Unintended Acceleration with a Confirmed Cause

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Abstract: An unusual form of unintended acceleration has been reported whereby the vehicle accelerates on its own after releasing the accelerator pedal on a flat road or when coming to a stop. Yet, the engine works normally when the vehicle is not moving. The problem has been traced to using the wrong size tires. After changing the tires back to the size recommended by the automobile manufacturer, the problem disappears. This paper explains how this unusual form of unintended acceleration is caused by the electronic stability control system on a rear wheel drive vehicle increasing the speed of the rear wheels when the front wheels are spinning faster than the rear wheels because the tires are different sizes.

I. Introduction

While researching the topic of sudden unintended acceleration, the author found nine references to an unusual form of unintended acceleration in vehicles with electronic throttles. The symptoms of these unintended acceleration incidents were as follows:

1. While driving with one's foot on the accelerator, the vehicle would speed up slowly with time. This was most noticeable at higher speeds around 50-60 MPH.
2. After releasing the accelerator pedal, but with the vehicle still in gear, the car would speed up and the driver had to keep his foot on the brake to slow it down. This happened when slowing down on a highway or entering a turnabout.
3. After releasing the accelerator pedal and pushing in the clutch, the engine would rev up to 4K to 6K RPM and stay there indefinitely. This happened when approaching a stop sign or a stop light.
4. In cruise control the speed did not stay constant. The vehicle would continue to accelerate, getting up to 90 MPH in just a few seconds.
5. When the vehicle was completely stationary, the engine did not over-rev any more.
6. The unintended acceleration behavior happened consistently, and did not go away when the ignition was turned off and then back on again.
7. No diagnostic trouble codes were found after the unintended acceleration.
8. The unintended acceleration behavior started immediately after changing the tires to a set having smaller tires on the front than on the rear.
9. The unintended acceleration behavior could be eliminated by changing the tires back to the tire sizes recommended by the auto manufacturer.
10. The unintended acceleration behavior could be eliminated by turning off the electronic stability control.

This was not the usual unintended acceleration reported often in the press, because:

1. it was not sudden,
2. it did not occur immediately after shifting out of PARK or NEUTRAL,
3. it happened consistently, and
4. it did not go away when the vehicle's ignition was turned off and then back on again.

What could cause this unintended behavior? Could it be another form of sudden unintended acceleration caused by electronic throttles?

II. Cause of the Unintended Acceleration

A. <u>Vehicle Types</u>. The vehicles exhibiting this unusual form of unintended acceleration were similar in that they were 2-door coupes with manual transmissions and rear wheel drive (RWD). One vehicle was a 2001 BMW E46 325ci Cabrio. The other was a 2009 Hyundai Genesis Coupe 2.0T. These two vehicles belong to a class of vehicles known as compact sport cars, which includes vehicles such as Ford's Mustang, Chevrolet's Camaro, Volkswagen's Golf GTI and Golf R, Nissan's 370Z, Honda's Accord V6 coupe, and Toyota's Scion FR-S. These vehicles are purchased by drivers who want the thrill of driving a sport car, but at a much lower price than most sport cars. The key features of these two vehicles are summarized in Table 1.

Table 1. Key features of the two vehicles exhibiting this unusual form of unintended acceleration.

	2001 BMW E46 325ci Cabrio	2009 Hyundai Genesis Coupe 2.0T
		
Chassis type	2-door coupe	2-door coupe
Engine	2.5L I-4, 189 hp, 181 ft-lb torque Naturally aspirated Electronic throttle	2.0L I-4, 210 hp, 223 ft-lb torque Turbocharged Electronic throttle
Transmission	5-speed manual	6-speed manual
Drive train	Rear wheel drive (RWD)	Rear wheel drive (RWD)
Safety features	Dynamic Stability Control (DSC-III), with: a) Anti-lock Brake System (ABS) with: • Electronic Brake Force Distribution (EBV) • Corner Brake Control (CBC) b) Automatic Stability Control & Traction Control (ASC+T) with: • Automatic Differential Braking (ADB) • Engine Drag Torque Reduction (MSR) c) Dynamic Stability Control (DSC) with: • Dynamic Brake System (DBS) • Dynamic Brake Control (DBC) • Maximum Brake Control (MBC)	Vehicle Dynamic Control (VDC)[1] with: a) Anti-lock Brake System (ABS) with: • Electronic Brake Force Distribution (EBD) • Brake Assist System (BAS) b) Electronic Stability Control (ESC) c) Traction Control System (TCS) d) Vehicle Dynamic Control (VDC)

Even though both of these vehicles had electronic throttles, it turned out that the unintended acceleration was not caused by the electronic throttle. It was caused by the wrong size tires.

