P0420 Catalyst System Efficiency Below Threshold
2007 Accord 2.4L 4CYL with 313k Miles
12/15/2015

This is my personal account of diagnosing and replacing a bad catalytic converter. I hope that this information is useful to other Honda owners finding themselves in a similar situation, especially given that there is not a lot of information for catalytic converter diagnosis via O2 sensor signals on 7th generation Accords which utilize an upstream LAF (Lean Air Fuel) sensor rather than traditional oxygen sensor.

1. Diagnosis

At 313k miles, the check engine light came on but there were no noticeable operational problems. I read the codes using a handheld scan tool. There is a single DTC, P0420 - Catalyst System Efficiency Below Threshold. As expected for P0420, the top reported fix (as reported by the scan tool) is replacing the catalytic converter:

P0420 ECM

Catalyst System Efficiency Below Threshold

TOP REPORTED FIX
1-Replaced Catalytic Converter(s)

FREQ REPORTED FIX
1-Replaced Air Fuel Ratio (AFR) Sensor

ALSO REPORTED FIXES
1-Programmed Engine Control Module (ECM)
2-Replaced Oxygen (O2) Sensor(s)

I am not sure how reliable these scan tool recommendations are, but I was surprised to see that the Air/Fuel Ratio Sensor and O2 sensor were listed as other possible fixes. There are numerous ECM tests performed on both of these sensors so it seems surprising that they could fail (generate a "false" P0420 code) without at least generating a code for a sensor failure as well. Next, I looked at the Freeze Frame data from the time of the fault, to see if there were any obvious operational problems that might have contributed to the failure (e.g. engine running very rich and fouling the cat):

TROUB CODE	P0420
FUEL SYS 1	CLSD
FUEL SYS 2	N/A
CALC LOAD(%)	54.9
COOLANT(°F)	181
ST FTRM1(%)	4.7
LT FTRM1(%)	0.8
MAP("HG)	16.2
ENG SPEED(RPM)	1485
VEH SPEED(MPH)	42
IGN ADV(°)	28.5
IAT(°F)	55
MAF(LB/M)	1.29
ABSLT TPS(%)	16.9
REL TPS(%)	6.3

The freeze frame data doesn't show any apparent issues that I can see. I like to look at the fuel trims as they seem to be a pretty good gauge of overall engine operational health. If the combined long term and short term fuel trims are low, then it rules out a lot of problems. In this case, the short-term fuel trim (ST FTRM1) is perhaps slightly elevated at 4.7% in this freeze frame data, but typically it runs even lower (a few percent). So it doesn't appear to me that there are any significant mixture/closed-loop problems causing unusual fouling of the catalytic converter. At this point, I am strongly suspecting that it is just a worn out catalytic converter at 313k miles, but I would like to completely rule out any O2 or air/fuel sensor problem before replacing the expensive cat. In my case, the secondary O2 sensor was just recently replaced which leads me to suspect that it is probably fine, but the LAF (air/fuel) sensor is the original.

Note: On this Accord, the upstream sensor is not technically an "oxygen sensor" but is instead a LAF (Lean Air Fuel) sensor, also known as a Lambda sensor or wideband oxygen sensor or simply air/fuel sensor. Rather than generating essentially a binary signal (high or low output) like the traditional oxygen sensor, the LAF sensor generates a continuous output over a wide range of oxygen levels. On some vehicles (see references) this allows the ECM to operate the engine at leaner mixtures then the stoichiometric ratio in order to improve fuel economy under certain driving conditions (but I am not sure whether this vehicle actually does this). Also since the traditional oxygen sensor only has two outputs (richer than stoich or leaner than stoich) the ECM has to bounce back and forth between the two outputs to maintain an average mixture near stoichiometry. In contrast, with the continuous output of the LAF sensor, the ECM can regulate the LAF output to the desired set point (mixture ratio) in a feedback loop and maintain the mixture continuously at the desired ratio. Therefore, the LAF sensor output does not typically oscillate up and down in closed loop operation like an upstream O2 sensor does. In addition, on this vehicle the downstream oxygen sensor does impact fuel trim (in fact it has its own short term fuel trim PID that can be read out on a scan tool). This secondary fuel trim is used by the PCM to fine tune the air/fuel ratio to maximize catalytic converter efficiency.

