

# Sudden Acceleration in Vehicles with Mechanical Throttles and Idle Speed Actuators

by

Ronald A. Belt  
Plymouth, MN 55447  
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**Abstract:** Between 1983 and 1986, automobile engine designs transitioned from carburetors with mechanical idle and dashpot controls to fuel injection systems with electronic idle and dashpot controls. In this same time frame, the occasional phenomenon of stuck throttles known to occur with mechanical throttles was accompanied by the new phenomenon of sudden acceleration incidents, even though both engine designs used mechanical throttles. Auto manufacturers dismissed the new sudden acceleration incidents as being caused by drivers hitting the gas pedal instead of the brake, and they were supported by a controversial 1989 NHTSA study. The NHTSA study, however, looked only at idle actuator operation, and did not consider the control functions associated with this actuator. In this paper it is shown that a problem can occur in the idle controller operation which causes the idle actuator to suddenly open to its maximum position while the mechanically actuated throttle valve remains closed, causing the engine to suddenly operate at about 3000 RPM or more. This behavior can explain a large number of observed sudden acceleration incidents occurring between 1983 and 2003 in vehicles having mechanical throttles with digitally controlled idle speed actuators.

## I. Introduction

When fuel injection systems replaced carburetors in the early eighties, several functions were changed along with the carburetor:

1. Fuel injectors took over the fuel metering function from the Venturi-based carburetor,
2. An idle speed control function replaced the idle set screw on the carburetor,
3. An idle speed actuator “idle-up” control function replaced several discrete air control valves, each meant to increase the idle when the engine load increased due to the activation of an accessory such as the air conditioner,
4. An idle speed actuator start-up control function replaced the mechanically-actuated engine start-up throttle setting on the carburetor,
5. An idle speed actuator high idle control function replaced the wax-controlled or bimetallic strip-controlled fast idle air bypass valve (FITV), used to create a high idle for fast engine warm-up after starting,
6. An idle speed actuator throttle “cracker” control function replaced the cam-operated “cracker” control function on some vehicles,
7. An idle speed actuator throttle follower/dashpot control function replaced the mechanical dashpot on the carburetor, and
8. An idle speed actuator calibration function was included to reset the actuator to a known state during each ignition-on drive cycle.

While the fuel injector function, idle speed control function, and “idle-up” functions are often discussed, the remaining five idle speed actuator control functions are rarely mentioned.

The idle speed control function is used to set the engine idle speed when the accelerator pedal is released. It is used in two different ways. When the engine is first started, idle speed control is done by an open-loop, or feed-forward, controller using predetermined ISC actuator openings until the engine is warmed up and the idle speed has stabilized close to the desired idle set-point for a fixed amount of time. Then, if

the accelerator pedal is released and the vehicle is in either PARK or NEUTRAL, idle speed control is transferred to a closed-loop controller which controls the idle speed based on the deviation of the engine speed from a desired idle speed set-point (e.g., 800 RPM). This closed loop controller is much more robust. When the transmission later is shifted into either DRIVE or REVERSE, idle speed control changes from the closed-loop controller back to the open-loop controller. In the open-loop case the idle speed control is less precise, and idle speed can vary as pre-determined adjustments are made in response to changes in the engine load from accessories turning on, such as air conditioner compressor clutch engagement, or radiator cooling fan turn-on. It is interesting to note that sudden acceleration incidents frequently occur when shifting the transmission from PARK into either DRIVE or REVERSE, but are never associated with high engine speed prior to shifting out of PARK<sup>Note1</sup>. On the other hand, once a higher-than-normal engine speed has occurred in either DRIVE or REVERSE, the higher-than-normal engine speed persists when shifting back into PARK or NEUTRAL, and may get even higher when the load on the engine is removed. The only way to stop the higher-than-normal engine speed is to turn off the ignition. This leads one to believe that the closed-loop idle controller is probably not at fault in causing sudden acceleration. However, the open-loop idle controller requires further consideration.

The idle speed actuator start-up control function is an open-loop controller mode which causes the idle speed actuator to go to its maximum open position while the engine is being cranked during engine start-up. This position provides the air that the engine needs for starting, since the mechanically controlled throttle valve is normally closed during engine start-up<sup>Note2</sup>. The idle speed actuator opening is then reduced to a smaller value while the controller is in the open-loop mode prior to entering the closed-loop idle control mode. Since this function is used only during engine start-up, it is unlikely that it could produce a higher-than-normal engine speed during subsequent engine operation unless the idle actuator happened to stick in the fully open position. In this case, it would produce a higher-than-normal idle speed while the vehicle was in PARK, which would alert the driver of a dangerous situation. For this reason, the idle speed actuator start-up function has little potential to be a cause of sudden acceleration.

The idle speed actuator high idle control function is an open-loop controller mode which causes the idle speed actuator to go to its maximum open position while the engine temperature is below its normal operating temperature. This causes the engine to heat up faster, allowing the engine to stabilize faster at its normal idle. As the operating temperature rises to its normal level, the idle actuator opening is reduced to a smaller value while still in the open loop mode. Once the engine temperature stabilizes near the normal value, control enters the closed loop idle control mode. This function is normally used only after engine start-up while the vehicle is in PARK. Therefore, it is unlikely that it could produce a higher-than-normal engine speed during subsequent engine operation unless the idle actuator happens to stick in the fully open position. In this case, it would produce a higher-than-normal idle speed while the vehicle was in PARK, which would alert the driver of a dangerous situation. For this reason, the idle speed actuator high idle function has little potential to be a cause of sudden acceleration.

The idle speed actuator cracker control function is an open-loop controller mode which causes the throttle to be “cracked open” slightly by small amounts as a function of vehicle speed above some fixed actuation speed in the range of 2 to 4 MPH. Below this vehicle speed the vehicle is assumed to be stationary, and the cracker throttle opening is set to zero. Since the cracker openings are so small at any given vehicle speed, the cracker function has little potential to be a cause of sudden acceleration.

An idle speed actuator dashpot control function is an open-loop controller mode which causes the engine speed to return slowly to the curb idle position when the driver’s foot is removed from the accelerator

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Note1. If the engine RPM was abnormally high while in PARK, most drivers would recognize the unusual mode of engine operation, and would avoid shifting out of PARK.

Note2. The idle speed actuator opening controls the amount of air that is bypassed around the mechanical throttle valve.

while driving at any higher engine speed. This function is required because removing one's foot from the accelerator pedal causes the mechanically-controlled throttle valve to close immediately, producing an abrupt deceleration that is very disturbing to the vehicle's occupants. The sudden loss of air through the throttle also causes the engine to run richer than normal, which increases hydrocarbon emissions. Therefore, a dashpot function is required not only to slow down the rate of deceleration, but also to satisfy OBD-I emission regulations. And because it must operate to slow down vehicle deceleration from any higher engine speed, the idle speed actuator opening must increase with engine speed before deceleration occurs. In fact, the idle speed actuator opens all the way from nearly zero at curb idle to fully open at normal engine cruising speeds. This capability of the idle speed actuator to open further with increasing engine speed gives it a high potential for causing sudden acceleration. It is interesting that the idle speed actuator dashpot function is rarely discussed by automobile manufacturers, and was never discussed in NHTSA's 1989 "Silver Book" report. Further discussion of this function is provided in the following section.

## II. Idle Speed Actuator Dashpot Operation

First we will explain how the idle speed actuator is supposed to work during dashpot operation. Then we will explain how it can fail to operate like it is supposed to.

### A. How the Dashpot is Supposed to Work.

In US patent 4181104<sup>1</sup> Toyota teaches why a dashpot is needed: "In automobile engines, if the throttle valve is abruptly closed to the idle position by full release of the accelerator pedal while the engine is running at relatively high speed, a high manifold vacuum is caused in the intake system of the engine whereby liquid fuel droplets attached to the inner wall of the intake passage violently evaporate and a large amount of fuel is drawn into the cylinders of the engine. On the other hand, since the flow of intake air is reduced by the closing of the throttle valve, the air/fuel ratio becomes too low, or too rich, thereby causing misfiring and delivery of a large amount of un-combusted components into the exhaust system. This causes the problem of air contamination. Furthermore, when secondary air is injected into the exhaust system for the purpose of purifying the exhaust gases, combustion of this un-combusted component occurs in the exhaust system and causes so-called after-fire. In order to avoid high emission of un-combusted components, or occurrence of afterfire, during deceleration in high-speed running, it has been proposed to incorporate a throttle control means such as a throttle positioner, throttle opener, dashpot, etc., which temporarily increases the idle opening when the throttle valve has been abruptly closed after a long-lasting full open condition".

Again, in US patent 4569803<sup>2</sup> Toyota teaches the following: "It is generally known the upon engine deceleration a great quantity of hydrocarbon (HC) and/or carbon oxide (sic) (CO) gases are discharged owing to imperfect combustion and misfiring which are caused by a rich air/fuel ratio and a lowering of volumetric efficiency. Accordingly, there have been introduced several kinds of engine deceleration control devices which prevent HC and CO gases from being discharged from the engine. In a dashpot device, such being one of such devices, when a carburetor throttle valve returns to an engine idle speed position upon engine deceleration, the return action of the throttle valve is delayed by means of a buffer action of a dashpot. Thus, the throttle valve gradually returns to the idle position to thereby prevent the occurrence of a rich air/fuel ratio and misfiring".