B. <u>Cause of the Unintended Acceleration</u>. The cause of the unintended acceleration was quickly determined by the drivers comparing their experiences on two different Internet sites.[2,3] Their experiences showed that the unintended acceleration was caused by using smaller size tires on the front of the vehicle than on the rear. The smaller size tires were installed because the drivers wanted their sporty cars to look sleeker and faster than the vehicles sold by the manufacturer. But several drivers noted that their unintended acceleration problems began as soon as the new tires were installed. Several other drivers noted that these same unintended acceleration problems stopped as soon as the different size tires were replaced by the tires recommended by the auto manufacturer. Table 2 summarizes the experiences of all the drivers involved.

Table 2. Tire characteristics for nine cases of unintended acceleration showing that unintended acceleration is caused by the rear-to-front tire diameters being larger than the auto manufacturers intended.

Case	Make of Vehicle	Drive Wheel	Tire Size With Unintended Acceleration	Tire Diameter With Unintended Acceleration[5]	Dia % Diff (R/F) with UA	Tire Size Without Unintended Acceleration	Tire Diameter Without Unintended Acceleration[5]	Dia % Diff (R/F) w/o UA	Original Equipment Tire Size	Original Equipment Tire Dia	Dia % Diff (R/F) OEM
NaomiONeill[1]	2001 BMW E46 325Ci Cabrio	RWD[6]	225/40R18 (F) 255/40R18 (R)	637 mm 661 mm	+4.2%	255/35R18 (F) 255/35R18 (R)	636 mm 636 mm	0%	205/55R16 (F) 205/55R16 (R)	632 mm 632 mm	0%
ABGEN15[2]	2009 Hyundai Genesis Coupe	RWD[2]	245/40R19 (F) 275/45R19 (R)	679 mm 730 mm	+7.2%	255/35R19 (F) 275/35R19 (R)	661 mm 675 mm	+2.1%	225/45R18 (F) 245/45R18 (R)	660 mm 678 mm	2.7%
Randycb7[3]	2009 Hyundai Genesis Coupe	RWD[2]	225/45R18 (F) 255/45R18 (R)	660 mm 687 mm	+4.0%	225/45R18 (F) 255/40R18 (R)	660 mm 661 mm	0%	225/45R18 (F) 245/45R18 (R)	660 mm 678 mm	2.7%
Everydae[4]	Hyundai 2.0T Genesis Coupe	RWD[2]	215/45R17 (F) 225/45R18 (R)	625 mm 660 mm	+5.3%	225/45R18 (F) 225/45R18 (R)	660 mm 660 mm	0%	225/45R18 (F) 245/45R18 (R)	660 mm 678 mm	2.7%
forwheeldrift[2]	2009 Hyundai Genesis Coupe	RWD[2]	225/40R19 (F) 245/50R19 (R)	663 mm 728 mm	+9.3%	--- ---	--- ---	---	225/45R18 (F) 245/45R18 (R)	660 mm 678 mm	2.7%
ESBjiujitsu[2]	2009 Hyundai Genesis Coupe	RWD[2]	Changed (F) ---	--- ---	+6.5%	--- ---	--- ---	---	225/45R18 (F) 245/45R18 (R)	660 mm 678 mm	2.7%
daniel1pist[2]	2009 Hyundai Genesis Coupe	RWD[2]	Only ratio given	--- ---	+7.2%	--- ---	--- ---	---	225/45R18 (F) 245/45R18 (R)	660 mm 678 mm	2.7%
renesis[2]	2009 Hyundai Genesis Coupe	RWD[2]	Changed (F) 245/45R18 (R)	--- ---	---	--- ---	--- ---	---	225/45R18 (F) 245/45R18 (R)	660 mm 678 mm	2.7%
Black&yellow[2]	2009 Hyundai Genesis Coupe	RWD[2]	No details provided	--- ---	---	--- ---	--- ---	---	225/45R18 (F) 245/45R18 (R)	660 mm 678 mm	2.7%
Rizor-Epb[2]	2009 Hyundai Genesis Coupe	RWD[2]	225/35R19 (F) ---	640 mm ---	---	225/35R19 (F) 235/35R20 (R)	640 mm 673 mm	+5.0%	225/45R18 (F) 245/45R18 (R)	660 mm 678 mm	2.7%
Red Raspberry[2]	2009 Hyundai Gen Coup 2.0T	RWD[2]	--- ---	--- ---	---	225/50R18 (F) 245/50R18 (R)	682 mm 702 mm	+3.0%	225/45R18 (F) 245/45R18 (R)	660 mm 678 mm	2.7%