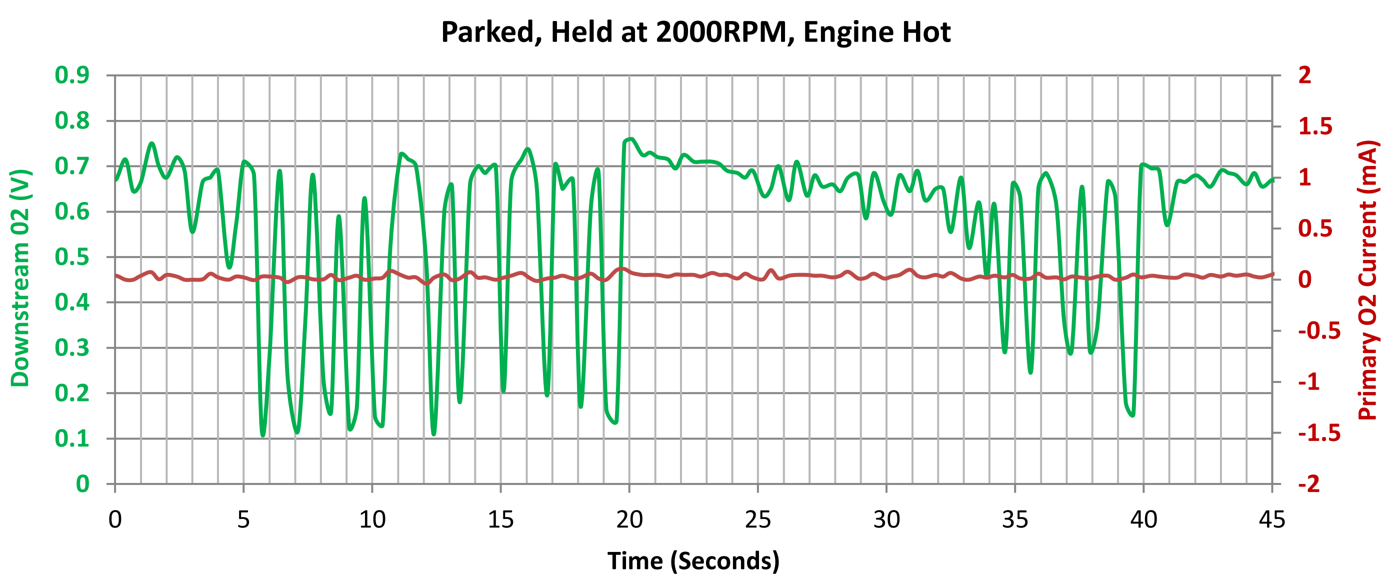
One way to gauge the health of the LAF and O2 sensors is to read back the O2 Sensor Test Results from the ECM via a scan tool. In my case, here are the results:

O2 Bank1 Sensor1		O2 Bank1 Sensor2	
Test $86		Test $38	
MOD	$09	MOD	$09
MAX	115	MAX	0.2(s)
MEAS	87	MEAS	0.1(s)
MIN	71	MIN	0.0(s)
Test $8D		Test $47	
MOD	$09	MOD	$09
MAX	255	MAX	1.270(V)
MEAS	128	MEAS	0.730(V)
MIN	96	MIN	0.050(V)
Test $8E		Test $48	
MOD	$09	MOD	$09
MAX	40	MAX	1.275(V)
MEAS	25	MEAS	0.810(V)
MIN	0	MIN	0.650(V)
Test $8F		Test $49	
MOD	$09	MOD	$09
MAX	50	MAX	0.290(V)
MEAS	28	MEAS	0.130(V)
MIN	0	MIN	0.000(V)

Unfortunately, my scan tool does not return full names for any of the O2 sensor tests (perhaps someone out there knows the corresponding descriptions for these tests?) but these results are basically a set of tests run by the ECM to verify functionality of the O2 sensors. Presumably if any test result falls outside of the noted MIN/MAX range, then it will set a code for a bad O2 sensor. Although the individual test descriptions are not known, these O2 sensor results are still quite useful. Notice that every tested parameter is very close to the middle of its respective operational range. This indicates to me that both sensors are probably good as I would expect if one was failing or marginal, at least one of its test results would be approaching either the min or max limit. With every test result pretty solidly in the middle of the range, I have high confidence both O2 sensors are in good operational order and that they aren't inducing the P0420 code.