Operation of the engine without a dashpot function is shown schematically in Figure 1. Manifold pressure increases with engine load as the vehicle accelerates by opening the throttle. When the driver releases the accelerator pedal to slow down, the throttle opening closes abruptly without a dashpot function, causing rapid deceleration due to the abrupt load change (vertical transition), and high emissions due to running the engine with the throttle closed while fuel is still present on the manifold walls (horizontal transition).

Emissions are increased even further if fuel continues to be injected into the engine cylinders while the throttle is closed.

Operation of a fuel-injected engine with an idle valve dashpot function is shown conceptually in Figure 2. In this case an idle valve controls the air flow in a channel which bypasses the normal throttle opening. When the throttle opening increases in response to the driver stepping on the accelerator pedal, the idle valve opens in proportion to the increased load on the engine as sensed by the manifold pressure until the idle valve is fully open at some throttle position. Above this throttle position an increase in the idle air flow is no longer possible. When the driver releases the accelerator pedal to slow down, the throttle opening still closes abruptly, but the idle valve controlling the bypass air closes more slowly, creating a dashpot function which smoothes deceleration and reduces engine emissions.

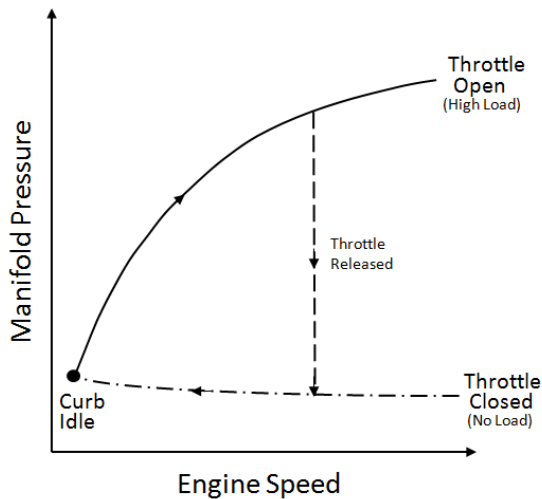


Figure 1. With no dashpot, the manifold pressure is high during acceleration, but drops abruptly when the throttle is released, causing rapid deceleration and high emissions<sup>3</sup>.

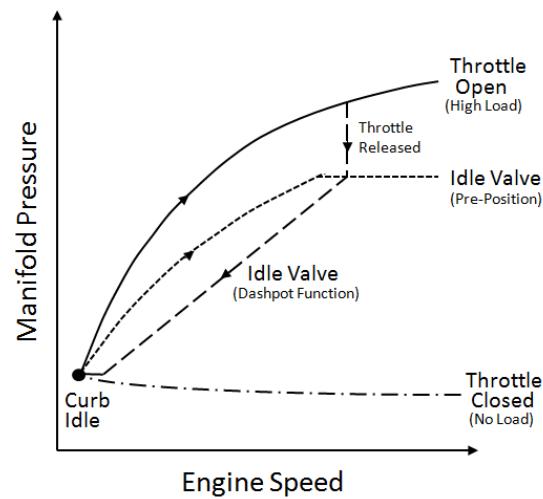


Figure 2. With a dashpot function in an idle valve controller, the idle valve opens during acceleration and closes slowly after the throttle is released, smoothing deceleration and reducing emissions<sup>3</sup>.

Figure 3 shows idle valve dashpot operation as a function of time as described by a Honda patent.<sup>4</sup> The left-hand diagram shows the case for low acceleration, where the IAC opening increases with throttle opening as sensed by a throttle position sensor (TPS). When the driver reduces the acceleration level at time  $t_1$  a lower value at time  $t_2$ , the IAC valve closes more slowly than the throttle closes, reaching a new level at time  $t_2'$ , and smoothing the deceleration. Later, when the driver releases the throttle completely at time  $t_3$ , the throttle drops to zero at time  $t_4$ , but the IAC valve closes again more slowly, reaching curb idle at the later time  $t_4'$ . In this way deceleration is smoothed and emissions are reduced.

The right-hand diagram of Figure 3 shows the case for high acceleration, where the IAC opening increases with throttle opening (TPS) at first, and then increases with engine speed after  $t_6$  until the maximum IAC opening is reached at time  $t_6'$ . The IAC opening then stays at its maximum until the driver releases the throttle completely at time  $t_7$ , after which the throttle drops to zero at time  $t_8$ . But the IAC valve closes more slowly than the throttle, reaching curb idle at the later time  $t_8'$ . Again, deceleration is smoothed and emissions are reduced.

While this Honda figure is good for explaining how a dashpot works in general, not all IAC valves operate in exactly the same fashion. This Honda patent shows that the IAC opening increases with throttle opening at low acceleration, or with throttle opening and engine speed at high acceleration.

However, only the earliest IAC valves opened as a function of the throttle opening. Later IAC valves open as a function of both engine speed and manifold pressure, or both engine speed and manifold air flow. And while this patent appears to show the idle valve closing only with time, some later idle valves close as a function of engine speed while others close as a function of time. Since we are most interested in sudden acceleration, we will look now into how the IAC valve dashpot opening is actually achieved in most vehicles.

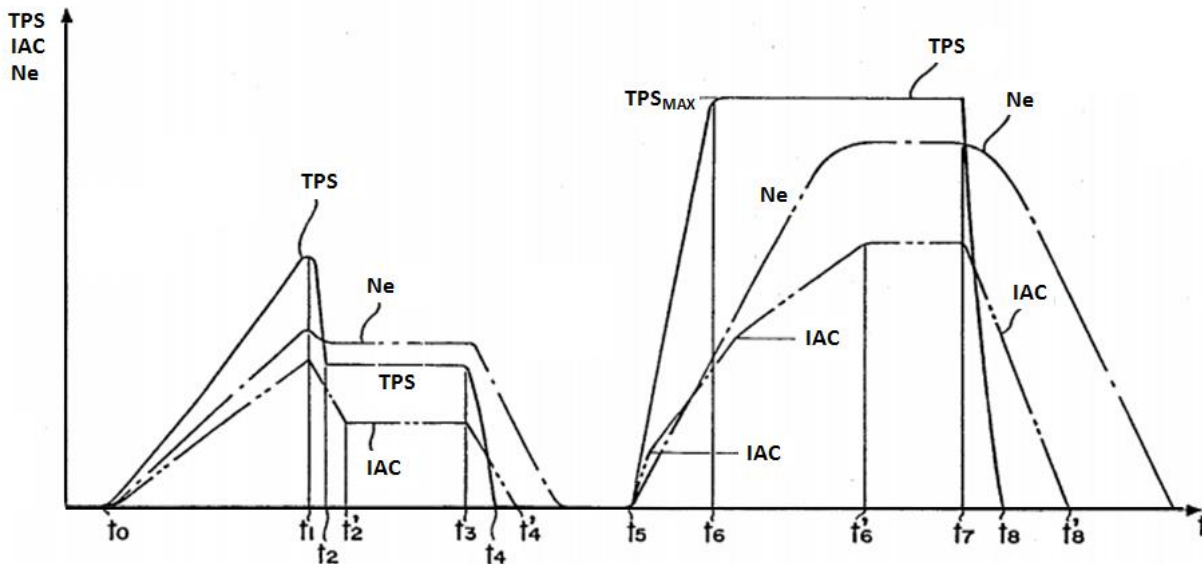


Figure 3. A Honda patent<sup>4</sup> shows that at low acceleration (left) the IAC opening follows the throttle opening (TPS) while at high acceleration (right) the IAC opening follows the engine speed  $N_e$ . In both cases, when the throttle is released the IAC opening decreases slowly with time to zero or to a lower value set by the engine speed. This figure shows the general concept of how the IAC dashpot function operates, but later IAC designs open as a function of engine speed and manifold pressure (or manifold air flow).

## B. How the Idle Air Actuator Dashpot Opening Is Controlled

In order to assess whether the idle valve dashpot function can cause sudden acceleration, we need to know how the idle valve control system works. Unfortunately, information about the idle air actuator dashpot function and how it is controlled in vehicles with fuel injection systems is rarely discussed by auto manufacturers in their training publications, service manuals, or the patent literature. The dearth of information about this function suggests that auto manufacturers have made a determined effort to keep knowledge of this function a closely guarded secret out of the hands of the general public. The only reference the author has found to idle air actuator control is from a Toyota training course which states: “The idle air control program is based on an ECM stored look-up table, which lists pintle step positions in relation to specific engine RPM values”.<sup>5</sup>

One might think that the only way to learn how the idle air control dashpot function really works is to look at the ECM software of a specific vehicle. However, it is possible to learn how idle valve control functions work from other sources, such as vendors of after-market engine management systems and the web sites of engine tuning enthusiasts. Based on information learned from these two sources, it is possible to deduce how the idle air control valve dashpot function works based on only some very general considerations. These considerations are summarized in Table 1. Table 1 shows that engine management systems for fuel injected vehicles come in only a few different types, distinguished by how they represent the engine load.

