



U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

ODI RESUME

Investigation: PE 16-006
Date Opened: 06/14/2016
Investigator: Kareem Habib
Approver: Michael Brown
Subject: Yaw rate sensor malfunction

Date Closed: 12/20/2016
Reviewer: Jeff Quandt

MANUFACTURER & PRODUCT INFORMATION

Manufacturer: Toyota Motor Corporation
Products: MY2001-2002 Toyota Sequoia
Population: 133,279

Problem Description: Intermittent yaw rate sensor malfunctions result in flashing VSC/TRAC slip indicators on the instrument panel accompanied by warning buzzers and grinding noise or vibration caused by pulsed brake application to one of the front wheels and steering pull in the direction of brake application.

FAILURE REPORT SUMMARY

	ODI	Manufacturer	Total
Complaints:	194	973	958**
Crashes/Fires:	0	0	0
Injury Incidents:	0	0	0
Fatality Incidents:	0	0	0
Other*:	0	914	914

*Description of Other: Warranty reports that relate to repair or replacement of the subject component.

** Total eliminates duplicates received by ODI and manufacturer.

ACTION / SUMMARY INFORMATION

Action: This Preliminary Evaluation is closed.

Summary:

On June 14, 2016, the Office of Defects Investigation (ODI) opened Preliminary Evaluation PE16-006 to investigate 135 complaints alleging incidents of yaw rate sensor malfunctions resulting in unexpected Vehicle Stability Control (VSC) activations and steering pull while driving in model year (MY) 2001-2002 Toyota Sequoia vehicles. ODI identified a total of 958 incidents in complaints provided by Toyota or submitted to ODI by consumers.

ODI conducted the following work to assess the alleged defect in the subject vehicles: 1) evaluated the design of the subject yaw rate sensor; 2) initiated vehicle testing and instrumentation; 3) performed failure analysis on subject components collected from the field; 4) analyzed field data for evidence of system faults; and 5) reviewed the performance of the subject system in fault simulations testing conducted by Toyota.

ODI review indicated that an overwhelming majority of incidents are related to flashing VSC slip indicators on the instrument panel accompanied by warning buzzers and grinding noise or vibration caused by pulsed brake application to one of the front wheels. Yaw rate sensor malfunctions resulting in VSC brake applications is accompanied by a brief duration of longitudinal deceleration with minimal changes in vehicle speed and will not result in abrupt lane change or loss of vehicle control due to steering controllability. This preliminary evaluation is closed. The closing of this investigation does not constitute a finding that a safety related defect does not exist. For additional information, see the closing resume appendix and the investigation file for PE16-006.

APPENDIX

ODI reviewed consumer complaints, information from Toyota, and reviewed extensive vehicle testing to assess safety risks associated with the alleged defect in MY 2001-2002 Toyota Sequoia vehicles. In total, there were 958 unique reports related to yaw rate sensor malfunctions in field technical reports, dealer assistance calls, third party arbitration cases and customer complaints. Approximately 71 percent of complaints reported VSC/TRAC flashing warning lights and a buzzer that may be accompanied by grinding noise or steering wheel vibration caused by pulsed brake application to one of the front wheels with no effects on vehicle controllability. Recovered part failure analysis identified an intermittent short condition in the internal sensor microelectronics due to red phosphorus which when exposed to heat and humidity over the age of the vehicle may result in a false yaw rate offset signal detected by VSC plausibility checks. While VSC activations may result in slight steering pull mostly to the right as reported in approximately 21 percent of complaints, the maximum duration of the pulsed front wheel brake activation is limited and unlikely to cause lane change. Vehicle testing and driving maneuvers indicated that the vehicle remained controllable and stable during all test conditions.