At this point, I am pretty confident that both O2 sensors are okay. I also checked for exhaust leaks (which could possibly produce a false P0420 code by introducing unmetered air into the exhaust stream) and I cleared the code a few times and it consistently returned (just to make sure it wasn't a fluke or intermittent condition). All of this evidence certainly supports the diagnosis of a bad catalytic converter, but I thought it would be interesting to try and prove it more definitively by monitoring the downstream oxygen sensor.

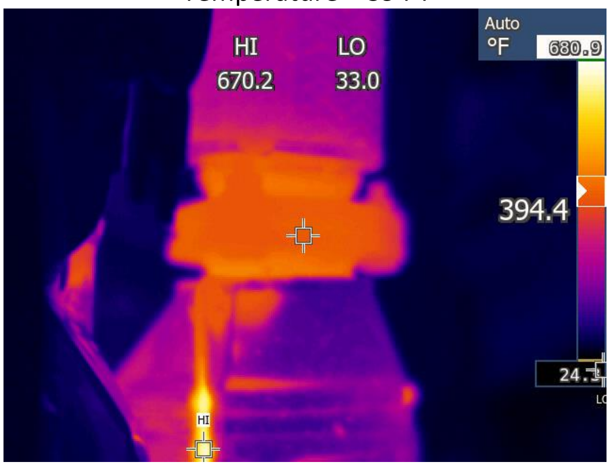
The classic catalytic converter test is to ensure the cat is fully warmed up and then compare upstream and downstream O2 sensor outputs. The upstream should oscillate (fluctuate rich/lean) at a rate of about once per second or so. With a good cat, the secondary O2 sensor should not fluctuate much at all, but instead should remain quite steady. If the cat is bad, then the exhaust gases are simply flowing through the cat without reacting, and the downstream O2 sensor will mimic the upstream sensor (show the same oscillations). However, as described earlier, this vehicle has a LAF upstream sensor, and not an oxygen sensor. In normal operation, the LAF sensor output (which is monitored as a current, not a voltage) fluctuates very little and there is very limited Internet information (at this time at least) on how to diagnose a bad cat by monitoring the downstream signal. There are however some reports that a bad cat will still result in large oscillations (fluctuations) in the downstream sensor, but this is pretty qualitative especially given that there is no upstream O2 sensor oscillation to compare to. In any case, here is what I measure for the LAF sensor (red) and downstream oxygen sensor (green) after ensuring the cat was up to full temperature. As expected, the upstream sensor has hardly any variation. The downstream sensor has more significant lean/rich oscillations (fluctuations from ~0.7V to <0.2V) then I would have expected. So I suspect that this is an additional indication that the cat is bad, but frankly I don't have the experience to look at that signal and know for sure.



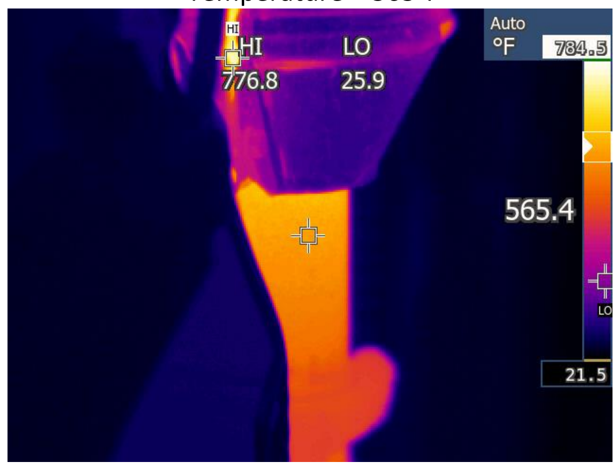
Another commonly cited technique for diagnosis of a catalytic converter is the "Temperature Test". In a properly functioning catalytic converter, the oxidation and reduction chemical reactions generate heat and as a result, the temperature inside the catalytic converter is actually higher than the temperature of the exhaust entering the catalytic converter. Therefore, a common test is to use a non-contact IR temperature probe to check the temperature at input (upstream end) and output (downstream end) of the catalytic converter. If the converter is functioning properly, the output temperature should be higher than the input temperature (typically cited as 100˚F or more). If the output temperature is the same or lower than the input temperature, then the catalytic converter is not functioning. As shown in the following images, the input and output temperatures on my catalytic converter look completely reasonable to me. The output temperature is about 160˚F degrees above the input temperature. I suspect that the temperature test is only effective if the catalytic converter is COMPLETELY dead and not just marginal.

