MOTOR AGE

FEBRUARY 2023
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ENDEAVOR BUSINESS MEDIA

PUSH-BUTTON PARKING:

ELECTRONIC PARKING BRAKE OPERATION AND DIAGNOSIS

As modules and wires replace ratchets and cables, technicians need to evolve their approach with the changing technology.

MOTOR AGE

Talk Shop Anytime

FEBRUARY 2023

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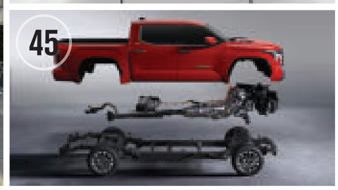
OPERATIONS

TECHNICAL



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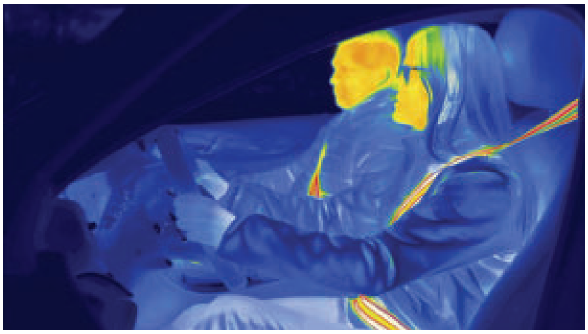

VIDEO

HUNTER INTRODUCES ITS NEW MAVERICK TIRE CHANGER

Hunter Engineering Co. has just unveiled its latest advancement in tire-changing equipment - the Maverick. MTD Editor Mike Manges talks with John Zentz, senior vice president of global sales for Hunter, as he explains how the company's new tire changer raises the bar on technician-controlled tire changing. Scan the QR code to learn more.

WEB EXCLUSIVES

VIDEO: MASTERING VEHICLE DIAGNOSTICS WITH BRANDON STECKLER: PART 2

Capitalizing on your tools' features will not only speed the return on investment but can make light work of even the most elusive faults. Learn about the lab scope trigger feature from a master diagnostician - Motor Age Technical Editor Brandon Steckler! For more information on the topics discussed in this video, scan the QR code.

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EV RESTRAINTS

BUCKLE UP TO SAVE ENERGY: ZF'S NEW HEATED SEAT BELT UNVEILED AT CES

BRENDAN BAKER, EDITOR

At the Jan. 5-8 Consumer Electronics Show (CES), ZF unveiled some interesting new technology aimed at improving the range and performance of future EVs. One thing that caught our eye, and which seemed a little strange, is the company's new heated seat belts. Yes, seat belts with heaters.

Upon further inspection, however, it's actually a smart idea, and here's why: EVs have a persistent range problem. Not only is every manufacturer looking for ways to improve the range of their battery-electric vehicles, but they also need to perform in all kinds of weather conditions. "Snowmaggedon" is not that far in the review that we have forgotten Christmas of 2022. In the North, we hit some brutally cold temperatures with windchills in the double digits below zero. Aside from those cold temperatures on the skin, it doesn't mix well with lithium battery chemistry, either.

Subsequently, Tesla's cold weather performance is now coming under scrutiny in South Korea. The country's Fair Trade Commission alleges that the EV manufacturer exaggerated the driving ranges of its cars on a single charge and is being fined $2.2 million. However, EVs still need heat exchangers and pumps to keep cabin occupants and drivers comfortable, but the inherent issue with this more "traditional' way of cabin heating is that it wastes a lot of energy.

It takes more power to crank up the heat than if the driver had some other lower voltage way of staying warm and comfy. According to AAA, "Cold weather can cut electric vehicle range by more than 40 percent." EVs often lose 12 percent of their range in cold weather, but the loss can jump to 41 percent with the heater on full blast.

Enter the heated seat belt. It seems silly on the face of it, but it's actually a good idea when you dive in deeper. Here's a brief look at what ZF has in store, and it may just be the next big accessory add-on in the coming years as electric vehicles proliferate the highways and byways of the country.

A climate control system in a typical EV is powered by battery current, as there is no usable waste heat as with the combustion engine. Reducing the amount of battery current used to heat the vehicle's interior may enable a gain of up to 15 percent range using contact heaters and reducing the usage of conventional climate control systems. With an integrated heating function, ZF's new heated seat belt can provide close-to-body warmth immediately after the driver starts driving, typically between 96 -104 degrees F (36 - 40 degrees C). In combination with heated seats, the heated seat belt has the potential to provide occupant comfort quickly, according to the company.

ZF used a special textile processing method for this new technology. The heating conductors are woven into the seat belt structure. The contact elements for the electrical heating circuits are positioned, so they do not interfere with belt operation or retraction. The heated seat belt is in no way inferior to its conventional counterparts regarding occupant protection.

The special webbing with integrated heating conductors woven in minimally increases the thickness of the webbing. This makes integration easier for vehicle manufacturers and offers occupants the same comfort as a normal seat belt.

Of course, drivers can control their accessories to reduce battery usage, but why would you want to freeze or wear gloves and a puffy jacket when you can travel in comfort and warmth at a minimal cost to your battery range? MA

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TECHFORCE FOUNDATION ANNOUNCES 2022 TECHS ROCK AWARDS WINNER

TechForce Foundation announced Automotive Technician Daniel McCrum of CarMax in Gulfport, Miss., as its 2022 Techs Rock Awards grand prize winner.

"What!? Wow... I'm in, like, shock right now. Thank you!" McCrum said joyfully upon learning of his award. "I kinda thought I had a pretty fair chance to win something because of everything I overcame, but I didn't think I could win the whole thing. This is a national contest… it's nationwide and I won!"

The Techs Rock Awards was created in 2018 to highlight the contributions of technicians in their workplaces and communities and demonstrate to the public that a technical education and career is a viable pathway to success.

The awards showcase the benefits of an in-demand technician career to spark students' interest, and the TechForce Network meets those students where they are with the resources needed to explore and pursue a technical education and career, noted the foundation.

As the grand prize winner McCrum will receive more than $10,000 in total prizes from TechForce and its industry partners. Prize sponsors include Advance Auto Parts, AutoZone, Caliber, Cengage Learning, CRC Industries, Ford Motor Company, Snap-on Industrial, and WD-40 Company.

Since the awards program launched, technicians have received more than $27,000 in prizes. Over $17,500 in prizes were awarded in the 2022 Techs Rock Awards alone, including:

- **Each Category Winner, including the grand prize winner, received tools, gift cards, and other prizes valued at over $1,700.**
- **The grand prize winner also received an all-expenses-paid trip to STX 2024 in Orlando, Fla. valued at $3,000 courtesy of Advance Auto Parts, along with an additional prize package valued at over $5,500.**

The five category winners represent less than one percent of the nearly 700 technicians nominated. Winners were selected by a panel of expert celebrity judges including Emily Reeves, Flying Sparks Garage; Charles Sanville, The Humble Mechanic; Bogi Lateiner, Bogi's Garage; Pete Meier, *Motor Age Magazine*; and Julia Landauer, Julia Landauer Racing.

Each category winner represented a distinct category. Honorees include:

- **Barrier Buster - Daniel McCrum, Carmax. The Barrier Buster category recognizes technicians for showing heart and passion in overcoming obstacles to succeed.**
- **Die Hard - Joshua Ferrantino, Rodman Ford. The Die Hard category recognizes industry superfans who live, breathe, sleep, and thrive in their career.**
- **Outstanding Mentor - Frank Mendoza, Flow Nissan & NASCAR Technical Institute. The Outstanding Mentor category recognizes techs for providing support and guidance to the industry's future technicians.**
- **Pay it Forward - Zachary Carlsen, Northern Auto Repair. The Pay it Forward category recognizes technicians for being a community advocate and inspiring the next generation of techs.**
- **Rookie of the Year - Kael Gortat, Carmax. The Rookie of the Year category recognizes up-and-coming tech professionals with under two years' professional experience.** MA

EV SUSPENSION TECHNOLOGY

BRIDGESTONE'S SMART CORNER DIGITALLY CONNECTS TIRES AND AIR SPRINGS FOR EVS

While on the show floor at CES 2023, one way Bridgestone demonstrated its vision for sustainable mobility was through its "Smart Corner", a solution to enhance the performance, comfort, and efficiency of electric and autonomous vehicles, while maximizing the lifespan of tires and air springs.

Smart Corner combines Bridgestone's tires and Firestone Airide's (previously Firestone Industrial Products) air springs that are engineered specifically for electric and autonomous vehicle applications.

The solution uses embedded, cloud-connected sensors in both the tires and air springs, enabling Bridgestone to deliver real-time and predictive insights that elevate safety, efficiency, and productivity.

The Bridgestone Enliten EV Concept Tire is constructed of new materials that are both renewable and energy-efficient, reducing rolling resistance to increase battery range while meeting the demands for higher loads and wear resistance associated with EVs.

The Enliten EV Concept Tire is paired with Firestone Airide Concept EV Air Springs, designed as part of the integrated corner system tire to optimize efficiency and ride quality. This digitally connected air spring will adapt to dynamic loads and enable active suspension systems to further isolate noise, vibration, and harshness, while maximizing safety and efficiency without compromise to ride comfort.

The air spring also enables proactive vehicle ride-height adjustment to maximize aerodynamic efficiency, improve user accessibility, and protection of underfloor components in urban and off-road environments.

Both the Enliten EV Concept Tire and the Firestone Airide Concept EV Air Spring feature integrated sensors that collect air pressure, temperature, and accelerometer data that, when combined with Bridgestone's proprietary data analytics technology, can inform native vehicle systems with real-time estimations of corner loading, road surface conditions, and the performance capabilities of the tire and spring.

These digitally enabled insights drive awareness and action to maximize safety in electric and autonomous vehicles, while enabling Bridgestone mobility solutions to anticipate vehicle needs and connect customers directly to services that increase productivity and convenience, extend product life, and deliver improved sustainability for the zero-emission, carbon-neutral future of mobility. MA


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CREATING SUCCESS WITH LESS SACRIFICE

BY DAVID ROGERS // Contributing Editor

Rising operating costs and technician shortages are the norm, and it's harder than ever to hire the help you need. So how are shop owners supposed to find the time to grow the shop? After all, there is only so much of you to go around. If you must micromanage every area of the business, then the only way to get it all done is to subtract from your personal and family time.

How else are you supposed to oversee inspections and bookkeeping and part/core returns and payroll and employee efficiency and profit margins? For owners in the thick of it, it can feel like the only way to get it all done is by sacrificing family, health, and well-being.

Is that just what it takes to run a successful shop? Absolutely not. It's not sustainable, practical, or necessary.

The real solution is to empower your team. When your employees have the right tools, they share the same goal, and they have the authority to make positive changes. Your shop can grow – better, faster, and more sustainably – than you could on your own. (And without having to sacrifice your own happiness to get there!)

So, how do you build a team that wants your shop to succeed?

Designate goals and who's responsible for achieving them

If the goal is for your team to do the things necessary for growing the shop without you having to micromanage, then the first step is to make it clear who is responsible for each specific, actionable, attainable metric. Just as important, you need to provide them with processes and procedures they can follow to hit their goals.

For example, if your team is going to help you manage profit margins, that means helping them understand where your shop is now, where it needs to go, and their daily steps for working toward that goal. Will they be responsible for adjusting pricing? Whose job is that, specifically, and what steps should they follow each morning to hit that goal?

The team can't manage daily what isn't being measured daily, though…if you can't see your profit margins until the month is over, then it's too late. The opportunity to hit your goals for that month has already passed.

Once your team understands what their goals are and how to hit them — and they can see their progress daily so they know if they're winning or losing — they can grow your shop without you having to micromanage.

Empower your team to make needed changes

One critical missing piece, though, is empowerment. If your team has the responsibility for hitting a goal but none of the authority to make the changes each day to hit it, then nothing will change. Not only can the team not make progress, but they'll also start to quit. Having the responsibility to hit a goal without being empowered to hit it is a helpless situation.

The good news, though, is that your team can manage a lot of the production pipeline when they have clear goals, policies, procedures, and measurements.

One such area is the shop's inspections. Top shop owners recognize that when technicians do a thorough inspection, they help create a full work pipeline. Customers trust the shop more when the service advisors educate them to make the right decisions for their vehicle, leading to future sales and repeat visits.

But for that to be true, technicians must complete a thorough inspection on every vehicle. When a tech pencil-whips the inspection, what happens next? Can the service advisor send it back to be redone?

That's what I mean by empowering the team. When they have the responsibility to improve a number, the steps needed to get there, the authority to make changes, and the optics to see their improvements each day, your team can help you make the changes you've always wanted to see in your shop.

Incentive-based pay plans must be customized

The only step left is to incentivize them so that they want to make those changes. This comes with a huge warning sign, however: pay plans are not one-size fits-all.

Proper incentive-based pay plans

must be built with the knowledge of where your shop is and where it needs to go. Any pay plan you can buy off the shelf is bound to create disincentives that hurt the shop, the employee, the customers, or all three.

These are not small warnings. Unless you're willing to find somebody with a lot of experience to help you build an incentive-based pay plan based on your history and goals, it would be better not to use incentives at all. There are immense downsides to getting this wrong.

But the inverse is true, too. When a pay plan is built for your unique situation and your unique goals, your entire team is invested in seeing your shop succeed. You no longer need to micromanage people or processes to ensure that your team does the right thing with every vehicle, every time.

To give you a picture of just how powerful the right incentive-based pay plans can be, my shop, Keller Bros. Auto Repair in Littleton, Colo., continues to set sales and profitability records year after year, even though we've been running the shop remotely for decades. The reason we're able to do that is because the team is trained, accountable, empowered and incentivized to do things the right way, every single time.

You don't have to sacrifice your time and health to grow your shop, and you don't have to miss out on time with friends and family to get your shop to the next level!

Follow these clear steps for empowering your team – and avoid major pitfalls when choosing incentive-based pay plans – and you'll make this next year your best yet, no matter what happens in the economy or job market.

You can do it! I'm excited to hear your success story! MM

Whether you need marketing that delivers results, incentive pay plans, training CDs, business coaching, or the same shop management system used by Keller Bros – Shop4D – to maximize your team's production, find the solutions you need at https://autoprofitmasters.com/empower.

DAVID ROGERS is president of Auto Profit Masters, Shop4D, and the award-winning Automated Marketing Group, and the COO of Keller Bros. Auto Repair in Littleton, Colo. Together, these companies form an ecosystem of success for shop owners, offering proven, sustainable solutions for maximizing efficiency and growth, growing customer bases, and creating a culture of excellence. With nearly half a century of experience in the automotive industry (and they're still growing exponentially), Auto Profit Masters and Automated Marketing Group have the tools and resources to help set your shop apart from your competition and elevate your business to the next level.

DISPELLING COMMON MYTHS OF EV REPAIR AND MAINTENANCE

THE IDEA THAT EV MAINTENANCE WILL COMPLETELY DIFFER FROM THAT OF A GAS-POWERED VEHICLE STEMS FROM CONFUSION AND THE LACK OF EXPOSURE TO THE SEEMINGLY DAUNTING TECHNOLOGY.

BY DUANE "DOC" WATSON // Contributing Editor

Electric vehicles are more mainstream than ever, and they will only become more prevalent as we approach 2035, the fully electric goalpost set by auto manufacturers and the State of California. The transition to electric vehicles will have a major impact on transportation, manufacturing, shipping, agriculture, and more, and the automotive maintenance and repair industry is no exception.

Fortunately, the idea that EV maintenance will completely differ from that of a gas-powered vehicle stems from confusion and the lack of exposure to the seemingly daunting technology. As a result, there are many myths around the servicing of electric vehicles, including the idea that EVs

need more maintenance, the thought that shop owners need to be prepared for EVs right away, and that EV tools and equipment may not bring a positive return on investment.

Of course, we will all develop a larger understanding of the evolved technology as more people run into electric vehicles in their everyday, in media, on the road, at the dealership, etc. For now, many technicians and shop owners are faced with a unique set of challenges in the transition to electric vehicles. including how to adequately communicate with customers about EV maintenance, when to invest in the right tools/equipment and more. Training, exposure and communication on all levels will give technicians the tools they need to succeed in this transition and overcome these myths.

MYTH:
EVs require more maintenance and are more difficult to repair than gas-powered vehicles

According to the Department of Energy, electric vehicles usually require less maintenance compared to conventional ICE vehicles for a myriad of reasons including:

- The EV battery, motor and other electronics require little to no regular maintenance
- There are fewer fluids, such as engine oil, that need regular maintenance
- Regenerative braking in EV's significantly reduce brake wear

Put simply, electric vehicles are no more difficult to repair than their gas-powered counterparts because they have fewer moving parts. While many elements of auto maintenance and repair may be evolving, there are some new additions to take note of.

Since EVs run on battery power and have fewer internal fluids, EV owners are able to save time and money by not needing to budget for two to three oil changes a year. Additionally, brake wear-and-tear will be reduced in electric vehicles due to regenerative braking, the process of a vehicle capturing heat energy from the brakes and converting it to usable energy for the battery. However, that is not to say maintenance will magically disappear in the transition to electric vehicles.

Lithium-ion batteries, the most common batteries found in an electric vehicle, can become very hot after long hours of use or due to other uncontrollable conditions. Anyone who's used a smart phone at the beach will agree. If we apply this logic to electric vehicle batteries, which are hundreds of times bigger than the average smart phone, then we truly see the importance of the battery cooling system.

EV cooling systems are meant to regulate the temperature of the battery pack through a series of cooling loops and radiators to reduce excess heat and an electric pump to circulate coolant within the battery. These cooling systems are important to the overall performance of the vehicle and lifespan of the battery, as overheating can accelerate the rate of battery degradation. Like anything, these cooling systems will need to be checked according to the manufacturer's instructions.

Finally, many parts and components on EVs will need similar repair/maintenance as any gas-powered vehicle including steering systems, air filters, and windshield wipers.

MYTH:
Shop owners will have to be prepared to service EVs right away

With the seemingly fast transition to electric vehicles, shops across the country feel like they are being forced to service them just as quickly. In reality, gas-powered vehicles will still be relevant in many parts of the country as EVs will only make up 13 percent of vehicles on the road in 2035. That number is expected to reach 95 percent in 2050, which leaves shop owners plenty of time to prepare for the EV transition by training technicians, investing in EV tools and equipment, installing electric chargers etc.

A shop's need to service electric vehicles will be determined by the location of the shop, the customer base and priorities of the owner. A repair shop in California, where over one million EVs have already been sold, will have many more electric vehicle repairs than a repair shop in Michigan, which has far fewer EVs on the road. On the surface, investing in EV-compatible equipment makes a lot more sense in California than for the shop owner in Michigan.

However, the benefits available to the Michigan shop owner, should they choose to make the investment, are worth noting. Although Michigan has far fewer EVs on the road than California, the repair options available to those who are driving electric within the state are slim. This presents a window of opportunity for the shop owner to become the EV repair expert within their region, ushering in a great deal of new business by embracing the current novelty of EV repair in rural areas.

MYTH:
Buying tools that service EVs will not provide an adequate return on investment

Many auto repair technicians are hesitant to invest in tools that service electric vehicles for fear they will not see adequate return on that investment.

First, consider that the equipment you purchase to service EVs can likely prove useful for ICE repair in a variety of ways. Take an EV-capable lifting table, for instance; while its main purpose is removing battery packs from EVs, you'll find it also functions as a work surface for taking engines apart and reassembling transmissions. Think outside the box of ways EV-compatible tools can be used elsewhere around your shop.

Preparing your shop's staff to take on electric vehicle repair also doesn't have to come at a loss. Introducing and offering electric vehicle-related training to technicians of all experience levels benefits everyone in the shop, especially the customer who will be looking for the best service. Additionally, providing technicians with EV training sessions, thereby expanding their EV knowledge and skill set, can be used as a valuable tool in recruiting technicians, especially when you consider the labor shortage.

Much of the training that readies technicians for EV repair can also come in handy when dealing with ICE vehicles. It's likely that any EV repair training program you enroll your technicians in will expose them to the ins and outs of things like emergency braking and ADAS – features which are hardly unique to EVs. This means that you can prepare for the days when EVs are dominating the auto landscape while still benefiting from what you learn when repairing the majority of ICE vehicles you encounter now.

Shop owners can take advantage of state and federal rebates by installing electric vehicle charging stations for their customers provided through state and federal energy rebates. Electric vehicle charging stations can act as an amenity for customers who may be leaving their vehicles at the shop for multiple days. They can also act as a form of marketing – possibly making the difference between someone choosing to go to one shop over another.

Electric vehicles will revolutionize many industries quickly and in major ways, however, current automotive repair and maintenance practices will remain relevant as the world transitions to electric vehicles. Any changes during the transitionary period will depend on how quickly the new form of mobility is adopted and how shop owners will respond, according to their goals and their regional market. MA

DUANE "DOC" WATSON is a field sales trainer with Bosch Automotive Service Solutions, specializing in electronics and vehicle diagnostics.

