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Experimental study for the reproduction of sudden unintended acceleration incidents

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ABSTRACT

A few cases of the sudden unintended acceleration have been reported over the last few years [1–11] and some of them seemed to be somewhat related to an electronic throttle control (ETC) system [11,12]. In this experimental study, efforts were made to reproduce the cases of sudden unintended acceleration possibly related to the ETC. Typically, an ETC of the engine is managed based on signals from airflow sensor, throttle position sensor and acceleration pedal sensor. With this typical sensor configuration in mind, these sensor signals were checked for noise levels. However, none of them showed any clear relationship with the sudden unintended acceleration mainly due to the robustness of the ETC logic software. As an alternative approach, supply voltage to an engine control unit (ECU) was tempered intentionally to observe any clues for the incidents. The observed results with the supply voltage drop and fluctuation tests were rather astonishing. The throttle valve position went all the way up to 100% for around one second when the battery voltage plunged down to 7 V periodically despite that the acceleration pedal position was kept steady. As an effort to confirm the case, multiple tries were made systematically on a chassis dynamometer as well as on the test road. In this paper, detailed procedures and findings are reported accordingly.

1. Introduction

Over the last few years, several cases of sudden unintended acceleration of vehicles have been reported around the world and some of them have resulted in fatal accidents [10]. During the early days of investigation [1–8], major causes of the incidents were thought to be human errors, namely the misapplication of acceleration pedal instead of brake pedal [1–8]. These results were obtained through the tests with human drivers with a certain sequence of pedal operations under designed driving scenarios. With this approach, the studies showed a certain possibility of human errors resulting into the sudden unintended acceleration however, it was hard to believe that the human misapplication of the acceleration pedal sustained for an extended period of time and ended up in fatal accidents afterwards as happened in many real cases.

Another cause of the sudden unintended acceleration was obtained from the investigations of similar car accidents which were obviously triggered by the sudden unintended acceleration but definitely without the driver mistakes. Conclusion from this investigation showed that the floor mat was one of the main causes of the incidents [9–11]. It explained that the acceleration pedal was pushed and/or stuck by the floor mat resulting in the situation where the acceleration pedal could not return to an idle position. This accidental case caused by the floor mat typically happened along with increased internal friction of old pedal components, poor pedal linkage arrangement or layout and/or unexpected friction of worn-out acceleration cable as the floor mat by itself could not hold the acceleration pedal down to the floor resulting in the wide open throttle operation.

Recent observations paid close attention to the electronic throttle control (ETC) system as the sudden unintended accelerations seemed to happen for the cars with the ETC system and the correlation between the number of incidents and the adoption of the ETC system in the vehicles seemed to be relatively strong [11,12]. Malfunction of the ETC due to whatever reasons could make the problems even worse since the adoption of electronic control and actuation systems in modern vehicles have become general trends for car manufacturing and it is certainly expected to grow in terms of application areas and production volumes [13]. In

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other words, any open or short circuits in the electronic control system made by any debris of conductive material, water or oil contamination of the electronic system may develop the unexpected behaviors of the electronic control system and may result into sudden unintended acceleration accidents. The assumption of possible malfunction of the ETC have gained momentum as the cases were revealed such that (1) the car was found to be accelerating with a brake light on and (2) the driver was discovered to make an emergency call reporting the failure of brake system while driving on a freeway [10]. For the above cases, it was clearly noticed that both drivers knew what was going on and both did whatever they could do to avoid accidents whether they were successful or not.

Major difficulty in the investigation of sudden unintended acceleration comes from the nature of random and rare occurrence of the incidents and on top of that, sources of the problematic behaviors are not only unknown but also different from one case to the other. Furthermore, for some cases, the sudden unintended acceleration occurred unexpectedly by unknown causes and then all of a certain it returned back to normal without any fixes or remedies. Nonetheless, it is strongly believed that many efforts are made to explain these tragic malfunctions and hopefully to provide the way to prevent the incidents one way or another [1–13].

