

A Layman's Account of Dr. Belt's Theory

by Dr. Ronald A. Belt

A new theory to explain the cause of sudden acceleration has been proposed recently by Dr. Ronald A. Belt, a retired engineer in Minneapolis, Minnesota. The theory applies to all vehicles which use electronic throttles, also known as "throttle by wire" systems. Dr. Belt explains that all of these vehicles use an electric motor to open and close the throttle under the control of a microcontroller that senses the driver's command to accelerate by stepping on the accelerator pedal. The electric motor is powered from the vehicle's 12 volt supply voltage, and is commanded to increase or decrease the throttle valve by rapidly switching the motor's supply voltage on and off at a rate that is proportional to the driver's depression of the accelerator pedal. Since the motor's speed and torque are related to the supply voltage, the motor's operation gets weaker as the supply voltage decreases below its normal value, even though the driver's input may remain unchanged. This can cause a noticeable sluggishness in the engine response of the vehicle. To prevent this from happening, it is common throughout the automotive industry to apply a correction to the switching rate of the motor to compensate for the decrease in the motor's responsiveness at lower supply voltages. This is done by having the microcontroller sense the vehicle's supply voltage every half hour or so and then multiplying the accelerator pedal output by the inverse ratio of this supply voltage, so that as the supply voltage decreases, the switching rate to the throttle motor increases. This eliminates the changes in the engine response due to changes in supply voltage. It all works correctly as long as the supply voltage changes slowly, as it normally does. However, a problem arises when there are negative voltage spikes on the voltage supply line. When this occurs, it is possible for the microcontroller to sense the vehicle's supply voltage at the same time that a negative spike is occurring. This causes the microcontroller to apply a voltage correction to the accelerator output which suddenly increases the throttle motor's response even though the voltage spike may no longer be present to decrease the supply voltage to the throttle motor. This produces a sudden increase in the throttle motor's normal response which causes a lurch, a sudden surge, or a sudden acceleration, depending on the magnitude of the negative voltage spike. The duration of a sudden acceleration incident can last as long as the incorrect voltage correction coefficient is active, which is the time it is stored between voltage samples. This can be up to a half an hour or so.¹

Dr. Belt's theory explains why many sudden acceleration incidents happen in parking lots or while stopped at an intersection. At these times the engine is usually at idle, causing the vehicle's supply voltage to be determined by the battery instead of the alternator. If the battery is weak, then the vehicle supply voltage can drop to a DC voltage of 11 volts or less. Negative voltage spikes caused by the inrush currents of radiator fan motors, ABS pump motors, and stop lights, can cause further temporary drops of the supply voltage to 8 volts or less.² The voltage correction coefficient for the throttle motor calculated under these conditions can increase the accelerator output by a factor of three or more, making it equivalent to the driver stepping on the accelerator three times as hard. This is enough to produce a sudden acceleration incident when the driver's foot is not on the accelerator, but on the brake as many drivers contend.¹

Dr. Belt's theory also explains why some sudden acceleration incidents occur at high vehicle speeds. At high vehicle speeds the vehicle's supply voltage is determined by the alternator, which is usually at 14.4 volts or so. However, an alternator can occasionally produce negative voltage spikes on the vehicle's voltage supply line as a result of worn or bouncing brushes that interrupt the alternator's field supply. The resulting negative voltage spikes can be very large, dipping as low as 7 volts or less.² If the microcontroller samples the vehicle voltage supply line

¹ See Dr. Belt's latest paper entitled "*A Detailed Electronic Mechanism for Sudden Unintended Acceleration*", for more details about this mechanism.

