Special Investigation and Countermeasure Suggestions on Electric Vehicle out-of-control Accidents

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Abstract—The number of electric vehicles keeps increasing, and security problems are becoming increasingly prominent. Through in-depth investigations of electric vehicle traffic accidents, the characteristics and laws of typical out-of-control accidents of electric vehicles are found, and the internal and external factors and mechanisms of such accidents are analysed. By summarising typical cases, pointing out the current problems in the investigation of electric vehicle accidents, it puts forward essential investigation items, investigation methods and new technical identification schemes for electric vehicles. The study fills the gap of the lack of special investigation and identification methods for electric vehicle out-of-control accidents and helps to identify the causes of electric vehicle out-of-control accidents.

1. INTRODUCTION
The increasing use of electric vehicles has caused more accidents. Reports of accidents caused by the loss of control of electric vehicles have occurred from time to time. However, there are few reports on the investigation and research on the accidents of loss of control of electric vehicles[1]. The electric vehicle’s power drive device has different characteristics from the traditional internal combustion engine. The electric vehicle’s electronic control unit and power electronic components are much more complicated than the traditional car, and its potential safety hazards are also different from the traditional car. The investigation of EV accidents is based on the investigation of the traditional vehicle accident and carries out special surveys and on-board data characteristics analysis based on the characteristic of electric vehicles.

Regarding the new safety risks brought by the rapid development of automobile electrification, there is no corresponding investigation standard and mature identification technology at home and abroad on how to conduct targeted investigation and analysis of EV after an accident. At present, the investigation and identification of EV mainly use traditional methods. On the one hand, some conventional data items are obtained through driving recorders, EDRs, etc. and analysed, yet there is a lack of analysis of the input/output data of critical electronic control units. On the other hand, the identification methods only include traditional ones, such as visual inspection, reference inspection, and oscilloscope display waveform inspection. The above investigation methods are no longer suitable for in-depth investigation of electric vehicle accidents.

Hesz[2] summarised the possibility of using EDR store data to reconstruct the accident process.
through numerical simulation. He believed that the approximation method in the existing model would cause the calculation simulation results to deviate significantly from the actual situation, which went against the analysis of the cause of the accident. He also analysed the main reasons for the difference between the simulation results and the actual situation. Guo[3] used EDR data to analyse typical accident cases. By analysing the basic data types and collision types of EDR, the role of EDR data in car accident reproduction is studied. The trigger threshold range of each collision type is explained, and the speed errors of many accident cases and reconstruction results are analysed. Fatzinger[4] used EDR data to study the speed loss in the collision between motorcycle and car and predicted the driving speed of the motorcycle through the car EDR data within a specific range.

Based on the investigation of the out-of-control accidents of EV in recent years, the article searches for the characteristics of accidents through typical accident cases and analyses the possible causes of runaway accidents. Regarding the current problems in the investigation of EV accidents, the investigation items and methods suitable for EV runaway accidents are proposed. The study also proposes to improve the effective investigation and analysis of the out-of-control accidents of EV by improving the hardware-in-the-loop testing technology and digging into the data characteristics of vehicle terminals.

2. Typical accidents of electric vehicles

In recent years, there have been numerous out-of-control accidents of electric vehicles. Our identification Center has conducted an in-depth investigation into the out-of-control electric vehicle accidents in China. Such accidents were caused by both passenger and commercial vehicles. The following are brief descriptions of 5 typical cases that have aroused high public concern of these accidents. The five accidents all showed that the vehicle suddenly accelerated and lost control when it first started, there was no sudden danger, nor distinct external interference factors. This feature is different from the traditional car accidents that occur when the driver is under the emergency state.

2.1. Summary of the accidents
(1). A hybrid SUV suddenly lost control and accelerated drastically after starting. After avoiding multiple vehicles, it first collided with a driving car in the opposite lane and then collided with multiple vehicles on the road causing casualties and damages to multiple vehicles.

(2). An electric bus lost control and accelerated drastically after starting. After rushing out of the station, entering the road, and colliding with a driving vehicle, it continued to drive forward through the central green belt to the opposite lane and collided with multiple vehicles, causing casualties and damages to multiple vehicles.