1. http://www.bimmerforums.co.uk/forum/f18/2001-e46-325ci-accelerating-its-own-fixed-t26145/index2.html
2. http://www.gencoupe.com/2-0t-discussion-2008-2012/115069-car-accelerating-revving-up-its-own-help.html
3. http://www.gencoupe.com/member.php?u=20636
4. http://forums.anandtech.com/showthread.php?t=2049913
5. http://www.tyresizecalculator.com/tyre-wheel-calculators/tire-size-calculator-tire-dimensions
6. http://www.boards.ie/vbulletin/showthread.php?t=2055779425. *See also:* https://en.wikipedia.org/wiki/BMW_3_Series_(E46)

Table 2 shows that nine drivers experienced unintended acceleration as a result of using the wrong tire size. Seven of these drivers reported that the unintended acceleration was experienced while using tires having a diameter difference of 4% or more between the front and the rear. In all nine cases the larger diameter tires were placed on the rear drive wheels. Four of these drivers gave the tire diameters for the new tires for which unintended acceleration was no longer present. The tire diameters in these four cases had a rear-to-front diameter difference of less than 2.1%. These acceleration-free diameter differences agreed with the tire diameter differences recommended by the automobile manufacturer, which were 0% for the BMW, and 2.7% for the Hyundai. Two other drivers reported that they used different diameter tires without experiencing unintended acceleration. In one case, the tire diameter difference was very close to the OEM value recommended by Hyundai (3.0% versus 2.7%), while in the other case it was quite a bit larger (5.0% versus 2.7%). The 5% case is an anomaly that may have been caused by the driver just not noticing the unintended acceleration. But a more likely explanation is provided later in this paper.

We see, then, that unintended acceleration can be caused on a rear wheel drive vehicle by using tires on the rear wheels that are about 3% larger in diameter than the tires on the front wheels[Note1]. But why should the wrong size tires cause unintended acceleration?

C. <u>Root Cause of the Unintended Acceleration</u>. One of the drivers went so far as to ask Hyundai for the cause of this problem. Hyundai replied that it was caused by the car's Vehicle Dynamic Control (VDC) system, which recognized the slower rotation of the rear wheels during deceleration as slip, so it opened up the throttle to speed up the rear wheels to match the speed of the front wheels. But no matter how fast the rear wheels spin the front wheels spin even faster. This makes the VDC system open up the throttle even

Note1. The same effect happens if either the original front tires are replaced by smaller diameter tires, or the original rear tires are replaced by larger diameter tires.

more to make rear wheels spin even faster, creating a positive feedback situation that produces a runaway engine condition. The driver receiving this explanation thought that the explanation sounded suspicious because the Electronic Stability Control System should work by braking, and not by increasing the throttle. So he thought that Hyundai was using this explanation merely to cover up their awareness that their vehicles were susceptible to normal sudden unintended acceleration. He therefore asked NHTSA to look into the issue as an example of sudden unintended acceleration in Hyundai vehicles. Several other drivers agreed with this driver's understanding of how the Electronic Stability Control System should work.

The present author has looked deeper into the cause of this unintended acceleration. He found that the Owner's Manual for the 2010 Hyundai Genesis Coupe contains the following warning in its chapter on the Electronic Stability Control (ESC) system[4]:

> ⚠ **CAUTION**
>
> ***Driving with varying tire or wheel sizes may cause the ESC system to malfunction. When replacing tires, make sure they are the same size as your original tires.***

.

He also found a Mercedes Benz Owner's Manual that contains the following statement: "Driving the vehicle with different size tires will cause the wheels to rotate at different speeds, therefore the acceleration slip control will activate (yellow ASR function indicator lamp on instrument cluster comes on). For this reason, all wheels, including the spare wheel, must have the same tire size".[5]

These references clearly imply that the origin of the unintended acceleration was in the electronic stability control system. Yet, an intensive search of Hyundai documents produced no descriptions of their Vehicle Dynamic Control (VDC) system or anything else that mentioned the throttle being used to control an undesired condition. The best description of the Vehicle Dynamic Control (VDC) system he could find from Hyundai was an advertising release that contains the following statement[6]:

> *"Hyundai safety is currently considered as one of the most admired safety systems in the automotive industry right now. This is because Hyundai has been very active in implementing its policies aimed to make their vehicles safer in almost every driving condition. The company's Research and Development division has been very busy in exploring a lot of technologies to further enhance the safety features of all the vehicles that they release in the market. Due to this, Hyundai has received a lot of recognitions from several agencies such as the IIHS and the NHTSA. Hyundai vehicles obtained these recognitions by using the most advanced safety technologies such as the following".*
>
> *"1. Active Safety Technologies"*
>
> *"Hyundai's active safety technologies are installed on the company's vehicles to ensure that each of these would be able to avoid or prevent accidents and collisions that could lead to damages and injuries. The Anti-lock Braking System (ABS) is offered as a standard safety feature in all Hyundai cars to enable these vehicles to avoid collisions by reducing the braking distance and enable the driver to gain full control of the vehicle in challenging conditions such as when travelling on slippery roads".*
>
> *"The Electronic Brake-force Distribution (EBD) which is also offered as a standard feature enables Hyundai vehicles to prevent the occurrence of accidents by properly distributing the brake force of the car in its front and rear wheels depending on the changes on the weight of the car. The Brake Assist System maximizes car's brake force to shorten the braking distance in emergency situations".*
>
> *"The Traction Control System (TCS) on the other hand, prevents wheel slips when the vehicle moves from a stationary position. In addition to this, the TCS also increases the car's capabilities to accelerate and climbing abilities most especially on slippery surface"* .

"The Vehicle Dynamic Control (VDC) enables Hyundai vehicles to handle sudden stops and turns without compromising the vehicle's stability by exercising full control over the engine's torque and brakes. The Brake Assist System (BAS) also helps Hyundai cars to become more responsive in emergency situations that require sudden stops by enabling the vehicles to produce greater brake force".

Finally, the author found two BMW documents which answered the question of why using the wrong size tires can cause unintended acceleration. The first document is entitled "*BMW E46 Traction Control Systems*".[7] This document contains a complete description of all the sensors and actuators comprising BMW's electronic stability control system, which it calls their Dynamic Stability Control (DSC-III) system, along with descriptions of how these components are used to control vehicle stability in every situation of interest. This document was used to prepare the BMW safety features entry in Table 1 of this paper, and is recommended reading for anyone interested in understanding how electronic stability control systems are supposed to operate. The document states the following on page 38:

> *"**ASC Sub-function Engine Drag Torque Reduction (MSR)***
> *If the vehicle is driven in low gear when coasting downhill, or if there is a sudden shift to a lower gear, the wheels may be slowed down by the engine braking effect to rapidly. This could result in an unstable situation.*
> *If the front wheels are turning faster than the rear wheels the DSC III control unit signals the DME via the CAN bus to **raise** the engine torque. DME cancels fuel cut-off and allows the engine speed to increase, this allows the drive wheels to accelerate to match the speed of the non-driven wheels.*
> *MSR regulation is cancelled if the brake pedal or hand brake is applied".*

The second BMW document is entitled "*BMW Vehicle Communication Software Manual*".[8] It contains instructions for testing BMW vehicles using a scan tool. In the section 4.3.2 on testing the ABS and Traction Control systems, it states the following on page 33:

> ***"ASC Engine Drag Torque Reduction (MSR)—Deceleration Slip Control***
> *During deceleration, if the front wheels are turning faster than the rear wheels, the DSC III control unit signals the DME (via the CAN bus) to accelerate the engine. The DME cancels fuel cutoff and allows the engine speed to increase, which accelerates the rear wheels to match the front wheels. This situation could happen if the driver shifts into too low a gear when coasting downhill, causing the rear wheels to slow down due to engine braking, which could cause vehicle instability.*
> *NOTE: MSR regulation is cancelled if the brake pedal or hand brake is applied".*

These two BMW references clearly answer the question of why using the wrong size tires can cause unintended acceleration. They are believed to apply to Hyundai vehicles as well because Hyundai often states that its vehicles are intended to compete with BMW vehicles.

C. Deactivating the Electronic Stability System. On both vehicles, the electronic stability control system is normally activated each time the vehicle's ignition is turned ON, and stays ON unless it is turned OFF. Both BMW and Hyundai provide the ability in their vehicles to turn the system OFF when desired. This feature is provided by the manufacturers ostensibly for test purposes or to allow rocking the vehicle to free to from being stuck in mud or snow. But many BMW and Hyundai owners like to turn it OFF in order to allow more thrill-seeking driving maneuvers like engine braking, sliding sideways when turning a sharp corner, or doing a 360-degree turn by sliding sideways with the wheels spinning ("doing doughnuts"). This is why they pay to purchase such a sporty vehicle.