² See Dr. Belt's previous paper entitled "*An Electronic Cause for Sudden Unintended Acceleration*", at <http://www.antony-anderson.com/Cruise/belt-hypo/sum.html> for more details about negative voltage spikes.

during one of these giant negative voltage spikes, then the resulting throttle motor correction coefficient is very large, and sudden acceleration --usually to wide open throttle -- can be produced.¹

Dr. Belt's theory also explains why no diagnostic trouble codes (DTC's) are found after a sudden acceleration incident. The reason is that the throttle and microcontroller hardware and software are all working exactly as designed by the automobile manufacturer. The only anomaly is that too low a supply voltage is sensed by microcontroller due to sampling the supply voltage at the time of a negative voltage spike. This unusual voltage level is not noticed by the microcontroller because there is no diagnostic software to detect it, and because there is no fail-safe software to take any action. Therefore, no DTC gets set when a negative voltage spike is sampled. And even the incorrect voltage sample, with its incorrect compensation coefficient, goes away when the next voltage sample is taken a short while later.¹

If the hardware and software are operating as designed, does this mean that the automobile companies are not at fault for sudden acceleration? "No", says Dr. Belt, "because manufacturers should have anticipated the effects of negative voltage spikes on their throttle electronics. These negative voltage spikes are always present in every vehicle, although their magnitudes may vary depending upon the vehicle's electrical design, accessory load, and battery condition. For automobile manufacturers to say that they are not responsible for faulty operation due to negative voltage spikes is analogous to bridge builders saying that they are not responsible for wind effects destroying their bridges or to aircraft manufacturers saying that they are not responsible for wings falling off due to metal fatigue causing cracks in the aircraft wings. Whether automobile manufacturers either knowingly or unknowingly failed to design their electronic throttle systems to withstand negative voltage spikes correctly, they are still responsible for the safe operation of their products. Negative voltage spikes are just one of many environments that they must consider in their designs".

Dr. Belt's theory explains why sudden acceleration is not just a Toyota problem, but a problem for every automobile manufacturer who uses an electronic throttle in its vehicles. All automobile manufacturers use the same basic permanent magnet DC throttle motor in their electronic throttle systems, and apply the same type of voltage correction coefficient to reduce its dependence on the supply voltage.¹ Hence, an incorrect throttle motor voltage correction coefficient produced by sampling the supply voltage during a negative voltage spike, can cause a sudden acceleration incident in all such throttle systems.

What does this imply for fixing vehicles against sudden acceleration? "Well", says Dr. Belt, "one way to fix the problem is to reprogram the ECU to eliminate the throttle motor voltage compensation coefficient. However, this would leave one with an underperforming vehicle that has a sluggish engine response. Another way to fix the problem is to reprogram the ECU to filter out negative voltage spikes and to use the true DC voltage of the vehicle's supply line to calculate the throttle motor voltage correction coefficient. This is difficult to do in practice because of algorithm complexity, but it may not be impossible. Either of these fixes would be relatively inexpensive for an automobile manufacturer. The best fix, however, would be to eliminate negative voltage spikes from reaching the ECM and the throttle motor entirely. This could be done by re-wiring the ECM and throttle motor to get their voltages directly from the battery, instead of sharing the same voltage supply line with other accessories that produce negative voltage spikes. This solution, however, would cost an automobile manufacturer hundreds of dollars for each vehicle repaired. With millions of vehicles on the road, this could be a severe financial challenge for each automobile manufacturer".

Some further implications of Dr. Belt's theory:

The fuel pump and fuel injectors also depend on the vehicle's supply voltage, and inject less fuel into the cylinders when the vehicle's supply voltage is low. Therefore, all fuel injection engines compensate for this effect by sampling the vehicle's supply voltage and using it to calculate a voltage correction value which increases the amount of time that the injectors stay open. This increases the amount of fuel injected into the engine to offset the amount

of fuel that is lost due to low voltage. This correction works well as long as the supply voltage changes slowly, as it normally does. However, if there are negative voltage spikes on the vehicle's voltage supply line, and if the microcontroller senses the supply voltage at the same time that a negative spike is occurring, then a larger correction is made to the injector opening time which may not be needed because the negative spike has already passed. In this case, the engine gets an extra shot of fuel above the amount normally needed, and the extra amount of fuel will last as long as the same correction value gets applied, which may be a half hour or so. Now, since this injector voltage correction value is calculated from the same supply voltage value that the throttle motor voltage compensation value is calculated, this means that when a sudden acceleration occurs due to the throttle motor getting the wrong voltage correction value, the injectors also get the wrong voltage correction value. This means that while the engine is getting an extra shot of air to cause a sudden acceleration incident, it is also getting an extra shot of fuel as well. And all this can happen while the driver's foot is off of the accelerator pedal.