(3). An electric taxi suddenly lost control after starting. It accelerated after turning, collided with the vehicle on the opposite lane, rushed onto the sidewalk and hit the passerby, and then collided with roadside obstacles until it stopped.

(4). An electric bus was ready to enter the departure area in the station. It suddenly lost control after starting and directly rushed into the ticket office, causing casualties and damages to the house.

(5). An electric bus traveled slowly on a congested road. After several starting and parking, it suddenly lost control and hit the vehicle in front of it after another start. The vehicle in front of it then collided with other vehicles after being hit, causing damage to multiple vehicles.

2.2. Similarities in the form of typical accidents
(1). In terms of accident patterns, the most representative feature of the above mentioned accidents is the uncontrolled situation upon vehicle starting.

(2). In terms of the accident traces on the road, two of the three above mentioned electric buses with uncontrolled accidents presented on-site braking traces; No braking traces were found in either passenger car accidents.

(3). Most of the brake lights of the crashed vehicles were not turned on during the accident (before crashing). The brake lights were instantly turned on during the collision, and most of them can be
turned on through brake pedaling after the collision.

(4). Among the data records during the accidents according to the background data of the crashed vehicles or the data of on-vehicle terminals, the position values of most accelerator pedals were very high (99%) while the values of brake pedals were 0% or only non-zero in very limited moments (see Fig. 1 and Fig. 2).

(5). The drivers of the 5 accidents reported that the vehicle suddenly accelerated and the brake failed during the process of starting and could not be controlled. Besides, the drivers have long driving experience, and the bus drivers are all professional drivers.

Fig. 1. The position values of accelerator pedal and brake pedal of accident 1

Fig. 2. The position values of accelerator pedal and brake pedal of accident 2

3. POSSIBLE REASONS FOR THE OUT OF CONTROL OF ELECTRIC AUTOMOBILES

3.1. Occasional fault of electronic control unit caused by electromagnetic interference
Generally, the electromagnetic interference of electric automobiles is caused by either internal interference of the automobile or the road condition. The internal electromagnetic interference refers to that generated by components such as engine, driving motor, generator, Cables, power battery and relay while they are working[5][6]. External electromagnetic interference refers to that caused by electromagnetic radiation of various electrical facilities including the high voltage transmission line, broadcasting TV devices and radio communication equipment as well as natural phenomena such as lightning.

Electromagnetic wave interferes the electric control system of automobile through wiring harness and car body to make it hard to perform or even send wrong instructions, leading to wrong actions of various actuators, affecting the safety, reliability and stability of automobile driving. The electromagnetic interference affects the automobile electronic control system mainly in two ways: one is to affect the input signal of the sensor of the electronic control system, causing distortion and...
resulting in electric control signal where the ECU output does not match the driver's intention, which leads to the wrong operation of the actuator; the other is to interfere the ECU output signal to result in its deviation, misleading the operation of the actuator.

3.2. Failure of the automobile system or components
There are many components or systems that may cause the automobiles to go out of control, among which the most closely related abnormality include the input part of the vehicle control unit, the vehicle control unit itself, the output part of the vehicle control unit, and the communication circuit.

Among the many reasons for the abnormal input of the vehicle control unit, the most dangerous failure is caused by the fault of the accelerator pedal sensor and the brake pedal sensor. The abnormality of the vehicle control unit itself mainly includes the hardware fault and the error of its built-in control program. The abnormality of the output of the vehicle control unit is mainly caused by the fault of the corresponding actuator and the control circuit. The faults of actuator closely related to out-of-control accidents mainly include abnormal operation of the driving motor and failure of the electric vacuum pump.

In order to obtain all the state information of the automobile and to coordinate and control the automobile, the vehicle control unit needs to exchange information with each subsystem, and the information exchange is carried out through the communication circuit. CAN bus is the most common, and the fault of CAN bus communication circuit mainly involves the circuit and connector, as well as hardware faults, which rarely happen, though. Abnormal communication circuit may also cause the automobile to go out of control.