ARE YOU READY FOR THE EV REVOLUTION?

UNDERSTANDING THE EV'S BATTERY MANAGEMENT SYSTEM AND WHY YOUR SHOP NEEDS A CHARGER FOR EV SERVICE WILL KEEP YOUR SHOP HEADED IN A PROFITABLE DIRECTION.

JOHN FORRO // Contributing Editor

The news is filled with stories about automakers going all-in on electric vehicles. Thirty-three electric models were released last year, and automakers such as General Motors have plans for all-electric vehicle lines by the start of the next decade. The first step in servicing them is to get familiar with a few concepts.

Since the introduction of smart charging systems in the '90s, battery management systems (BMS) have existed in some form. Electric vehicles (EVs) have a more sophisticated BMS to help protect the high-voltage (HV) battery and extend its life.

AUTEL

AUTEL'S MAXISYS ULTRA EV provides a comprehensive analysis of electric and hybrid vehicles with expanded topology mapping and battery pack analysis that can be performed via OBD or directly with included specialty cables and jumpers.

Three main functions

BATTERY PROTECTION: A BMS is designed to keep a battery safe (during its normal use) to operate the electric vehicle and while charging the HV battery. It does this by closely monitoring the pack's temperature at various locations, controlling the battery's voltage and amperage while

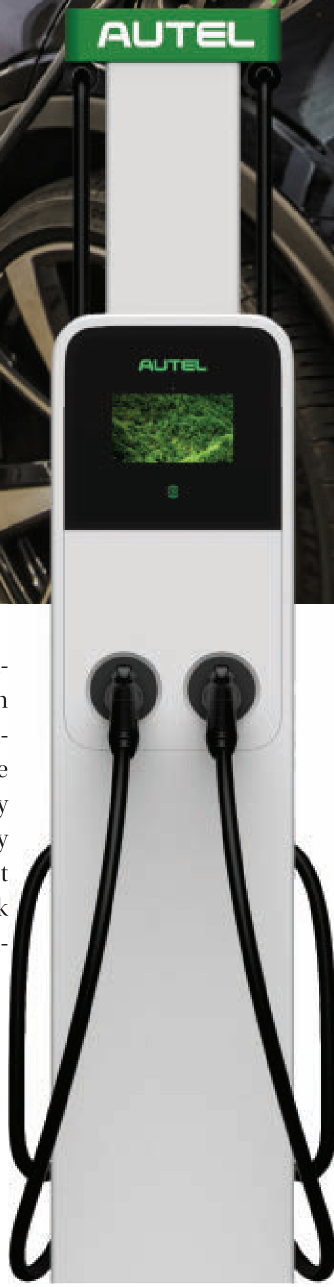
AUTEL

driving and charging, and keeping the battery balanced amongst its cells. These are just a few of the BMS' primary functions in keeping the battery safe.

BATTERY MONITORING: Throughout the operation and charging of the HV battery, the BMS monitors the state of charge (SoC) and its state of health (SoH).

BATTERY OPTIMIZATION: Its ability to monitor the above items accurately and closely will keep the battery properly balanced, which will help ensure the HV battery's long-term health. It will monitor the individual battery cell/block/module voltages by receiving specific voltage values (through the battery cell voltage PID monitoring physical connections).

The BMS can measure various strategically placed thermistors (temperature sensors) within an HV battery pack and can use this information to aid in thermal management of the pack and to help determine if there is a shorted cell within the battery pack. While the typical hybrid pack may only consist of 20-50 NiMH cells, it is not uncommon for a fully electric vehicle pack to consist of more than a thousand lithium-style cells.



THIS IS THE MOST POWERFUL dual-port AC charger on the market, acccording to Autel. The system was designed to ensure form meets function, with a footprint for limited space applications. This is an ideal solution for commercial charging sites, with an 8-inch HD screen that offers the ability to generate additional ad revenue.

The Vehicle Controls the Charge

Regarding charging an EV or plug-in hybrid vehicle (PHEV), we need to understand that the vehicle's onboard charging module (OBC) works in conjunction with the BMS to provide a safe charge of the vehicle's battery pack. A handshake occurs every time a charger is attached to the electric vehicle. Although DC Level 3 fast chargers can deliver 1,000 volts to the battery, most vehicles limit the voltage and amperage rate at which the battery can accept the charge (for safety reasons). During a typical charge, the BMS will also closely monitor the temperature of the HV battery pack to prevent the temperature from rising too high and potentially causing a fire.

As the number of electrified vehicles increases (and so does their need for servicing), it will become crucial for repair shops to purchase a Level 2 charger. These chargers output alternating current (AC), are very affordable, single-phase, and necessary to keep one's bays profitable. Unlike an internal combustion engine (ICE) that only burns fuel when running, EVs drain electrons most of the time while running them. For an electric vehicle, a charger is like a fuel can.

Level 1, level 2, and level 3 charging

LEVEL 1: This usually involves using the emergency charger provided with the EV when purchased.

- Pros: a 110-volt cord able to be used on 15-amp circuits.
- Cons: Charging speed is slow; the battery will gain three to five miles of range for every hour of charging.

LEVEL 2 CHARGING: These are 220-volt style AC chargers that are single-phase. Pros: Can be hardwired or installed with standard NEMA 14-50 or 6-50 plugs into an existing outlet. Some Level 2 chargers, such as the Autel MaxiCharger Commercial chargers, are designed to enable shops to monetize charging, allowing drivers to pay to charge their vehicles. Via a cloud-based portal, shop owners can control and monitor the charging station/s. The Level 2 chargers offer dramatically faster charging; for every hour of charge, the battery gains 12 to 80 miles of range. Cons: They are still AC, meaning the vehicle's electronics found within the OBC and inverter will need to convert the electricity to DC before sending it to the battery. It may also be necessary to step up the voltage via the vehicle's DC-to-DC converter.

LEVEL 3 DC FAST CHARGING: These units, sometimes referred to as SuperChargers, are three-phase 480V chargers. Pros: The voltage is already DC and, with the higher voltage, often doesn't require the usage of any of the vehicle's electronics to convert it. The Level 3 charging rate is typically 3 to 20 miles of range per charging minute. Cons: Higher initial infrastructure and out-of-pocket installation costs for charge point owners. Routinely using fast chargers may also affect the longevity of the HV battery.

There are two popular designs of charging connector types on EVs—the CCS and the J1772 plug standards. Note that the CCS has a J1772 atop the DC portion of the plug. The Tesla has its design; adapters enable the use of non-Tesla chargers.

It is safe to say that it is only a matter of time before EVs start appearing—if they haven't already— in your service bays for charging complaints or BMS-related DTCs. It is important that you have a thorough understanding of how these systems work and the proper tooling to diagnose these types of complaints.

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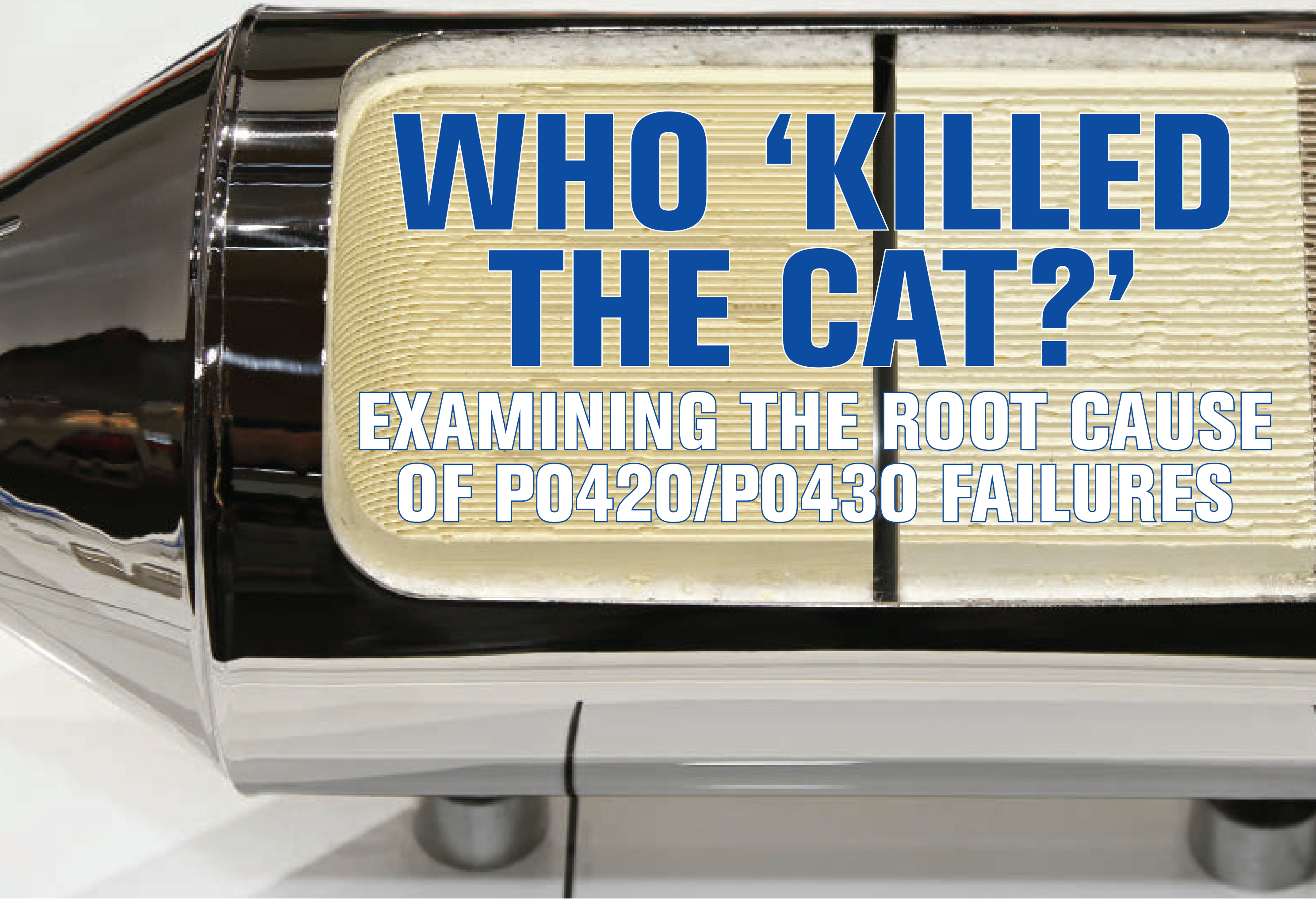
JOHN FORRO is an ASE certified Master Automobile Technician and also holds the L-1 Advanced Engine Performance certification. John has authored 26 automotive manuals to date, produced several automotive training videos, appeared in many of the industry trade magazines, and won the PTEN Innovation and Motor Top 20 Tool award for 2022. John continues to be a working automotive instructor and technician, which enables him to relate to the students' needs as technicians.



WHO 'KILLED THE CAT?'

EXAMINING THE ROOT CAUSE OF P0420/P0430 FAILURES

REPLACING A CATALYTIC CONVERTER IS THE EASY PART. DETERMINING WHY IT FAILED IN THE FIRST PLACE SEPARATES THE TECHNICIAN FROM THE MECHANIC.

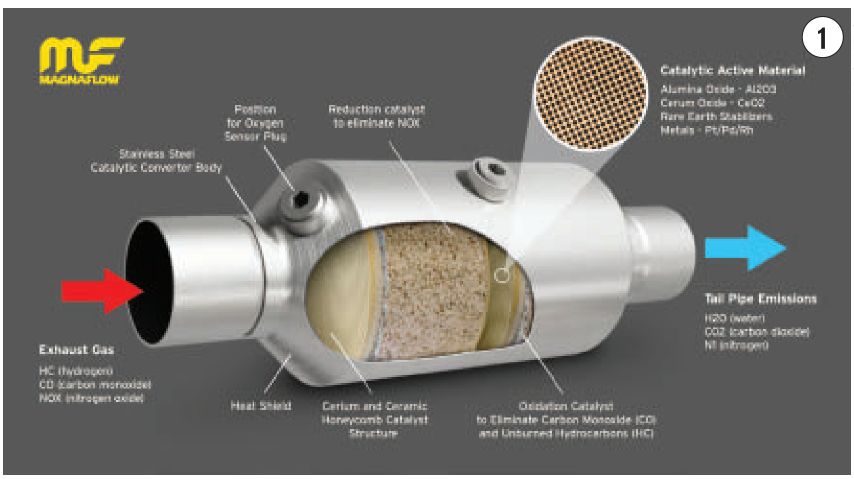
BY CHRIS FARLEY // Contributing Editor

I promise, no pets were harmed in the writing of this article.

Wait! What? That car I replaced a catalytic converter in last month… is it back with a P0420 (again)? It must be that inferior quality part you ordered. Oh! Did we get an OEM cat? Umm...

We have all been there. So, let us talk about how to handle it, or better yet, what to do so we do not get there in the first place.

Both P0420 and P0430 are ranked #1 and #2 on the "top-10 most common OBD codes stored" for years. With these statis-



MAGNAFLOW

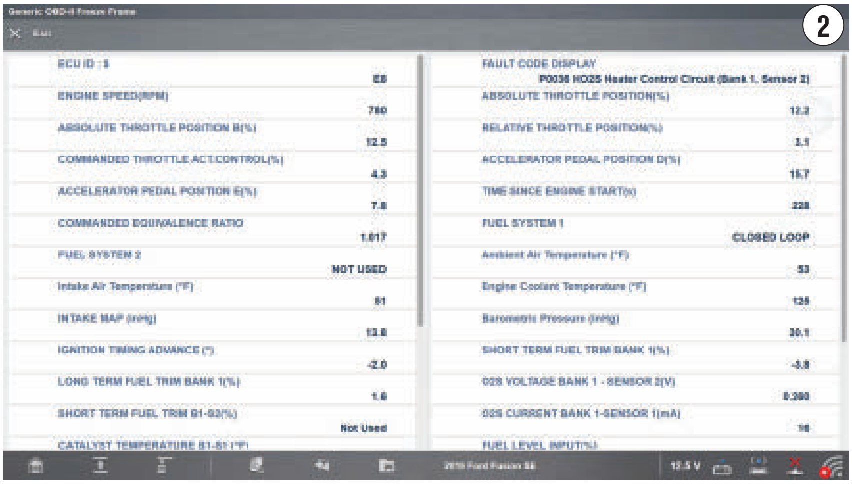
IN THIS CUTAWAY VIEW OF A CONVERTER, you can see the monolith core the exhaust gases pass through.

tics, we need to sharpen our skills to get these faults diagnosed fast and accurately.

A quick review of the catalytic converter

Catalytic converters consist of a body/shell typically composed of stainless steel. The inner core is made up of a substrate, a ceramic monolith core with a honeycomb design to maximize the surface area the exhaust gases must pass over **(Figure 1)**.

The substrate is dosed in a wash coat, which consists of numerous chemicals and elements. These initialize the catalytic reactions that chemically alter the harmful exhaust gases to less harmful gases. The precious metals we always hear about in the converters may consist of rhodium, platinum, palladium, cerium, and nickel.



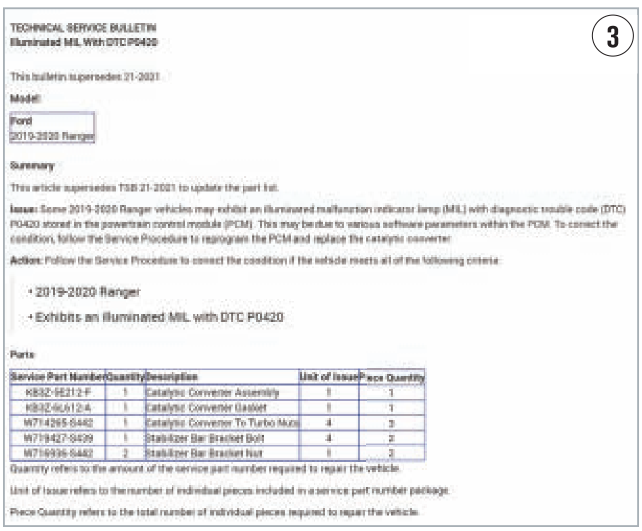
HERE IS AN EXAMPLE of a "freeze frame" snapshot. The number of PIDs stored varies by year, make, and make.

The wash coat may contain all or some of these components and many others. Each one of these components has a specific role in the process. Some are catalyst agents capable of withstanding the extreme temperature in which they work, and others have storage capabilities of components (like oxygen and hydrogen) that are required for the proper operation of the converter.

When the cat stops 'meowing' - P0420/P0430

We need to have a proper diagnostic plan to accurately diagnose these codes. I am going to share mine with you:

- I prefer to start with the customer interview to try to get a repair history. I am looking for repairs relating to engine misfires, sensors (inputs), internal coolant leaks, engine oil-burning issues, and such. I also like to ask about smoke or odd burning odors they may have been experiencing.
- I then move on to scanning the vehicle to retrieve DTCs, review the freeze frame, and mode $06 data. The variety of PIDs and info available in the freeze frame has grown significantly to the point where some vehicles have pages available for each code set **(Figure 2)**. I also try to grab PCM software calibration number info while I'm connected with the scan tool, to verify the update level of the software. Sometimes, a change in software corrects a miscalculation of cat



TECHNICAL SERVICE BULLETIN
Illuminated MIL With DTC P0420

3

This bulletin supersedes 21-2021

Model:

Ford
2019-2020 Ranger

Summary

This article supersedes TSB 21-2021 to update the part list.

Issue: Some 2019-2020 Ranger vehicles may exhibit an illuminated malfunction indicator lamp (MIL) with diagnostic trouble code (DTC) P0420 stored in the powertrain control module (PCM). This may be due to various software parameters within the PCM. To correct the condition, follow the Service Procedure to reprogram the PCM and replace the catalytic converter.

Action: Follow the Service Procedure to correct the condition if the vehicle meets all of the following criteria:

- 2019-2020 Ranger
- Exhibits an illuminated MIL with DTC P0420

Parts

Service Part Number	Quantity	Description	Unit of Issue	Piece Quantity
KB3Z-5E212-F	1	Catalytic Converter Assembly	1	1
KB3Z-9L612-A	1	Catalytic Converter Gasket	1	1
W714265-S442	1	Catalytic Converter To Turbo Nuts	4	3
W719427-S439	1	Stabilizer Bar Bracket Bolt	4	2
W716936-S442	2	Stabilizer Bar Bracket Nut	1	2

Quantity refers to the amount of the service part number required to repair the vehicle.

Unit of Issue refers to the number of individual pieces included in a service part number package.

Piece Quantity refers to the total number of individual pieces required to repair the vehicle.

THIS TSB INDICATES the manufacturer recognized a parameter problem in the software that is causing the early demise of the catalytic converter. To correct the problem, it states the converter requires replacement and an update of the PCM software.

efficiency and performance. A road test at this time is also a good idea to determine whether the engine has any other issues pertaining to this repair (low power/runs rough) or not. It is very important to document your findings. Save your freeze frame, save your pre-scan, and make a record of your tests/results.

THIS IS THE BLOWER I use to pressurize the exhaust systems for leak detection. The rubber tip will seal in the tailpipe to allow the pressure to build in the exhaust.

- This step is essential; consult service information! We need to look at two key items here, the first item being the code-setting criteria and the strategy used to monitor the system. Some manufacturers monitor switch ratios of front and rear air fuel/O2 sensors, and if the rear is switching too often (mirroring the front), then it will set the fault.
- Other strategies monitor the oxygen storage capacity of the converter by running the engine through a set air-fuel ratio cycle. The cycling deliberately depletes the oxygen stored in the converter. The converter is then flooded with oxygen and the fill time is monitored to determine how long it takes to absorb the oxygen to full capacity. This filling is inferred by the activity of the rear O2 sensor. When it signals a rise in O2, it indicates the cat is full and cannot store any more oxygen.
- The second item (this is one I have been bitten by before) is to check to see if there is a TSB that may apply to this code **(Figure 3)**. This is the reason I grab the software/calibration number in the previous step-so I know if the update has already been done. Many vehicles may have a bad converter, but it has been recognized by the manufacturer that a software update, changing the parameters, and operational strategies may extend the life of the converter. Some can be related to a faulty part that is damaging the converter that needs to be replaced, the root cause of a repeat failure of the converter.

THIS SCREENSHOT DEMONSTRATES a manual oxygen storage capacity test result for a catalytic converter.

What types of failures are there?

The first failure we will talk about is structural. A structural failure consists of a dented shell, damaged threads, flex pipe failures, or cracked/leaky welds. These failures are usually found with a visual or audible inspection. Sometimes the little leaks we cannot see or hear can get tough.

There are a few methods out there we can use to check for these leaks. Some techs suggest using a smoke machine, which I have done, but sometimes this does not work as the converter fights us by absorbing the smoke, or we find a bunch of smaller leaks down the line.

