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Research on Board-level Hierarchical Fault Detection and Standardized Component Maintenance Technology for Vehicle-mounted On-Board Charger

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Abstract

Aiming at the industry pain points of lack of standardized processes for on-board charger (OBC) fault maintenance and high maintenance costs caused by excessive assembly-level replacement, this paper proposes a five-level board-level hierarchical maintenance process system: non-destructive disassembly, visual preliminary diagnosis, precise instrument-aided detection, component-level repair, and pre-assembly static re-inspection. This paper systematically elaborates on anti-static tooling configuration, board-level functional partitioning and hierarchical fault-location methods, and analyzes high-frequency error-prone risks in maintenance and corresponding avoidance countermeasures. Verified by complete maintenance cases of typical faulty samples, the proposed maintenance process can realize accurate repair of faulty components such as power devices and electrolytic capacitors, effectively eliminate the risk of component burnout caused by secondary power-on, and significantly improve the reliability and cost-effectiveness of OBC board-level maintenance. The proposed process has direct application value for on-board power supply maintenance practice and new-energy-vehicle maintenance teaching and training.

Keywords

On-Board Charger (OBC); Board-Level Maintenance; Hierarchical Maintenance; Power Device; Maintenance Technology

1. Introduction

The On-Board Charger (OBC) serves as the core execution unit of the electric-vehicle charging system and undertakes AC-DC power conversion. Internally, an OBC integrates a PFC power conversion circuit, an input EMI filter, a DC-DC converter, as well as output filtering and control modules. With the continuous growth in the ownership of new-energy vehicles, the number of OBC faults rises year by year.

Currently, OBC maintenance suffers from three major pain points. First, most 4S stores and maintenance stations adopt direct assembly-replacement solutions for OBC faults, which incurs high costs. Second, maintenance lacks hierarchical detection procedures; blind desoldering is common. Maintenance personnel follow inconsistent operating procedures, leading to uncontrollable maintenance quality. Third, standardized static re-inspection is absent after maintenance, so the risk of component burnout upon secondary power-on cannot be effectively mitigated.

To address the above-mentioned problems, this paper puts forward a five-level hierarchical board-level maintenance process covering the full chain of disassembly, detection, repair and re-inspection: "non-destructive disassembly — visual preliminary diagnosis — instrument-aided detection — component-level repair — static re-inspection". Based on functional partitioning for diagnosis, the core philosophy of this process is "prioritize detection without component removal, and conduct disassembly and repair only after accurate fault localization". The aim is to establish a replicable and promotable standardized operating procedure for OBC board-level maintenance.

2. Preparations and Tooling System for OBC Board-level Maintenance

2.1. Preconditions for Maintenance

Board-level maintenance of an OBC must be premised on the completion of vehicle high-voltage power-off and safe removal of the OBC assembly from the vehicle. During disassembly, screws shall be sorted and stored, and hole positions shall be photographed for reference in subsequent reassembly.

2.2. Anti-static and Testing Tooling Configuration

The OBC PCB integrates a large number of electrostatic-sensitive components such as CMOS devices and IC chips. Human bodies may generate static electricity up to tens of thousands of volts, while IC chips can be damaged at voltages above 300 V. Therefore, three categories of tooling shall be equipped for maintenance:

Anti-static tooling: anti-static wrist strap (with grounding resistance of 1 MΩ ± 10 %), anti-static work mat (surface resistance ranging from 10^6 Ω to 10^9 Ω). Operators shall wear the wrist strap connected to the ESD grounding system before operation.

Welding and maintenance tooling: constant-temperature soldering station (350 ± 20 °C for lead-free solder; 320 ± 30 °C for lead-containing solder). The soldering iron must be reliably grounded to prevent component breakdown induced by electric leakage.

Testing instruments: multimeter (diode mode for on-board measurement of power devices), ESR capacitance meter (for accurate capacitance detection and troubleshooting of latent aging faults).

2.3. Core Competency Requirements for Maintenance Personnel

Maintenance personnel shall master precision disassembly-assembly techniques, screw position management and PCB insulation-structure recognition. They shall be familiar with components in different functional zones of the OBC PCB, including the AC input zone, PFC power zone, low-voltage power-supply zone and high-voltage output zone. They shall be capable of identifying power devices, resistors and capacitors, and proficient in on-board component measurement methods.

