
A close-up, low-angle shot of a car's front end, focusing on the headlight and grille. The car is dark-colored, and the background is a blurred landscape under a bright sky.

# TURN ON YOUR EXHAUST ANALYZER— IT'S A GAS!

**BY SAM BELL**

There has been continuous improvement in on-board diagnostic systems as well as in the scan tools that report the data they provide. But there are still occasions when the best tool for the job is an exhaust gas analyzer.



**I**field a lot of technical phone calls in a week, most of them driveability issues of some sort. In some cases, technicians have an equipment problem: They need access to a PID their scanner doesn't report, or they want to do a bidirectional test but don't have the right software interface to command it. Sometimes I can help them find a viable work-around, sometimes I can't. Some callers need help finding or understanding test criteria, doping out arcane details of circuit operation, or even finding a diagnostic starting point in cases involving multiple symptoms.

Ultimately, what we do on a daily basis—what these phone calls are all about—is science. We gather data, formulate hypotheses and conduct experiments to verify or disprove our hypotheses. In pursuing this endeavor, we use many scientific tools, ranging from multimeters and scopes to vacuum gauges and scanners. A good exhaust gas analyzer should have a place in your diagnostic lineup as well. If you have one and aren't using it, you may want to dust it off, and perhaps your skills with it as well. If you don't have one, this article will give you a taste of how it could make life better.

### Behind the MIL

The evolution of on-board diagnostics has helped make driveability work easier in most cases. One of the critical things to remember about the malfunction indicator lamp (MIL) is that it's supposed to illuminate when the PCM has detected a condition which *might* result in tailpipe (or evaporative) emissions of regulated gases which exceed federal standards by 50% or more.

Detailed case studies show that approximately 70% of all MIL-on conditions do not, in fact, result in increased emissions as measured during dynamometer testing based on the Federal Test Procedure (FTP) for new cars. This is true largely because modern powertrain management systems have the ability to compensate for a broad range of malfunctions through such mechanisms as adaptive fuel trim. Even a large percentage of evap malfunctions do not cause increased hydrocarbon (HC) emissions, indicating instead a failure of one

or more components in the monitoring system, rather than in the vapor storage and containment system itself.

That means that approximately 30% of all MIL-on faults are associated with actual emissions issues. Does it make a difference? The answer will depend both on your customer's perspective and the details of your local air-quality/vehicle testing program, if there is one. (At last count, over 30 states had some sort of periodic emissions testing requirements in place.) If your customer's chief complaint is that the MIL is on, or if your local air quality testing program is MIL-driven (an illuminated MIL is an automatic failure), your primary task will be to "kill the MIL" and make sure it stays dead! Where the primary complaint stems from a failed *tailpipe* emissions test, your job is to bring the actual emissions into compliance. Of course, where the primary complaint is "simply" some sort of driveability issue, overcoming the particular symptoms will be your main concern.

Here are a few helpful things to remember:

- Not all driveability complaints result in a MIL-on condition, a code or even in a pending code.
- Not all DTCs or illuminated MILs are accompanied by noticeable driveability symptoms.
- The information in data stream is only as good as the sensors supplying it and the software interpreting it.

So does that mean you should ignore MIL status, DTCs and data stream? Of course not! These are all certainly front-line tools in our daily work, and I wouldn't want to be without them if I could avoid it.

So what *does* it mean? Simply that scanners are not the only valuable tools for driveability diagnostics. I often joke, for instance, that if someone invented an "iVac" today as a smartphone app that provided vacuum readings, he could retire tomorrow. And he'd probably deserve to, because paying a bit more attention to vacuum readings would increase the efficiency and accuracy of driveability diagnostics considerably. Along with scan tools and vacuum gauges, most well-equipped shops have scopes or at least graphing multimeters, but sometimes even these are not

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enough to efficiently arrive at a diagnostic solution. Back in the corner, covered with dust, may be just the tool you need to help solve your latest automotive headache—an exhaust gas analyzer.