Another method is using a shop vacuum (I have also used a small rechargeable leaf blower) with a rubber tip connecting the hose of the vacuum to the output port and then connecting the other end to the tailpipe (skilled engineering may be required here). Simply fill the exhaust system with pressurized air. I want to point out this works much better on a cold system because if you cannot hear the leak, you spray soapy water and look for the bubbles (hi-tech, right?) If the exhaust is hot, the water will boil off before the leak can be found **(Figure 4)**.

The leaky exhausts can skew a cat's performance in two ways. First, if there are leaks upstream of the air-fuel ratio sensor, it will alter the ECM's fuel control strategy (which can lead to damage to the substrate). The second is if a leak exists after the primary air/fuel ratio sensor but before the downstream O2 sensor. This will cause false oxygen to be detected, which again may alter the fuel strategy, but it could also skew an oxygen capacity storage test result and trigger a DTC.

The second failure is not as common but requires the mentioning of thermal

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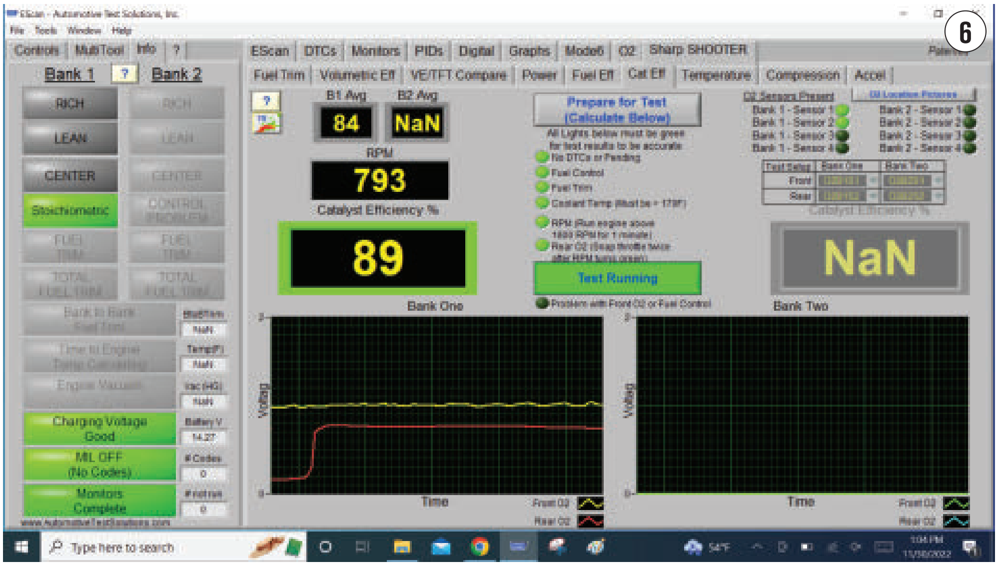


6

THE ESCAN ELITE FROM AUTOMOTIVE TEST SOLUTIONS directs you through the steps required to prepare the vehicle for the converter test and then performs the test automatically once the criteria are met. The tool then displays the test results with a score in the percentage of efficiency.

shock. The converter's normal operating temperature is anywhere between 500 to 1,200 degrees F; now drive that through a nice cold puddle, and we get a thermal shock.

Thermal shock is the sudden contraction of the materials that occurs with a sudden drop in temperature. This can cause the substrate to be crushed or damaged and break free to become a rattling converter. Construction design improvements and the use of heat shields have made these faults less common.

The third failure is poisoning. Poisoning is harder to diagnose without disassembly because the evidence is internally on the substrate internally. This typically comes from antifreeze or oil being consumed during the combustion process and contaminating the substrate (this is why I question the customer about recent repairs).

The system can also be poisoned by fuel or oil additives and the use of improper sealants, especially on the exhaust gaskets (I have seen assorted color rubber sealants holding flange gaskets on). Depending on layout or construction, we may be able to remove a sensor and see the substrate with a borescope. If not, this is one of those situations where you eliminate all the other possibilities and explain the required steps to the customer. I live in the northern half of the country, where road salt is utilized and rust thrives, so it is not likely that we can just unbolt a flange for a quick peak & reassemble.

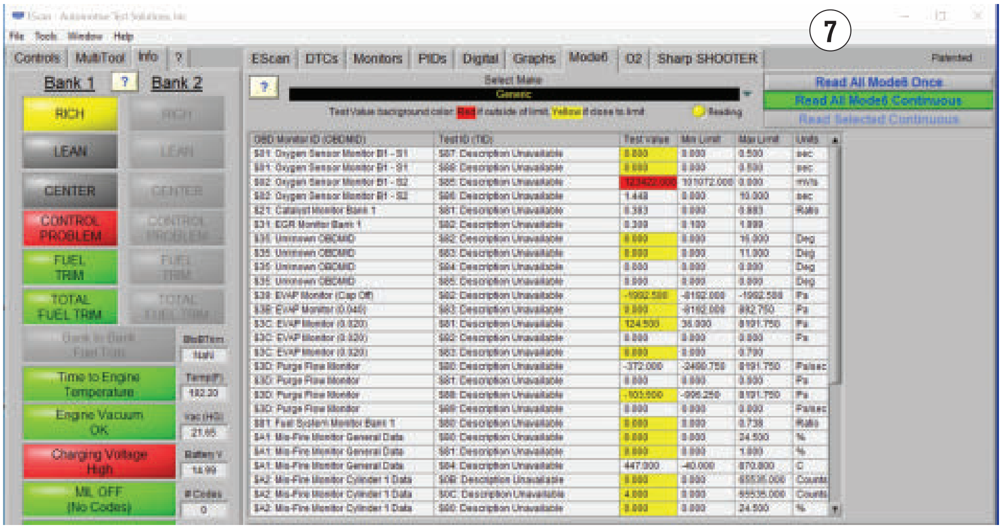
I saved the best for last, overheating and melting of the substrate. When the exhaust gas levels get too high (whether it be from misfires or incorrect fuel control), the reactions in the converter and the associated temperatures rise above normal operating temperatures. Overheating destroys the active components of the wash coat, making them inert and unable to perform their tasks. Melting is when the temperatures get so hot the substrate melts and starts to restrict the flow of the exhaust gases. This can result in a loss of power because the engine can no longer breathe properly.

If we have followed our diagnostic procedures and eliminated the first three causes, TSBs, and previous repair issues, we now get into the meat of the testing. This is not a problem though because we already understand the criteria for setting the code and the method the ECM uses to determine the fault.

I like to do easy testing methods whenever possible. Don't get me wrong; I love using my oscilloscope when it is required, but this can be handled with most scanners. If the vehicle in question is using switch ratio to determine the fault, we should up our scanner to read the data PID graphs for the upstream and downstream sensors. Essentially, we would be monitoring the same data the ECM does to determine the switch ratio under the same (or as close to the same) conditions as the ECM does. I know what you are thinking… "If it has an air-fuel ratio sensor, we cannot read it." We can; we just need to read differently.

If we look at the current (or amperage, in "uA"), it will be of smaller amplitude, but it will still be a swing. This picture demonstrates the data being monitored while I was testing oxygen storage capacity **(Figure 5)**. You should notice sensor 1/1 signal movement with the lambda value and how it changes with the mixture. Not perfect, but it works. If we see either sensor not behaving as anticipated, we then need to test their functionality to ensure they can perform their job properly. The sensor needs to be able to read rich and lean mixtures and react fast. A biased sensor (one that favors rich or lean readings) can and does cause a lot of converter issues.

The systems that employ oxygen storage capacity test strategies may require a little more effort, but we can alter the mixture with vacuum leaks and alternate



IN THIS SCREENSHOT OF MODE $06 DATA, the EScanELITE scan tool from Automotive Test Solutions displays the MIN/MAX criteria for the test parameters and shows the vehicle's results. The color changes depending on how close to failure the results are.

fuel sources while watching the reaction time. Or, as I've said, I like "easy," so I get out the scan tool and monitor upstream and downstream (as described above). However, this time, I take the vehicle out on a road test or elevate the RPM in the bay. I then allow the engine to idle normally, give it a wide-open throttle snap, and watch the response time of the downstream sensor before it starts reading oxygen **(see Figure 5)**.

I also use tools that perform the tests for me **(Figure 6)**. This tool guides you through the steps and then calculates the results (this is only one of many useful features for testing fuel control systems). I like this tool for the way it lists its mode $06 data as well. **(Figure 7)**. The actual purpose of our testing is to verify the ECM is getting fed the proper data from the sensors, and then responding properly and as expected.

Valuable information available

The last two resources available are freeze frame data and mode $06. The freeze frame data may be too slow to catch glitches that set DTCs. For P0420/P0430 it puts us in the general range when the fault happens.

We need to review this data to see if any readings were off (not completely out of spec to set a code, but enough to change our air-fuel mixture). The scanners we are using give us an overload of PIDs and I have found myself guilty of passing right by some PIDs that were indicating some issues without me realizing it.

The freeze frame has a smaller list of relevant PIDs and displays those for you to see at the approximate time the fault was detected. Look at the PIDs that can affect the fuel mixtures (like the temperature of the engine and air, MAF or MAP sensors, and the upstream & downstream o2 sensors).

The other source of information we have is mode $06. Although it was not initially intended for us to use as technicians, and some of the descriptions of what is being tested are not perfect, it is a treasure chest of info.

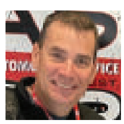
The screenshot I shared is from a good-running vehicle with no faults (see Figure 7). You can see the information provided here and what the computer is using for its parameters to set faults. Why is this valuable to see?

What occurs when parameters are close to failing but just not crossing the threshold yet? Could they be affecting the ECM's decision for fuel mixtures? You bet! I am from a state where we perform mandated emissions inspections. These consist of reading the OBD2 monitors to see if all or most (depending on the year) have run and passed.

Sometimes monitors will not run, and we will find the culprit in mode $06 data. We could easily see if one of those sensors was close to failing. In other words, we can now see the "gray area" (not just "black and white"). This might be the root cause that prevents a monitor from running.

Some other key data shown is the misfire parameters. Although there may not be any misfire DTCs, there may be misfires occurring (just not enough to cross that threshold of turning the MIL on), but over time can be a culprit to the early demise of our dear old cat.

I'm honest when I say ECMs and scan tools process data faster than I ever could, but despite what every customer thinks about these magic machines, they do not tell us what is wrong with their car. It is still our task to analyze the data and diagnose the faults. We do this by following a process of logical testing which leads not only to the faulty component but beyond that, to what caused that component to fail in the first place.



CHRIS FARLEY is a 25+ year veteran of the industry and is currently the owner and operator of Automedic LLCs, a mobile programming & diagnostic business servicing both auto body and repair shops in central NJ.

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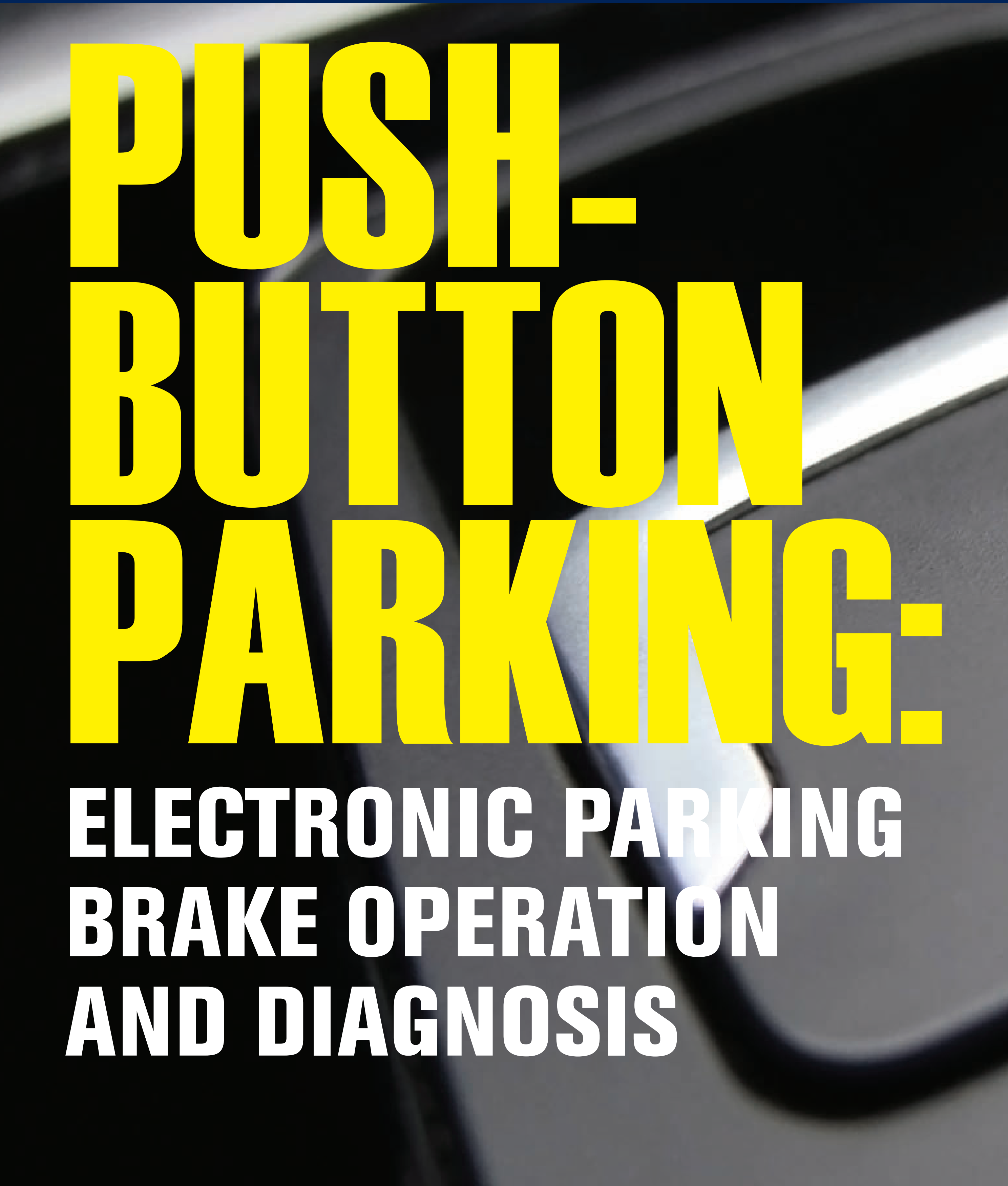

PUSH-BUTTON PARKING:

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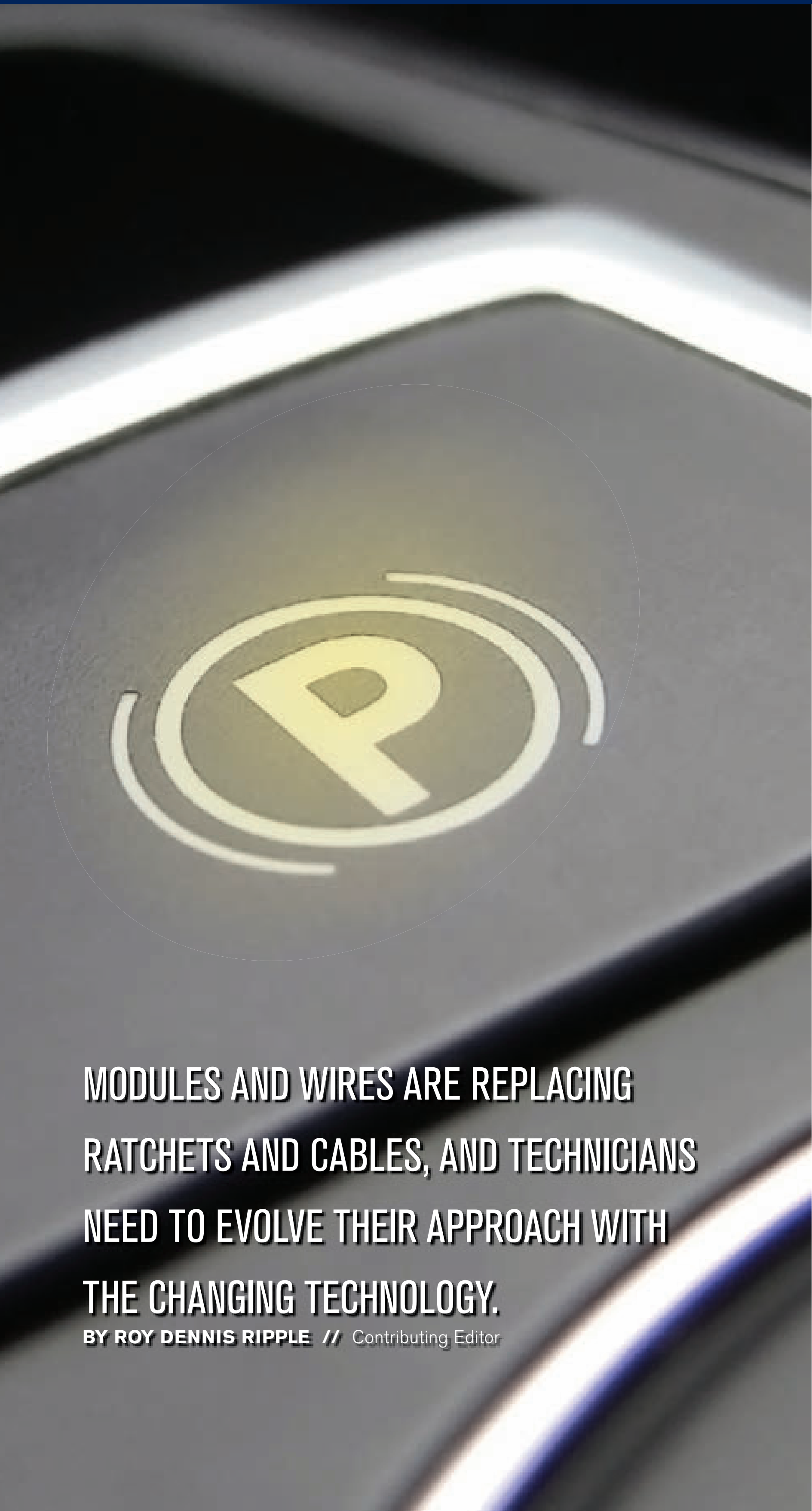


MODULES AND WIRES ARE REPLACING RATCHETS AND CABLES, AND TECHNICIANS NEED TO EVOLVE THEIR APPROACH WITH THE CHANGING TECHNOLOGY.

BY ROY DENNIS RIPPLE // Contributing Editor

Way back in the dark ages, automotive brakes were strictly mechanical. Long metal rods turned backing plate-mounted cams, which applied brittle brake shoes to steel drums. Two Hail Marys and a “Whoa, that was close!” later would hopefully bring that 1937 coupe to a stop. It was one small technological leap from the Flintstones’ feet-first braking system. Until recently, parking brakes used pretty much the same technology. It was time for a change. Enter the electronic parking brake (EPB).

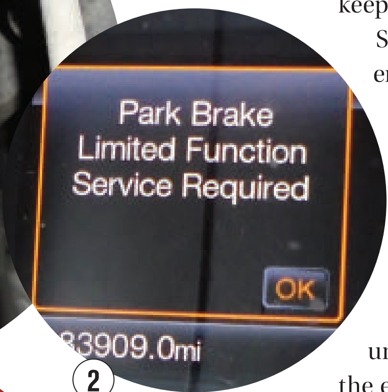
The birth of EPB

In the infancy of EPB, manufacturers used a single electric motor that tugged on conventional parking brake cables that engaged the rear brakes. This system neglects to address the main problem with parking brakes: seized cables. New technology meets horse and buggy—like writing a computer program with a typewriter.

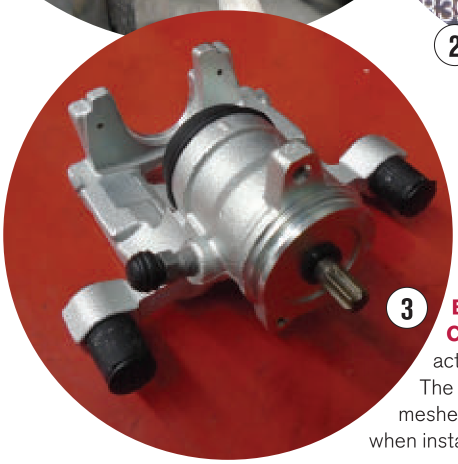
Today's most common EPB system uses two switch-activated motors to apply and release the rear brake calipers **(Figure 1)**. Most manufacturers use the anti-lock brake system (ABS) module to monitor and control the parking brake system. A diagnostic trouble code (DTC) is stored in the ABS module when a fault is detected, illuminating the parking brake warning indicator or a warning message in the instrument panel cluster or IPC **(Figure 2)**. The EPB indicator also illuminates when the parking brakes are applied and when they are released.

The parking brake actuator motors are single-speed reversible electric motors mounted on and splined to the rear brake calipers **(Figure 3)**. In most cases, the motors can be serviced separately from the calipers.