3. Standardized Hierarchical Board-level Maintenance Process for OBC

3.1. Stage 1: Non-destructive Physical Disassembly of OBC Assembly

Preliminary visual inspection. Before disassembly, perform visual pre-inspection to identify obvious faults such as ablation, water intrusion traces, capacitor bulging and housing deformation. This step provides preliminary fault hints for subsequent board-level detection.

Key points for non-destructive disassembly. Use plastic pry bars to separate the housing to avoid scratches and stress concentration caused by metal tools. After removing sealing adhesive, take off shielding covers, thermal-insulation cotton and insulating mica sheets in sequence, and record the original positions of each insulating component. Photograph inter-board cables before unplugging to guarantee correct wiring during reassembly. Avoid collision and mechanical stress on components when taking out the PCB assembly.

Black insulating sheets are usually installed between the OBC aluminum-alloy housing and the PCBA module, and green thermal-conductive pads are attached to heat-generating components. Integrity of these insulating and thermal-conductive structures shall be preserved during disassembly, and damaged parts shall be replaced.

3.2. Stage 2: Zoned Visual Preliminary Diagnosis on Board-level

The PCB is divided into four functional zones: AC input zone, PFC power zone, low-voltage power-supply zone and high-voltage output zone. The AC input zone is equipped with fuses, varistors, NTC thermistors and relays. The PFC power zone contains MOSFETs, freewheeling diodes and high-power sampling resistors. The low-voltage power-supply zone integrates power-supply chips and optocouplers. The high-voltage output zone is furnished with output diodes, high-voltage filter capacitors and equalizing resistors.

Perform visual inspection for obvious failures such as component charring, capacitor bulging, electrolyte leakage, device cracking and burnt-off PCB copper traces. Zoned visual inspection can rapidly narrow down the suspected fault area and reduce unnecessary component desoldering.

3.3. Stage 3: Precise On-board Instrument-aided Detection

On-board measurement of power devices. Use the diode mode of a multimeter to test power devices including MOSFETs, IGBTs and rectifier bridges for open-circuit or short-circuit faults. Key power devices such as IGBTs, MOSFETs and SiC devices in OBC undertake high-frequency, high-voltage and large-current main power channels; their working status directly determines energy-conversion efficiency and safety. On-board measurement can screen suspicious devices without component removal.

Capacitance measurement and latent-fault troubleshooting. An ESR capacitance meter is adopted to measure the equivalent series resistance (ESR) of electrolytic capacitors. Under high-temperature operating conditions, the ESR of electrolytic capacitors increases significantly. In one practical case, the ESR of an input capacitor increased by three times when its surface temperature reached 67 °C. Capacitor aging is also manifested as capacitance degradation. In an OBC fault case of a certain vehicle model, the measured total capacitance of the filter circuit was merely 20.285 nF (nominal value about 125 μF), indicating substantial failure of the filter circuit. ESR measurement serves as a critical means to identify such latent aging faults.

Low-voltage control-loop detection. Perform on-board measurement for control chips, optocouplers and surrounding resistive-capacitor components in the low-voltage power-supply zone to verify the integrity of low-voltage power-supply and control-signal links.

3.4. Stage 4: Precision Component-level Repair and Replacement

Carry out component-level repair after faulty components are located. The repair consists of four sub-steps. First, pre-process the soldering station: set the constant-temperature soldering station to an appropriate temperature, clean pads and pre-tin them to repair damaged or peeled-off pads. Second, component replacement: replacement components must match the original ones in withstand voltage, current rating and package. Third, precision soldering: inspect finished solder joints to eliminate virtual soldering, solder bridging and cold soldering. Fourth, structural restoration after repair: remove flux residues, reinstall insulating gaskets, thermal-insulation cotton and shielding covers, and implement PCB insulation protection.

3.5. Stage 5: Pre-assembly Static Re-inspection

Prior to housing assembly, perform comprehensive short-circuit re-inspection across the whole PCB. Use a multimeter to measure insulation impedance between high-voltage loops and low-voltage loops, as well as between each power terminal and ground, to rule out hidden short-circuit risks.