Yaw Rate Sensor

The yaw-rate sensor is a gyroscopic device that measures the vehicle's angular velocity around its vertical axis and is used to determine the vehicle condition and locus of travel. The sensor is located in the center console and comes as standard VSC component on MY 2001-2002 Toyota Sequoia vehicles. The VSC system continuously monitors the yaw signal for fault detection and sensor data to automatically control the brake fluid pressure applied to the wheels and regulate the engine output to maintain traction in case the vehicle is about to experience side slips during an unexpected occurrence, such as a sudden change in the road conditions. According to Toyota, the VSC system continuously evaluates the measured data from at least 4 sensors (e.g. steering angle sensor, yaw signal, lateral and speed sensors) and compares the driver's input with the actual behavior of the vehicle. In the event that a fault is detected in the yaw sensor, the VSC system will be disabled and Diagnostic Trouble Code (DTC) C1234 will be stored accompanied by the VSC/TRAC warning and VSC/TRAC OFF indicator lights; these lights will remain on until the next ignition cycle.

Recovered yaw sensors showing evidence of field failures were purchased from complaint vehicles by ODI in order to be analyzed, tested and cross sectioned to identify all sensor failure mechanisms. Recovered part analysis performed on all 5 sensors collected from the field indicated a shorting condition due to silver migration resulting in an erroneous sensor output signal. Cross sectioning showed evidence of flame retardant red phosphorus particles of varying size and voids (see figure 1) in the sensor digital potentiometer Integrated Circuit (IC) plastic molding compound. Optical images and electron microscopy identified a failure mechanism related to electrochemical migration resulting in an intermittent shorting condition between the IC adjacent pins.

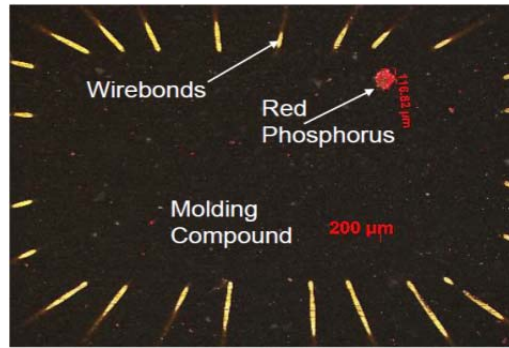


Figure 1

Teardown analysis indicated that when the sensor is exposed to heat and humidity especially over the vehicle lifecycle, red phosphorus may form an electrolytic combination of phosphine gas and phosphoric acid resulting in extremely low leakages currents due conductive filaments and corrosion. Heat and humidity effects on sensor field life are confirmed in complaint data with 72 percent of complaints are related to hot and humid states. Complaint incident dates indicated that sensor malfunctions related to Phosphorus Flame Retardants may take approximately 7 years of field exposure to manifest any intermittent shorting conditions due to migration, see figure 2. Toyota and its suppliers, Continental and Analog Devices, changed the molding compound from Phosphorus Flame Retardant (PFR) to non-PFR effective October 2002.