1 **THIS IS AN IMAGE OF A LEFT REAR EPB CALIPER.** The black actuator motor is attached to the back of the caliper.



2 **THIS WARNING MESSAGE APPEARS** on the IPC of a Ford Fusion when the ABS module sees a fault with the EPB system.



3 **BRAND NEW CALIPER** with the actuator motor removed. The splined shaft visibly meshes with the actuator when installed.

Here's a generic version of the sequence of events when the EPB is commanded to engage:

- A reference voltage is sent back to the ABS module when the driver moves the parking brake switch to the APPLY position.
- The ABS module assures that conditions are correct for EPB actuation, then sends power and ground to the parking brake actuator motors.
- Once the parking brakes are fully applied, the ABS module sends a message to the IPC, which illuminates either the red BRAKE warning indicator or an EPB-specific warning indicator.
- When the driver moves the parking brake switch to the RELEASE position, the reference voltage is sent back to the ABS module, indicating a RELEASE request.
- The ABS module assures that conditions are correct for the EPB release, then sends reverse polarity current and ground to the parking brake actuator motors.
- Once the parking brakes are fully released, the ABS module sends a message to the IPC, which turns off the EPB warning indicator.

The ABS module looks to the network to ensure that all conditions are correct before allowing the EPB to engage. The service brake needs to be applied, the throttle position sensor (TPS) needs to report that the throttle is closed, and the transmission must be in park. The latter is vital because a reported transmission gear position other than park can keep the EPB from disengaging.

Suppose the transmission range sensor reports a different gear position to the powertrain control module (PCM) than the gear shifter (whether it's a gear shift module (GSM) or a mechanical shifter). In that case, the EPB will engage and stay there. It will not disengage until it sees the same value from both sources. When faced with an EPB that will not disengage, this should be the first thing you check.

Most manufacturers design the EPB to disengage under certain circumstances. With the driver door closed, the engine running, and the transmission in any forward gear or reverse, the EPB will release when the TPS reports a throttle tip-in. The EPB on a manual transmission vehicle will automatically release when the driver door is closed, the engine is running, and the clutch pedal is pressed. A vehicle driving away up an incline requires more accelerator pedal input to disengage the EPB than a vehicle driving away on level ground.

Precautionary measures

A rear brake caliper fitted with an EPB motor can be dangerous if the proper precautions aren't taken before servic-

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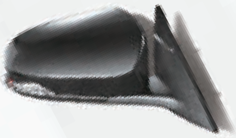

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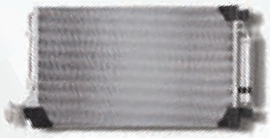
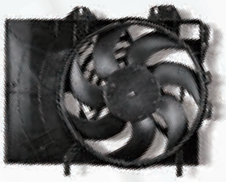
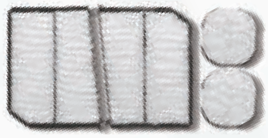


CONDENSERS



COOLING FAN ASSEMBLIES



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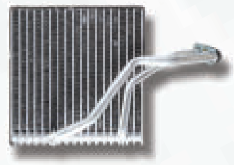

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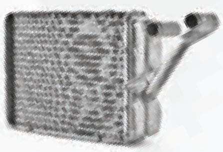

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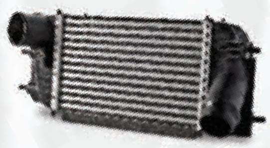

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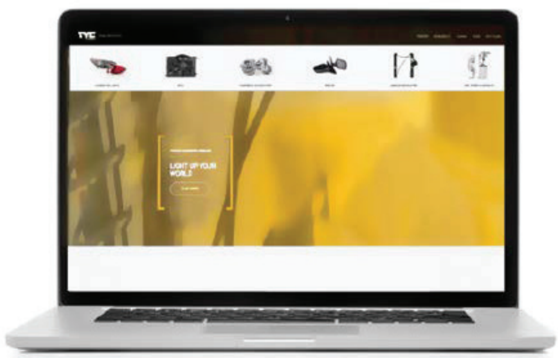


ing. The piston moves out of the caliper hard and fast, and it doesn't stop until something stops it, whatever it may be.

The parking brake system must be placed in service mode, also known as maintenance mode, to service the rear brake pads or when removing any rear brake components for servicing. The EPB system can be placed in service mode using a diagnostic scan tool or following a series of steps that can be executed from the driver's seat. For example, a 2019 Ford Fusion will enter service mode by turning the ignition switch ON, depressing the accelerator pedal to the floor and the EPB switch to the release position. You'll then have to cycle the ignition switch to finalize the procedure.

The IPC will indicate that the system is in service mode. The only way to reactivate the parking brake system is by correctly exiting service mode. Besides the possible damage to your valuable fingers, the caliper can be damaged if the piston fully extends during a non-commanded EPB actuation event when the caliper is detached from the vehicle.

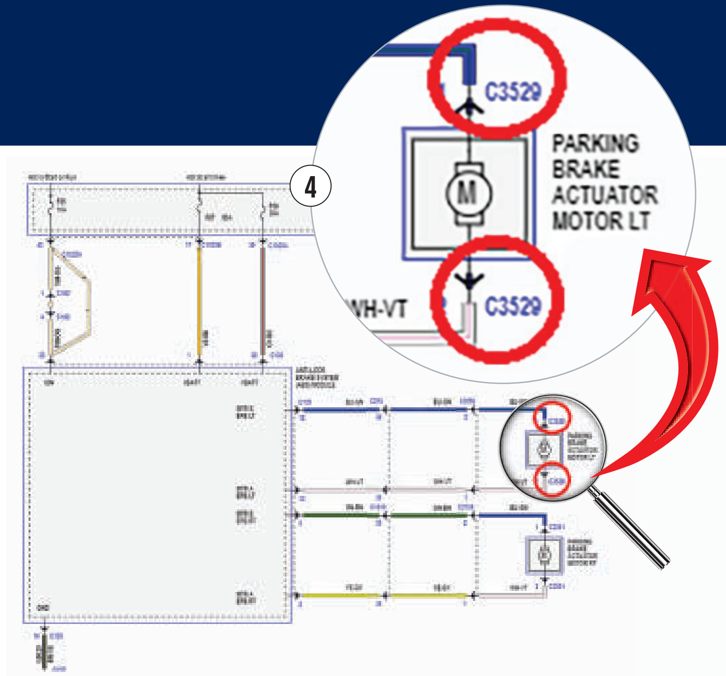
The emergency brake feature hasn't been lost on the EPB system. Applying the electronic parking brake while moving will engage the anti-lock braking system, slowing down or stopping the vehicle. The ABS module will continue to run the pump and apply the rear brakes as long as the driver is engaging the EPB switch.

EPB diagnosis usually begins with an illuminated warning indicator. Some manufacturers use the same indicator to report a service brake issue as they do to report an EPB issue. Pull the DTCs and service any ABS or service brake concerns before diagnosing an EPB failure. The ABS module will set a DTC and turn on the warning indicator if it sees a circuit, a calibration, or a parameter memory issue with the EPB system. This means that the position of the EPB actuator motors is not what the module expects to see, or the position values are not available. It doesn't take much for the ABS module to set a DTC and turn on a warning indicator if it doesn't like what it sees.

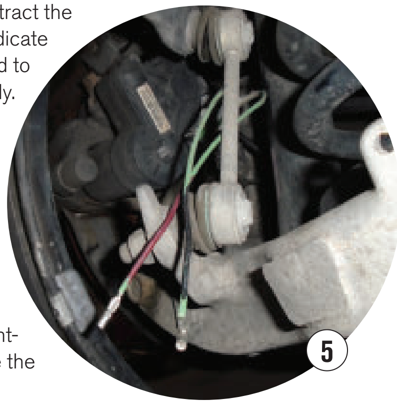
Real-world example

We diagnosed a 2017 Ford Fusion with an illuminated EPB warning indicator and DTC C2005:74 (the clamp request from the ABS module takes longer than 8 seconds to perform) stored in the ABS module. The DTC applied to the right rear actuator motor.

Since there were no circuit DTCs, and the actuator motor was eventually applying, we could assume that the wires between the ABS module and the actuator motor were a complete circuit, not shorted to ground, not shorted to voltage, and not shorted to each other. This is a performance DTC, which means that the ABS module didn't like what it saw when it activated the EPB.



WIRING DIAGRAM FOR AN EPB SYSTEM. Notice how each actuator motor has an A and B circuit. Current polarity is reversed on these circuits to extend and retract the caliper piston. The RED circles indicate where the jumper leads are placed to retract the caliper pistons manually.



HERE'S AN IMAGE OF ONE OF MY PIGTAILS attached to an actuator motor. Notice how the wires are marked red and black, identifying the proper polarity to retract the caliper piston. Using a tool like a Power Probe can make light work of supplementing voltage and ground to operate the actuators.

A visual inspection revealed that the thickness of the rear brake pads was about 7mm. Extremely worn brake pads would set this DTC, but that is not the case here. This meant that we had either a sluggish actuator motor or a sticking rear caliper.

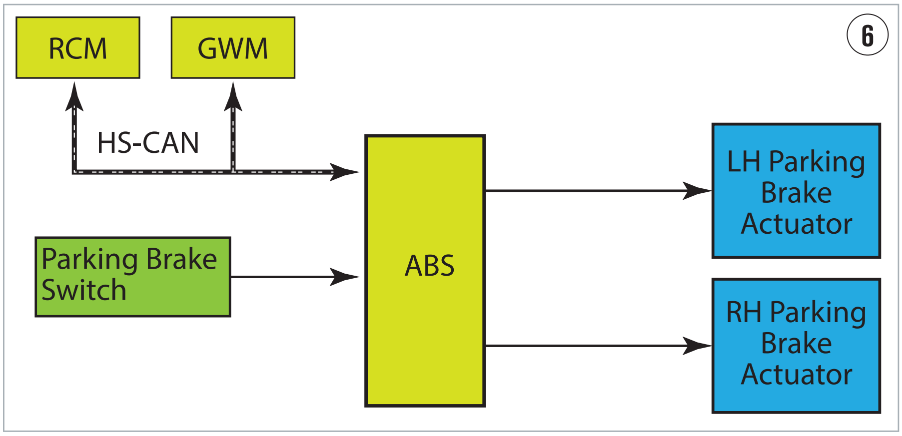
We removed the actuator motors from both rear calipers so we could compare the applying effort of the suspect caliper to a known good component. After turning the ball screw on both calipers, it was evident that much more torque was needed to extend the right-side caliper piston than was needed to extend the left-side caliper piston. The actuator motor was doing its job, and the ABS module was seeing the extra time it took for the actuator motor to reach the end of its travel. We replaced the caliper, cleared the DTC, and all was fine.

Finding the root cause of the concern

Road conditions can cause havoc with the EPB actuator motors. Ice, snow, mud, and basic road debris can contaminate the actuator motor harness connector and the actuator motor itself. It's no big secret that the visual inspection is the most critical step in all diagnostic procedures, and it should be the first step when diagnosing an EPB concern.

Check for contamination in the harness connector and cracks in the actuator motor housing. If the heads of the screws that attach the actuator motor to the caliper are badly rusted, so is the actuator motor.

Newly replaced rear brake pads can be a clue when diagnosing an EPB concern. The caliper could have been damaged if the installer did not correctly enter service mode before disassembly. Metal dust from metal-to-metal brake pads could have severely damaged the caliper or the actuator motor. New parts should always raise a red flag.



HERE'S ONE EXAMPLE of the many network configurations that you'll see on an EPB system. Notice how the gateway module is used to deliver messages that originated from other modules and sensors to the ABS module.

If multiple DTCs are stored in the ABS module, always service the ABS DTCs before attempting to diagnose an EPB DTC. Sometimes a DTC represents the result of an issue, not the cause.

A little logic goes a long way

Here's something that happens way too often: A vehicle gets towed into your shop with no power and an engaged EPB. You jump the battery, no go, no power. You need the vehicle pushed into the shop, but if the locked-up rear wheels aren't rolling, the vehicle isn't rolling.

The manufacturer's solution to this issue is to remove the actuator motor from the caliper and turn the ball screw with a pair of pliers to disengage the parking brake. The problem is that there's always one screw tucked behind a shock absorber or a spring shackle, which makes removing the actuator motor (while lying under the vehicle in the parking lot) a frustrating task. It's much easier to reverse the actuator motor using a jump box, two jumper leads, and a couple of flex probes.

The wire schematic is referenced to determine the polarity needed to reverse the motor and retract the caliper piston **(Figure 4)**. It takes less time and eliminates the possibility of damaging an actuator motor during disassembly. I've made up a couple of harness connector pigtails for the types of actuator motors I see most commonly. This way, I can disconnect the vehicle harness connector, plug in my pigtail, and connect the jumper box **(Figure 5)**. You can hear the motor retract when applying power and ground. Ensure the vehicle is secure before releasing the actuator motors; it will start to roll.

We haven't talked much about EPB systems that utilize a central actuator motor and parking brake cables. In these systems, the actuator motor is tucked up under the body, which keeps it safe from road debris issues for the most part. Seized cables are the actuator motor killers on these systems. The tighter the cable becomes, the harder the motor must work.

In most cases, the cables come with the actuator motor when replacing the component. Check the operation of the calipers before replacing the motor and cables. A seized cable can eventually lead to a seized caliper, damaging a new actuator motor.

EPB systems really aren't that complex. The ABS module only outputs voltage and ground to the actuator motors and warning lamp info to the IPC. The switch is a one-trick pony that sends a voltage signal to the ABS module when it's moved in either direction, and the actuator motors are just that, DC motors.

The ABS module receives inputs from the brake switch, accelerator pedal, clutch pedal, door-ajar switch, engine RPM, transmission range, and the airbag module to determine vehicle attitude. Some of this information will detour through other modules via the network **(Figure 6)**. Note how the gateway module (GWM) is used to deliver inputs to the ABS module.

You'll find that most EPB issues are mechanical rather than electrical. Don't forget to enter service mode before disassembly; save the digits. MA

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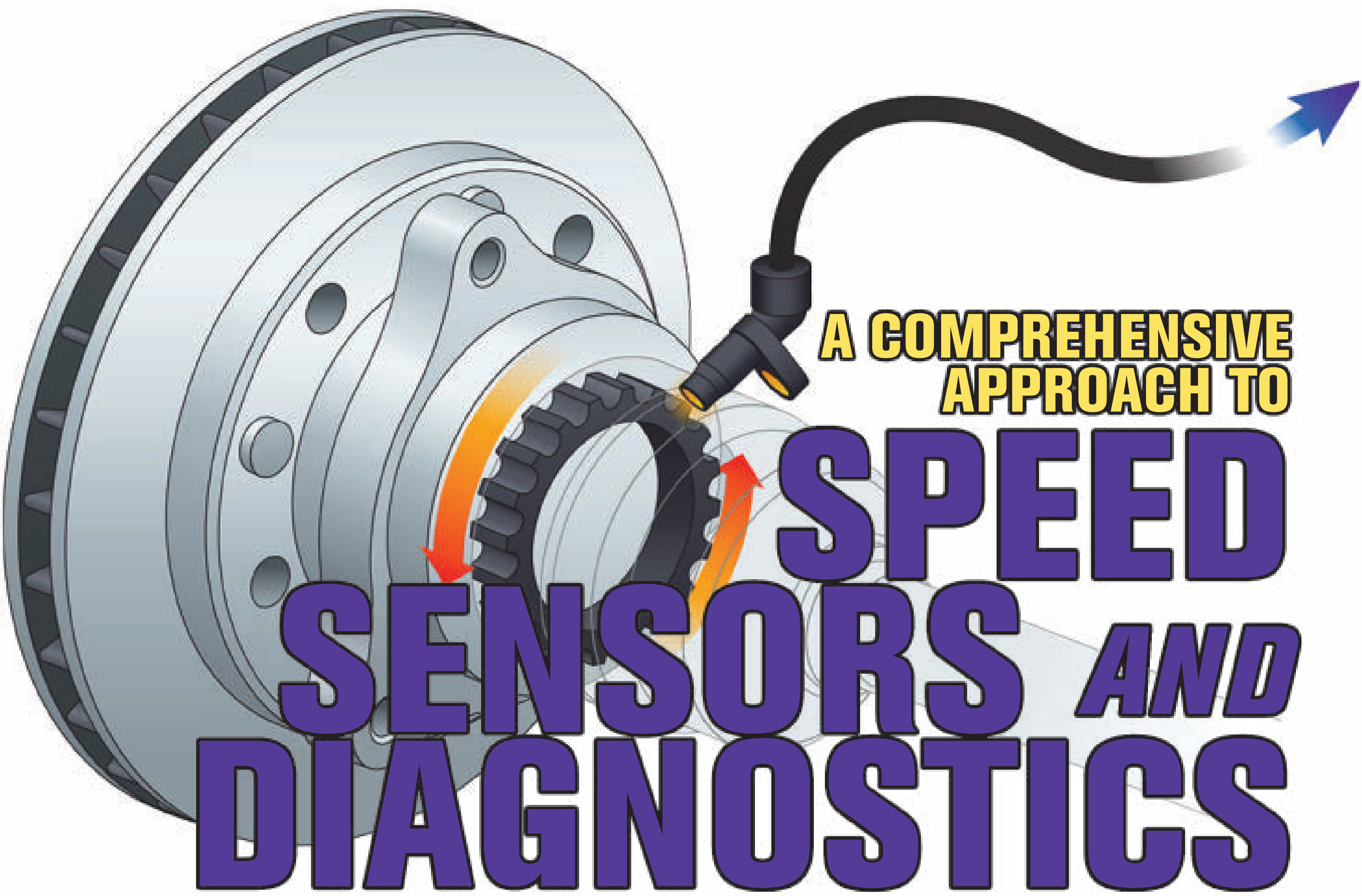


A COMPREHENSIVE APPROACH TO SPEED SENSORS AND DIAGNOSTICS

SERVICE INFORMATION AND APPROPRIATE TOOLING CREATE THE NECESSARY RESOURCES FOR NONINVASIVE SPEED/POSITION SENSOR TESTING.

BY CHRIS REYNOLDS // Contributing Editor

When we consider the longevity of speed/position sensors in the automotive industry, we must also recognize how critical the information is that such elements of powertrain systems provide for diagnostic purposes.

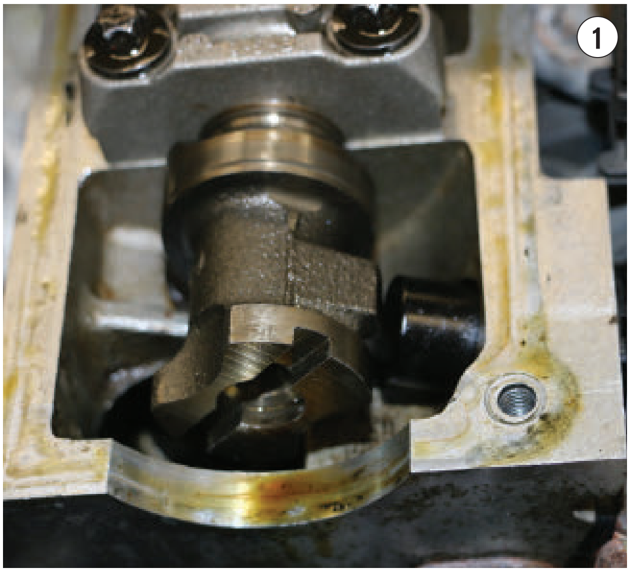
As a technical instructor at a public college, I typically embed diverse methods of testing multiple systems for my student population. Such a routine provides similar outcomes for students regardless of available tools, equipment, materials, and supplies at their future site(s) of employment.

Fortunately, many technicians and tool developers have created strategies that provide simple and intermediate methods for generating test results to objectify mechanical relationships among engine components.

Two of the most common engine speed sensor designs are variable reluctance and Hall effect. In this article, I will provide the following:

- Theory and operation of both common sensor designs
- Diagnostic methods that are proven benefits of both designs
- Procedural information to enhance your diagnostic routines when confronting systems that rely on speed/position sensors

To begin, I need to describe the hybridized term of speed/position. "Speed" projects a measurement of distance divided by time. "Position" describes the location of componentry to a reference point. Knowing the fundamental relationship between speed and location enhances our ability as technicians to use features embedded in common digital storage oscilloscope technology to enhance our diagnostic methods



THIS TWO-WIRE, variable reluctance sensor generates an analog voltage output to locate the intake camshaft position on a 2.0L Ford Zetec engine.

when addressing driveability concerns that rely on such fundamental principles.