Let me give you an example. The vehicle that came in was a Chevy Venture with 168,000 miles on the odometer that was recently acquired by a good customer. The complaints were that the MIL was on and fuel economy was suddenly lower than when the vehicle was first purchased. A scan showed a familiar code—P0171. Since this is a single-bank motor for emissions purposes, the code meant simply an overall lean condition. Freeze frame data seemed consistent with the code (any time it doesn't, you should be worried!), with combined fuel trim corrections adding over 50% more fuel than base programming called for. Scan data showed HO<sub>2</sub>S crosscounts, but the upstream HO<sub>2</sub> sensor voltage rarely went

even as high as 600mV. Adding propane in a situation like this will normally cause the fuel trims to go sharply negative as the HO<sub>2</sub>S voltage climbs, but this time



Photos & screen capture: Sam Bell

Like most portable gas analyzers, mine requires uninterrupted power or it has to go through the entire warm-up cycle again. I keep the analyzer plugged in on a stable 12-volt supply so it's always warmed up and ready for in-shop use. If I need to take it on a road test, I temporarily plug in a power cord from one of my jump boxes to the multiport power adapter seen here. A second power jumper connects me to the car's power point once I have secured the sample hose out of harm's way. Only once I've started the car do I disconnect from my jump box. For the purposes of this picture, I have the analyzer powered up from the 120-volt heavy-duty extension cord, from a jump box and from the car simultaneously. Then all I have to do is unplug from the wall, start the car and go. Remaining connected to the jump box once the car has been started is optional, at least until you're ready to transfer back to wall power:

low HO<sub>2</sub> sensor voltages and high positive fuel trims persisted. *Hmm.*

Now was the time to confirm the code by verifying the HO<sub>2</sub> sensor data. My exhaust gas analyzer was already on, as usual, so I zeroed it and inserted its probe into the tailpipe. The numbers I saw on my analyzer were anything but supportive of a lean condition. In fact, this van was running extremely rich, as the readings attested (see "Learning to Read," starting on page 30). In this instance, lambda readings were a very rich .89—about 11% richer than ideal. At this mileage, the original oxygen sensor was ready for retirement, but like a punch-drunk veteran boxer in the late rounds, it would pop its head up just often enough to seem like it was still in the fight.

As expected, a new sensor took care of the immediate problem, and my gas analyzer verified that the now-lower trim corrections were, in fact, now resulting in stoichiometry. Still, the fuel trims, though lower, remained considerably elevated until an injector cleaning and engine decarbonization procedure were performed. Final repair confirmation came when lambda was displayed as 1.01 and fuel trims fluctuated from positive to negative as the oxygen sensor cycled during the road test.

While this example is a relatively easy case that could have been diagnosed through other means, I've seen a variety of problems stemming from damaged or contaminated sensors. For example, a sensor that had suffered contamination from coolant in the exhaust still switched, but not at the normal point of stoichiometry. It left lambda off by about 5%, just enough to cause long-term coking damage to the catalytic converter.

Long before OBD II was rolled out, many top-level shops routinely checked exhaust gas emissions (usually at idle, and sometimes additionally under "loaded-idle" conditions), in conjunction with what we then called "tune-ups." Once

### Care & Feeding of Your Gas Analyzer

How do you resuscitate your old exhaust gas analyzer and get it back to making money for you? For starters, give it a thorough cleaning, inside and out. If it's been sitting for some time, there may be an accumulation of dirt, grime or even cobwebs. Remove the sample hose and blow it out thoroughly with dry compressed air. Clean or replace any filters. Your analyzer has an oxygen sensor which is a relatively high-failure-rate item. If the analyzer shows a calibration or general bench error message, this is the sensor to suspect first. Depending on the model and its usage, I find most such sensors last about a year or two at the most. Calibrations can drift, especially over extended periods of storage and disuse. Specialized "Cal-Gas" is used to bring everything back into adjustment. You can buy

some to do it yourself, or you can pay for a service call from your local equipment specialist.

Once calibrated, your analyzer will benefit from being used on a regular basis, and you'll benefit, too. The most common problems arise from shutting off the analyzer too soon after sampling. While most instruction manuals call for a minimum purge cycle of 30 seconds, experts suggest that waiting an additional 5 to 10 minutes helps prolong sensor life and the life of the whole analyzer. The extra time allows an opportunity for any trapped moisture or contaminants to work their way through. My practice is to remove the sample hose, run a couple of purge cycles, then set the analyzer to the task of checking the atmosphere. Meanwhile, I blow out my sample hose with compressed air.