3.3. Defects in design of control strategy
In case of defects in the design of automobile start-up control strategy, the automobile can be started and selecting / shifting gears can be made possible without stepping on the brake pedal, and the torque of the driving motor can reach the maximum value instantaneously, which may cause the automobile to run suddenly and quickly the moment when it starts, posing serious safety risks. According to in-depth investigation carried out in recent years of accidents of electric automobiles that go out of control, it is found that the above defects exist in the design of automobile start-up control strategy. An electric automobile manufacturer with such defects and accidents finally recalled the relevant automobiles. So defects in the design of automobile start-up control strategy are likely to be the main cause of accidents where automobiles go out of control.

3.4. Man-made maloperations
Driving a car involves frequent human-machine interaction; therefore, it is essential to have a full understanding of driving characteristics of the car. Electric automobiles are significantly different from traditional gasoline automobiles in terms of starting and accelerating. For electric automobiles, the driving motor can output the maximum torque the moment it starts, and it is constant torque below the basic rotation speed, with the torque tending to decline while the speed gradually increases. For traditional gasoline automobiles, the output torque of internal combustion engine is relatively small at low speed, so the starting torque is also relatively low, which gradually increases with the increase of the speed. Therefore, if a driver fails to control the accelerator pedal properly during the start of a car, such as stepping on the accelerator pedal violently or wrongly out of panic, the electric automobile is more likely to rush out and lose control.

4. CURRENT ISSUES IN THE EV INVESTIGATION

4.1. Unclear Investigation Information
The structural principle of EV is quite different from traditional fuel vehicles, so the items that need to be investigated for electric vehicle runaway accidents are also different from traditional ones. However, in-depth studies found that in the on-site investigation of EV accident, the police often
neglect or miss essential investigation information of the first accident site, as they lack relevant case experiences. For the on-site investigation of the runaway accidents of electric vehicles, specific investigation records should be carried out according to the characteristics of electric vehicles.

4.2. Inapplicable Evaluation Techniques

Traditional identification techniques mainly include visual inspection, reference inspection, resistance inspection, oscilloscope display waveform inspection, etc[7]. However, for the investigation and identification of electric vehicles, these methods do not perform well, because the general electrical parts failure is challenging to find on the surface.

5. Countermeasure and Suggestion

5.1. Special investigation on the out-of-control accident of electric vehicle

According to the in-depth investigation on the out-of-control accident of electric vehicle in recent years, the core investigation contents after the out-of-control accidents of electric vehicle were reviewed, thereby recording and preserving the original and significant first-hand information of the accidents, and providing a basis for the accident cause analysis.

During the investigation of electric vehicle accident, it is proposed to ensure the safety of the site, and avoid fire, electric shock and other secondary accidents related to electric vehicle; and save long-term and short-term physical and data evidence, and regulate the investigation steps, which is the most critical link. In the process of accident investigation, rationally adopt the following investigation contents and steps according to the actual situation and characteristics of the accident, and combine the preliminary investigation with the special investigation. The scene investigation should conform to the basic principles of observing before acting, taking photos before extracting, investigating surface before investigating interior.

As for the investigation of electric vehicle accident, in addition to the regular investigation and evidence collection, the special investigation of electrical units should be strengthened, such as the relevant components of the “three electric systems”, pedal sensor, harness of sensor from VCU to pedal and connector clips, and the investigation and evidence collection of the special information of electric vehicle should be implemented. The terminal data and supervision platform data of new energy vehicle should be fully utilized to provide a basis for accident reconstruction and cause analysis.

On the aspects of driver investigation, vehicle investigation and environmental investigation of accident section, through the in-depth investigation conducted by the identification center on the out-of-control accidents of electric vehicles with great social impact in recent years, the main investigation contents and methods were reviewed and summarized as follows:

5.1.1. Driver investigations

a) Basic information, sleep quality and emotion before the accident.

b) Shoe prints. Preserve and fix material evidence as early as possible. Compare the shoe print to the features and the extracted micro of the accelerator/brake pedal of the vehicle to offer a reference to the accident cause analysis.

c) Type and status of the driver’s shoes during the accident.

d) Driving experience.

e) Familiarity with the vehicle model.