BMW provides a DSC-III switch on the dashboard for this purpose. The switch allows switching between three different states:

1) normal electronic stability control system operation,

2) de-activating only the yaw control function (short press <2.5 sec), and
3) de-activating all ASC, ADB, DSC, GMR (yaw control) and DBC control functions (long press > 2.5 sec).

Complete instructions on how to do the switching, and how to know what state the system is in, may be found in the BMW Owner's Manual[9], the BMW E46 Traction Control Systems document[10], or the BMW Vehicle Communication Software Manual[11]. Instructions have also been posted by several individuals on the Bimmer Owner's Forum.[12]

Hyundai provides an Electronic Stability Control (ESC) ON/OFF button for this same purpose. By pressing the ESC OFF button for 0.5 seconds or more, one can cancel all ESC operation. Complete instructions on how to do the switching and how to know what state the system is in can be found in the Hyundai Genesis Coupe Owner's Manual.[13]

This DSC ON/OFF button explains the experience of the BMW driver who noted that the unintended acceleration could be eliminated in the BMW 325ci Cabrio by pressing the DSC-III button, which turns OFF the electronic stability control system. It also may explain the observation of the Hyundai Genesis Coupe 2.0T driver "Rizor-Epb" who noted that unintended acceleration was absent even though he was using different size tires on the front and rear with a diameter difference of 5%. This would happen if he consistently drove with the ESC button OFF, which is the practice of some Genesis Coupe drivers who like the thrill of pushing their car's performance.

It is clear now that unintended acceleration is caused by the engine drag torque reduction (MSR) function in the vehicle's electronic stability control system when decelerating and when the vehicle's front wheels are spinning faster than the rear drive wheels because the tires are different sizes. This causes the MSR function to speed up the rear drive wheels to maintain traction as a countermeasure against the perceived tire rear slip. To understand more deeply how this happens, we must look at the control system operation.

D. Control System Operation. A 1993 Bosch patent[14] explains how the MSR function works in the vehicle's electronic throttle system. Figure 1 below shows a figure from the Bosch patent that explains how the slip-removing torque T_{MSR} calculated by the ASR and/or MSR unit is temporarily inserted into the engine power control system in place of the torque T_{REQ} requested by the driver or the cruise control system. The processing unit 36 interpolates between T_{MSR} and T_{REQ} to smoothe the transition between the two torques. The author has added to the patent figure a schematic of the vehicle showing its engine and wheels, along with four wheel speed sensors that connect to the ASR/MSR unit. He has also re-named the output of the patent's ASR/MSR unit as T_{MSR} instead of DKE, and the output of unit 32 as T_{REQ} instead of DKV to clarify that these two outputs are engine torque commands that control the engine's torque by controlling the engine's electronic throttle. These torque commands appear between the pedal map, which converts the accelerator pedal position at a given engine speed into a requested engine torque, and the inverse engine map, which converts the requested torque at a given engine speed into a requested cylinder air charge or throttle opening command. Other torques may be added to the driver-requested torque to satisfy internal engine functions, such as idle-ups, transmission shift smoothing, or external functions, such as cruise control.

The way the MSR function is supposed to work is as follows. The ASR/MSR unit continually monitors the four wheel speed sensors for tire slippage. If no tire slippage is sensed, then the requested torque T_{REQ} from the accelerator pedal map is used to set the engine torque and speed. If rear tire slippage is sensed during a deceleration on a rear-wheel drive vehicle, then the ASR/MSR unit calculates a new engine torque T_{MSR} that will stop the slippage by backtracking the wheel speeds from the desired non-slip wheel torques through the tire diameters, through the powertrain system, and the through engine, to an engine torque command T_{MSR} that will stop the slippage. The slippage-free torque T_{MSR} that results is greater than the torque T_{REQ} currently being used for engine control. The slippage-free torque T_{MSR} temporarily increases the wheel speed of the slipping rear tires to make them the same speed as the front tires. If everything works as planned, this stops the slippage of the rear wheels, or at least reduces their slippage so that another iteration of the loop can reduce it some more. Eventually, the ASR/MSR unit detects no slippage, and the original torque controlling the engine, T_{REQ}, is used once more. This means that the loop shown in red in Figure 1 is active only when there is tire slippage, and is inactive or absent when there is no tire slippage. Usually, this loop is allowed to be active only above some minimum vehicle speed, such as 25 MPH. The loop can also be disabled by a button on the dashboard which turns off all or part of the electronic stability control system.