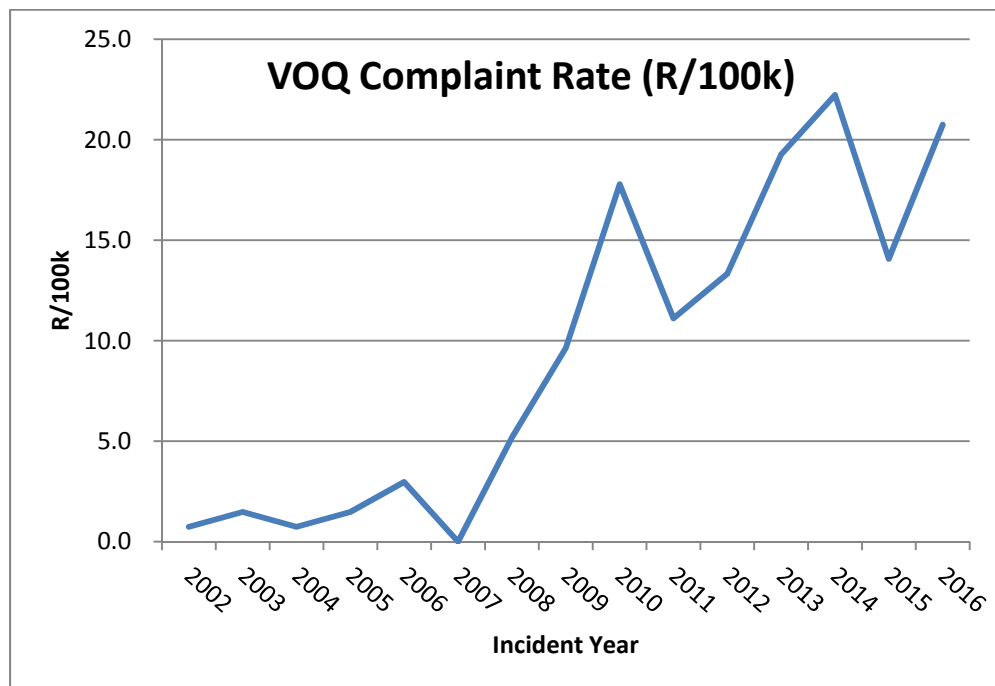


Figure 2

Vehicle Testing

In addition to reviewing test data submitted by Toyota, ODI conducted the following work to assess the alleged defect in the subject vehicles 1) evaluated the design of the subject yaw rate sensor, including VSC plausibility fault detection and monitoring; 2) initiated vehicle testing and instrumentation to analyze the frequency and severity of unintended VSC activations under various operating conditions; 3) reproduced fault conditions of subject components collected from the field to identify and validate failure root cause; 4) performed controlled fault injection pulses to identify any evidence of marginal system faults that may be related to the alleged defect; and 5) reviewed the performance of the subject system in fault simulations testing scenarios conducted by Toyota.

Vehicle testing performed at NHTSA Vehicle Research and Transportation Center (VRTC) and conducted by simulating various yaw rate sensor offset conditions during driving maneuvers and vehicle speeds could not yield any significant path deviation or vehicle deceleration as a result of inappropriate VSC interventions. Failure cases of the yaw rate sensor attempted to reproduce vehicle owner complaints and extensive evaluation of the VSC fault detection logic was conducted using modified yaw rate data with a failure signal routed into the VSC controller, see figure 3. Testing results showed that no VSC intervention related to sensor malfunctions in straight line driving, understeer or oversteer conditions caused any vehicle directional changes that were likely to result in lane departure or difficulty controlling the vehicle. The longest VSC intervention occurred with yaw sensor output below 10deg/sec and resulted in pulsed brake application to the front right wheel for approximately 15 second under straight steady driving conditions above 30mph. Under these conditions, the offset steering torque required to maintain vehicle direction is consistent with a vehicle pull condition that a customer may experience due road crowns, crosswind or wheel misalignment. In the event the operator does not maintain control of the vehicle by keeping his hands on the wheel, small changes in the vehicle direction of travel may occur which may be counteracted by small steering angles. VSC interventions due to yaw sensor offset conditions above 10deg/sec are extremely brief lasting no more than a fraction of a second resulting in abrupt noise and vibration from the steering wheel (frequently reported as steering wheel jerk by the driver) without any effects on vehicle steering or controllability.



Figure 3

Crash and Injury Assessment:

ODI analyzed 5 crash incidents that involved allegations of VSC activations that may be related to yaw rate sensor repairs or warning lights associated with the yaw sensor diagnostic trouble code (DTC) C1234. Evidence was either insufficient to assess cause or pointed to other factors in 3 incidents and the other two crashes involved minor impacts (e.g. curb strike). One incident (VOQ 10493352) alleged that the Sequoia hit a surface post on the side of the road when the truck moved back and forth with the seatbelt tightening. The driver referenced no allegations of vehicle pull to the side and VSC activations will not result in seatbelt retractor activation. The second incident involved a minor curb strike and damage to front right wheel. According to Toyota repair records, the yaw rate sensor for this vehicle was replaced under warranty one month prior to the incident. Intermittent yaw rate sensor malfunctions related to the encapsulated PFR material requires approximately 7 years of exposure to heat and humidity, and the service part is unlikely to have caused the alleged minor impact.