In the current research, efforts were focused on electronic control systems, especially the electronic throttle control system and the engine control unit. Firstly, the sensors in the electronic control system were tweaked by intentionally modifying resistance of sensor wires. During the experiments, none of the disturbance to the sensor signals triggered the sudden unintended acceleration. Secondly, supply voltage to the electronic control system was purposely lowered and perturbed to simulate bad alternator and/or battery system. The result from the manipulation of supply voltage was rather astonishing. The control systems seemed to work even with the perturbed supply voltage but not correctly. As a matter of fact, it seemed to cause the sudden unintended acceleration repeatedly. The supply voltage to the ECU can be disturbed by minor mishap in the alternator output function and possibly by the overload of ever increasing use of electric devices in the vehicle by the driver. In any case, the current study showed the reproduction of the sudden unintended acceleration when the supply voltage changes abruptly by sudden drop of the alternator output voltage or by overload of the electric devices.

2. Experimental setup

A mid-size passenger car with a 3.0 L V6 engine (front loaded engine, front wheel drive) that is equipped with a specific ECU model was selected for the current experimental setup and the specification of the test vehicle is provided in Table 1. Prior to the current investigation, number of suspicious SUA incidents were reported from the cars with similar engines and ECU models. Thus, the current model was selected to be investigated for the possible cause of the SUA incidents. The test vehicle was installed in a chassis dynamometer with which various driving patterns could be simulated. However, in the current investigation, the vehicle speed was limited at 40 km/h by the vehicle power absorbing dynamometer regardless of the throttle position. This test condition is called speed regulation mode and this is an appropriate test setup for the sudden unintended acceleration experiment because the vehicle speed can increase only up to 40 km/h as the power absorbing dynamometer regulates the speed regardless of the throttle position whether it is intended or unintended. With this speed regulation mode of the chassis dynamometer, absorbed horsepower is monitored to identify any suspicious acceleration events since the absorbed power increases as a result of the vehicle acceleration regardless of the source of the acceleration event. Therefore, sudden accelerations of the test vehicles can be detected by observing the changes of the absorbed power over a certain time period. Moreover, it is safe to continue to operate the test vehicle even in the events of sudden acceleration thanks to the speed regulation mode of the chassis dynamometer since the dynamometer would limit the velocity of the vehicle only up to 40 km/h absorbing all excessive power from the test vehicle.

A low voltage power supply system called LVTGO-VBS was installed in the test vehicle as shown in Fig. 1. LVTGO-VBS is a low voltage vehicle battery simulation device specifically developed for vehicle electric system testing with various functionality and the device has been approved and used by a number of well-known automotive manufacturers such as Ford, VW, BMW, Mercedes-Benz and more. LVTGO-VBS has a capability of generating an engine cranking voltage pattern, certain voltage dropout patterns and various waveforms in a randomized fashion along with repeatability imposed on top of the randomization. With the LVTGO-VBS used in the current investigation, various vehicle operating conditions such as a high voltage and high current flow for engine cranking operation, diminutive cycling voltage for alternator output change and electrical load variations were simulated to study possible correlations between the unintended sudden acceleration and the vehicle battery voltage changes and/or drops. A specification of the LVTGO-VBS used in the current study is provided in Table 2. The low voltage and the current level up to 22 V/150 A can be set for various vehicle battery simulation with the maximum response frequency of 1 kHz and furthermore, the ground offset voltage can also be set up to 2.5 V. With this functionality and the specification, the device was deemed to be appropriate for providing vehicle reference electricity replacing the battery in the test vehicle.

Table 1
Specification of test vehicle.

Vehicle size	4910 mm × 1860 mm × 1470 mm
Wheel base	2845 mm
Tire base	1606 (F)/1607 (R) mm
Driving wheel	Front wheel
Transmission	Automatic 6 stages
Fuel	Gasoline
Fuel economy	10.4 km/L
Engine power	270 PS
Engine type	V6
Engine volume	2999 cc
Maximum torque	310 Nm

3. Experimental method

In order to simulate a possible voltage drop pattern of an engine cranking process, LVTGO-VBS provides a voltage pattern template with configurable parameters such as a series of voltages and time intervals. As shown in Fig. 2, the voltage parameters (U0–U7) and the time interval parameters (T0–T9) can be constructed to mimic the voltage drop pattern during the cranking process. Furthermore, these parameters can be re-arranged to furnish any possible abnormality in voltage supplies to various electronic control systems in the test vehicle. With this abnormal voltage supply patterns which can occur during a life time of vehicle operation, simulated tests for the vehicle responses from erratic and unpredictable electric situations can be performed for its fool-proof operation. It is fully anticipated for the vehicle to be robust and reliable under any circumstances. In other words, it is absolutely expected for the vehicle electronic systems to be safe and graceful in handling of faulty conditions under any unexpected voltage perturbations to its power supply lines.