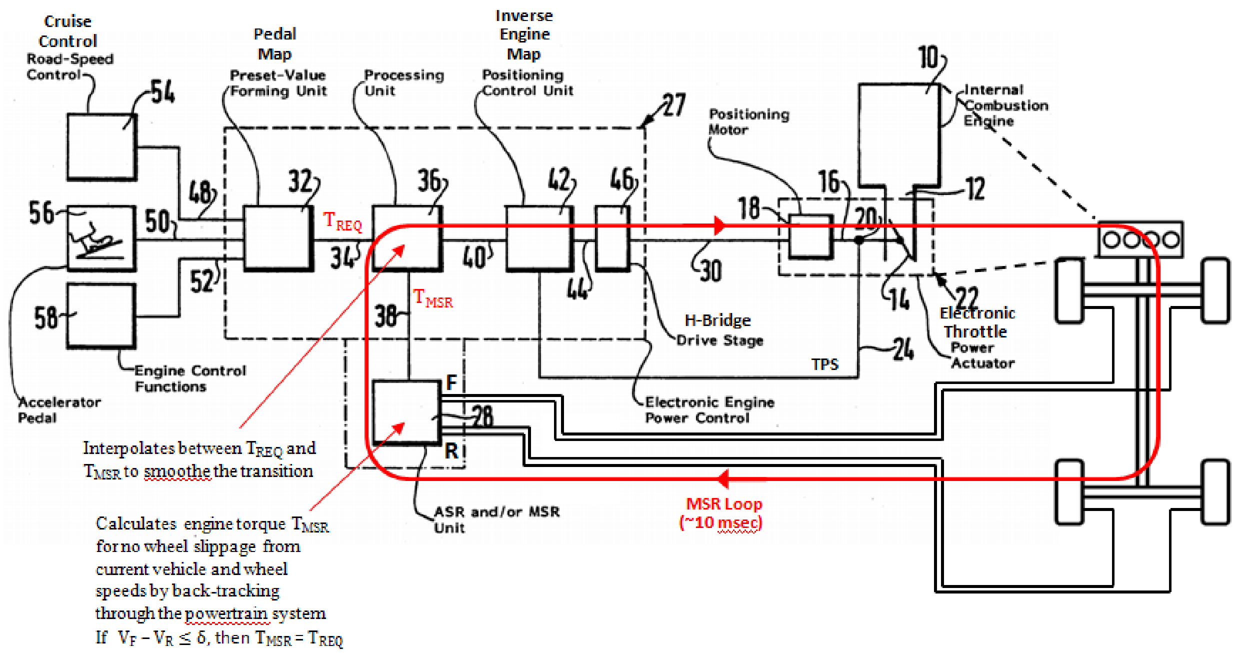

Figure 1. Bosch patent US5235950 shows how the engine drag torque (MSR) reduction function in the electronic stability control system calculates a higher torque T_{MSR} than the normal engine torque T_{REQ} requested by the driver or the cruise control whenever the car is decelerating and the rear drive wheels are detected as slipping because the rear wheels are turning slower than the front wheels. This new torque T_{MSR} creates a control loop that is active as long as the wheel speeds differ by a given amount δ.

Consider now what happens when the tire diameters differ by more than the auto manufacturer recommends. In this case, the wheel speeds of the front and rear tires differ by an amount greater than the auto manufacturer has assumed during the controller design, and the ASR/MSR unit interprets this difference of wheel speeds as slip. If this happens during deceleration, when the rear wheels are spinning slower than the front wheels because the rear tires are larger in diameter, then the ASR/MSR unit calculates a new engine torque $T_{MSR} > T_{REQ}$ which will reduce the rear wheel slip. When it does this calculation, however, it assumes the OEM values of the tire diameters when backtracking the wheel speeds through the powertrain system into the new engine torque T_{MSR}. This new torque T_{MSR} then sets the engine torque. But when this engine torque is transferred to the rear drive wheels, the vehicle uses the radius of the current tires, which have a larger radius than the OEM tires. This means that a greater torque is applied to the rear wheels than assumed by the ASR/MSR unit, making the rear wheels spin faster than expected by the ASR/MSR unit.[Note2]

[Note2] Increasing the tire radius increases the wheel torque, since wheel torque equals force times wheel radius.