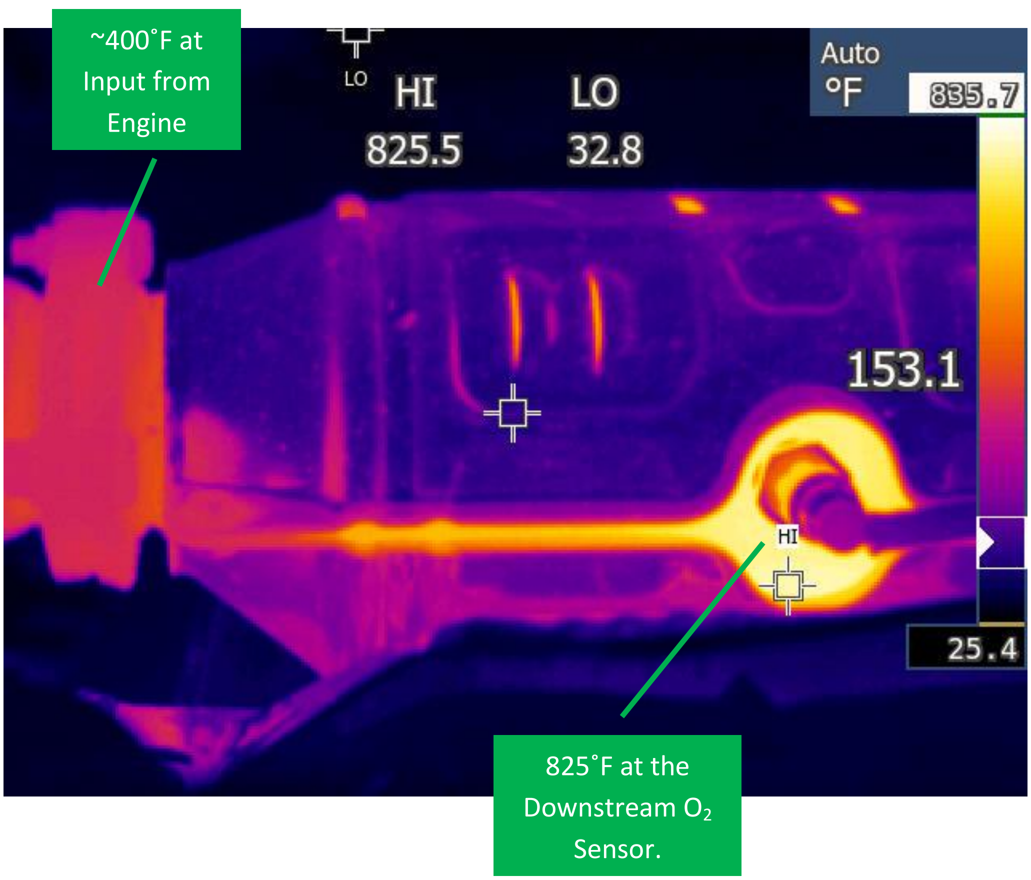
Measured Temperature of the BAD Catalytic Converter