f) Driving hours of this model, and previous vehicle model and driving hours.

g) Operating habits when starting the accident vehicle.

h) Whether the driver has participated in any new model training for this electric vehicle; type and contents of training; and training duration.

i) Implement evidence collection and investigation on the process of slamming on the brake during the accident, including whether the intensity and route of the pedal are the same as usual, and whether there is abnormal noise after slamming on the brake.
j) Whether any out-of-control phenomenon/accident has happened before.
k) Remedial measures and the vehicle response when the accident occurred.
l) Storage and disposal of the accident vehicle after the accident.
m) Before the accident, whether the following operations have been conducted for the vehicle: crash on chassis, fording, soaking, battery replacement, refitting, retrofitting, etc.

5.1.2. Vehicle investigations

Although most electric vehicles are designed with the function of power-off after the collision, it is needed to turn off the high-voltage switch once the accident occurred, and to ensure the high-voltage safety, implement high-voltage protection and wear personal protective equipment before the investigation.

a) Whether the vehicle is equipped with starting interlock.
b) Starting mode when starting the accident vehicle, and driving mode during the accident.
c) State of the cruise control system.
d) State of the anti-lock braking system.
e) Operating state of the vehicle during the accident, including starting, driving, after collision, charging and parking.
f) State of charge (SOC) during the accident.
g) Whether the brake light can be turned on after the accident.
h) Collect the information from the instrument panel and central control display. Traffic police shall timely photograph and extract the information in the instrument panel and central control display of the accident vehicle in the primary scene, such as the fault prompt; during the preliminary investigation, and extract the final record in the instrument panel after the power is restored.
i) Vehicle body investigation, including collision, crack, condition affected with water, apparent damage of control unit, looseness or damage of wiring harness, oil leakage, etc. Intensively check whether the wiring harness and connector clip of control unit is loose or damaged, and whether the oil of the whole vehicle is in normal state. (Steps: turn off the starting switch, demount the negative pole of the low-voltage battery, and inspect whether the wiring harness and connector clip of control unit is loose, damaged, affected with water intake or damp, etc.)
j) Check whether there is any foreign matter near the pedal, and preliminarily analyze whether it may cause the blocking of the brake pedal or linkage of the brake pedal to the accelerator pedal.
k) Detect the power supply circuit, grounded circuit and signal circuit of the pedal sensor. Based on the connection between the position sensor on the accelerator pedal and the vehicle control unit (VCU), use the multimeter and oscilloscope to implement the investigation. (Steps: turn off the starting switch, unplug the position sensor on the accelerator pedal, turn on the starting switch, use multimeter to detect the voltage between the power supply terminal of the position sensor plug on the accelerator pedal and the grounding, and identify the state of the power supply circuit of the sensor; turn off the starting switch, and detect the resistance between the ground terminal of the position sensor on the accelerator pedal and the grounding, and identify the state of the grounded circuit of the sensor; connect the position sensor plug on the accelerator pedal, insert a probe into the rear of the signal terminal, observe the dual-path signal of the position sensor on the accelerator pedal by virtue of oscilloscope, and identify the state of the signal circuit of the sensor.)
l) Demount the accelerator pedal and brake pedal of the accident vehicle, and mount them on the vehicle of the same model to compare and test the two collected data streams. Assess the test results of the same pedal sensor under the VCU and Controller Area Network (CAN) line, and read and record the data stream to implement the preliminary investigation of the VCU and CAN line.
m) Due that the electrically controlled system of the electric vehicle is more complex than that of
traditional vehicle, it is difficult to identify problems through visual inspection. Therefore, it is necessary to strengthen the data collection and analysis of the vehicle storage device, the reading and analysis of the fault code and data stream of the associated electronic device, and the detection of the associated electronic components and electrically controlled units, as well as timely extract fault and alarm information, thereby tracing and analyzing the accident, and improving the efficiency of investigation.

① Collect storage device data: After the vehicle is powered on, read the vehicle terminal, data storage module of air bag, EDR data and video data of dash cam; if the vehicle fails to be powered on, demount the above-mentioned main electronic recording module, so that the special device can be used to interpret the important data in the future, thereby avoiding the damage of storage device caused by fire, short circuit and other accidents on the vehicle.