Determining speed and position

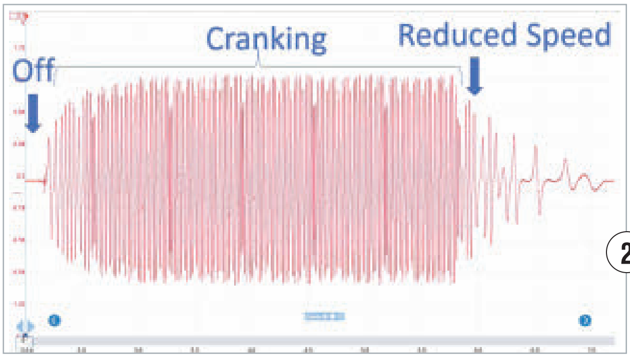
Variable reluctance (also considered analog) sensors use concepts of magnetism to generate values that project an increase or decrease in voltage based on the relationship to moving components. These sensors use two wires, rely on a coil of wire, and house a permanent magnet within the sensor assembly.

Using a nearby reluctor wheel, the variable reluctance sensor generates a near and dense magnetic field, converts the field to voltage, and generates an analog voltage output later converted to digital by a receiving module. Such a design also creates the necessity to share events that impact sensor output.

In relationship to a reluctor tine (tooth) on a reluctor wheel, as the tooth approaches, the internal magnetic field of the variable reluctance sensor will be more centralized on the windings (in proximity to its housing), therefore creating a positive rise in voltage output of the sensor **(Figure 1)**.

As the reluctor tine moves away from the sensor element, an inverse reaction occurs, creating a decrease or negative response of energy concentrated within the winding. Due to this notion, the sensor creates an analog signal, an AC voltage output. Knowing that this relationship occurs also creates a demand to understand such a sensor's behavior based on speed.

Variable reluctance sensors do not generate output based on just proximity but rely on frequency in proximity to a rotating component to increase voltage output. As speed increases, voltage output and frequency increase. As speed decreases, voltage output and frequency also decrease **(Figure 2)**. As a result, this style of sensor is considered passive.



A VARIABLE RELUCTANCE SENSOR'S VOLTAGE RANGE and frequency are dependent on rotational speed of the reluctor wheel.

Another fortunate idea related to this sensor's design is that traditional electrical values may be used to infer conditions. That value, specifically, is resistance. Manufacturers often provide such resistive values to generate go/no-go specifications for component conductivity **(Figure 3)**.

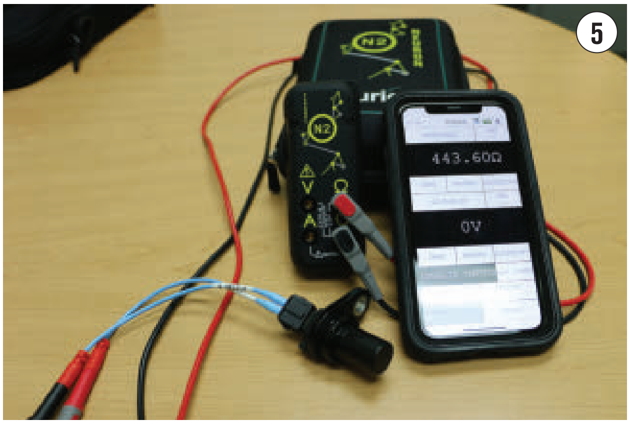
Hall effect sensors (those that convert analog values to digital values internally) have become more common in the automotive industry. These sensors rely on similar interactions among static and dynamic components as variable reluctance sensors but have the power to convert analog values to digital values internally. Such a design is beneficial for two major reasons:

- The sensors do not output a variation of voltage (dependent on time)
- The sensors generate a language (digital) already familiar to receiving modules

The Hall effect sensor is equipped with three wires: power (range up to source voltage), ground (as the sensor is a load-

USING A DMM TO MEASURE STATIC RESISTANCE can provide a critical clue when diagnosing sensor low or no output concerns. This sensor displays a resistive value well within the normalized range of 200-1,000 ohms.

THIS GENERAL MOTORS GEN II LS ENGINE uses a Hall effect sensor, generating 24 digital pulses per revolution, to provide crankshaft speed and position information to the powertrain control module. Its output voltage is stable, typically operating between the reference and source voltage range (~0-12V).



THE CURIEN N2 IS A BLUETOOTH METER capable of measuring voltage, current, and resistance. It also has graphing functions, making measured values easily displayed through a peak of 8,000 Hz sample rate and up to 256 samples in its buffer. Here, it is used to display the static resistance of the variable reluctance camshaft speed/ position sensor found in a Ford 2.0L Zetec.

consuming supplied energy), and signal (as the sensor provides internal analog amplification and digital output upon the fluctuation of concentrated magnetism).

The Hall effect design is also unique in the sense that its manufacturers do not provide traditional points of measure for static resistive value. Essentially, a Hall effect sensor is treated as an engineered load requiring power, ground, and a predetermined threshold of voltage output based on proximity to an exciter, therefore forcing the solid-state electronics internally to generate a traditional digital signal **(Figure 4)**.

In contrast, the only fundamental relationship Hall effect sensors have in common with variable reluctance sensors is frequency. As proximity to a reluctor tine increases and decreases more rapidly, the sensor's frequency climbs while maintaining consistency in output voltage.

This circuit design is considered superior, as modules are only capable of immediately recognizing digital inputs for data (therefore requiring no analog to digital conversion internally) to predict the speed and/or position.

Testing sensor functionality

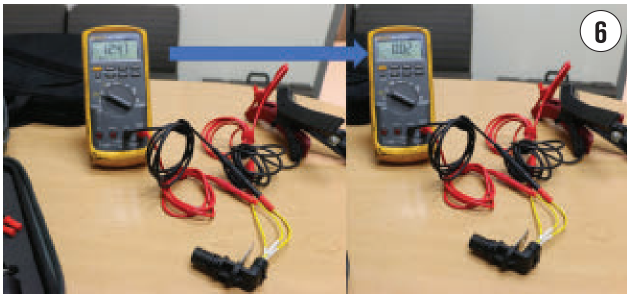
Tools that can be implemented for testing purposes include a digital multimeter, test light, and oscilloscope. While scan tools can also be used to determine a module's ability to receive and/or report speed variations, this method requires data to be transmitted from the sensor to a control module, then reported in a delayed "live" display on a scan tool for interpretation. It is not always an ideal way to approach speed/ position sensor component-level testing.

In the context of using a digital multimeter, speed must be considered. DMMs are great for measuring steady variables that commonly include voltage, current, and resistance, but they are not ideal for determining rapid peak captures when detecting the amplitude of the signal output of a component with a considerable frequency. In the case of a variable reluctance sensor, a DMM proves valuable for measuring static continuity and dynamic voltage consumption during operation throughout the positive and negative connections within the circuit **(Figure 5)**.

In the case of a Hall effect sensor, a DMM proves beneficial for measuring power supplied to the sensor, and energy remaining (or consumed) on the ground side of the sensor, but it has limitations in displaying a frequency that could be easily interpreted for diagnostic purposes.

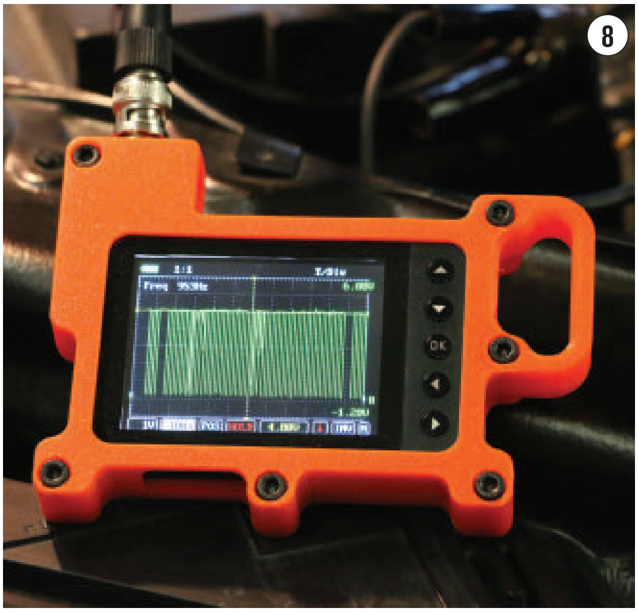
If referencing service information for DTCs, many OEMs may recommend using a DMM to assess a Hall effect CKP's output. As the sampling capabilities of a DMM are limited, peak and valley voltages are not often detectable, therefore displaying an average output.

In the Gen 2 LS engine, General Motors specifies a signal voltage output between the range of 4-6V when measuring with a DMM actively, though actual voltage output switches



WITH THE GEN II LS CKP SENSOR on a bench and cycled from high to low, notice measured voltage output cycles between source voltage (peak) and low voltage (valley) with manual lower frequency exciting.

A TEST LIGHT, when referenced to ground, can provide illumination that helps us infer voltage available and variations of output illumination indicating the sensor is generating a signal.



THE AESWAVE USCOPE PROVIDES technicians with the convenience of portability and diverse integrated features and does not require a PC or laptop to display measurements.

from near 0Vs to near battery voltage **(Figure 6)**.

Haakan Light, operator of Shotgun Diagnostics, provided critical feedback for this article's development. In doing so, he indicated a test light could also be used for diagnostic purposes. While using a controlled engineered load to assess speed/position sensor circuit functions, one could infer illumination of a test light when checking power availability, pulsation of signal, and energy remaining in a circuit is illustratable with this tool. All would require further pinpoint testing, but using such a tool has its place in our diagnostic routine **(Figure 7)**.

In the case of using a digital storage oscilloscope (DSO) to assess speed/position sensor performance, options are almost limitless. For a quick capture, I typically use the AESwave uScope. It is a single-channel DSO with a +/-40V (80V total) range, can measure 10mV to 10V vertical division on a 1x probe, displays 10uS to 10S per horizontal division, and has a capable sampling rate of 1Msps. This tool also has capture (storage) capabilities, a dense array of preset options for component testing, adjustable points of measure, and fits in the palm of your hand. It can display DC (direct current) voltage inputs for traditional digitized speed/position sensors (Hall effect) and has an AC voltage filter option for variable reluctance speed sensors. Overall, this DSO is capable of measuring, displaying, and capturing data critical for diagnosing speed/position sensors **(Figure 8)**.

For more enhanced functions, I typically use a Pico 4425A DSO from AESwave. This unit has four channels, utilizes Pico BNC+ probes for auto identification and/or probe potential energy supply, and has a user interface that is simple to navigate. This tool also has enhanced capabilities we will explore to determine mechanical relationships with data derived from live captures.

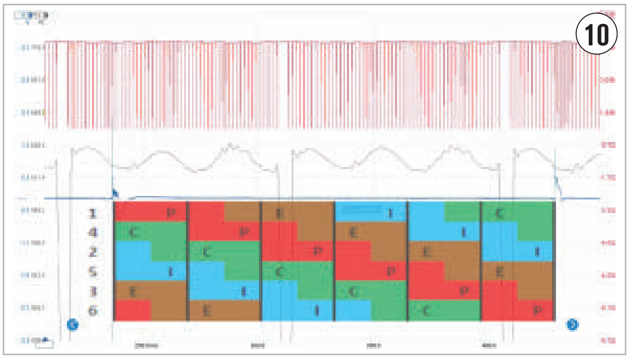
To begin testing any speed/position sensor with a DSO, I rely on OEM or aftermarket diagrams to locate the sensor and access the signal generated by the sensor.

In the case of my 2017 Ford F-150, the crankshaft position sensor was not easily accessible, so I decided to use the PCM as the locating point for signal measurement **(Figure 9)**.

Using service information, I also identified the type of the sensor as Hall effect (since it contained voltage, ground, and signal connections). Service information also provided the theory and operation of this unit, indicating a reluctor wheel tooth count of 58 teeth. For every revolution of the crankshaft, 58 digital pulses must be displayed, followed by two empty high slots of the sensor element. For a complete four-stroke cycle to be witnessed, this rotational event must happen twice.

An oscilloscope may also be used (with a bit of creativity) to project the power contribution of cylinders in less familiar platforms. Synchronizing this event with cylinder 1's secondary ignition output and converting the frequency of the crankshaft position sensor to a viewable math channel display also provided a broad image of cylinder contribution.

THE CKP SENSOR ON A FORD 3.5L ECOBOOST is in the transmission bellhousing behind the bank 2 turbocharger and heat shield. Conveniently, this CKP signal wire was located on connector 1951E at the PCM on the passenger side bulkhead. Probing the signal feed wire provided convenient access to the CKP signal for testing.



OVERLAYING TDC2'S IMAGERY with the selected firing order helped locate events indicating an increase in crankshaft speed. Implementing a frequency plotting math channel with the Pico7 provided a clearer image of the consistency in cylinder contribution related to speed. With the naked eye, it is difficult to measure which cylinder(s) are contributing less. With the math channel function selected and manually ranged between 0-1,000 Hz, cylinder contribution came to light. You notice that frequency drops low when the two missing teeth of the reluctor wheel are plotted in analog frequency.

To reference cylinders, I used the overlay feature of The Driveability Guys' TDC2 software as an indication of cylinder cycle events. Using this methodology provides a clear and consistent benefit when locating cylinder misfire events that are potentially unreported or misreported **(Figures 10+11)**.

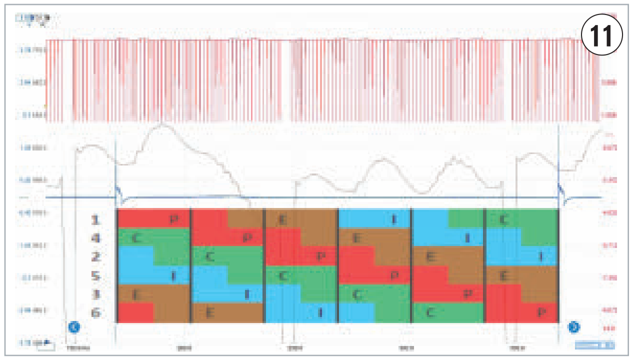
Testing techniques also apply to diesel engines

As the program I serve also maintains a basic diesel certificate, students explored the relationships of cranking current and cylinder identification on a 2001 Cummins ISM 330-equipped Volvo day cab. This system uses a variable reluctance camshaft position (titled engine speed) system but maintains two points of input from the sensors:

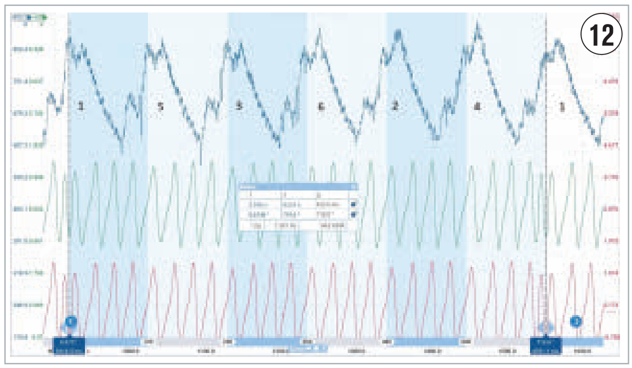
- One for rpm display
- One for engine control functions

As measuring compression in this engine may require up to 7.1 hours of book time because of injector removal and installation, students concluded that a DSO could provide imagery to infer engine condition more conveniently. To do so, the students located and back-probed the signal wire of the engine speed sensors, connected an amp clamp to the B+ feed on the massive starter to measure current, and manually supplied source voltage to the starter solenoid feed.

The capture indicated 25 pulses from the engine speed sensor per revolution, with two pulses being near one another. In a basic investigation with a few phone calls, students concluded that shorter pulses were used to indicate the location of cylinder number 1's compression event.



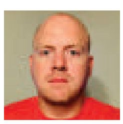
IN WANTING TO VALIDATE the Pico7 math channel function, I intentionally disabled cylinder 4's ignition coil to generate a reduction in the velocity of the crankshaft during its normal firing event. The capture provides validity to this method.



THE ENGINE SPEED SENSOR(S), when overlaid with cranking amperage, helped my first-year diesel tech students better understand the theory, operation, and the benefit of using more advanced methodology while saving critical diagnostic time.

Overlaying the firing order provided sufficient information to conclude each cylinder's contribution was similar and took less than 1 second to conclude the engine's mechanical condition **(Figure 12)**.

To conclude, we've explored the basic theory of two common speed sensors, methods for testing statically, and more advanced dynamic methods often critical in the diagnostic process. If you have the tools and equipment described in this submission, I must recommend using them to your most enhanced benefit for diagnosing speed/position sensor-related concerns. Diverse methods of assessment can provide accommodation regardless of your inventory. MA



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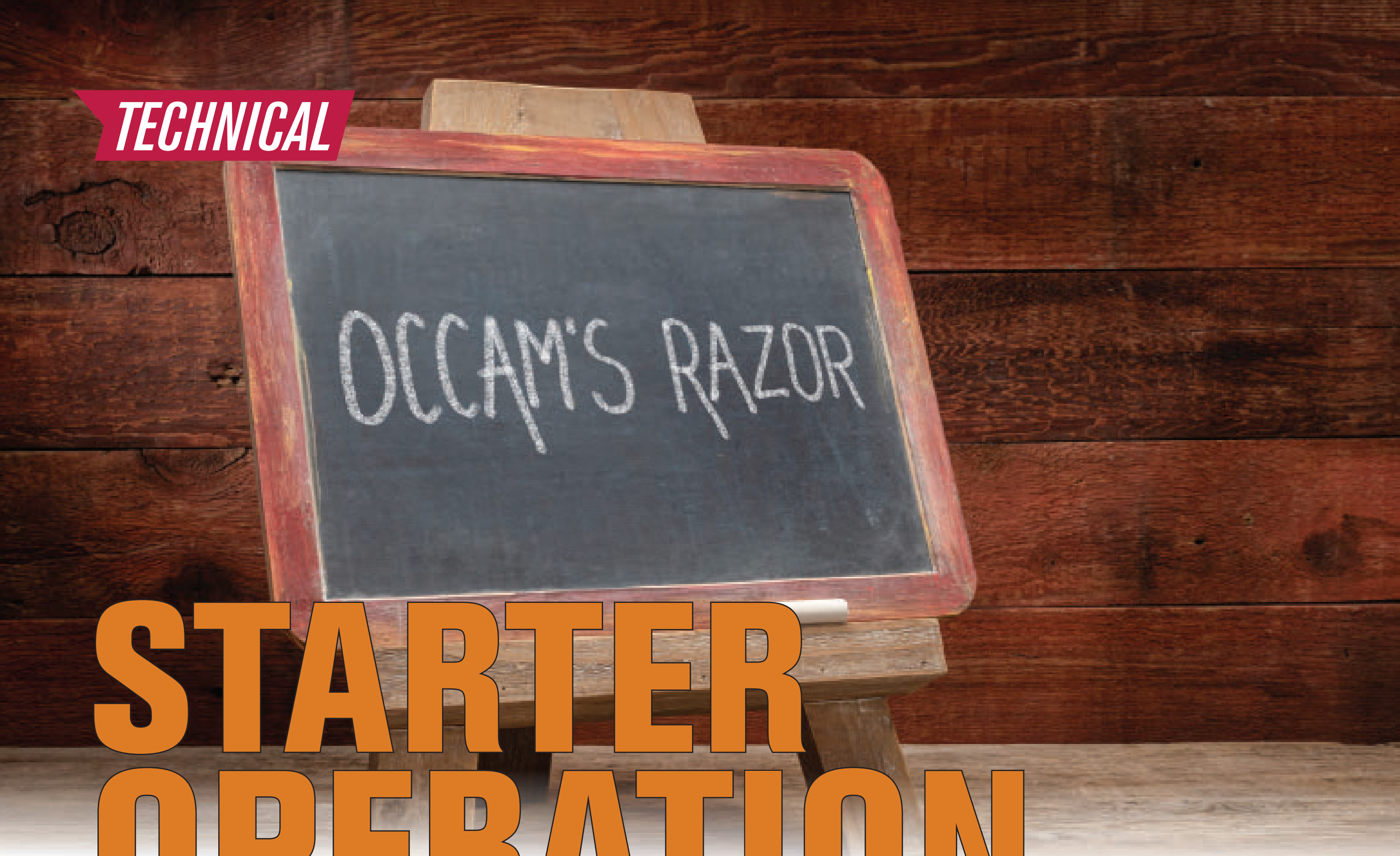


STARTER OPERATION

THROUGH THE EYES OF THE SCOPE

APPLY OCCAM'S RAZOR AND LEARN HOW YOU CAN EFFICIENTLY TEST MOST OF A SYSTEM FROM ONE SIMPLE NON-INVASIVE LOCATION.

BY ROBERT STAGE // Contributing Editor

The most efficient way to diagnose a starter circuit is by using an inductive high-amperage clamp and a lab scope. If you've been a technician for any length of time, you'll likely relate to this scenario. A customer places a call to your shop and speaks to an advisor. The customer says he has a minor annoyance with a message from his driver information system on the instrument cluster. For peace of mind, he'd like to have the issue researched and checked out.

In our customer's situation, it is the "Battery Low – Start Vehicle" message on his 2021 Chevrolet Silverado LT 4WD 5.3L Trail Boss Z71 with 20,203 miles on the clock. This engine has never failed to start, and the customer states that this message is very intermittent. He also adds that he has only witnessed one "slower than normal" engine cranking event so far **(Figure 1)**.