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you became accustomed to it, you learned to use the information to verify basic mechanical integrity, combustion efficiency and the correct functioning of the engine management system. A two-minute test could rule out a long list of potential problems or, just as importantly, point you in a fruitful diagnostic direction. Before OBD II testing supplanted it, many jurisdictions used dynamometer-based emissions testing such as the I/M 240 test. Back then, many shops had a BAR-certified gas analyzer, and many still have one gathering dust in a corner.

So if this is such a great tool, how come no one's using it? Near as I can tell, the biggest reason gas analyzers aren't used more widely is simply that no one wants to wait through the warm-up period. Most analyzers need a warm-up of 5 to 15 minutes before they'll produce reli-



Technician Joe Sandow checks for the presence of the combustion byproducts CO or CO<sub>2</sub> in the cooling system, seeking positive proof of a leaking head gasket. Don't be misled; I've seen high HC readings from misfilling the coolant reservoir with washer solvent! As always, there are caveats to be observed. Most importantly, don't allow any liquid to enter the sample hose; it's an expensive drink.

able, stable readings. For road-portable units, the warm-up clock often resets during cranking, when many power-points are momentarily disabled. The photo on page 26 shows my work-around for this problem.

My suggestion is to turn on your analyzer every morning when you get in and leave it on all day, as I do with mine. You'll more than make up for the minimal increase in your shop's carbon footprint (and utility bills) by offsetting it against the efficiency gains and greenhouse gas reductions from your customers' tailpipes. With a gas analyzer, my mantra is, if it's on, you'll use it. If it's not, you won't even think of it except as a last resort.

### All the World's a Nail?

An old saw has it that to a man with only a hammer, all the world's a nail. What does

the world look like to a tech with a gas analyzer?

First, and perhaps most importantly, consistent practice with your gas analyzer allows quick verification of oxygen sensor data, easy answers to tough running problems stemming from mechani-

If you haven't used your gas analyzer in a while, or if you're new to the subject, a quick review may be in order. Most repair-grade analyzers measure hydrocarbons (HC), carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO) and oxygen (O<sub>2</sub>). Some may also measure oxides of nitrogen (NO<sub>x</sub>).

**HC** represents unburned fuel and is usually measured in parts per million (ppm). Good-running modern cars often show HC levels of 10 ppm or less. Ideal value: zero.

Fully burned fuel shows up as **CO<sub>2</sub>** and is measured as a percentage of the sample volume. Higher numbers generally indicate greater engine efficiency, while lower numbers indicate the opposite. Ideal value for conventional injection systems: >14.5% to 15.5%. However, gasoline direct injection (GDI) engines, which are substantially more efficient than their normally fueled counterparts, produce much lower than normal levels of CO<sub>2</sub> under most operating conditions.

**CO** represents partially burned fuel and shows up as a percentage reading, too. High CO readings indicate a rich mixture. Ideal value: zero.

### Learning to Read

**O<sub>2</sub>** is unburned oxygen, also registered as a percentage. High O<sub>2</sub> readings indicate a lean air/fuel mixture. This can really throw you for a loop, because high HO<sub>2</sub>S voltages mean a rich condition. Throughout this article, I denote the concentration of oxygen as an O<sub>2</sub> value, while I use HO<sub>2</sub>S to refer to oxygen sensors and their voltages. Conventional fuel system management is geared toward metering the exact amount of fuel required to consume all of the oxygen entering the engine while simultaneously keeping CO at a minimum. Ideal O<sub>2</sub> value: zero. GDI proves to be an exception to that rule. Under most operating conditions, considerable unburned O<sub>2</sub> may persist in a GDI exhaust stream.