Subsequently, verify continuity of key loops. Focus on the power loop, drive loop and sampling loop. Continuity verification of the power loop prevents inoperability

caused by open-circuited power devices; verification of the drive loop ensures normal transmission of PWM control signals to the gate of power devices; verification of the sampling loop guarantees accuracy of voltage and current feedback signals.

Finally, conduct static safety validation. The core objective of static re-inspection is to “eliminate the risk of component burnout upon secondary power-on”. Systematic short-circuit and continuity tests ensure that the repaired PCB will not suffer secondary damage caused by latent faults at the moment of power-on. It constitutes the final and most critical safety barrier in the whole maintenance process.

4. Analysis of High-frequency Failure Risks and Error-prone Points in Board-level Maintenance

Summarized from practical maintenance training and engineering cases, four typical types of errors are concluded:

1) Violent disassembly and mixed use of screws. Forcible prying of shielding covers may crack the PCB; mixing long and short screws may pierce the circuit board during assembly and induce hidden short-circuits. Countermeasures: sort and store screws separately; follow torque requirements specified in maintenance manuals during disassembly and assembly.

2) Incomplete fault judgment. Maintenance technicians merely replace visually damaged components while ignoring latent faults such as capacitor aging and resistance drift. Countermeasures: adopt combined visual inspection and instrument-aided detection and do not overlook non-visual failures.

3) Defective soldering workmanship. Problems include solder bridging, pad peeling and excessive flux residues after soldering. Countermeasures: precisely control soldering-station temperature and thoroughly clean the PCB after soldering.

4) Omission of insulating and shielding components. Forgetting to reinstall mica insulating sheets, thermal-insulation cotton and other shielding structures after maintenance may degrade high-voltage insulation performance and bring safety hazards. Countermeasures: take photographs during disassembly and cross-check all insulating accessories against photos during reassembly.

5. Process Verification via Practical Case

5.1. Overview of Faulty Prototype

An on-board charger of a certain vehicle model failed to initiate charging after AC power supply was connected, and relevant charging-system fault codes were read via a diagnostic instrument. After vehicle high-voltage power-off and assembly removal, board-level maintenance was carried out.

5.2. Maintenance Following the Five-level Process

The OBC was repaired in accordance with the five-level maintenance process. First,

the OBC assembly was disassembled; non-destructive disassembly was implemented in an anti-static working environment, and photos were taken to record positions of all insulating components. Second, zoned visual preliminary diagnosis on PCB was performed. Slight ablation traces were observed in the PFC power zone without large-scale explosion damage, so faults were preliminarily localized to the PFC power conversion zone. Third, on-board instrument-aided detection was conducted. Diode-mode multimeter measurement detected breakdown of the PFC power MOSFET, while ESR testing revealed no obvious aging of surrounding capacitors. Fourth, the faulty MOSFET was desoldered on a constant-temperature soldering station and replaced with a device of identical specifications. After replacement, the PCB was cleaned and surrounding insulating gaskets were reinstalled. Finally, pre-assembly static re-inspection was executed. No short-circuit was detected between high-voltage and low-voltage circuits, and continuity of the power loop, drive loop and sampling loop was fully confirmed.

5.3. Board-level Maintenance Result

Subsequent bench tests of the repaired sample showed normal upper-computer communication after 12 V wake-up and no active fault codes. After 220 V AC power was supplied, the PFC circuit built-up voltage normally without error reports or shutdowns, and no-load functional tests were passed. This case validates that the proposed hierarchical maintenance process can efficiently locate faults and reduce maintenance costs.

6. Conclusions

This paper presents a hierarchical board-level maintenance process for OBC, establishing a complete standardized workflow covering disassembly, fault localization, component repair and pre-assembly static re-inspection. Adopting the fault-location philosophy of “zoned visual preliminary diagnosis plus on-board instrument-aided detection”, it prioritizes detection without component removal to mitigate PCB damage risks. The pre-assembly static re-inspection step is introduced to avoid secondary damage upon power-on. The proposed workflow can be applied in after-sales maintenance of new-energy vehicles and serve as a standardized teaching procedure for on-board power-supply maintenance in vocational colleges. Future work will integrate bench-based whole-machine verification tests to further improve the full-chain quality control system for OBC maintenance.

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