On the next iteration through the loop, the wheel speeds of the front and rear tires differ again by the same amount because their tire diameter ratio is fixed, so the ASR/MSR unit again interprets this difference of wheel speeds as slip. Again, it calculates a new engine torque $T_{MSR} > T_{REQ}$ by backtracking the wheel speeds through the powertrain system, but again using the OEM values of the tire diameters. Again, this new torque T_{MSR} sets the engine torque. But when this new engine torque is transferred again to the rear drive wheels, the vehicle uses the current tire diameters, which have a larger tire radius than the OEM tires. So when this new engine torque is transferred to the rear drive wheels, the vehicle uses the current tire diameters, which have a larger radius than the OEM tire diameters. This means that a greater torque is applied to the rear wheels than assumed by the ASR/MSR unit, making the rear wheels spin even faster than expected. This increase in wheel speed, brought about by the difference between the current tire diameter ratios to the OEM-recommended tire diameter ratios, causes the vehicle speed to increase without bound. It is very similar to a cruise control function. But the cruise control function uses a closed-loop feedback controller that can reduce the vehicle speed if it exceeds a given set-speed, while the ASR/MSR unit controller uses a feed-forward type controller without feedback that can only increase the rear wheel speed. Therefore, the ASR/MSR controller cannot detect that its torque commands are increasing the rear wheel speed without bound, and the vehicle speed runs away. The only way to stop the behavior is to apply the brakes with brute force to bring the vehicle speed below the minimum speed of about 25 MPH. But when this is done, the engine speed stays high because the ASR/MSR torque command T_{MSR} is still active, causing the engine to have a higher torque than the driver requests. This is very hard on the vehicle's brakes.

III. Comments and Observations

It is interesting to compare the unintended acceleration caused by wrong tire sizes as explained above with the sudden unintended acceleration caused by electronic throttles and IAC valves as explained in the author's earlier papers.[15] This comparison is shown in Table 3 below. Both types of unintended acceleration are caused by the vehicle, and not by the driver pressing on the accelerator pedal. And both types of unintended acceleration are caused by feed-forward open-loop controllers issuing commands to the engine that are modified by vehicle conditions that were not anticipated during the design of the control system. Because the controllers are incapable of feedback control, their commands can only increase the engine torque, which results in a runaway of either the engine speed or the vehicle speed.

Table 3. Comparison of two types of vehicle-produced unintended acceleration

Type of Unintended acceleration	Control Instability	Control Loop	Controller Issuing Engine Command	Type of Controller	Cause of Larger Command than Expected
Unintended acceleration by different size tires	Runaway vehicle speed	Wheel speed to ASR/MSR controller	ASR/MSR controller	Feed-forward open-loop	Larger drive wheel size
Sudden unintended acceleration by electronic throttle or IAC valve	Runaway engine speed	Engine speed to inverse engine map	Inverse engine map	Feed-forward open-loop	Larger throttle motor or IAC gain

It is also appropriate to make the following comments comparing this new form of unintended acceleration to the more common form of sudden unintended acceleration usually found in the press:

1. This new form of unintended acceleration is not caused by pedal confusion, stuck accelerator pedals, or by unsecured floor mats. In fact, it is not caused by the driver doing anything unusual at all. From a liability viewpoint, it is caused by the vehicle owner putting the wrong size tires on the vehicle against the manufacturer's recommendation. But from a technical viewpoint, it caused by

the design of the vehicle's electronic stability system reacting to the increased torque produced when using the wrong size tires. The auto manufacturers know that this can happen, and warn car owners against using the wrong size tires for this reason. But their warnings are buried deep in the details of their owner's manuals, and do not state clearly that using the wrong size tires will result in unintended acceleration or the reason why the unintended acceleration is produced.

2. This new form of unintended acceleration is not caused by a vehicle mechanical problem because no mechanical defect has been observed. And it is certainly not caused by the driver pressing on the accelerator pedal. Furthermore, no vehicle software defect has been cited by the manufacturers even though they are aware of the problem. Therefore, the unintended acceleration must have an electronic cause. Specifically, the electronic cause is a feedback condition in the control system design which opens the electronic throttle whenever the electronic stability system is used with the wrong size tires.
3. This new form of unintended acceleration leaves no diagnostic trouble codes. This shows that even though the auto manufacturers have known that unintended acceleration can be caused by their electronic stability control systems when using the wrong size tires, they have not designed their ECM's to detect a fault and store a diagnostic trouble code when the unintended acceleration happens, or to perform a fail-safe function to avoid the unintended acceleration. They have essentially used the driver as the fault detector for this problem and relied on the driver's skills to perform the fail-safe function.
4. This new form of unintended acceleration cannot be prevented by brake override because the driver is not pressing on the accelerator when the unintended acceleration happens. The unintended acceleration should be stopped by pressing on the brake pedal; however, driver experiences seem to indicate that this may not occur. If the brake pedal is not pressed and the accelerator pedal is released, then the unintended acceleration will continue instead of the engine returning to idle. This is contrary to the USA's Federal Motor Vehicle Standard FVMSS No. 124, which requires that the engine should return to idle within one second after the accelerator pedal is released. This should not be allowed to happen.