The repair order ends up in your hands. Where do you start with such an ambiguous request? Wouldn't you like to be able to go the farthest and the fastest with testing this issue

1 **"BATTERY LOW—START ENGINE"** driver's information.

2

Items	Quantity	Price	Amount
Vehicle Information 2012 Chevrolet Silverado 1500 Custom TBoss 4WD 5.3L V-8 configured 8-Cyl DI OHV 325 CID VIN: 1GCPYCEF8MZ447148 Miles: 20,203	1	$0.00	$0.00
Electrical Issue Diagnosis Customer States: Vehicle intermittently will show in the driver information system "Battery Low — Start Engine", vehicle has only seemed to crank "slower than normal" once so far. Please check and advise. Customer advised that technician will check system and record findings first .5h approved by customer.	0.500 hr	$129.99/hr	$65.00
Subtotal			$65.00
Sales Tax			$4.55
Total Due			**$69.55**

STAGE1MOBILE INVOICE for electrical circuit check time.

so you can get to your next repair order?

This brings up what can often be a challenging situation: how to properly charge a customer. What can a customer expect to pay for a service and/or checkout that might produce no definitive action plan? Or find a problem? And how should a shop charge a customer for a checkout like this?

I believe we all too often make this a much harder situation than it must be. As business owners or professional technicians, we must be very good at communication and should always be honing that craft. Besides, we might repair automobiles, but we are in the "people" business, too. It's my opinion that the terms of service should be discussed upfront. Most customers do not like to work for free in their positions at their jobs. And since the larger part of our economy is driven on a fee-for-service basis most customers should expect to pay at least a nominal fee for a service.

If there is not a clear resolution at the end of testing, what did they receive? They know that a series of components in the system in question have each been thoroughly checked by an automotive professional. Additionally, they now know what is not causing the issue they are experiencing (**Figure 2**). Diagnosing an issue is a process of elimination in most cases. Back to the diagnosis.

THE BEGINNING OF LAB SCOPE SET UP. The starter circuit and components can easily be evaluated right from under the hood with minimal effort or time invested.

Having a mobile diagnostic and auto repair business has its pros and cons:

The pros:

- You always have the "largest" bay
- There isn't a phone ringing off the hook in the shop
- Other distractions are also at a minimum because you are on your own
- You are not tied to the shop

It cuts out one of the largest objections in the sales process, which is the inconvenience of taking your vehicle somewhere for service.

The cons:

- You must keep all your tools and equipment put away, clean, and accessible always, no "Friday" drawers, guys and gals.
- Sometimes a vehicle's location isn't convenient or safe to be repaired e.g., steep driveways, dangerous streets, or roadways.

As luck would have it, I was able to look at this customer's vehicle inside the warehouse where he serves as manager.

I arrived at the customer's appointed place and time and gathered the keys to the vehicle in question. I asked the customer some additional closed-ended probing questions and approached the vehicle in question to begin my diagnostic process (**Figure 3**). While at the vehicle, I did my best to confirm the customer's complaint (remember, it's an intermittent issue).

If I left the driver's door open for more than approximately 30 seconds, the driver's information system would display (as he had described) a "Battery Low – Start Engine" message. At the time of system testing, the ambient air temperature was

29 degrees F. After I verified the complaint, I performed the next step in my action plan, which was to research existing recalls and technical service bulletins for this vehicle's VIN. I found that there were no safety recalls and no technical service bulletins that were germane to the customer's complaint or symptom(s).

Follow the data

I know that some will say I'm preaching to the choir on this point I'm about to share, but I am going to say it anyway. Any diagnostic challenge, especially one that's electrical in nature, and on a modern vehicle should start with a baseline system voltage recording and battery health check, including a load test.

What's included:

- Visual inspection of the terminals for corrosion and terminal integrity or looseness
- Visual inspection of the battery for acid leakage
- An attempt at gaining the manufacturer date from it
- Performing a computerized battery test using a tool that is of higher quality.

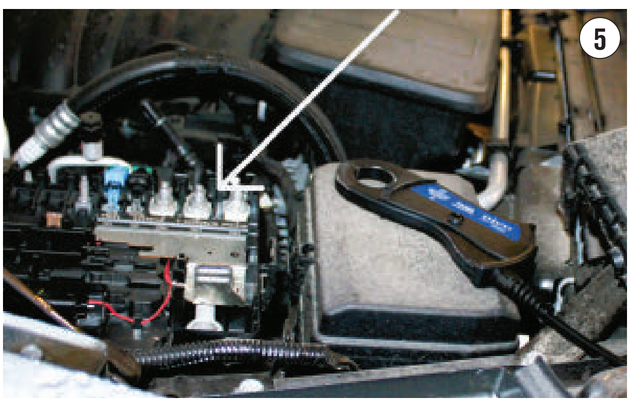
I begin here, because I know how easy it is to sometimes get ahead of myself in the diagnostic process. Even with 32 years of experience in the automotive industry, I still sometimes inadvertently self-sabotage. Whiteboarding a brainstorming session and laying out in dry-erase ink what you're going to test and what you've already tested is a great help. Most of what you will add to your clock when diagnosing a vehicle is often stacked up with things you've checked already (or wasted time on). Take notes, record measurements, and be a professional.

I own and use the Midtronics PBT-300 handheld battery, starting, and charging system tester **(Figure 4)**. The factory rating for the battery in this vehicle was 800 cold-cranking amps (CCA), and it tested sufficiently at 727 CCA. After confirming the battery was within specifications, and since the vehicle's engine cranks and starts, I move on to testing the motor side of the starter circuit using the PicoScope 4425A and the Pico 0-2000 A inductive clamp.

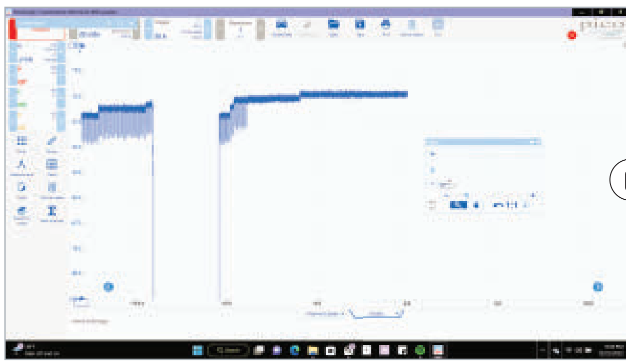
The vehicle's positive or negative cable can normally be used to perform the starter current draw and health check because the current is the same anywhere in a series circuit. This Chevrolet will have to be tested using the negative battery. The positive cable is not easily accessible, as it has a giant plate engineered on it (for a junction block and fusible plate, **Figure 5**).

Attaching the PicoScope inductive clamp is straightforward. The arrow on the clamp faces toward the direction of conventional current flow and will be drawn on the scope in a positive amplitude to display an increase in current flow.

FIGURE 4- THE MIDTRONICS PBT-300 computerized battery, starting, and charging system tool.

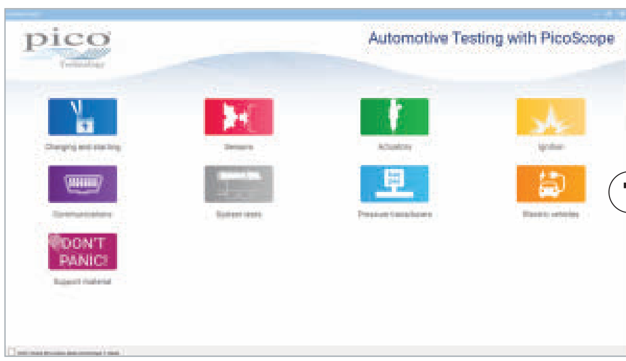


POSITIVE BATTERY CABLE terminal fusible plate.



6

PICOSCOPE 7 SOFTWARE showing an inverted amperage waveform because I hooked the amp probe up backward.



7

PICOSCOPE 7 START-UP SCREEN indicating guided tests.

Don't worry if it is not connected in this preferred direction. Because the probe is connected non-invasively, you are not going to hurt anything. The trace will simply display invertedly. I connected it backward the first time and the trace is upside down **(Figure 6)**.

The PicoScope lab scope is a robust unit and very forgiving to the apprentice-level technician. Using the guided tests portion of the PicoScope 7 software will take you step-by-step through connecting the scope and leads properly **(Figure 7)**. Once the scope is attached the testing usually takes just a few minutes. The PicoScope 4425A has intelligent probes that set their parameters automatically. Simply connect them to the scope and they self-identify.

Per service information, placing a Chevrolet in clear flood mode is easy enough. You push the accelerator to the floor and crank the engine over. By doing this you are indicating to the computer to reduce the injector pulse. This should prevent to engine from starting. This waveform is produced while cranking the engine with the accelerator pedal depressed to the floor **(Figure 8)**.

Analyzing the data

There are two cranking events shown in Figure 8. Each event was approximately 10-15 seconds in duration. Take notice of the inrush direct-current (DC) spikes at 908.1A. Some might say that it is too high, but I don't believe this is an issue as it occurs for only a short period, and it's consistent with the first cranking event of a normal operating system. Getting the engine to turn (from a stop) is more of a load on the starter than it is to keep the engine turning.

Something else to consider. A modern lab scope is among the most sensitive and accurate testing equipment we use in the industry. It displays a lot more resolution of the circuits' electrical activity than other equipment (with a slower sample rate) would. This information can be used to gauge the health of the battery, the starter circuit, and the starter motor's integrity. The highest delta amperage (or difference in amperage, between the upper and lower peaks) measured on continuous current flow, as the engine is being cranked over was 186.7A, and this is within specification (cursors are not being displayed to demonstrate in this capture). This number combined with the other known measurement of 10.5V (while cranking) can give you the dynamic resistance value of the entire starter motor circuit.

We've all seen Ohm's law equation of V = I x R, or put another way, V = A x R. To work/solve any electrical problem backward, you only need two of the three factors. It can trip a lot of technicians up, so I always use an Ohm's law calculator (which can be found on the internet). For instance, when entering the cranking voltage of 11V, and the current flow of 186.7A, the resulting dynamic resistance is .058 ohms (which translates to 2053W of power used), and this information is valuable (power= voltage * amperage).

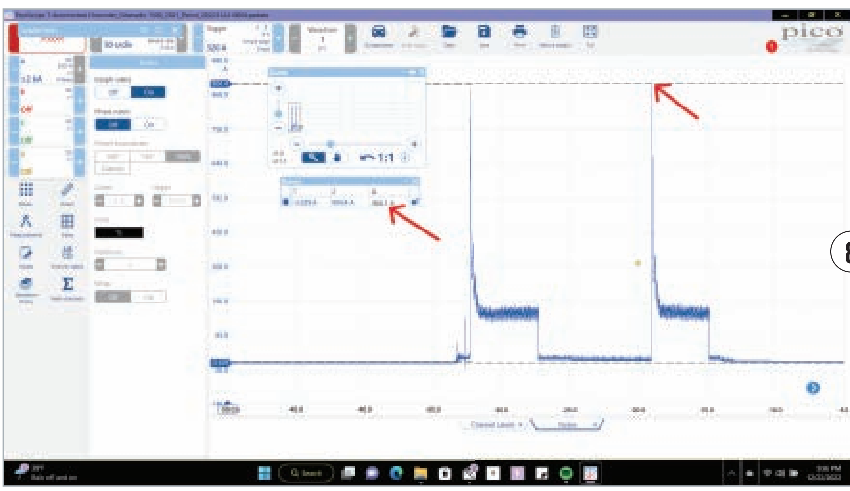
Let's say when you cranked the engine over, the average available voltage was 10 V, with 500A of continuous current flow, yielding 0.02 ohms of dynamic resistance. This shows a tremendous load on the starter motor. At that amperage, you are more than likely to hear a horrendous noise from the starter motor, and it may physically rotate the engine much slower. At that measurement, it is taking 5000W of power to move the starter armature.

Inferred engine health

The other measurement you will see is the engine rpm. This is because using the vertical cursors to demonstrate the time difference between them can yield the cycle time (or the time it takes the engine to rotate 360 degrees). In this hypothetical, you'd see a much lower number than what a known good would have displayed. Our testing displayed 218.9 rpm. Depending upon the starter construction type (gear reduction, direct drive) you can have a slightly different reading on this. However, in most cases, you will see a known good engine RPM between 175-230 rpm.

The best way to describe what you are seeing when using a lab scope is voltage, amperage (or whichever domain is being measured) being displayed over time. Having a lab scope in your arsenal is a must-have for any technician that performs any electrical diagnostic work.

In Figure 8, although the data is captured, the large time base makes it difficult to see the actual measurement. We are going to zoom in and see how we were

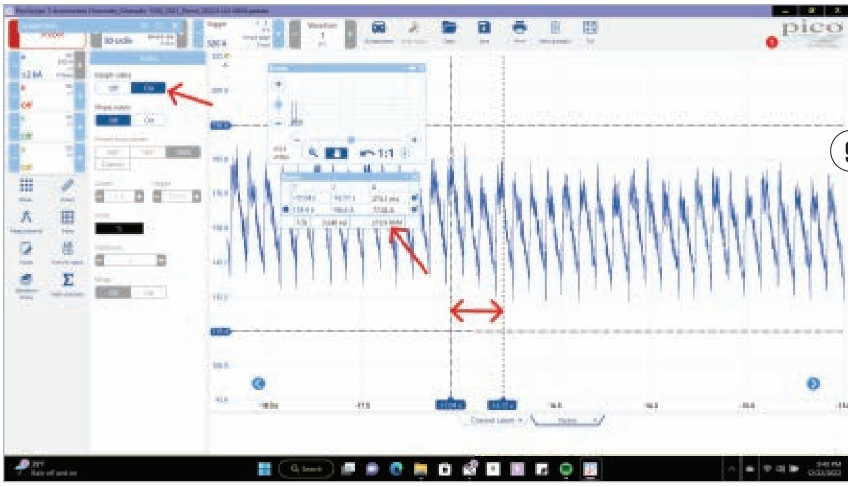


8

PICOSCOPE 7 SOFTWARE with graphing rulers moved to measure DC inrush current flow.

able to determine with the scope, that the engine's cranking speed was 218.9 rpm. Zooming in to capture less time on the screen displays more valuable information about individual cylinders' compression, and the effects it had on the starter circuit **(Figure 9)**.

We are testing an eight-cylinder gasoline four-stroke Otto Cycle engine (named after the man who invented the technology). All we must do is use the graphing/measurement portion of the PicoScope 7 software and measure out four compression events. Considering this is an eight-cylinder engine, half of the engine's eight cylinders completed a compression stroke in 360 degrees of crankshaft rotation (one rotation of the crankshaft, hence the cursors spanned to measure only four relative-compression peaks).



9

PICOSCOPE 7 SOFTWARE with the graphing rulers set to indicate the measurement for the engine rpm

This scope allows multiple testing vectors all at once. By using this testing method, you can also determine if the engine has any possible mechanical issues, like compression loss. A scope is not a crystal ball, but it's pretty close.

One PTEN (Professional Tool & Equipment News) contributor, Mario Rojas, of Super Mario Diagnostics, has said before that he uses a clear-flood cranking cadence and relative compression test on virtually every vehicle he looks at. One main reason is efficiency, as this test gathers so much pertinent information in the diagnostic process. On a misfire diagnosis, these tests are invaluable. It can help identify a compression or mechanical issue without any engine teardown.

Practice makes perfect

If you are lucky enough to work at a shop that provides a lab scope, or you're lucky enough to have purchased a lab scope of any channel count or quality, use it often. The best way to get better at using any tool is to attend as much training as you can for its operation and use it often. Use all resources available. You will only grow as much as you are willing to sacrifice. Meaning, read magazine articles like this one. Read and invest in yourself.

If your shop doesn't offer to pay for your training, pay your own way. After all, your skill is a highly sought-after commodity. It can only be of benefit to you and your future. I also recommend getting to know your scope better by gathering known good waveforms and using those to build a library of them.

If you are a technician and you have spent your valuable time reading this, thank you; you are appreciated. I hope that you have found it of value and that it was enjoyable. If you are one of the many customers we have the privilege of serving every day in our shops, I hope you have gained perspective of what we attempt to do every day, which is to do the very best by you and fix your vehicle right the first time. We appreciate you!

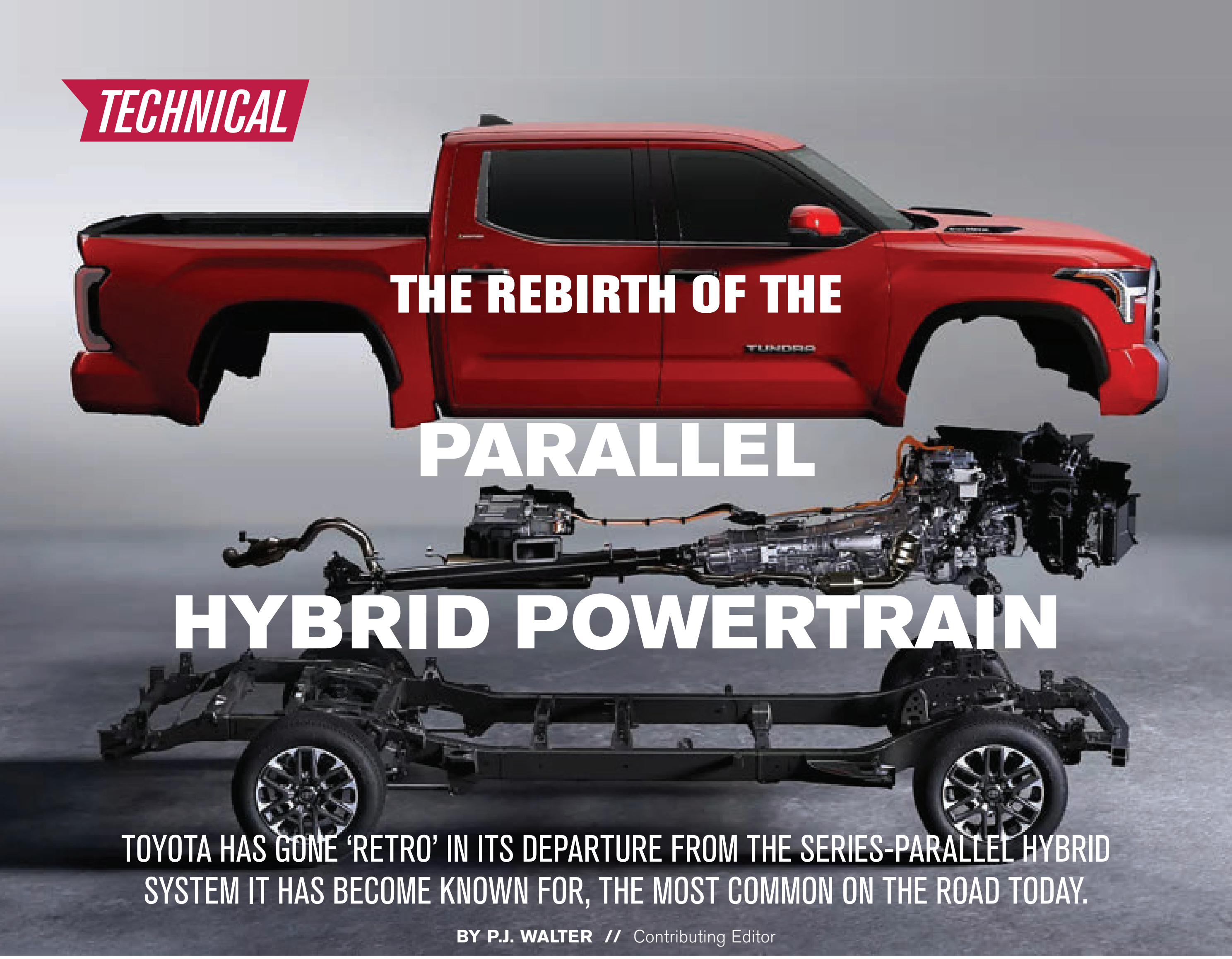
In my customer's case, after some additional probing questions, he said his vehicle had sat in his garage for 10 days while he and his family had been on vacation. He had started it when he came home and didn't see any warning lights. By his own admission, he wasn't looking for any, either.

After sharing all the diagnostic data recorded, I advised he add a battery tender if he was going to continue to leave it to sit for any extended length of time.