② Analyze terminal data: Read and interpret the data of vehicle terminal, and analyze the interpreted data (the opening of the accelerator and brake pedals, gear stage, etc.).

③ Read data stream: The output signal of brake pedal and accelerator pedal, the remaining electric quantity of power battery, temperature, temperature of the driving motor and other information can be read by special diagnostic instrument.

④ Read fault code: Turn off the starting switch, connect the special diagnostic instrument to the diagnostic interface, turn on the starting switch, successively enter into all the modules to read the fault code, including vehicle control unit module, driving motor control unit module, brake system module, etc., and note the alarm condition of the brake system, the fault of driving motor control unit and VCU communication, and other communication faults.

n) Retrieve backend data: Retrieve the background data of manufacturers, the data of national and local monitoring platforms during the accident as required.

o) Investigate vehicle configurations: ADAS Configuration List.

p) Documents provided by vehicle manufacturer

① Key electronic control unit test report, electromagnetic interference test report, definition of user-defined terms of enterprise backend data, vehicle operation instruction, vehicle maintenance instruction, brake vacuum pump data, vehicle safety test report for factory acceptance, and driving test report.

② Relevant technical data, mainly including control strategies of power control, brake energy recovery and brake light, logic of accelerator/brake pedal, etc.

③ Information of the “three electric systems” of electric vehicle: A. power battery; B. driving motor; C. electric control unit.

④ Wiring diagram of Grade B circuit

⑤ Previous maintenance records of the accident vehicle

⑥ Remote monitoring data of the vehicle within 7 days before the accident

⑦ Fault code definition list of the “three electric systems”.

⑧ Fault alarm control strategies of the “three electric systems”.

5.1.3. Investigation on the environment of the accident section

Investigate the surrounding environment of the road section where the accident occurred, and check whether there are strong interference and special road condition. Test the radio wave, electromagnetic interference source and electromagnetic environment on the accident section.

5.2. Application of new identification method

Apply and improve the Hardware-In-The-Loop Test Technology, strengthen the analysis of vehicle electronic data characteristics, and implement the inspection, identification and safety test of relevant electrically controlled components.

On the one hand, based on the Hardware-In-The-Loop Test System, adopt the simulation model to simulate the operating state of the controlled object in the processor, and connect the tested electrically...
controlled unit to the system via the I/O interface, in order to test the electrically controlled unit. Although the Hardware-In-The-Loop Test has been broadly applied in the automobile development, it is still needed to improve the accident investigation and identification according to the actual demands. For example, in the process of accident identification, emphasize the operating conditions during the occurrence of test case to improve the test efficiency; if there is no strict real-time requirement for the tested units, the configuration of the hardware system can be reduced to save cost. By using multi-source evidence of accident investigation, the accident condition test, fault diagnosis and response analysis of the tested electrically controlled unit can be implemented. On the other hand, analyze the vehicle data to identify the accident cause by virtue of the detailed data collected by the terminal of the electric vehicle.

6. CONCLUSION
1) Many similarities in the form of typical out-of-control accidents of electric vehicles were discovered by an in-depth investigation on such accidents.
2) The possible causes of electric vehicles’ loss of control are analyzed from the perspectives of electromagnetic interference, failure of the automobile system or components, defects in design of control strategy or man-made maloperations.
3) Regarding the indistinct investigation information and Inapplicable Evaluation Techniques for electric vehicle investigation, it elaborates on the investigations and relevant testing steps and methods for the accidents arising from the electric vehicles that are out of control.
4) By borrowing and improving hardware in-loop testing technology and using on-board electronic data feature analysis, it is proposed to improve the inspection, appraisal, and safety testing of the electronic components of electric vehicles.

ACKNOWLEDGEMENTS
This work was supported by the special funds for the Basic Scientific Research Operations of the Central Public Welfare Research Institutes(2019SJA20), Technical research program of the Ministry of Public Security of China(2019JSYJC18), and the National Key R&D Program of China (2018YFB1600802, SQ2019YFB160074).

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