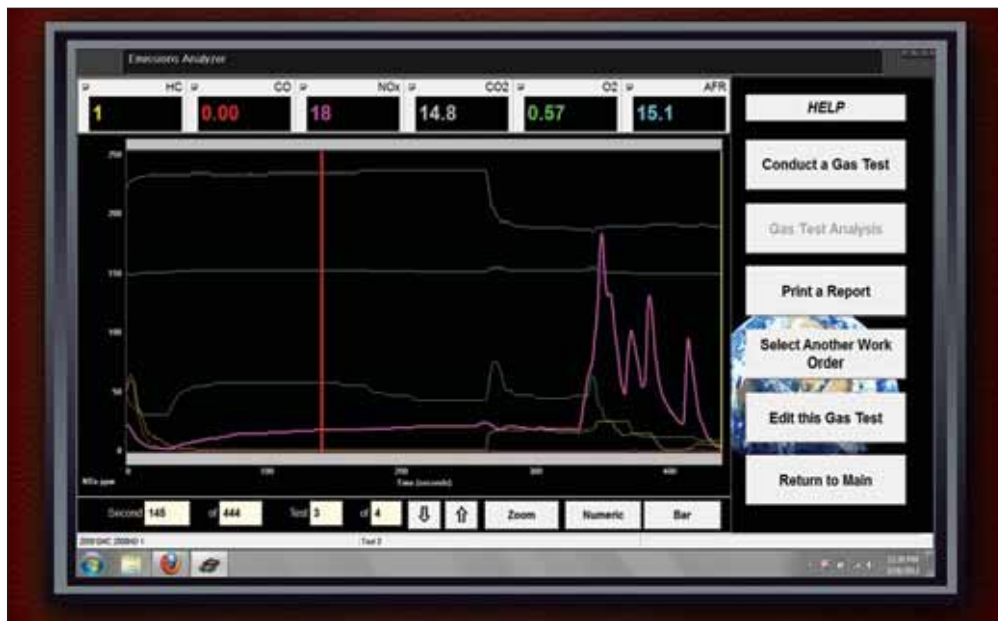
**NO<sub>x</sub>** represents the products of burning nitrogen when combustion chamber temperatures exceed about 2500°F, and is measured in ppm. NO<sub>x</sub> readings are usually low when the engine is not under load, so are most useful when taken as part of a road test. Ideal value: zero. By themselves, high NO<sub>x</sub> levels are

more likely to accompany the higher combustion chamber temperatures associated with a lean mixture. However, it's not uncommon to encounter high NO<sub>x</sub> levels after resolving a rich-running issue, as leftover soot deposits raise the effective compression ratio and thereby combustion chamber temperatures as well. A carbon cleaning treatment will usually set everything back to rights.

Now that you've brushed up on your reading skills, make sure your analyzer is fully warmed up and properly zeroed and calibrated before you begin sampling. The exhaust must be leak-free or the sample will be diluted. Of course, the sample probe must be fully inserted. If you're using a road-portable unit, secure your sampling hose carefully, avoiding moving tires, driveshafts or other components. Many experienced techs use a breakaway hose coupler. You can probably guess why!

*Important safety note:* Your exhaust gas analyzer pumps a small amount of exhaust gas directly into the passenger compartment during your road test. That sample then exits the analyzer

Good data-plotting software makes exhaust gas analysis much easier. If you don't have a means of recording the data on the fly, you'll need an assistant to drive while you watch the readouts. This sample shows a snippet of data in which the somewhat elevated O<sub>2</sub> values suggest a tired oxygen sensor. The first 180 seconds or so were taken during a prolonged hot idle. Although the NO<sub>x</sub> trace looks scary, it's not. I enlarged it to show detail I needed for the particular case I was working on. Much more worrisome would be the CO<sub>2</sub> drop-off and other gas changes at around 260 seconds. In fact, this trace change reflects a change from gasoline to CNG (compressed natural gas) in this bifuel vehicle.



cal inefficiency and a good “window” into the combustion chamber.

Beyond that, here are some ways to use your gas analyzer that you may have forgotten:

**Faulty head gaskets.** Make sure you've zeroed your probe; the concentra-

tions we're looking at are typically quite low. Use a large funnel like the one shown in the photo on the opposite page. Coolant level should be no more than 1 or 2 in. above the bottom. Secure a large plastic bag to the mouth of the funnel with a rubber band or a long zip-tie.

Make a very small incision in the top of the bag, just large enough to put the tip of the probe barely inside. Don't let any liquid coolant enter the probe tip! The presence of CO or CO<sub>2</sub> indicates that exhaust gases are entering the cooling jacket. How much is too much? I use .2%

through what is typically a very short hose. Keep the windows open as much as possible, and keep the blower motor on at a moderate to high setting, with its intake set for fresh air. CO concentration of less than 1% can be fatal. 'Nuff said.