Remember when diagnosing, if you hear hoofbeats, it's probably a thoroughbred and not a zebra. Just a fun way of sharing Occam's razor (the principle, attributed to William of Occam, that in explaining something, no more assumptions should be made than are necessary). MA

ROBERT E. STAGE JR. is a veteran of the automotive industry and has worked in multiple positions over the last 32 years. He and his wife, Cynthia, live in the greater Columbus, Ohio, region, where they own and operate Stage1Mobile Diagnostic and Auto Repair, a mobile automotive diagnostic, programming, and repair business.
He and his wife have four grown children. In his spare time, he likes to read, watch movies and documentaries. He likes to try new restaurants and explore new cuisine with his wife. Robert is very active on LinkedIn and participates in the Ted Ings Fixed Ops Roundtable advisory panels that are produced four to seven times yearly. These panels discuss the challenges and triumphs of the service department side of the dealership life and lifestyle. They also discuss mobile service as an emerging service option for clientele. In the future, Robert expects to write more often and possibly pursue teaching automotive technologies across many formats.

TECHNICAL



THE REBIRTH OF THE PARALLEL HYBRID POWERTRAIN

TOYOTA HAS GONE 'RETRO' IN ITS DEPARTURE FROM THE SERIES-PARALLEL HYBRID SYSTEM IT HAS BECOME KNOWN FOR, THE MOST COMMON ON THE ROAD TODAY.

BY P.J. WALTER // Contributing Editor

With the exciting release of the 2022 Toyota Tundra Hybrid, the automotive industry will see the rebirth of the parallel hybrid powertrain system. This is done by sandwiching a 3-phase motor/generator (known as 1MG, for single motor generator, in Toyota terminology) between the internal combustion engine and a traditional automatic transmission. Like other hybrid platforms, the motor generator is used during low-speed driving and to aid the engine during high-load driving in situations such as towing.

The parallel hybrid system is a departure from the series-parallel hybrid that Toyota has become known for. To understand this change, it is beneficial to understand the differences between the three core types of hybrids currently on the road today.

Series, parallel and series-parallel hybrids

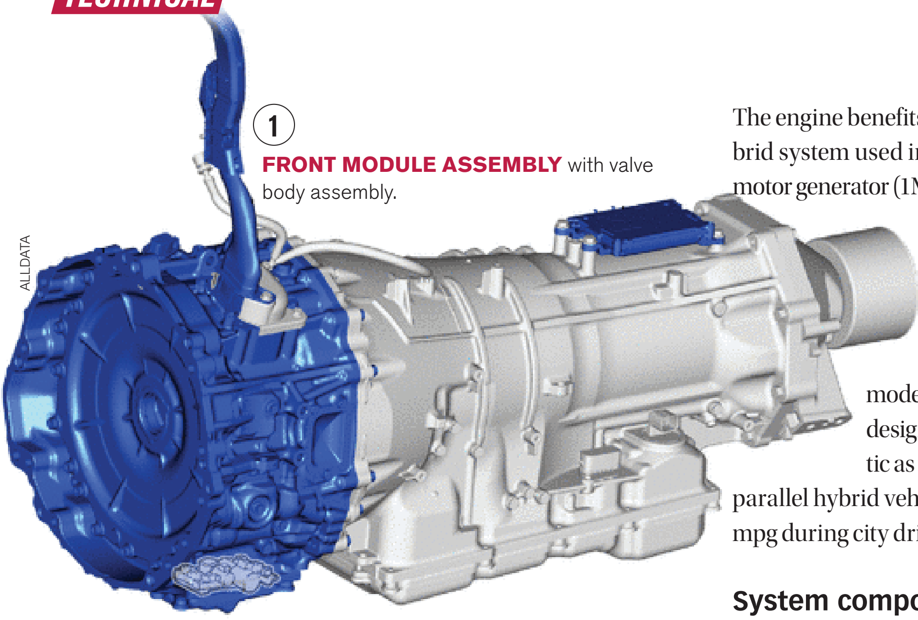
Toyota has led the hybrid market for years with the series-parallel configuration hybrid system used in most of the Toyota hybrids on the road. This started with Toyota Prius, the world's first mass-produced hybrid passenger vehicle released worldwide in 2001.

Series HV powertrain systems seen in Tesla vehicles use one or two motors to drive the vehicle's wheels. Extended-range series hybrid systems also utilize a generator. The internal combustion engine drives a generator that will charge the high-voltage (HV) battery. The HV battery then has the energy to supply the motor to drive the wheels.

A series-parallel hybrid is possibly the most common hybrid on the road today, used by many manufacturers but made famous by the Toyota Prius. They consist of two motor-generator assemblies, referred to as MG1 & MG2. MG1 is responsible for starting the engine when operated as a motor. Through computerized switching circuits, MG1 can also be utilized as a generator by using the kinetic energy produced from the engine to create electrical energy and charge the HV battery (essentially operating as a standard alternator).

MG2 is used to drive the wheels of the vehicle when electrical energy is provided to the motor, or to generate electricity during deceleration (utilizing regenerative braking to charge the vehicle's high-voltage battery).

When MG2 is used as a motor, electrical energy is used to propel the ve-



FRONT MODULE ASSEMBLY with valve body assembly.

ALLDATA

hicle. But during deceleration, the wheels drive the permanent magnetic rotor of MG2 and create electrical energy to recharge the HV battery.

In a series-parallel hybrid vehicle, the vehicle achieves movement through the electric motor output, the internal combustion engine output, or a combined effort from both. The power distribution between the engine and the electric motor is designed to keep the engine running in its optimum range, thereby increasing performance and reducing emissions.

The new Toyota hybrid platform named the 1MHV Hybrid System (currently used in the Tundra) is a parallel hybrid system. The engine benefits the most significant gains in the parallel hybrid system used in Toyota Tundra Hybrid systems. The single motor generator (1MG) can be used to supply tremendous torque to the wheels by using the electric motor to aid the engine during high-load conditions.

By adding the motor-generator assembly to the vehicle, torque is increased by over 100 lb.-ft when compared to the non-hybrid model, maxing out at 583 lb.-ft. The downside to this design is that the fuel mileage gains are not as drastic as what is usually expected from a typical series-parallel hybrid vehicle (only increasing fuel mileage by about 2 mpg during city driving).

System components

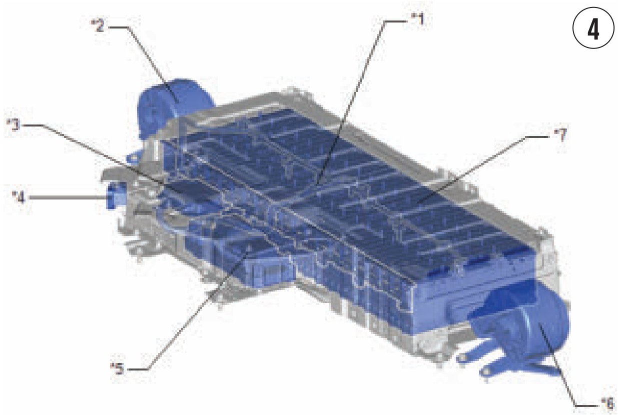
Front module assembly: The first substantial change in the Tundra hybrid system is the front module that holds the K0 clutch and the motor-generator assembly (1MG) and a dedicated valve body **(Figure 1)**. The front module is between the engine and transmission **(Figure 2)**.

The K0 clutch is a wet clutch used to blend the torque from the internal combustion engine (ICE) and the motor-generator. To apply the K0 wet clutch before the engine is started, the transmission is equipped with an electric pump, which allows the system to operate during engine starting and stop-start operation.

The K0 clutch also has a dedicated valve body within the front

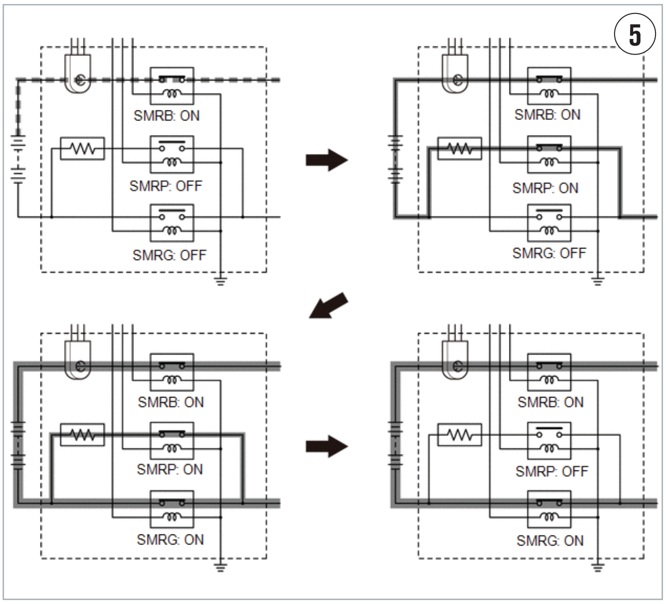
THE FRONT MODULE ASSEMBLY located in front of the transmission.

DRAIN PLUG LOCATED on the front module assembly near the engine.



*1	Hybrid Battery Thermistor	*2	Battery Cooling Blower Assembly
*3	Battery Voltage Sensor	*4	Service Plug Grip
*5	No. 1 Traction Battery Device Box Assembly • System Main Relays (SMRs) • Battery Current Sensor • Precharge Resistor	*6	No. 2 Battery Cooling Blower Assembly
*7	HV Battery Modules	-	-

2022 TOYOTA TUNDRA HV Battery assembly.



SYSTEM MAIN RELAY operation showing the order of operation for SMRB, SMRP, and SMRG.

module assembly to increase clutch responsiveness. Within the valve body, two separate solenoids control torque depending on whether 1MG is starting the engine or the K0 clutch is transmitting engine torque to the transmission.

When it comes to servicing these components, there are few serviceable parts available. The valve body inside of the front module assembly can be replaced separately, otherwise, the entire front module assembly gets replaced as a unit. The unit comes with the K0 Clutch, valve body, and motor-generator assembly.

The front module assembly does have a separate service drain plug, so use caution when performing oil changes to not loosen the incorrect drain plug **(Figure 3)**.

HV battery: When discussing system components and operation between a parallel hybrid system and other style hybrids, the components are not all that much different. The NiMH (nickel metal hydride) battery has a nominal voltage of 288VDC and 6.5 Ah. This voltage is created within the high-voltage battery by running 240 cells in series (each having 1.2 volts). Six cells are combined into one module pack, and there are 40 modules total within the battery **(Figure 4)**.

The NiMH battery uses an alkaline electrolyte (by mixing potassium and sodium hydroxide) that is then absorbed into battery cell plates. This mixture should prevent any leakage from the battery including if a collision occurs.

Remembering back in the "olden days," we were always told to use baking soda (which is an alkaline) to neutralize the high acidity of lead-acid batteries. But with the NiMH battery measuring a pH of 13.5 (which can damage the skin or eyes), we must use proper protective equipment in the rare case that spillage does occur. An acid (such as vinegar) can be used to neutralize the high-voltage battery leak.

The HV battery is located under the rear seat of the truck. The battery is cooled using two brushless motor cooling fans that use air from the passenger compartment under the rear seat. Obtaining the greatest cycle life for a NiMH battery requires temperature control. Luckily, NiMH batteries operate best in the same temperatures that we do, between 32 and 104 degrees F.

So, by using the passenger compartment's HVAC system, we are also keeping the NiMH battery at its optimum temperature. There are also battery intake filters that are easily accessible (on the sides of the rear seats) and will need periodic cleaning to keep the cooling system working at its best.

Based on the experience from earlier model hybrids, these intake filters can easily become clogged with pet hair, lint from clothes, or dust and dirt. If they become too clogged, the battery will eventually start to overheat.

System main relays: Low-voltage systems use the vehicle chassis for a ground path throughout the vehicle. But HV systems must be isolated from the rest of the vehicle. To accomplish this, large HV cables are run between the HV battery and the HV components. For added safety when the vehicle is "off" all high voltage must be contained within the HV battery. This is done using three power-side controlled system main relays: SMRB, SMRP, and SMRG.

When first "readying" on the vehicle, the SMRB relay closes, followed shortly thereafter by the SMRP relay. The SMRB relay is connected to the positive side of the HV battery and the SMRP to the negative side (with a pre-charge resistor in series). This reduces current flow through the system while allowing the inverter capacitors to charge.

HYBRID INVERTER LOCATED on the passenger side of the engine compartment along the firewall.

Once the capacitors are charged and no faults are detected, the SMRG relay will also close, now allowing current to bypass the pre-charge resistor. But because the capacitors are already charged, the contact points of the SMRG relay are protected from a rush of current. Lastly, the SMRP relay opens, and the vehicle is now "readied on" **(Figure 5)**.

The inverter with converter assembly: The hybrid inverter is found under the hood of the Tundra and contains the inverter assembly, the MG ECU, and the DC/DC converter (**Figure 6**). Unlike recent Toyota hybrids, the Tundra Hybrid inverter does not have a boost converter. Within the inverter assembly, there are six insulated gate bipolar transistors (IGBT) that are used to convert DC electricity into three-phase electricity to drive the U, V, and W phases of the motor generator assembly.

The DC/DC converter works just like most other hybrid models and takes the high voltage stored within the HV battery and uses step-down transformers, rectifiers, and smoothing capacitors to drop the stored high voltage down to 14V (and 150A) to power all the low voltage accessories on the vehicle (like radios, power windows, wipers, etc.).

The DC/DC converter is also used to charge the 12V lead-acid auxiliary battery also found underneath the Tundra's rear seat. Due to the placement of the 12V battery, the battery is also equipped with a vent to rid any fumes created by the auxiliary battery to the exterior of the truck.

With all the heat created by the inverter assembly, it has a dedicated cooling system including a separate radiator assembly and electric fan. By having an electric cooling fan separate from the engine's mechanical cooling fan, the electric fan can be turned on to cool the inverter even when the engine is not running.

Driving conditions

Now, let us dig into different driving conditions and how the motor generator comes into play! When first starting the engine, the front module (housing the motor-generator) is used to spin the engine. It does this by applying a wet K0 clutch that engages the motor-generator.

Once the vehicle is idling and the state of charge of the HV battery is low, the K0 clutch engages the motor-generator, and the engine will spin the motor-generator's permanent magnet rotor to create three-phase electricity (very much like a conventional alternator functions). The hybrid inverter must convert that three-phase electricity to charge the HV battery with a nominal voltage of 288VDC.

Once the transmission is in gear and the accelerator is lightly pressed, the K0 clutch (that locks the engine and 1MG together) disengages. Electrical energy supplied from the HV battery is supplied to the motor-generator to propel the vehicle forward using the high torque produced by 1MG.

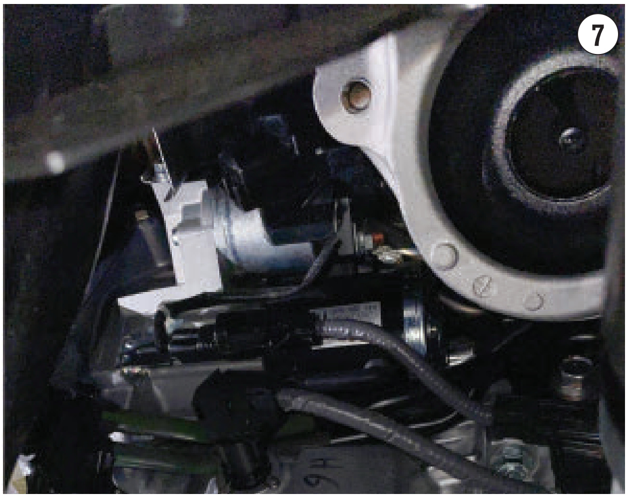
After the vehicle reaches approximately 25 mph, the K0 clutch is re-engaged, locking the engine to 1MG to start the engine. With the engine and transmission locked together, the engine is used to drive the vehicle forward.

Keep in mind, when the voltage levels of the HV battery are low, the engine can also spin the rotor of 1MG while driving to charge the hybrid battery through the inverter assembly. As the driver increases throttle input, the 1MG can aid with acceleration.

Lastly, during deceleration, the K0 clutch will disengage to allow the drivetrain's kinetic energy to spin the rotor of 1MG, producing electrical energy to charge the HV battery.

Starting and start/stop system operation

With the constant need for better fuel mileage and reduced tail-



STARTER MOTOR LOCATED on the passenger side of the engine, hidden under the exhaust manifold.

pipe emission numbers, manufacturers, including Toyota, have implemented start/stop systems into their vehicles.

While sitting at a red light, instead of idling and burning unnecessary fuel, the vehicle will shut the engine off if certain requirements are met. Some of the requirements include:

- The engine must be at operating temperature
- The heater switch must be off; the engine must be running to heat the passenger compartment.
- The HV battery must not have a low state of charge
- The vehicle cannot be in tow/haul mode
- The transfer case cannot be in 4H or 4L
- The shifter cannot be in sport mode if the hood is opened; the engine will not shut off due to safety reasons

There have been changes made to improve the customer driving experience during start/stop events. The first concern that needed to be addressed was the time it took for the engine to start.

To combat this, the crankshaft position sensor angle gets stored as the engine is shut off. This allows the engine the ability to spray fuel and create ignition on the next cylinder about to fire for faster starting.

A second issue that needed to be addressed was within the transmission. Without the engine running, a typical automatic transmission cannot create transmission fluid pressure because the fluid pump is not turning. So, to allow instant engagement inside of the transmission during engine start, the transmission is also equipped with an electric transmission fluid pump (in conjunction with a mechanical pump).

12V starter

Another unique feature of the Toyota Tundra Hybrid system is that it also has a typical 12V starter motor installed (**Figure 7**). Most parallel or series-parallel hybrids, including the Tundra, use an MG to start the engine. But the Tundra also comes with a 12V starter, although it is not used often.

To prevent the starter from seizing from a lack of use, the starter is used for the first start-up every time the vehicle senses that the fuel door was opened and closed. If you happen to have a customer who experiences a slightly different starting sensation after startup, know that it could be because the starter is being used to start the vehicle instead of the hybrid motor. The starter is also used in cold temperatures. Once the temperature drops below 5 degrees F, the 12V starter is used to start the engine.

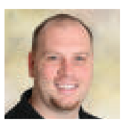
With that said, the 12V starter does have a service life. To prevent a situation where a customer's vehicle shuts off during start/stop operation and does not restart, the vehicle keeps track of the starting events.

At 384,000 starting events, the 12V starter must be replaced. Once that threshold is hit, the vehicle will no longer go into start/stop mode and the engine will not shut off. The start/stop indicator on the dash will blink letting the customer know that the starter will need to be replaced. Once the starter is replaced, a scan tool will need to reset the start counter.

The stop/start ECU also has a service life. Once the stop/start ECU reaches 1,000,000 starting events, the ECU will also need to be replaced. Although (if I am being honest), it is hard to imagine that count being reached. But it is something to keep in mind.

Electrification is here to stay

Regardless of our views, electrified vehicles are going to be around for a while. It is not just Toyota that is releasing trucks with hybrid packages. Stellantis is now delivering Rams with its optional 48v eTorque optional package. And General Motors is releasing the Hummer EV. It is safe to say that these vehicles are going to eventually be rolling into our bays with failures, so it is best to become familiar with how these systems and how they operate so that when we see a failure, we have the knowledge and ability to properly and safely diagnose and repair them. MA



P.J. WALTER began his career after attending Forbes Road Career & Technology Center in Monroeville, Penn. After graduating in 2005, he started working as a technician at a Saturn dealership for two years before transitioning in 2007 to a Toyota dealership. He quickly became an ASE certified Master technician and obtained certifications for Advanced Engine Performance, Light Duty Hybrid/Electric Vehicles and advanced driver assistance systems through ASE. He later became a Toyota Master Diagnostic technician, the highest certification offered by Toyota, and was selected for the Toyota Quality Champions program.

Today, PJ is an instructor with Worldpac Training Institute and continues to share his love and passion for the industry with technicians across the country. P.J. also started a mobile programming and diagnostic business, providing technical solutions and support to independent repair shops.

A 'SOUND DESIGN':

HOW HIDDEN EXTERNAL SPEAKERS IMPROVE PEDESTRIAN SAFETY

'QUIET CAR' STANDARD REQUIRES ALL CARS SOLD AFTER FEB. 2021 TO EMIT SOUND WHEN GOING FORWARD OR BACKWARD OVER 20 MPH.

BY LEE PROCIDA // Contributing Editor

Editor's note: This article originally appeared in Dorman's Shop Press and is republished with permission.

For more than a century now, people have been getting used to what it sounds like living around machines powered by explosions. The soundscapes of our roads, parking lots, communities and cities are filled with the familiar noises from engines and exhaust pipes.

Of all the changes we'll experience as we transition to more electric and hybrid vehicles over the coming decades, this is currently one of the most underrated: what will this new world sound like?

Automakers have been determining that over the past several years in response to new laws and regulations over the minimum amount of sound that hybrid and electric vehicles must produce. In the United States, a relatively little-known law called the Pedestrian Safety Enhancement Act of 2010 required the creation of these new standards, which led to the issuance of the "Quiet Car" standard in 2016, or FMVSS 141. After a slight delay due to COVID, manufacturers needed to have all new vehicles meet the rules by the end of February 2021.

These changes all stem back to the early 2000s, not long after the first Prii arrived in America, when people started realizing these alternative powertrains were nearly silent at low speeds. That soon led to concerns about the risks posed to pedestrians and bicyclists who would be less likely to hear them coming, particularly the visually impaired.

