

As charging power levels increase and intelligent features are integrated, future designs will demand even greater innovation in material science, structural optimization, and electronic integration—all while maintaining manufacturability and cost efficiency.

Through disciplined application of material selection, structural design, precision manufacturing, and quality assurance, EV charging gun developers can deliver products that support the continued growth and reliability of electric mobility.