The third incident (VOQ 10461478) involved an allegation that the VSC activated and the vehicle pulled to the right causing a crash at highway speed. The crash took place on interstate I-95 while the vehicle operator was driving on a trip from FL to VA. According to the police crash report, the driver was executing a lane change to the right and reacted to a vehicle in the blind spot by rapidly aborting the maneuver and jerking the steering wheel causing loss of control, fishtail and crash. Toyota and ODI independently inspected the vehicle and retrieved chassis and airbag diagnostic trouble codes including DTC C1234 associated with the yaw rate sensor. DTCs recovered during inspection were most likely associated with the artifact of loss of vehicle control due to the evasive maneuver undertaken by the driver resulting in a crash. Additionally, the yaw rate sensor malfunction was diagnosed and repair declined approximately eighteen months prior to the crash. Yaw rate malfunctions have no significant effects on vehicle steering or controllability and will not cause the vehicle to abruptly change lane.

A fourth incident involved allegations of ABS failures resulting in a minor rear end crash when the preceding vehicle suddenly applied the brakes. Complaint records indicated yaw rate sensor DTC C1234 and brake repair approximately one month prior to the incident related to ABS and the owner indicated no stopping distance concerns prior to the incident. In the event VSC inappropriately activates as a result of a yaw rate sensor malfunction, the vehicle braking performance is maintained and the vehicle can be stopped by brake application. The last incident did not involve any DTCs or warning lights associated with the yaw sensor.

VOQs: The following VOQs are associated with the closing resume for PE16-006:

10049104, 10137681, 10139641, 10166357, 10166473, 10232169, 10233745, 10238578, 10250448, 10251654, 10266864, 10268705, 10277153, 10277283, 10280989, 10283454, 10293341, 10307457, 10313456, 10322783, 10326046, 10328039, 10328193, 10332273, 10335253, 10336305, 10336461, 10340336, 10345425, 10346267, 10346862, 10350806, 10362837, 10363694, 10363807, 10365058, 10365937, 10367931, 10369049, 10371231, 10372308, 10382828, 10393560, 10394361, 10398012, 10402588, 10405657, 10410211, 10410758, 10413334, 10414662, 10415928, 10417138, 10422228,

10422611, 10423033, 10428158, 10428170, 10440213, 10443162, 10446216, 10452949, 10454205, 10456979, 10457214, 10459160, 10459819, 10460771, 10461478, 10461748, 10461749, 10465160, 10466862, 10467877, 10468481, 10469248, 10470780, 10484951, 10490568, 10492321, 10493352, 10502275, 10504909, 10512744, 10515727, 10519373, 10519417, 10524511, 10532776, 10533611, 10536498, 10538259, 10538429, 10544345, 10545390, 10545651, 10546430, 10547393, 10548121, 10548390, 10553756, 10554761, 10557541, 10562563, 10563106, 10574622, 10585822, 10586493, 10594348, 10598228, 10598410, 10604499, 10604887, 10606105, 10606484, 10607843, 10609313, 10615167, 10615491, 10622590, 10626485, 10627946, 10628214, 10632010, 10632788, 10638442, 10639128, 10648921, 10649475, 10671957, 10676233, 10680083, 10692211, 10712903, 10715406, 10715759, 10721840, 10722542, 10723782, 10725403, 10731062, 10731635, 10734673, 10735958, 10735983, 10748894, 10759414, 10760105, 10761804, 10762033, 10765299, 10783037, 10785944, 10789869, 10794540, 10816351, 10816792, 10822732, 10825460, 10836713, 10838509, 10855618, 10860250, 10862787, 10865303, 10865587, 10870753, 10874562, 10874949, 10876498, 10882941, 10884342, 10884709, 10885373, 10886256, 10887636, 10896143, 10896879, 10897014, 10897201, 10897868, 10898957, 10899180, 10901906, 10903913, 10905674, 10905997, 10907303, 10908032, 10909417, 10911337, 10914008, 10915170, 10917967.