In 2005, Debbie Stein, a writer and activist with the National Federation of the Blind, had her first encounter with an HEV when her friend brought over his new Prius.

"It'd be a great burglar's car," he told her. "You could glide down the street in the dead of night, and nobody would hear a thing."

Stein proposed an experiment, she recounted in The Braille Monitor, the NFB's semi-monthly publication. She would stand on the sidewalk while her friend drove by, so she could prove she could hear this supposed stealth vehicle. She heard his door close, then a short while later, heard a door open.

"Why didn't you start up?" she asked.

"I did start up," he said. "I drove to the end of the block. Then I backed up and went about three houses past yours. Then I drove back and parked here in front of you again."

LEE PROCIDA

AVAS SPEAKER, as seen through the grille of a Toyota RAV4 Hybrid. On an EV there obviously wouldn't be a grille, so the speakers are often mounted behind body paneling or beneath the vehicle.

Stein said she was shocked, and she finished that column saying the NFB would work with NHTSA and other authorities to address these potential issues. Soon after, researchers found further evidence that people indeed couldn't hear HEVs coming until they were much closer than ICE vehicles, and there has been some further evidence that EVs and HEVs have a higher likelihood of being in an accident with pedestrians and bicyclists.

You probably have to be a sound engineer or musician to understand the specific requirements that wound up in FMVSS 141, but suffice it to say that these vehicles need to emit an audible sound when traveling forward or backward at less than 20 mph. (Technically the "crossover" speed is 18.6 mph, or 30km/h.) The logic is that above that speed the wind and tires are making more noise than the engine, and an electrified vehicle is just as audible as an ICE.

The mechanism by which they do that is pretty straightforward – externally mounted speakers, such as between the right headlight and wheel well in a Tesla Model Y, between the grille and hood latch on the Toyota RAV4 Hybrid, or mounted underneath the electric delivery vans Rivian has made for Amazon.

The sounds those speakers emit, however, have not been as simple to create as you might imagine. Presented with the opportunity to define the way their vehicles sound through audio engineering rather than mechanical engineering, many have turned to high-profile composers and production studios to literally set the tone for their brands.

For instance, BMW hired Hans Zimmer – the famous composer who scored "Dune," "Gladiator," "The Dark Knight" trilogy, etc. – to produce the various sounds for its Vision M NEXT concept sports car. Other European makes like Volkswagen, Porsche and Jaguar worked with big-name producers to outfit the audio of their ID.3, Taycan Turbo S, and I-Pace, respectively.

Meanwhile, Ford hired the automotive tech company Harman and T-Pain – the famous auto-tuned rapper and producer behind such hits as "Bartender," "Low" and "Buy U a Drank" – to produce the sound profile for the Mustang Mach-E.

For some manufacturers, these warning sounds have been around for more than a decade, although they have updated their acoustics since to ensure they meet the newest regulations. Nissan debuted a pedestrian alert on the Leaf all the way back in 2011, and in 2017 updated its sound to a new "bespoke sonic identity" named "Canto." General Motors first equipped the Chevrolet Bolt with an AVAS system in 2012, and their internal sound engineering team has created new warning sounds for its growing line of EVs like the GMC Hummer EV and Cadillac Lyriq.

In some cases, all this work amounts to a 1-second WAV file that is continuously looped, like in the Nissan example. The FMVSS regulations actually require that this sound algorithmically increases in volume as the vehicle speeds up, to help provide a sense of momentum similar to a combustion engine revving up.

Of course, all of these automakers are aiming to not only be compliant, but also make their vehicles more appealing. Each wants to appear at the forefront of technology, which is why they all so far have a vaguely futuristic, space-age sound, rather than a conventional engine sound. As the executives at the "sonic branding" firm in the video above say, they want consumers to be drawn to a vehicle based on its sound, but in a way that also feels new, not just a synthetic version of pistons firing.

(Note that AVAS is not to be confused with sounds that manufacturers add to the interior or exterior to simply improve the auditory driving experience. There's a solid episode of WheelHouse from Donut Media that looks at the history of these kinds of fake automotive sounds.)

For some, though, AVAS has been a big turn off, annoying owners to the point of unplugging their speakers. Other have pointed out that many are now louder than modern, relatively quiet ICE vehicles.

One solution by automakers was to provide consumers with various options to select from. Several OEMs petitioned NTHSA to modify their rules, but that petition was denied just this past summer. Instead, these sounds have to be consistent across models and trim levels.

In anticipation of noncompliance, Tesla issued a recall/update earlier this year for a feature called Boombox, which allowed drivers to play a variety of audio through their external speaker, and even upload their own sounds. Boombox still works, but only while parked now, so as not to conflict with the pedestrian warning system. That just further frustrated owners who apparently liked driving around with ice cream truck music and making sounds of "breaking wind" at passers-by. When someone asked Elon Musk about it on Twitter, he replied "The fun police made us do it (sigh)."

Right now, as alternative powertrain vehicles still only make up less than 1 percent of vehicles on the road in America, these sounds are few and far between in most of the country. In 20 years, though, electrified vehicles could make up all new car sales in the United States. Some people have been wondering now whether all these new sounds being produced in studios will start to make our roads sound like a symphony, or cacophony. In other words, will it become more pleasant in the long run, or more annoying? MM

LEE PROCIDA. Before writing for Shop Press, Lee was a staff writer for The Press of Atlantic City daily newspaper. Now he writes about the stories behind auto parts, and the issues affecting the people who work on cars and trucks. His favorite automotive-themed songs are "Daddy's Cup" by Drive-By Truckers and "Gear Jammer" by George Thorogood. He thinks if the world were fair then Mazda would have Lincoln's marketing budget.

ANALYSES: THE STEPPINGSTONES TO A CONCLUSIVE DIAGNOSIS

A DIAGNOSTICIAN'S ANALYSES PROVIDE GUIDANCE AS DO AIRCRAFT INSTRUMENTS FOR A PILOT. WILL YOUR CURRENT ANALYTIC SKILL SET BRING YOU IN FOR A SMOOTH LANDING, OR ARE YOU LIKELY TO CRASH AND BURN?

BY BRANDON STECKLER // Technical Editor

INFORMATION

Due to the tremendous feedback received in my Facebook posts over the years of what I refer to as interactive case studies, we are bringing them back! Each month, *Motor Age* will feature a fresh case study with inquiries of what the next diagnostic step should be. The answer will be revealed in the following issue along with a new case study. How confident are you in your diagnostic approach? I guess you shall see! Best of luck to all of you.

— Brandon Steckler, Technical Editor

Like any skill set, mastery takes an investment of free time. And once you've mastered the skillset of data analysis, it tends to look easy from an onlooker's perspective. However, getting to that point takes practice, patience, and a ton of hard work. The point being, you can lean on the data once you learn to trust it, because the data never lies.

This case begins with a request for a second opinion from my good friend and fellow diagnostician, John Hufnagel (of John's Mobile Diagnostics). John was faced with a 1999 Ford F350 with a V10 engine. The vehicle initially came to the shop with a timing fault on one bank of the engine (this was previously confirmed with disassembly and with visible inspection). Only the timing components were removed and replaced (by John himself) and the engine was assembled by the book. But after starting the engine, John confirmed that all five cylinders of bank #1 were misfiring and under all operating conditions.

Establishing a baseline

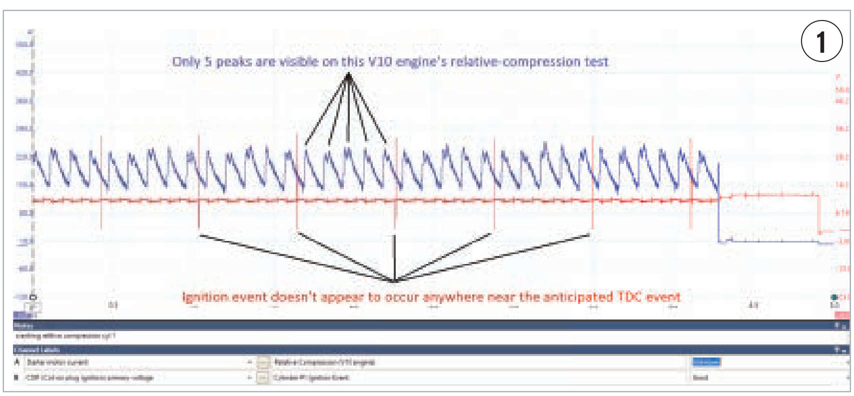
Like any efficient diagnostician, John began with a simple test that would yield him a lot of information about the nature of the full-bank misfire issue without much time invested. He began with a relative compression test **(Figure 1)**.

As can be seen, this is the relative-compression test with ignition events. Two subsequent ignition strikes are those of #1 ignition coil. Together, they represent one complete engine cycle. This V10 engine should produce (you guessed it) ten relative compression peaks. The results of the relative compression test confirmed John's suspicions of a mechanical engine fault but simultaneously offered some very valuable clues that left him with more questions than answers. John reached out to me with this info, and we both agreed that something was drastically wrong with this V10 powerplant.

To gather more information supporting the strange presentation of the current engine mechanical data, I had suggested John remove a spark plug and obtain a cylinder pressure waveform/ignition strike from either bank of the engine. Bank #2 (without fault) displayed a normal looking pressure waveform with a properly correlating ignition strike (just where we would anticipate occurring, right before peak compression). However, bank #1 (the suspect bank) told a different story **(Figure 2)**.

The pressure waveform looked just fine. However, the spark event was almost exactly 360 crankshaft degrees (180 cam-

JOHN HUFNAGEL



THE RESULTS OF THIS RELATIVE COMPRESSION TEST reveal a mechanical fault as there are only five visible peaks per cycle (this V10 engine should yield ten relative compression peaks).

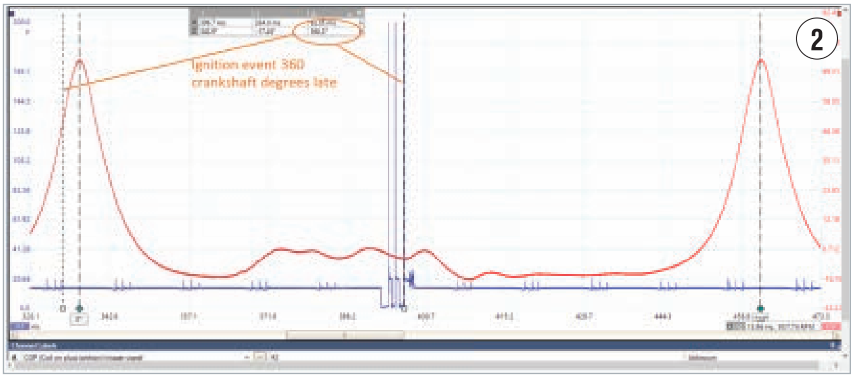
shaft degrees) later than expected. This data confirmed our findings and justified the need to invest more time in pursuing an engine mechanical fault.

The path of least resistance

After viewing these captures, I had thoughts on what might be wrong and where to test next, but John is savvy and took the words right out of my mouth. Before I could say anything, he was off to obtain a correlation waveform.

The correlation waveform is just as it sounds. It's a comparison of the signals from both the crankshaft position sensor and the camshaft position sensor(s). The timing of these signals (compared to one another) can indicate if a camshaft is out of place, if you are familiar with what they should look like.

To save time, I've omitted the "known-good" waveform (from a library), but I can assure you, the correlation waveform of our engine was an identical match. So, although the latest data is contradictory to the previous data, we must consider the limitations of the test results we have obtained. Technically speaking, the signals are generated from a tone wheel affixed to the nose of the camshaft. The waveform showed that the tone wheels were in proper alignment. There was a strong possibility that the camshaft was damaged at the location of the tone wheels. No one likes to hear "the engine has to come back apart," and I'd never recommend doing so unless I was confident. At this point, disassembly was justified.



USING THE DSO RULERS AND MEASUREMENT CURSORS, this capture demonstrates the ignition strike occurring approximately 360 degrees later than expected.

Another afternoon had gone by, and I had received a picture of the timing components from John after disassembling the engine again. The marks compared identically to what was indicated in service information. However, John has not displayed the points where the tone wheels connect to the camshafts. He then removed the tone wheel fasteners at the nose of the camshaft and revealed a lack of damage (and more importantly) that the tone wheels and camshaft were properly indexed to one another **(Figure 3).**

The data doesn't lie

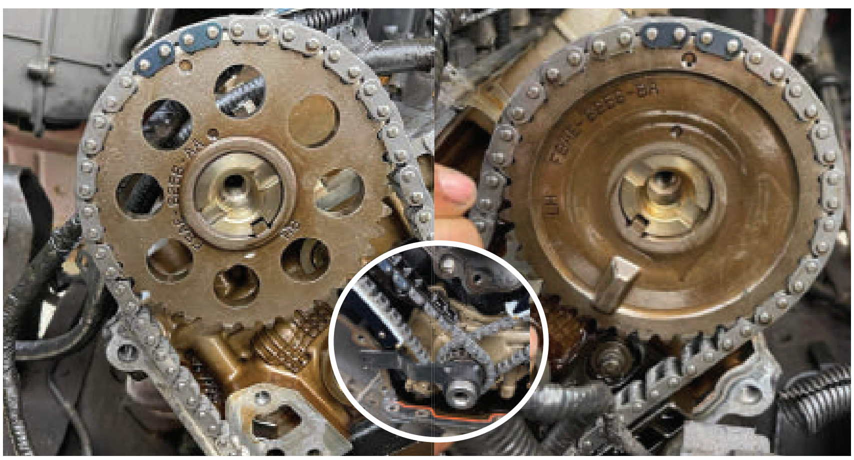
With all the conflicting information in front of us, John and I were forced to retrace our steps. I will list some bullet points of what we know to be factual, and I will ask all you diligent readers for your input:

- All of bank #1 cylinders are misfiring under all operating conditions
- The relative compression test shows a mechanical fault with only five (of the 10) compression peaks shown
- Correlation waveform reveals the camshafts' tone wheels are properly timed
- Visual inspection of the camshafts reveals no damage to the indexing point with the tone wheels (infers the camshafts are in time)

What would you recommend John do next, given the data bullet points above?

- Reassemble the engine and start fresh
- Measure cam lobe peaks with a degree wheel
- Remove cylinder head for machine work
- Replace PCM due to logic processing error

Be sure to read next month's Motor Age issue for the answer and what was discovered! MA



THE CAMSHAFT TIMING AND TRIGGER WHEEL (inset) indexing are verified to be correct after engine teardown and visual inspection, yet the previous tests show conflicting evidence that the engine is not timed correctly.

BRANDON STECKLER is the technical editor of *Motor Age* magazine. He holds multiple ASE certifications. He is an active instructor and provides telephone and live technical support, as well as private training, for technicians all across the world.

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The Power Probe PPTAMP and PPTPWM Adapters are designed to cut diagnostic times and increase diagnostic accuracy. The PPTAMP allows any Power Probe circuit tester to read current. When a component powers up, users can monitor its current to determine the health of that component up to 20A and as low as one milliamp. The PPTPWM allows any Power Probe circuit tester to use pulse width modulation, a feature used to control new vehicle components with an adjustable duty cycle.

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RATCHET SWITCHES FROM CLOCKWISE TO COUNTERCLOCKWISE DRIVE

The Lisle Corporation 5-pc Actuator Motor Wrench Set, No. 64180, features a toothless infinite ratchet and hinged handle design to make it easier to remove and replace fasteners on small, electric HVAC motors. The ratchet can be flipped to switch from clockwise to counterclockwise drive. Set includes 5.5mm socket, 7mm socket, 8mm socket, and 1/4" square drive adapter for use with 1/4" sockets and bit holders. The set can also be used in other hard-to-reach applications and includes a vinyl holder for sockets and adapter for storage.

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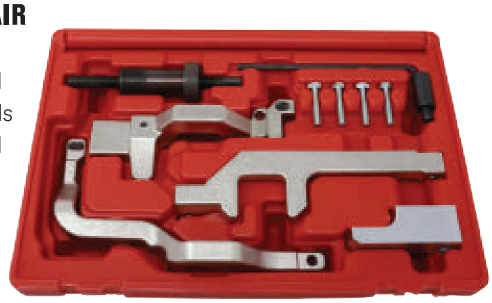
FOR TIMING SERVICE AND REPAIR



The CTA Manufacturing BMW/MINI Timing Chain Tool Kit - N12, N14, and N16, No. 3770, features specialty tools required to perform timing service and repair, including camshaft locking blocks, flywheel locking pin, timing chain tension block, and upper chain tension locks. With the kit, users are able to accurately locate TDC for servicing and repairing head gaskets and timing chains. The tools service R55-R61 models 2007 to 2016 (Cooper, Paceman, and Countryman).

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MEASURES INSIDE AND OUTSIDE BRAKE PADS

The Tool Aid In-Line Brake Pad Gauge, No. 65300, is calibrated for standard 6mm backing plates and measures both inside and outside brake pads. The inline style allows readings to be taken without removing the wheels on many vehicles. The metric, color-coded scale allows for quick at-a-glance readings.

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COVERS EVERYTHING ATSG HAS LEARNED IN THE PAST YEAR

ATSG's 2022 Seminar Book Set and DVD covers everything ATSG has learned in the past year from being on the front lines and taking tech calls everyday. Our techs with a combined 300+ years of transmission experience are ready to tackle any transmission problem, big or small. The 2022 Seminar Book Set includes three books that focus on GM & Medium Duty Trucks, Ford & Chrysler, and Imports. You are sure to find what you need in the 2022 Seminar Book Set. PLUS get an included DVD and free shipping!

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FEATURES A THREE-POINT JAW DESIGN

The Tool Aid Sharktooth Sway Bar Pliers, No. 13570, feature a three-point jaw design intended for use on sway bar links as well as stripped and rounded fasteners. The 7" length and thin profile allows for easy access in hard-to-reach areas.

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CAN JUMP START BOTH 12V PETROL OR DIESEL ENGINES

The SP Tools USA HD Diesel 1600A Jump Starter / Jump Box, No SP61073, is a compact, high-density jump starter that can supply a lot of power in a short time to start both 12V petrol or diesel engines up to 10 liters in capacity. The jump pack is equally suitable to jump-start motorcycles, ride-on mowers, cars, outboard motors, etc. While not being used as a jump starter, it can be used to power or charge low-voltage accessories and USB-compatible electronics. The storage case with EVA insert includes 14 interchangeable tips and cords to connect to most devices, extra heavy duty cable clamps, and chargers.

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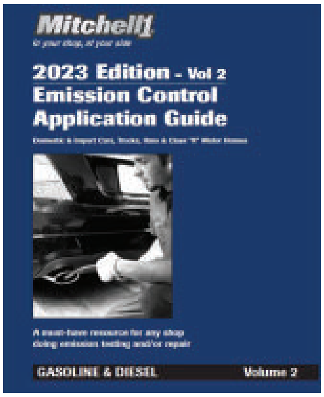
A RESOURCE FOR SHOPS THAT DO EMISSIONS TESTING AND/OR REPAIR



The Mitchell 1 2023 Emission Control Application Guide is a resource for any shop that does emissions testing and/or repair. The guide is for domestic and import cars, light trucks, vans (diesel engines), and Class 'A' motor homes with gasoline engines, model years 1966 to 2023. Specific content features in the 2023 edition include an emission application table, engine displacement conversion charts, emissions control visual inspection procedures, approximately 40 years of domestic and imported basic ignition timing specifications, 1980-2022 maintenance reminder light reset procedures, the latest EPA emission recall bulletins, and a quick reference listing for major systems, devices, and components.

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AD INDEX

AD INDEX

THE TRAINER #134: HYBRID ELECTRIC MOTOR DESIGNS

DID YOU KNOW THAT EVS USE DIFFERENT ELECTRIC MOTOR DESIGNS?

PETE MEIER // Creative Director, Technical

The electric car is not new. It was first introduced in the late 1800s and was one of the first means of propulsion used by the early automobile. In fact, 40 percent of the vehicles on the road in the early 1900s were electric! And I'm sure that you are aware that today's hybrids and electric vehicles use an electric motor, just as the early EVs did. But do you know what kind of motor it uses?

Yes, there are different types and that's the subject for this edition of The Trainer!

All electric motors work by mounting one set of magnets or electromagnets to a shaft and another set to a housing surrounding that shaft. By periodically reversing the polarity (swapping the north and south poles) of one set of electromagnets, the motor leverages these attracting and repelling forces to rotate the shaft, thereby converting electricity into torque and ultimately turning the wheels. Conversely—as in the case of regenerative braking—these magnetic/electromagnetic forces can transform motion back into electricity.

The difference is in how we make all this happen.

Just like our knowledge of various engine designs help us better diagnose and repair problems when they occur today on an internal combustion engine, understanding the differences in EV motor design will help you prepare for the challenges of the EV era to come. Are you prepared to embrace the change? MA

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