Table 1. Engine Management Systems for Fuel Injection Systems and Their Characteristics

Engine Management System	Load Sensor	Load vs Engine Speed Map Coordinates <sup>a,b,c</sup>
Alpha-N	Throttle position sensor (TPS)	TPS vs Ne
Speed-density	Manifold absolute pressure sensor (MAP)	MAP vs Ne
Air mass	Manifold mass air sensor (MAF)	MAF vs Ne
Engine torque (Te)	Torque Te computed from air charge as a function of either MAF or MAP	Te vs Ne
Wheel torque (Tw)	Torque Tw computed from air charge as a function of either MAF or MAP	Tw vs Ne

- a. Control maps are used for computing all critical engine parameters, including fuel injection charge, spark angle, variable valve timing angle, idle actuator position, turbo boost pressure, etc.
- b. All control maps use the same two coordinates, with the table values at each coordinate denoting the commands for the critical parameter being controlled.
- c. Commands at coordinates lying in between the coordinate values in the map are obtained by 2-dimensional interpolation of the command values at the nearest coordinates

The earliest fuel injection engine control systems used alpha-N systems, with a throttle position sensor (TPS) serving as the load sensor. This system had problems with load estimation at low loads and low engine speeds, because the engine load is a function of both throttle opening and manifold pressure. After a few years, engine management systems were improved to the speed-density type, with a manifold pressure sensor (MAP) as the load sensor. This system was much better, although it was still not ideal. Eventually, engine management systems were improved again to the mass air flow type, with a mass air flow sensor (MAF) as the load sensor. The MAF sensor provided a much more accurate load sensor, but one which had a relatively slow response. Therefore, a manifold air pressure sensor (MAP) was retained along with the MAF sensor because the MAP sensor is faster, although not as accurate. More recently, torque-based engine management systems have become commonplace, with either engine torque (Te) or wheel torque (Tw) used to represent the engine load. The use of torque as a load indicator simplifies the design of the engine management system. But the torque is still computed from the air charge, which is a function of either the MAF or MAP sensors. Therefore, the idle valve control operation in torque-based engine management systems is very similar to idle valve control operation in speed-density engine management systems and air mass engine management systems.

Table 1 shows that:

- a. All the maps for an engine management system have load on one axis and engine speed on the other axis.
- b. If a vehicle has an idle air control actuator and no MAP sensor or MAF sensor, then the vehicle has an alpha-N engine control system, and the map that controls the idle actuator has coordinates of TPS vs Ne.
- c. If a vehicle has an idle air control actuator and MAP sensor, then the vehicle has a speed-density engine control system, and the map that controls the idle actuator has coordinates of MAP vs Ne.
- d. If a vehicle has an idle air control actuator and MAF sensor, then the vehicle has a mass air flow engine control system, and the map that controls the idle actuator has coordinates of MAF vs Ne.
- e. Furthermore, a speed-density engine management system is used whenever an engine has a turbocharger (i.e., whenever the manifold air is under pressure).

Based on these observations, we can deduce that the idle air control actuators in vehicles with MAP or MAF sensors are controlled by a map that has MAP or MAF sensor values on one axis and engine speed on the other axis, like the one shown in Figure 4. Maps for all the other critical engine parameters, such as fuel injection charge, spark angle, variable valve timing angle, and turbo boost pressure, will have the same MAP/MAF vs. engine speed coordinates, but will contain the control positions for those actuators.

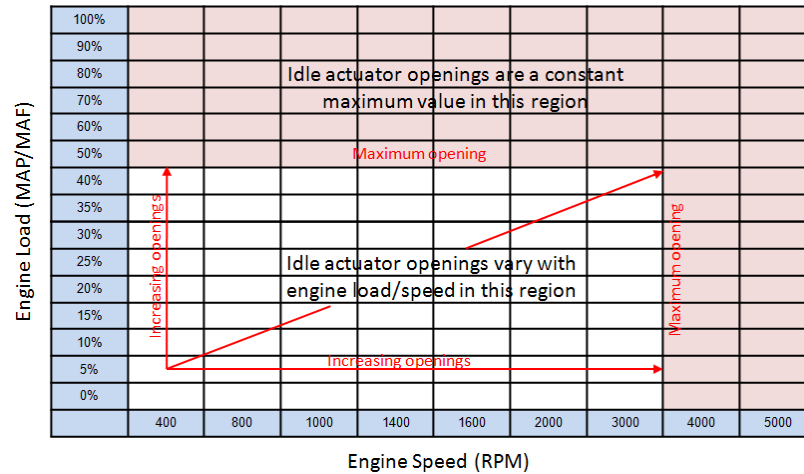


Figure 4. Map characteristics for the idle air actuator control map in a speed-density or mass air engine control system. The absolute values of the coordinates may vary from one vehicle to the next. Each map location contains the command for opening the idle speed actuator at those coordinates. Commands for coordinates lying in between the coordinate values on the axes are obtained by 2-dimensional interpolation of the parameter values at the four nearest coordinates.

### C. How the Idle Speed Actuator Dashpot Function Can Fail to Operate Correctly

Now that we have seen how the idle speed actuator is controlled by a map like the one shown in Figure 4, we can determine how the idle speed actuator dashpot control function can fail to operate correctly. We are aided in this analysis by the author’s previous papers<sup>6,7</sup> and a 2007 Visteon patent<sup>8</sup> which states: “Other modes such as dashpot mode operate entirely using an open loop, where any error in the IAC position will significantly impact performance. For example, if the actual IAC position is greater than expected based on the perceived number of steps then engine run-on can be an issue, as well as making parking maneuvers more difficult”. With these references as a hint, let us look at what can happen if the IAC gain is larger than expected by the idle speed actuator control map.

Let’s assume, for example, that the vehicle is stationary with the engine at curb idle and the transmission in either DRIVE or REVERSE. In this case, the idle speed actuator is controlled by an open loop controller with a map like the one shown in Figure 4. If the gain of the idle speed actuator agrees with the gain assumed by the map when the map was created, then during the next iteration through the map the same operating point for the idle speed actuator will be selected. However, if the actuator gain differs from the gain assumed when the map was created, then a different map location will be selected on the next iteration.

This difference in gain is not a problem when a TPS sensor is used as the load sensor, because a larger idle actuator gain cannot change the TPS sensor value, which is determined only by the accelerator pedal and its linkage. Therefore, with each map iteration only a small offset of the idle actuator opening relative

to the values in the map is produced at all map coordinates, and the offsets will not accumulate. Such a behavior will not lead to a runaway condition, or sudden acceleration, with the alpha-N control system.

However, if a MAP or MAF sensor is used as the load sensor, then a larger idle actuator gain will change the load coordinate by increasing the manifold pressure or the air mass slightly more than what the throttle requests. In this case, with each map iteration a small offset of the idle actuator response relative to the values in the map is produced at all map coordinates, and the offsets will accumulate with successive iterations. This will cause a progressive movement of the operating point through the map as shown in Figure 5. In this case, we find:

- a. The iteration of the control map acts as an incrementer,
- b. The load coordinate acts as an accumulator,
- c. The two together act as an incrementer/accumulator.

This increment/accumulate function will cause an increase in engine speed and engine torque with each iteration, leading to a runaway of the engine speed to a speed determined by the maximum IAC opening, or sudden acceleration. This will happen even though the driver does not have his foot on the accelerator pedal.