Even in vehicles without an electronic throttle, the response of a fuel injected engine to an improper injector correction coefficient, caused by sampling the battery voltage during a negative voltage spike, may produce a sudden surge or lurch of the vehicle from a stopped position. In this case only an extra shot of fuel is injected into the engine. This may explain the existence of some sudden acceleration incidents before electronic throttles came on the market.

Dr. Belt's theory also explains why loss of brake function occurs in some vehicles undergoing sudden acceleration. It is not due merely to the loss of vacuum boost as the engine operates at high RPM during a sudden acceleration incident. This would cause a "hard pedal" feel to the driver. It may also be caused by negative voltage spikes affecting the operation of the ABS brakes, whose operation is known to depend upon the vehicle's supply voltage. It is possible that these negative voltage spikes cause the ABS controller to reset, and that coming out of reset the controller enters into a temporary diagnostic test mode as it is designed to do each time that the vehicle's ignition is turned on. During this test mode, the ABS brakes are cycled through all the normal modes to see if they operate properly, one of which is a mode that reduces pressure on the brake lines. This could cause a "soft pedal" feel to the driver by which the driver's brake pedal may go to the floor as many drivers have contended. This condition could be caused by a single negative voltage spike, which also initiates the sudden acceleration, if it is sampled by the microcontroller and used for calculating the throttle motor voltage correction coefficient.

Dr. Belt's theory explains why sudden acceleration can occur in Toyota's hybrid vehicles like the Prius and the Camry hybrid. These vehicles all have gasoline engines with electronic throttles of the same ETCS-i design as Toyota's standard vehicles that are powered with gasoline engines only. Therefore, negative voltage spikes can affect the electronic throttles in these hybrid vehicles just like they can affect the electronic throttles in Toyota's standard vehicles. The cause of sudden acceleration is exactly the same in both types of vehicles.

Dr. Belt's theory also explains why the sudden acceleration incident rate is higher for older people, and especially for older women. The reason is that many of these people are retired, and hence make infrequent shorter trips with their vehicles to the grocery, library, mall, and church, instead of commuting longer distances each day to places of employment. This means that their vehicles' batteries run down more easily because they never get charged back up properly, causing a lower voltage on the vehicle's voltage supply line. This lower voltage makes the supply line more susceptible to negative voltage spikes produced by the inrush currents of radiator fan motors, ABS pump motors, and stop lights. Such negative voltage spikes are the cause of most sudden acceleration incidents.

What does Dr. Belt think about NHTSA and their constant assurances that sudden acceleration is not an electronic problem, but is caused by driver pedal confusion, sticky accelerator pedals, or accelerator pedal entrapment by floor mats? Well, Dr. Belt concedes that sometimes these other causes of sudden acceleration may occur. But he thinks that most sudden acceleration incidents in vehicles with electronic throttles are caused by his proposed electronic mechanism. He does not fault NASA and NRC for failing to find the root cause of sudden acceleration during their studies, saying they did a good job in a short amount of time, and were forthright in explaining that they could not

confirm that the electronics was not at fault, just that they could not find an electronic cause of sudden acceleration during their study. But Dr. Belt is more critical of NHTSA. He believes that NHTSA has actually misrepresented incident data, lost incident data, and failed to investigate sudden acceleration incidents because of their biased judgment that all sudden acceleration incidents are caused by driver error.