IV. Conclusion

An unusual form of unintended acceleration has been reported whereby the vehicle accelerates on its own after releasing the accelerator pedal on a flat road or when coming to a stop. Yet, the engine works normally when the vehicle is not moving. The problem was traced to using the wrong size tires. After changing the tires back to the size recommended by the automobile manufacturer, the problem disappeared. This paper explains how this unusual form of unintended acceleration is caused by the electronic stability control system on a rear wheel drive vehicle increasing the speed of the rear wheels when the front wheels are spinning faster than the rear wheels because the tires are different sizes.

V. References

[1] Hyundai patent US2011/0112716, "*Apparatus for Controlling Vehicle Chassis Having Integrated Fail-Safe Controller*", J. Yeong, May 12, 2011, assigned to Hyundai/Kia. This patent states that Hyundai's Vehicle Dynamic Control (VDC) system is another name for Electronic Stability Control (ESC). It is also referred to by Hyundai as its Electronic Stability Programme (ESP).

[2] http://www.bimmerforums.co.uk/forum/f18/2001-e46-325ci-accelerating-its-own-fixed-t26145/index2.html

[3] http://www.gencoupe.com/2-0t-discussion-2008-2012/115069-car-accelerating-revving-up-its-own-help-2.html

[4] Owner's Manual for the 2010 Hyundai Genesis Coupe, p.5-29. http://pdfsr.com/pdf/hyundai-genesis-coupe-owners-manual-operation-maintenance-specification.

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[14] Bosch patent US5235950, "*System for the Electronic Open-Loop and/or Closed-Loop Control of the Power of an Internal Combustion Engine of a Motor Vehicle*", by J. Schmitt, M. Knoss, and D. Loehr, August 17, 1993, assigned to Robert M. Bosch Gmbh.

[15] See "*Sudden Acceleration in Vehicles With Mechanical Throttles & Idle Speed Actuators*", and "*Simulation of Sudden Acceleration in a Torque-Based Electronic Throttle Controller*", by R. Belt, which can be found at: http://www.autosafety.org/dr-ronald-belt%E2%80%99s-sudden-acceleration-papers

Note Added in Proof

The author found the function of engine drag torque reduction (MSR) very interesting because he almost had a terrible accident back in the early seventies before this function was invented by Bosch in 1974. While he was driving his 1968 Dodge Coronet with rear wheel drive and a manual transmission on an interstate highway one winter day with about two inches of snow on the road, he broke over a large hill. At the bottom of the hill about 800 feet ahead was a stationary vehicle that was blocking the left hand lane. Several people were walking around it on the highway trying to determine why it had spun out of a nearby on-ramp. Although the author was traveling in the right hand lane at a reduced speed of about 40 MPH, he quickly thought that jamming on the brakes would cause a loss of control of his car. So he applied a maneuver he learned from a fellow student who participated in road rallies, and threw the manual transmission into second gear to use engine braking to slow down the vehicle. Immediately, this caused the rear end of his car to slip sideways about a foot or so, causing the vehicle to slide down the hill uncontrollably in a diagonal manner. Fortunately, he did not hit any of the people around the stationary car, but he did hit the stationary car with a glancing blow that caused relatively little damage to either car. After he regained control again at the bottom of the hill, he pulled his car over to the side of the road to await the state highway patrol. While filling out an accident form in the back of the highway patrolman's cruiser at the foot of the hill, the cruiser was struck by yet another vehicle which had lost control coming down the same slippery slope. Fortunately, this corroborated the author's story about the road conditions causing the incident, and caused the patrolman to issue no citation. It never occurred to the author until researching this paper that the very act of using engine braking on a rear wheel drive vehicle could cause lateral wheel slip of the type he encountered. He can attest that this engine drag torque reduction (MSR) function is a worthwhile function, and can be a life-saver under the right conditions.