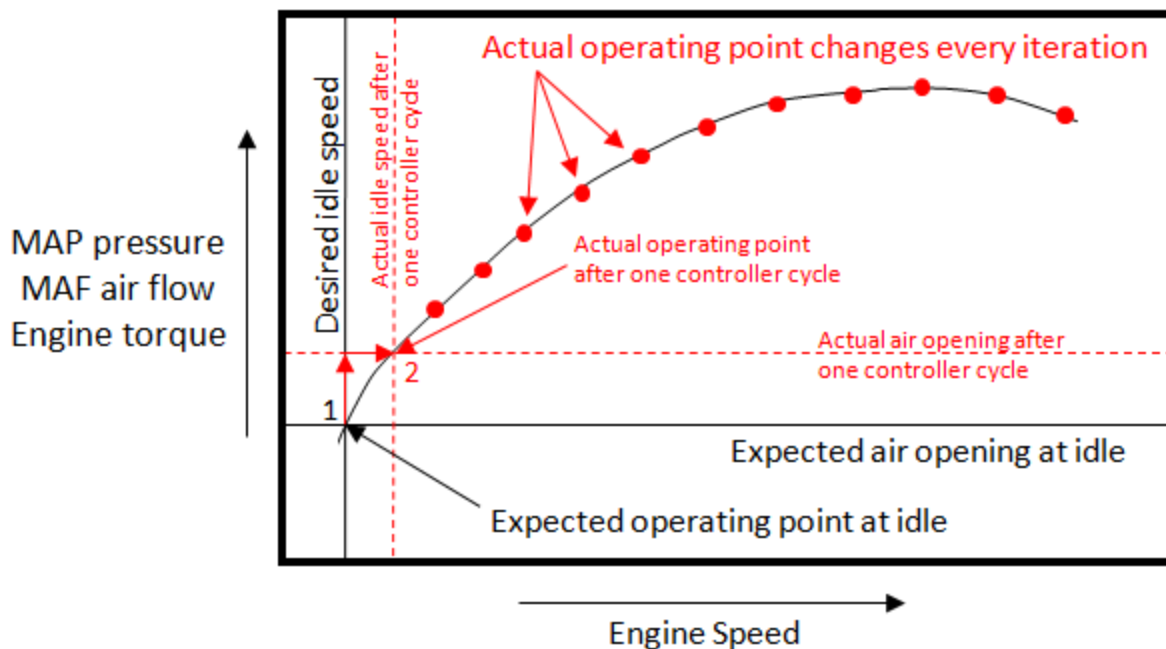


Figure 5. For an engine idling in DRIVE or REVERSE in the open loop idle mode, if the gain of the idle air control valve is higher than the gain assumed by the control map, and if the idle speed control map has a load coordinate that increases with increasing idle air valve opening, then the operating point of the engine changes with each iteration of the control map, causing the engine to run away to a speed determined by the maximum IAC opening.

Looking back at Figure 4, one might conclude that the maximum engine speed achievable during a runaway condition is the speed at which the idle actuator reaches its fully open state, or about 3000 RPM. However, engine speeds of 6000 to 7000 RPM have been reported by some drivers during sudden acceleration incidents. It is not known at this time how such high engine speeds can be achieved with the throttle closed. It is known, however, that in some turbocharged engines the boost pressure can continue to increase while the throttle opening is fixed at its maximum opening as a result of changes in the opening of the wastegate valve. Since the wastegate valve is powered from the 12V battery supply by a PWM signal, it is likely that this PWM voltage must be compensated for changes in battery voltage. If



so, then the wastegate PWM control input might be increased by the same A/D sample of the battery voltage that that increases the gain of the IAC valve, which could explain the higher engine speeds. One should not dismiss these reports of higher engine speeds until all possibilities for explanation have been exhausted.

One more thing happens as the IAC control map is being stepped through on each iteration. It is known that the engine torque increases with engine speed as the throttle opening gets larger until some maximum is reached, and then the torque begins to decrease at still higher engine speeds. This produces a negative slope on the torque-versus-engine-speed characteristic which causes an engine at a high engine speed to increase its torque as the engine speed decreases when a load is placed on the engine by the driver applying the brakes. This explains why many drivers have complained that stepping on the brakes actually increased the vehicle's acceleration, which is a layman's way of saying that the engine torque increased as the engine speed was reduced by the load placed on the engine by the brakes.

Something else happens during a runaway condition while the IAC control map is being stepped through with each iteration. Since the MAP/MAF vs Ne coordinates on the IAC map are changing with each iteration, this means that the same MAP/MAF vs Ne coordinates on all the other engine control maps are also changing, causing all the other control maps to be stepped through with each iteration. This means:

- a. The fuel injection and spark advance maps are being stepped through simultaneously, supporting the increase of engine speed and torque caused by the increase of IAC air flow. (The engine doesn't know that the throttle has not been opened, but only that it sees a larger air flow. Therefore, the engine thinks this larger air flow is caused by the throttle being open, and supports the larger air flow with more fuel and an advanced spark).
- b. The engine is running richer than normal because it has less air than normal to support the higher engine speed.

This means that the engine is running in a high speed state, but with an air-to-fuel ratio (AFR) lower than normal, causing higher hydrocarbon emissions. We will see later in this paper that the fuel injector voltage compensation coefficient is also higher than normal because this coefficient is based on the same voltage sample as the IAC compensation coefficient, creating an even larger fuel charge and causing the engine to run even richer. This rich engine condition explains the observations of some drivers that they could smell gasoline after sudden acceleration. The gasoline smell comes from the unburned hydrocarbon emissions produced because there wasn't enough air to burn all the fuel.

All of these changes take place as a result of the IAC opening (i.e., IAC gain), being larger than expected by the IAC control map. Figure 6 shows that it does not take much of an IAC gain increase for this to happen, because the increase in air flow accumulates with each map iteration. For example, after 100 iterations the air flow can increase by over 10x with an IAC gain increase of less than 3%. Assuming a typical map iteration time of ~10 milliseconds, this change in engine speed can take place in less than one second. This explains why drivers often state that the engine "revved up suddenly", or that the tachometer jumped suddenly to several thousand RPM.

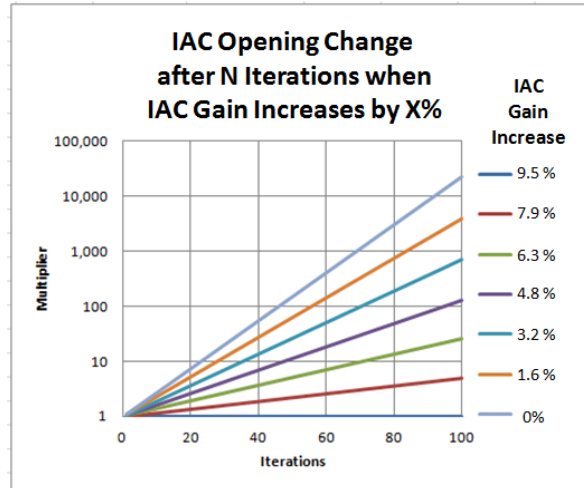


Fig. 6. A small IAC gain increase of X% can cause a large change in the IAC air opening after many iterations. At ~10 msec per iteration, 100 iterations take only one second.

It is interesting to consider what would happen if the IAC gain is less than what the IAC control map assumes. In this case, a lower IAC gain will decrease the manifold pressure or the air mass over what the throttle requests at each iteration, causing a progressive movement of the IAC opening to smaller values, leading the IAC valve to close completely. This will cause the engine to stall. The fact that this happens rarely, if at all, gives us a clue to what can cause the IAC gain to change; namely, a negative voltage spike.

Before delving into what can cause the IAC gain to change, it is worth citing some references which support the previous discussion. These references include:

1. The author's previous paper<sup>6</sup>, which explains that a higher throttle gain is responsible for sudden acceleration in vehicles with electronic throttles.
2. The author's previous paper<sup>7</sup> which explains that a higher electric motor gain is responsible for sudden acceleration in a passenger vehicle with electric traction motors.
3. Visteon patent no. 7191755<sup>8</sup>, which states:
 

“Other modes such as dashpot mode operate entirely using an open loop, where any error in the IAC position will significantly impact performance. For example, if the actual IAC position is greater than expected based on the perceived number of steps then engine run-on can be an issue, as well as making parking maneuvers more difficult.”
4. The experiences of a hobbyist engine tuner<sup>9</sup>, who reports on a problem with his IAC actuator randomly raising the idle speed to 2K RPM and holding it there. He found:
  - a. It happened intermittently, usually when stopped at a light, when the RPM's all of a sudden raise up to 2K and never go down,
  - b. Turning off the engine and turning it back on again caused the problem to go away for a few minutes, but then the idle went back up on its own again, when the engine is restarted.
  - c. Swapping IAC motors with two new ones did not solve the problem,
  - d. Tapping on the IAC's while at high idle to see if they were stuck open did not cause the idle to go down,
  - e. Unplugging the IAC while at high idle caused the engine to stall immediately,
  - f. Replacing the electronic control module that controls the IAC and its dashpot function did not solve the problem,

- g. The normal idle speed is 864 RPM during which the IAC duty cycle was 49%. When the idle speed jumped to 2K RPM, the IAC duty cycle jumped to 100%.
  - h. When the idle speed was at 100%, data logs showed that the fuel injection pulse width was maxed out, the MAF voltage was good, but showed a high air flow, the IAC was at maximum open, and the fuel trims went to the maximum rich condition.
  - i. He thought the cause of the problem was a bad TPS sensor, but this would not explain the symptoms he saw in the data logs of a longer pulse width and the trims maxed out. It would also not account for the ISC changing randomly or going back to normal after turning the engine off and then back on again.
5. Comments by brian1703<sup>10</sup>, remarking on a car accelerating on its own. He states:
- a. "I am aware of at least one reported instance of a faulty idle air control valve causing the vehicle to accelerate on its own. The specific case I recall involved a Ford Taurus and it happened after the idle air control valve was cleaned. (Ford doesn't recommend cleaning them--maybe that's why)".
  - b. "It (the IAC valve) definitely is not cut out of the circuit above idle. Above idle, on Ford vehicles, it is fully open so that the computer can gradually close it so as to provide smoother deceleration if the driver lifts completely off the gas pedal".
6. Volkswagen recall No. 24M9/R7<sup>11</sup>, dated May 22, 2008, (NHTSA Campaign ID Number: 08V235000), which states:
- Summary: Volkswagen is recalling 4079 MY 2008 Passat and 2500 Tiguan passenger vehicles equipped with 2.0T FSI ULEV II engines. These vehicles have an engine control module (ECM) containing software that may not properly control engine idle with the air conditioning turned on. In rare cases, the ECM may unexpectedly increase engine RPM.
- Consequence: An engine surge caused by an unexpected increase in engine RPM may surprise the vehicle operator and can result in a crash without warning.
- Remedy: Dealers will inspect and update the ECM software free of charge."