Most gas analyzer probes use a lengthy hose to bring the sample to the analyzer. This, coupled with the length of the exhaust system itself, imposes a time delay between combustion chamber events and their subsequent display on the analyzer. Depending on the exact details, this delay may be as long as 30 or 40 seconds, though it's usually somewhat less. If I'm recording both exhaust gas composition and scan data at the same time, I generally add some sort of easily recognizable “signature,” such as a series of three brief snap-throttle events to allow me to coordinate the time-stamps of each recording. Later, I can identify the sudden TPS and rpm changes and their corresponding brief HC spikes to better align the data for analysis.

As with most other diagnostic equipment, the time to break out your gas

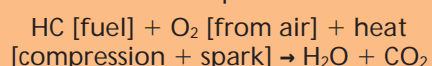
analyzer is when you're working on a known-good car. Familiarity with normal readings taken under a variety of controlled, reproducible conditions provides the firmest foundation for diagnosis of abnormal conditions.

Since catalytic converters may substantially alter the composition of the exhaust gases, indications of rich, lean or hot-running conditions may be masked. There's a way to figure out the composition of the original mixture from the readings on your analyzer. From the “lambda” value or the “air/fuel ratio” your analyzer provides, or from the results you calculate based on your current tailpipe readings, you can determine whether the original mixture was rich, lean or, as Goldilocks would have it, just right. iATN offers a handy calculator available online for free to members; just input your readings for an instant answer at [tinyurl.com/7owcapc](http://tinyurl.com/7owcapc).

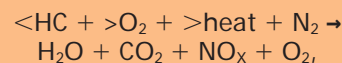
The brief explanation of lambda is this: Numbers greater than 1.00 indicate a lean mixture condition entering the combustion chamber; numbers below that indicate a rich condition. The difference indicates how far the actual

ratio has strayed from its ideal value. There are still a few 2- or 3-gas units in service, but since they don't provide a full suite of data, they cannot be used to determine lambda.

The ideal basic combustion reaction in its most simplified form is:



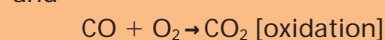
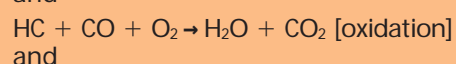
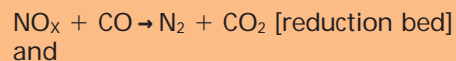
Less desirably, a lean mixture results when



while a rich mixture results when

>HC + <O<sub>2</sub> → H<sub>2</sub>O + CO<sub>2</sub> + CO + HC

To clean up the latter two conditions, the catalytic converter utilizes these reactions:



and, of course, the now-familiar

$$\text{HC} + \text{O}_2 \rightarrow \text{H}_2\text{O} + \text{CO}_2.$$

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CO<sub>2</sub> and .02% CO as cutoff values. Anything above those levels means there's a sealing problem. Any CO value above .15% means it's time to formulate a plan for immediate action, whether it involves repair, sale or trade. A CO or CO<sub>2</sub> reading of 1.00% or more is an indicator of imminent trouble. (HC is an unreliable indicator. And we've even seen false re-

sults from someone mistakenly filling the coolant reservoir with washer solvent!)

**Evap leaks 1.** Smoke is nice, but even with added UV dye, it's not always visible, especially when a porous fill neck is covered with years of accumulated salt and road grime. In fact, pores of .010 in. in diameter are too small to allow smoke to escape in visible form.

The gas analyzer's probe can be your magic wand, making the invisible visible as the HC readings flare up.

**Evap leaks 2.** Sometimes you need to use your smoke machine and gas analyzer simultaneously. A small amount of CO<sub>2</sub> can be added to the system via your smoke machine. Your analyzer recognizes CO<sub>2</sub> readily, making it easier to find the leak. Never add compressed air, only CO<sub>2</sub> or nitrogen (N<sub>2</sub>). A mixture of compressed air and fuel is a bomb just waiting for a source of ignition.

**A/C leaks.** The compressed CO<sub>2</sub> trick works on evaporators as well as on evap systems. Not coincidentally, it can also help pinpoint leaks in condensers, compressors, hoses and other a/c components.