We shall now consider what can cause the IAC gain to change.

#### D. How the IAC Gain Can Exceed the Value Assumed by the IAC Control Map

To understand how the IAC gain can exceed the value assumed by the IAC control map, one must first understand how an IAC actuator works. IAC actuators come in three major types as shown in Figure 7: 1) a DC stepper motor, 2) a linear solenoid, and 3) rotary slide valve type. The DC stepper motor type is the most common, and is used on most GM and Chrysler vehicles. The linear solenoid type is used on most Ford motor company vehicles. The rotary slide valve type is used on many Asian and European vehicles, but has largely been superseded by the stepper motor type. All three types are powered by the 12V DC battery voltage using pulse width modulation (PWM) to vary the actuator current, which causes the IAC valve opening to change in proportion to the PWM duty cycle. The proportionality constant between the IAC opening and the PWM duty cycle is called the IAC actuator gain.

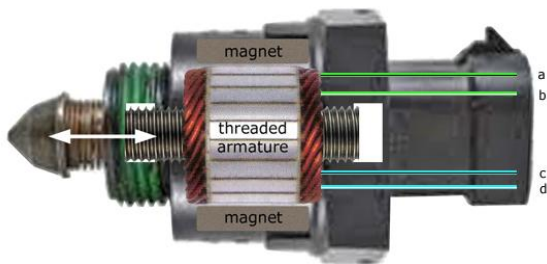


Fig 7a1. Stepper motor IAC valve used on many GM and Chrysler vehicles.

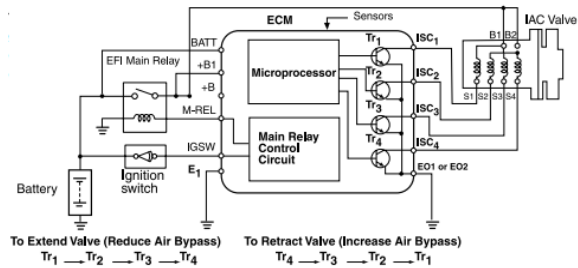


Fig 7a2. Stepper motor drive circuitry<sup>12</sup>  
Microsteppers commonly use 256 total microsteps.

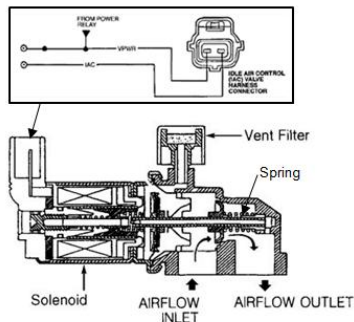


Fig 7b1. Linear solenoid IAC valve used on many Ford motor company vehicles.

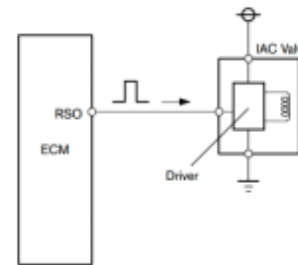


Fig 7b2. Linear solenoid drive circuitry. The opening force is opposed by a closing spring.

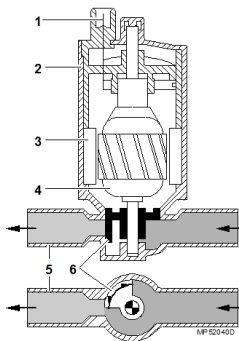


Fig 7c1. Rotary slide type IAC valve used on many Asian and European vehicles.

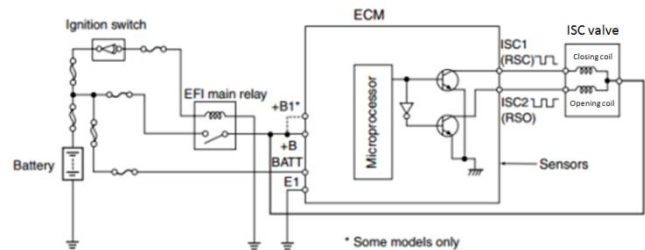


Fig 7c2. Rotary slide valve drive circuitry<sup>13</sup>. One coil opens the valve while the second coil closes it.

Figure 7. IAC valves are of three different types. All three are powered from the 12 volt battery supply and all three use PWM to control the air opening.

1. IAC gain varies with the battery supply voltage.

The torques in the stepper motor type IAC valve and the rotary slide type IAC valve, and the force in the linear solenoid type IAC valve, are proportional to the currents in the coils. These currents are controlled by the PWM duty cycle of the waveforms applied to the actuator inputs (i.e., the coil inputs), which switch between the 12 volt battery voltage and ground. This makes the actuator coil currents sensitive to

variations in the 12 volt battery voltage, which changes the applied torques in the stepper motor valve or the rotary slide type valve, or the applied force in the linear solenoid type valve. Since these applied torques, or force, cause the valves to open to their desired positions in response to a duty cycle input, thereby determining the normal gain of the actuator, then changes in these torques, or force, brought about by changes in the 12 volt battery voltage, cause changes in the normal gain of all the actuators. Therefore, the IAC gain of all three actuators varies with the battery supply voltage.

2. IAC gain must be stabilized by compensating the PWM duty cycle for changes in battery voltage.

Because the IAC gain of all three actuators varies with battery voltage, one must compensate the IAC gain for voltage changes to maintain a proper idle speed while operating in either DRIVE or REVERSE. The in-gear idle speed is a fine adjustment which trades off using less air flow to minimize idle creep while using more air flow to reduce the chances of a stall.<sup>Note 3</sup> Since this idle function is a feed-forward controller function, it is adjusted *a priori* and assumes a specific gain for the idle actuator. If the IAC actuator gain changes with battery supply voltage, the engine will either idle faster at a voltage higher than 12 volts, causing it to creep more while in gear, or it will idle slower with a voltage less than 12 volts, causing it to possibly stall. Since the IAC gain is voltage dependent, maintaining this creep rate idle adjustment requires voltage compensation. Similarly, the idle-up needed for maintaining idle speed when the air conditioner turns on, thereby increasing the load on the engine, also requires voltage compensation. Bosch patent number 4580220<sup>14</sup> shows that battery voltage compensation is used for the idle speed actuator. Hewlett-Packard patent 6441579<sup>15</sup> shows that stepper motors must allow for variation of the power supply.

Battery voltage compensation requires sampling the battery voltage with an A/D converter. This is done within a minute or so after starting on most vehicles, when the battery voltage is at its lowest and the idle speed has stabilized. The compensation coefficient is formed by dividing the nominal battery voltage of 12.6 volts by the sampled battery voltage,  $V_{B+}$ , where  $V_{B+}$  is the ignition-switched value of the DC battery voltage. In vehicles with IAC valves, this same  $V_{B+}$  voltage sample is used to compensate other actuators as well, such as the fuel injection pulse width and the spark dwell time. It is usually assumed that the battery voltage does not change rapidly with time, so the battery voltage is sampled only occasionally, such as each time the ignition switch is turned on, or after an elapsed time at a higher engine speed, such as 30 MPH, when the accelerator has been released and the engine speed is back down to idle. This means that the same battery voltage compensation coefficient is used for a prolonged time on the order of minutes to hours.<sup>Note4,16,17</sup>

3. Once in a while a negative voltage spike can occur while the battery voltage is being sampled, causing an incorrect battery voltage coefficient that increases the IAC gain. This precipitates a sudden acceleration.

Once in a while something can go wrong with the A/D converter sampling operation. This is because there are negative voltage spikes on the battery supply line and if one of these spikes occurs during the A/D sampling operation, then the A/D converter will read a voltage that is lower than the true DC supply voltage. If this happens, the resulting compensation coefficient will be larger than unity, causing the IAC

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Note3. The torque converter on a vehicle with an automatic transmission always transmits torque while the gears are engaged in either DRIVE or REVERSE. The only time it does not transmit torque is when the transmission is in either PARK or NEUTRAL. <http://www.off-road.com/atv/tech/hondas-torque-converter-how-it-works-2003-honda-rincon-21514.html>. This means that creep is caused by the engine idle speed, and raising the engine idle speed while in either DRIVE or REVERSE will increase the engine torque and cause the vehicle to creep faster without pressing on the accelerator pedal. Creep is merely slow acceleration with the accelerator pedal released.

Note4. Auto manufacturers prefer not to reveal that battery voltage compensation of the IAC valve gain is performed, or the details of when the battery voltage is sampled and how often it is sampled. However, the manufacturers of several after-market engine management systems, or ECM's, have mentioned that their products incorporate this function.<sup>16, 17</sup>

gain to increase. The probability that a negative voltage spike occurs during A/D sampling of the DC battery voltage determines the probability that sudden acceleration occurs, because once this happens sudden acceleration is sure to follow as a result of the actuator gain being larger than the IAC gain assumed by the control map.

It doesn't take much of a voltage spike to cause a sudden acceleration. Figure 8 shows how a small negative voltage spike can change the IAC air flow in a short amount of time.

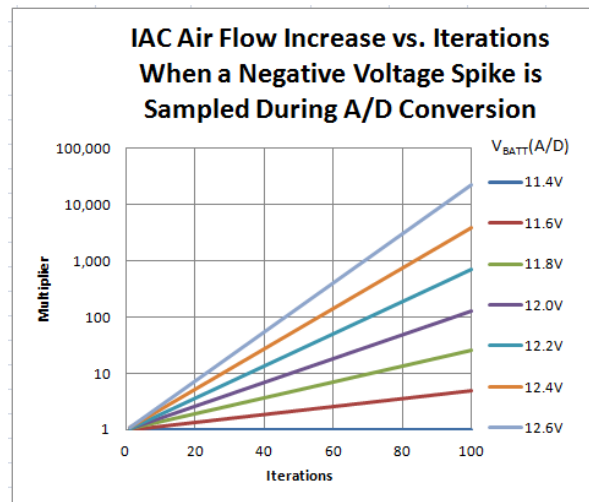


Fig. 8. A small negative voltage spike occurring during A/D sampling of the DC battery voltage to get a  $V_{BATT}(A/D)$  value for battery voltage compensation can cause a large change in the AIC air flow after many iterations of the control map. At ~10 msec per iteration, 100 iterations take only one second.

### III. Summary of the Complete Mechanism for Sudden Acceleration

A. Complete mechanism for sudden acceleration in vehicles with mechanical throttles and idle speed actuators.

This section explains the complete mechanism for sudden acceleration in vehicles with mechanical throttles and idle speed actuators. The explanation is provided in the time order that the events occur, using a scenario format to make the description more understandable to non-technical readers.

Assume that you have a vehicle with a mechanical throttle and an idle speed actuator, or IAC valve. Normally, after starting your car in PARK or NETURAL, the engine speed stays high for a minute or two, and then slowly dies down to about 800 RPM. While the engine is idling normally in PARK or NEUTRAL, an A/D converter in the ECM takes a 50 microsecond sample of the battery voltage to form a compensation coefficient for actuators which depend on the battery voltage, like the IAC, the fuel injectors, and the spark dwell. Normally, this 50 microsecond sample turns out to read 12.6 volts, which is the DC voltage of a healthy battery. In this case, the compensation coefficient becomes unity, which means it makes no change to the gain of the idle actuator control valve. When you shift the vehicle into DRIVE or REVERSE with your foot on the brake, nothing happens besides feeling the normal idle creep of the vehicle in gear. Your car is working normally and you are happy.

Once in a blue moon, however, something can go wrong. Assume, for example, that you have started your vehicle in PARK or NETURAL. The engine speed stays high for a minute or two, and then slowly dies down to about 800 RPM. Again, while the engine is idling normally in PARK or NEUTRAL, an

A/D converter in the ECM takes a 50 microsecond sample of the battery voltage to form a compensation coefficient for actuators which depend on the battery voltage. But this time a negative voltage spike occurs during the 50 microsecond sampling time. The negative voltage spike is caused by some electric motor turning on, like the air conditioner compressor or a radiator fan, which causes practically a dead short across the battery for a very short time like 100 microseconds. The chance of this negative voltage spike occurring during the 50 microsecond A/D sampling time is about one in a million, which seems like it might never occur. But the chance is not zero. The magnitude of the negative voltage spike may be anywhere between one half a volt to several volts, depending on the state of charge of your battery after starting your car. Therefore, the negative voltage spike makes the A/D sample voltage read lower than 12.6 volts, say 12.0 volts, instead of the normal DC voltage of 12.6 volts. In this case, the compensation coefficient that results is larger than unity. Normally, if this compensation coefficient results from a low DC voltage without a spike, and is applied to the idle actuator valve when the DC battery voltage is at the same low voltage, then the gain of the IAC valve, which decreases with a lower DC battery voltage, is brought back up to the normal gain once more. However, in this case, when the lower A/D sample voltage is caused by a negative voltage spike, then the larger-than-unity compensation coefficient is applied to the normal idle actuator gain associated with the normal DC voltage of 12.6 volts. This causes the gain of the IAC valve to become higher than normal. While the engine continues to idle in the PARK or NEUTRAL state, this causes no observable change in the engine speed, because the idle controller in the PARK or NEUTRAL state is a closed-loop idle controller which merely re-adjusts itself to maintain the normal idle speed of 800 RPM.<sup>Note5</sup> However, the engine is running in a non-equilibrium state. The snowball has been placed on top of the hill.

Assume, now, that you place your foot on the brake and shift the car into either DRIVE or REVERSE. This changes the idle speed controller from a closed-loop controller to an open-loop controller that is much more sensitive to the gain of the idle actuator<sup>Note6</sup>. Unbeknownst to you, this gives the snowball a little nudge down the hill. What happens next is completely beyond the control of the driver. The IAC valve is controlled by commands contained in a map, or table. While your foot is still on the brake, on the first iteration through the control map, the higher-than-normal IAC gain causes more air to flow into the engine than the control map expects, increasing the engine speed slightly. Ten milliseconds later, on the second iteration through the control map, the higher air flow and higher engine speed cause a different map location to be selected, resulting in a command to the IAC valve to increase the air opening just a little bit more. But, again, the higher-than-normal IAC gain causes more air to flow into the engine than the map expects, increasing the engine speed even more. With each successive map iteration the IAC valve opens further and the engine speed increases. This causes a runaway engine condition which results in the engine revving up suddenly to approximately 3000 RPM or more. The time it takes for this to happen is less than one second, because each map iteration takes only about 10 milliseconds. Therefore, in one second about 100 map iterations occur, which is more than enough to cause the map to be completely traversed. The snowball is now rolling down the hill.

While this takes place, your foot remains on the brake. You know it is there because you had to put it there to shift out of PARK. Now, with the engine revving suddenly at its maximum RPM, the vehicle begins to move because it is in either DRIVE or REVERSE. Normally, when the car is in either DRIVE or REVERSE, the car would be creeping slightly. But with the engine revving at its maximum RPM, the creep becomes a high acceleration. The acceleration is high because the engine torque is multiplied by a

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Note 5. The closed-loop idle controller can reduce the engine speed if it gets too high or increase it if it gets too low. The open-loop idle controller gets no feedback of the engine speed, so it does not know if the engine speed gets too high or too low. It merely issues an idle command and assumes that the result is what was expected by the design engineer.

Note6. This sensitivity is why an IAC gain compensation coefficient is needed in the first place, because if the IAC gain becomes higher, then the engine speed will be made higher than the control map expects, causing a higher creep rate at idle. If the IAC gain becomes lower, then the engine speed will be made lower than the control map expects, causing the engine to possibly stall.

factor of 4 to 5 in either first gear or reverse gear, and by another factor of 2 in the torque converter. And as you apply the brake harder to control the car, the brake puts a higher load on the engine, which slows down the engine speed and increases the torque that the engine puts out. The result is that pushing on the brake seems to increase the acceleration (i.e., torque), just like a car in cruise control going up a hill seems to increase the engine acceleration (torque) because the hill is putting a higher load on the engine.

The only thing that stops this runaway engine behavior is to turn off the ignition, shift into neutral, or to crash into some object, which puts such high load on the engine that the engine speed is reduced to zero, causing the engine to stall. But your attention is so consumed by steering the car away from danger that you have little time to turn off the ignition or shift into neutral. This explains the high number of parking lot crashes, as well as crashes into store fronts, houses, trees, pools, lakes, rivers, and even from high-rise parking lots. The crash happens while your foot remains on the brake. The snowball has finished rolling down the hill. It has crashed.

The crash is only the beginning of your nightmare, however. The police come to investigate and you tell them everything that happened as accurately as you can. All you can say is that the engine revved up suddenly while your foot was on the brake. Maybe you even explain to the policeman that the engine accelerated a little bit more as you pressed on the brake pedal. The policeman smiles kindly, and then turns to a reporter and says “He (she) put his (her) foot on the accelerator instead of the brake”. However, he does not cite you for the accident. You claim that it was not your fault, but the car’s fault, and submit a report to the NHTSA. If you are fortunate enough to have NHTSA investigate your accident, they finally conclude that you put your foot on the accelerator instead of the brake because there is no mechanical defect to explain the accident. And if you sue the auto manufacturer in court, their defense is that you put your foot on the accelerator instead of the brake. The jury nearly always agrees.