**No-starts.** Look for HC levels of 2500 ppm or more during cranking. Depend-

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## DOING THE O<sub>2</sub> MATH

Here's a quick and easy way to determine how many cylinders are misfiring. Remember, though, that it does not necessarily hold true for GDI vehicles.

Oxygen makes up a bit less than 21% of atmospheric air by volume (20.95% is the accepted figure). If there were no combustion, a gas analyzer probe in the exhaust would still show 20%-plus O<sub>2</sub>. If half the cylinders were firing, tailpipe O<sub>2</sub> concentrations would drop proportionately, to about 10.5%. A single-cylinder misfire on a 4-cylinder engine should result in tailpipe O<sub>2</sub> readings of about 5%. On a 5-cylinder engine, that drops to 4%. A 6-cylinder with a single misfiring cylinder would consume 1/6 of the available O<sub>2</sub> entering the engine, leaving only about 3.5% O<sub>2</sub>. An 8-cylinder engine with one misfiring cylinder consumes 1/8 of the available quantity, leaving a signature tailpipe O<sub>2</sub> of about 2.5%. Obviously, a V8 with three cylinders down would show about 7.5% O<sub>2</sub>. The mathematical rule is simple: Where m = measured O<sub>2</sub> concentration, N = total number of cylinders and X = number of misfiring cylinders, the equation  $X = m \times N \div 21$  will hold.

Obviously, partial misfires will impact the readings similarly, though not identically.

Watching O<sub>2</sub> readings with this mathematical relationship in mind can help verify or disprove the validity of an engine misfire code, but it may not tell the whole story. Here's why: The higher O<sub>2</sub> content in the exhaust stream is reflected in lower HO<sub>2</sub>S voltage readings. In


ing on design details, ambient conditions and other variables, HC levels may reach 10,000 ppm or more. To see what normal concentrations might look like, disable spark on a known-good engine after a cold soak, then run the cranking HC test. Restore normal operation, warm the vehicle up, then perform the test again. You may be surprised at how much difference engine temperature can make! Be sure to record the values you see, along with engine size, year, model, etc. Remember, you're building a database of known-good values here.

**Dripping injectors.** Pull the spark plug out of a suspected cylinder and insert your probe. High concentrations of HC (hundreds or even thousands of ppm) show up at once.

**Misfires.** Is it spark or fuel? Lambda

readings or calculations can answer the question. Is it a single-cylinder miss or multiple? O<sub>2</sub> concentration can provide a quick answer, though closed-loop effects may throw you a curve if you're not careful (see "Doing the O<sub>2</sub> Math," below).

Modern fuel systems are generally pretty robust and offer a broad data stream, so it's easy to overlook the reali-

ty of exhaust gas composition and get caught up in the data. Using your gas analyzer early on will help you avoid wasting time chasing the wrong problem. Equally important, it will add 

This article can be found online at [www.motormagazine.com](http://www.motormagazine.com).

closed-loop operation, the lower voltage is interpreted by the PCM as evidence of a lean exhaust condition. In response, the PCM adjusts the air/fuel mixture richer. Depending on the original misfire cause, this *may* impact the composition of the exhaust gases after they have passed through the catalytic converter.

For example, suppose a cylinder is misfiring because of a clogged injector. The HO<sub>2</sub>S voltage will drop to indicate a lean mixture. If the consequential closed-loop enrichment response by the PCM is large enough, the overall mixture entering the catalytic converter may approach the ideal air/fuel ratio. The catalyst will then clean up the higher-than-normal CO from the nonmisfiring cylinders by using the excess oxygen from the misfiring cylinder to complete the combustion process. Since all the O<sub>2</sub> has then been consumed, tailpipe levels may look normal!

If you suspect such a situation, unplugging the upstream sensor for a few seconds should restore the system to open-loop operation, allowing verification and scaling (measurement) of the misfire(s). Alternatively, shut the car off and allow the converter to cool down, then insert your probe and begin sampling before you restart the engine. This allows you to view the exhaust gases before either the converter or closed-loop effects come into play to mask what's really happening. You have to be set up in advance and ready to work quickly. A modern oxygen sensor can reach closed-loop operational temperatures in 30 seconds or less.

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