One reason why it is difficult to convince the NHTSA or a jury that the driver is not at fault is that no one has offered a plausible explanation for how the engine can rev up on its own while the driver’s foot is on the brake, and yet leave no evidence for investigators to find. This paper, for the first time, offers such an explanation. It is the same explanation that causes sudden acceleration in vehicles having electronic throttles, which was discussed by this author in an earlier paper. Clearly, if NHTSA and the auto manufacturers would have investigated sudden acceleration more carefully thirty years ago in vehicles with mechanical throttles and idle control valves, they would have found this cause and would have avoided the problems we are having today in vehicles with electronic throttles. However, thirty years ago they chose to blame the driver for the problem, and continue to blame the driver yet today. And if they do not fix the problem soon, we will continue to have the same problem for another thirty years or more.

Another reason why it is difficult to convince the NHTSA or a jury that the driver is not at fault is that no diagnostic code is set during a sudden acceleration incident. The reason why a diagnostic code is not set during a sudden acceleration by this mechanism is as follows:

1. Sudden acceleration is essentially caused by an increase of the curb idle speed while in gear, which normally causes a vehicle with an automatic transmission to creep while in either DRIVE or REVERSE. If this creep idle speed is increased slightly, no diagnostic code will be set. Creep is merely slow acceleration. Therefore, increasing this same idle speed to the engine speed determined by the maximum IAC opening will cause no diagnostic code to be set. One company has even stated that it does not check the accelerator pedal position sensor (APS) or the throttle position sensor (TPS) while at idle<sup>18</sup>.
2. More specifically, sudden acceleration is caused by the normal idle actuator dashpot function operating with an increased air flow and engine speed. Normally, the dashpot function causes the IAC valve to open more as the air flow and engine speed increase as a result of the accelerator pedal opening the throttle valve by a mechanical linkage. During sudden acceleration, however, the air flow and engine speed increase as a result of additional air flow



caused by a higher gain of the IAC valve due to an incorrect battery voltage compensation coefficient. The IAC controller doesn't know the difference between these two sources of increased air flow. It only responds to the measured air flow sensed by the MAP or MAF sensor and the engine speed. Therefore, no diagnostic code is set because there is no way for the MAP or MAF sensor to tell the difference about whether the increased air flow is caused by the mechanically-actuated throttle opening or by an increased idle actuator gain.

3. Even if a fail-safe routine in the ECM were to detect a functional error during sudden acceleration, OBD-II regulations say that it is not necessary to post a diagnostic code unless the same error occurs a second time. This is to eliminate false errors which can occur on a transient basis. If the same error does not occur a second time, then the pending code is erased. Turning the ignition off and then back on again is considered to be the second sample. But turning off the ignition off and then back on again causes the ECM to re-sample the battery voltage. Since the occurrence of a negative voltage spike during A/D sampling is a statistically rare event, the likelihood of this same rare event occurring a second time immediately after a first event is practically negligible. Therefore, a diagnostic code is never set, and a pending code is erased whenever the ignition is turned off and then back on again. The ignition is turned off and then back on again after nearly every sudden acceleration incident.

NHTSA appears to be unfamiliar about how the dashpot function works in vehicles with either idle speed actuators or electronic throttles. In their Notice of Proposed Rule Making on brake throttle override dated March 28, 2012, they propose maintaining the existing requirement of one second for the idle to return to normal operation after release of the accelerator pedal in light vehicles.<sup>19</sup> They define normal idle operation as “the normal running condition of a vehicle’s engine or motor with no faults or malfunctions affecting engine or motor output when there is no input to the driver-operated accelerator control”. This requirement appears to exclude any dashpot operation which may take longer than one second to return the engine speed to curb idle from any higher engine speed. Yet, the normal dashpot function in most vehicles takes longer than one second to return the engine to curb idle from a high engine speed. This longer settling time results from the auto manufacturer’s desire to make deceleration more gradual and to reduce engine emissions. Auto manufacturers seemed reluctant to point this out to NHTSA in their responses to NHTSA’s proposed rule. Apparently, they are more concerned about passing the emissions tests in most states than they are about passing the proposed federal regulation on idle speed return. Perhaps this is because the federal government (i.e., NHTSA) is not aggressive enough in testing new cars for this standard.

#### B. Comparison of Idle Speed Actuators and Electronic Throttle Actuators.

The sudden acceleration mechanism for vehicles with mechanical throttles and idle speed actuators is identical to the sudden acceleration mechanism vehicles with electronic throttles. This is because idle speed actuators and electronic throttle actuators are similar in many respects. Table 2 lists these many similarities. A negative voltage spike affects both types of actuators in exactly the same way to cause sudden acceleration. The two types of actuators and associated controllers are so similar that Bosch needed to make only minor changes in their ME7 engine management system for vehicles with electronic throttles to derive their M7 engine management system for vehicles with idle actuators.<sup>20</sup>

Table 2. Idle speed actuators and electronic throttle actuators are very similar in many respects

	<b>Electronic Idle Speed Actuator</b>	<b>Electronic Throttle Actuator</b>
Air opening controlled	Throttle bypass opening	Throttle opening
Actuator type	Electric motor or solenoid <sup>a</sup>	Electric motor
Actuator torque multiplier	Gears not used on most IAC's	Gears

Actuator control approach	Motor torque proportional to motor current	Motor torque proportional to motor current
Actuator current control	Motor current controlled by PWM	Motor current controlled by PWM
Actuator position sensor	Most IAC's have no position sensor	Redundant throttle position sensors
Parasitic effects	Motor current proportional to: <ol style="list-style-type: none"> <li>1. Battery voltage</li> <li>2. Actuator resistance and temperature</li> </ol>	Motor current proportional to: <ol style="list-style-type: none"> <li>1. Battery voltage</li> <li>2. Actuator resistance and temperature</li> </ol>
Elimination of parasitic effects	Controller compensates for: <ol style="list-style-type: none"> <li>1. Battery voltage variation</li> <li>2. Actuator temperature variation</li> </ol>	Controller compensates for: <ol style="list-style-type: none"> <li>1. Battery voltage variation</li> <li>2. Actuator temperature variation</li> </ol>
Control approach	Two-levels of control: <ol style="list-style-type: none"> <li>1. PID closed-loop controller for inner loop actuator control</li> <li>2. Feed-forward function-based controller for outer loop</li> </ol>	Two-levels of control: <ol style="list-style-type: none"> <li>1. PID closed-loop controller for inner loop actuator control</li> <li>2. Feed-forward function-based controller for outer loop</li> </ol>
Feed-forward controller functions:	<ol style="list-style-type: none"> <li>1. Start-up air control</li> <li>2. Fast warm-up idle</li> <li>3. Closed-loop curb idle</li> <li>4. Open loop running idle</li> <li>5. Idle-ups on load change</li> <li>6. Throttle follower opening / dashpot return</li> <li>7. Idle speed changes with engine and vehicle speed</li> </ol>	<ol style="list-style-type: none"> <li>1. Start-up air control</li> <li>2. Fast warm-up idle</li> <li>3. Closed-loop curb idle</li> <li>4. Open loop running idle</li> <li>5. Idle-ups on load change</li> <li>6. Throttle opening / dashpot return</li> <li>7. Idle speed changes with engine and vehicle speed</li> </ol>
Feed-forward controller iteration time	Digital controller adjusts air opening approx every 10 msec	Digital controller adjusts air opening approx every 10 msec
Potential defect operation	Iteration of IAC actuator gain larger than the calibrated actuator gain causes runaway to engine speed determined by the maximum IAC opening	Iteration of ETC actuator gain larger than the calibrated actuator gain causes runaway to the fully open throttle position
Control authority	Limited authority of bypass air limits engine speed to <3000 RPM and vehicle speed to <40 mph	Full authority of throttle air allows engine speed >6000 RPM & vehicle speed >90 mph
Fail-safe controls	Fail-safes on idle function: <ol style="list-style-type: none"> <li>1. Return spring closes idle opening on loss of supply voltage<sup>b</sup></li> </ol> No limits on idle speed	Numerous fail-safes on throttle function: <ol style="list-style-type: none"> <li>1. Two springs produce a limp-home opening on loss of supply voltage</li> <li>2. Redundant accelerator and throttle position sensors</li> <li>3. Limits on throttle torque reduce throttle functionality</li> </ol> No limits on idle speed
Electronic defects reported	Intermittent shorts in PWM driver transistors produce high idle condition	<ol style="list-style-type: none"> <li>1. Opens in potentiometer-type TPS sensors produce high throttle condition</li> <li>2. Tin whisker shorts in APS</li> </ol>

		sensors produce elevated throttle condition
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- a. Idle actuators come in three basic types. All are powered from the 12 volt supply and all are PWM controlled.
- b. Some idle actuators have a return spring which closes the throttle opening on loss of supply voltage, but this is intended to simplify control of the actuator rather than to be a fail-safe control.

#### IV. Conclusion

It has been shown that the idle speed actuators in 1983-2003 model year cars with sudden acceleration are controlled by a map of idle valve position as a function of intake manifold pressure (or intake manifold air flow) versus engine speed. This means that if the actual the idle valve opening for a given manifold pressure and engine speed is larger than the value contained in the map, then a higher manifold pressure and engine speed will result. This creates an incrementing function whereby the idle opening is incremented to a larger value each 10 millisecond iteration of the engine control system. And, since opening the idle valve further increases the manifold pressure and engine speed, each increment of manifold pressure and engine speed is accumulated, causing the manifold pressure and engine speed to be incremented and accumulated with each iteration of the control system. The result is that the manifold pressure and engine speed reach the maximum value in the control map in less than 100 iterations, or less than one second, which results in a sudden acceleration. The reason that the idle valve opening can be larger than expected by the control map is that the battery voltage compensation coefficient used to make the idle opening independent of battery voltage can occasionally become incorrect as a result of a negative voltage spike occurring during the sampling of the DC battery voltage by an A/D converter in the ECM. This sampling occurs soon after the engine is started, and occasionally when the engine has been running above a given engine speed for some elapsed time, but has been then returned to idle.

This means that the same negative voltage spike hypothesis advanced by the author in several earlier papers can explain sudden acceleration, not only in all vehicles with electronic throttles (from about year 2000 to the present), but also in all vehicles with idle air control valves (from about 1983 to about 2003). The root cause of sudden acceleration is the same in both types of vehicles. This same negative voltage spike hypothesis can also explain all of the observed symptoms that drivers have observed during sudden acceleration incidents. The consequences of such a simple hypothesis are so comprehensive that they testify to the validity of the hypothesis in the real world.

The validity of this hypothesis means that thousands of sudden acceleration incidents occurring after 1983 could have been prevented if the automobile manufacturers and NHTSA had looked more closely into the cause of these incidents when they were first reported instead of brushing aside the complaints of hundreds of drivers involved in these incidents as being the result of driver confusion by stepping on the accelerator instead of the brake. This clearly shows what can happen when an entire industry fails to listen to the voice of the customer, and is motivated instead by saving their corporate reputations and profits. NHTSA is encouraged to step up to its mandate of making cars safer by testing this hypothesis in vehicles with idle air control valves and electronic throttles. Only by such testing, and fixing the vehicles if they prove faulty, can we prevent another 30 years of sudden acceleration incidents.

#### V. References

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<sup>1</sup> K. Shinoda, US patent 4181104, “*Idle Speed Controller for Internal Combustion Engines*”, Toyota Jidosha Kogyo Kabushiki, January 1, 1980.

<sup>2</sup> Y. Takakura (Toyota) and K. Kitamura, US patent 4569803, “*Dash Pot Device*”, Aisin Seiki Kabushiki Kaisha, February 11, 1986.

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<sup>3</sup> Y. Otobe, S. Fujimoto, and A. Kato, US Patent 4788954, “*Method for Controlling By-Pass Air Flow on Deceleration of Internal Combustion Engine*”, Honda Giken Kabushiki Kaisha, December 6, 1988. Figures 1 and 2 are adopted from Figure 6 in this patent to further clarify the concepts.

<sup>4</sup> Ibid, Figure 3 comes from Figure 7 in Honda patent 4788954.

<sup>5</sup> Toyota Engine Control Systems I -- Course 852, Section 6, p.6-7. <http://www.testroete.com/car/Toyota/mr2%-20spyder/References/Technical%20Training/01%20-%20Engine%20and%20Engine%20Control/07.pdf>

<sup>6</sup> R. Belt, “*Simulation of Sudden Acceleration in a Torque-Based Electronic Throttle Controller*”, January 30, 2015. <http://www.autosafety.org/dr-ronald-belt%E2%80%99s-sudden-acceleration-papers>.

<sup>7</sup> R. Belt, “*Sudden Unintended Acceleration in an All-Electric Vehicle*”, February 27, 2015. <http://www.autosafety.org/dr-ronald-belt%E2%80%99s-sudden-acceleration-papers>.

<sup>8</sup> M. K. Vint, US patent 7191755, “*Idle Air Control Valve Stepper Motor Initialization Technique*”, Visteon Global Technologies, March 20, 2007

<sup>9</sup> PoweredByAFR185, on the EEC tuning forum at <http://eectuning.org/forums/viewtopic.php?t=20208&p=112612#p112313>

<sup>10</sup> brian1703, <http://ths.gardenweb.com/discussions/2265770/car-accelerating-on-its-own>

<sup>11</sup> Volkswagen recall No. 24M9/R7, dated May 22, 2008, as quoted by Mickey in a comment on February 26, 2010 to the article “*Toyota Unintended Acceleration Hearings Summary*”, <http://www.tundraheadquarters.com/blog/toyota-unintended-acceleration-hearings-summar/>

<sup>12</sup> Toyota Engine Control Systems I -- Course 852, Section 6, p.6-3.

<sup>13</sup> Toyota Engine Control Systems I -- Course 852, Section 6, p.6-8.

<sup>14</sup> Gunter Braun, Wolfgang Kosak, and Alfred Kratt, US patent 4580220, “*Failsafe Emergency Operation Device for Idling Operation in Motor Vehicles*”, Robert Bosch GmbH, April 1, 1986, columns 2, 3, 4.

<sup>15</sup> C. Van Lydegraf, S. Gothard, S. Kranz, and G. Brown, “*Current Magnitude Variation Correction for Operating Stepper Motor Drive Circuit*”, US patent 6441579, August 27, 2002.

<sup>16</sup> Euro 1EFI Engine Management System User Manual, Ole Buhl Racing (UK) Ltd, par 3.15.17, p30, [http://www.obr.uk.com/support\\_pages/Euro1-430%20handbook.pdf](http://www.obr.uk.com/support_pages/Euro1-430%20handbook.pdf).

<sup>17</sup> MegaSquirt Tuner Studio MS Lite Reference, “*MegaSquirt MS2/Extra Firmware Version 3.3.3 Release, 2015-04-08*”, p.124, which states in paragraph 11.13: “PWM Idle Voltage Compensation. Some 2-wire PWM idle valves will operate differently depending on the system voltage. This slows a compensation to be applied for that difference. Typically, at lower voltages the valve will need slightly more duty (positive number) and at higher voltages it will need less duty (negative number)”.

<sup>18</sup> Volkswagen Audi Vehicle Communication Software Manual, EAZ0031B01E Rev. A, August 2013, p.72. Available from: [https://www1.snapon.com/Files/Diagnostics/UserManuals/VolkswagenAudi-VehicleCommunicationSoftwareManual\\_EAZ0031B01D.pdf](https://www1.snapon.com/Files/Diagnostics/UserManuals/VolkswagenAudi-VehicleCommunicationSoftwareManual_EAZ0031B01D.pdf)

<sup>19</sup> Notice of proposed rulemaking (NPRM) on electronic throttle (ETC) failure modes and test procedures, and on brake throttle override (BTO), as part of 49 CFR Part 571, [Docket No. NHTSA–2012–0038], Federal Motor Vehicle Safety Standards, Accelerator Control Systems, published in the Federal Register, Vol. 77, No. 73, Monday, April 16, 2012, Proposed Rules p. 22638.

P59 states: “Response Time for Normal Operation. This proposal maintains the existing requirement that, in normal operation (i.e., without faults in the ACS), return to idle must occur within 1 second after release of the accelerator pedal for light vehicles”.

p90 states: “Response Time. When tested in accordance with S6.3 and S6.4, the maximum time to return to idle as indicated by the throttle position or other selected idle state indicant shall be (a) Not greater than 1 second for vehicles of 4536 kilograms (10,000 pounds) or less gross vehicle weight rating (GVWR)...”.

p89 states: “Idle or idle state means the normal running condition of a vehicle’s engine or motor with no faults or malfunctions affecting engine or motor output when there is no input to the driver-operated accelerator control....Idle state conditions are conditions which influence idle state during normal operation of a vehicle, including but not limited to engine temperature, air-conditioner load, emission control state, and the use of speed setting devices such as cruise control.... Idle state indicant means a vehicle operating parameter which varies directly with engine or motor output, including: throttle position, fuel delivery rate, air intake rate, electric power delivery, and creep speed”.

<sup>20</sup> J. Gerhardt, H. Honninger, and H. Bischof, “*A New Approach to Functional and Software Structure for Engine Management Systems*”, International Congress and Exposition; Detroit, Michigan, February 23-26, 1998, SAE Technical Paper, No.980801, p.11. This reference states on p11: “M7: System without ETC. To create this

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conventional or basic system without ETC the cylinder charge control has to be limited to the operating range of the idle speed actuator. Due to the fact that there is a fixed mechanical link between the pedal and the throttle position, the throttle position represents the driver's request. With the help of these major supplements the M7 system (for vehicles with idle speed actuators) was derived (from the ME7 system for vehicles with electronic throttles) very easily and in a very short development time." Words in parentheses have been added to clarify the meaning.