Exhaust Pipe At Input (Engine End)
of Catalytic Converter
Temperature = 394˚F



Exhaust Pipe At Output (Muffler End)
of Catalytic Converter
Temperature = 565˚F





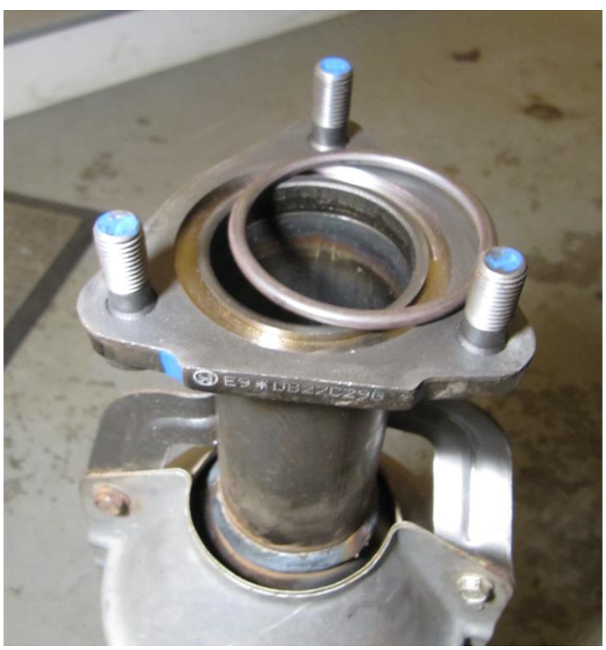
2. Installation of New Catalytic Converter

The new cat (OEM) arrived in the mail, so that puts an end to the diagnosing (and I need to pass inspection this month!). The old bolts are super rusty, in fact you can't even really see where the nuts end. In fact, they rusted so much that the correct socket for these nuts (14mm) fits so loosely over the nut that it doesn't grip at all. I was going to try heat and a stripped nut extractor, but decided to not even bother and just cut all the nuts off. The bottom ones were easy to get at with an angle grinder and cut-off wheel. The top ones I had to cut with a dremel and cut-off wheel.

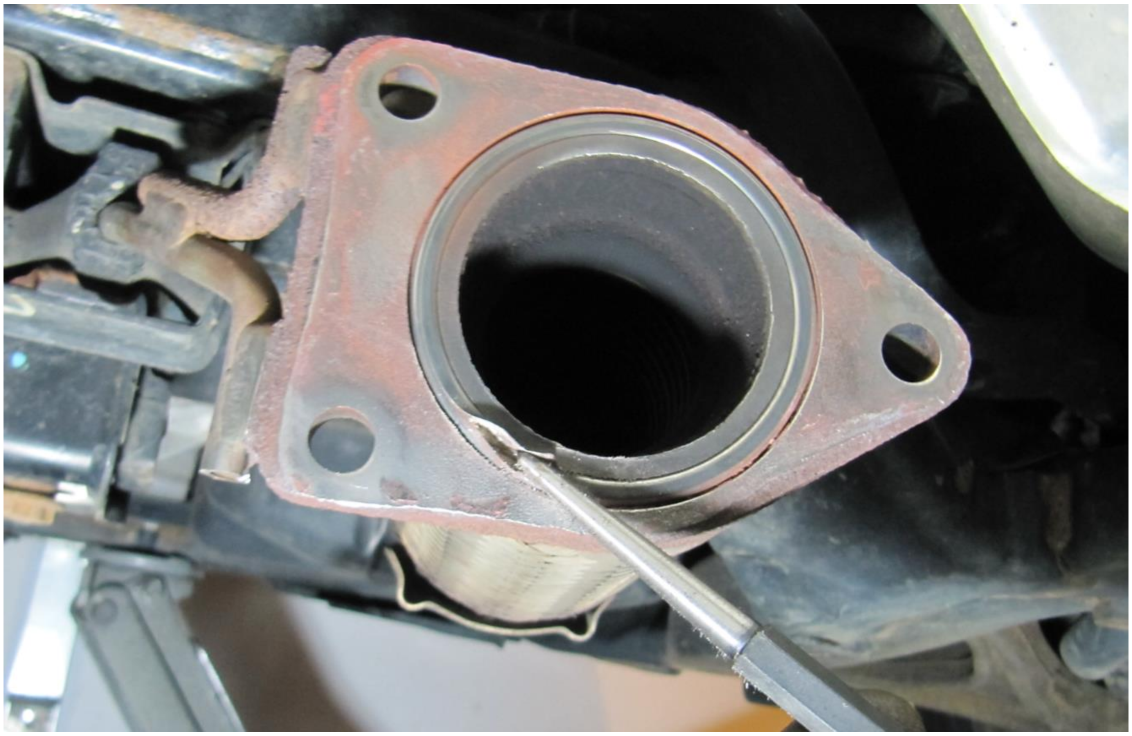
Here are the back and front exhaust pipe connections with the cat removed:

You'll need to transfer the heat shields from the old cat to the new cat:

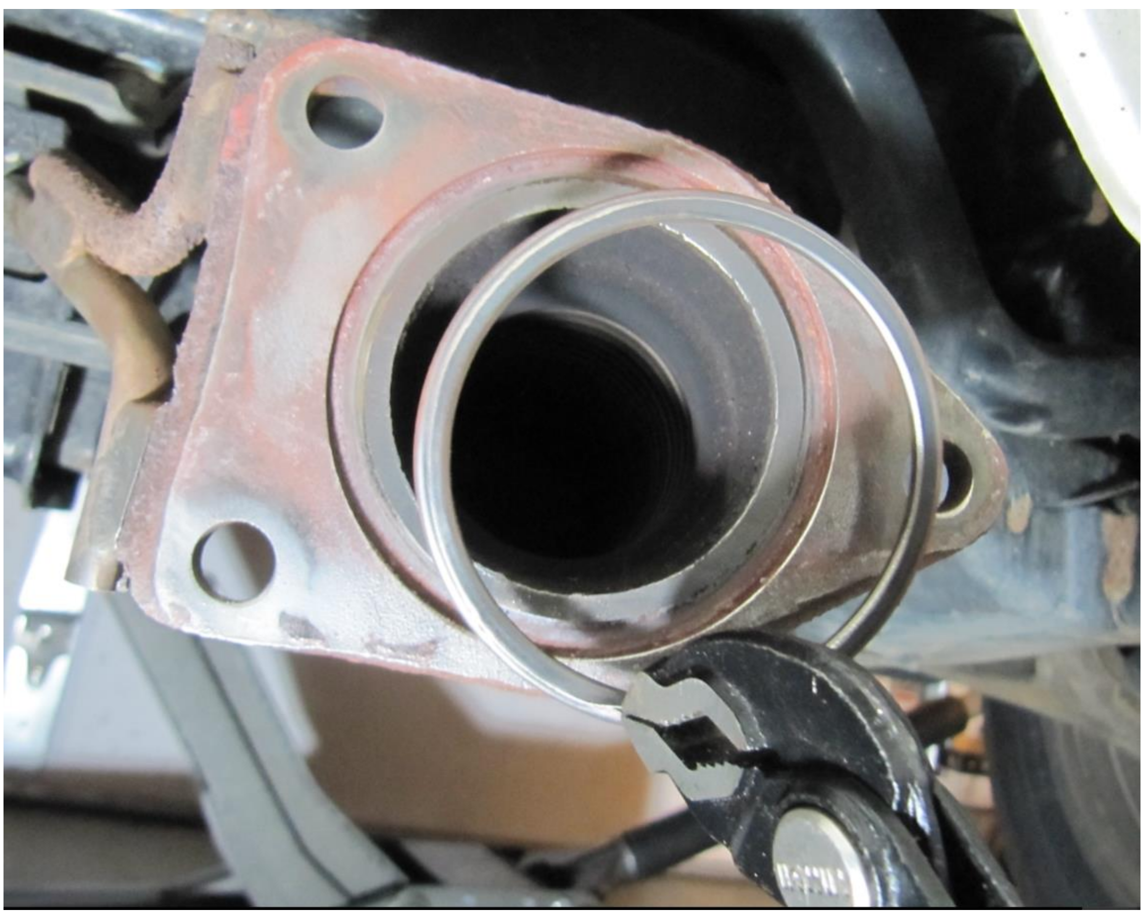
Insert a new gasket in the exhaust end of the new cat:



It took a little digging with a pick to pry out the gasket on the engine side exhaust pipe (end of the flex pipe):



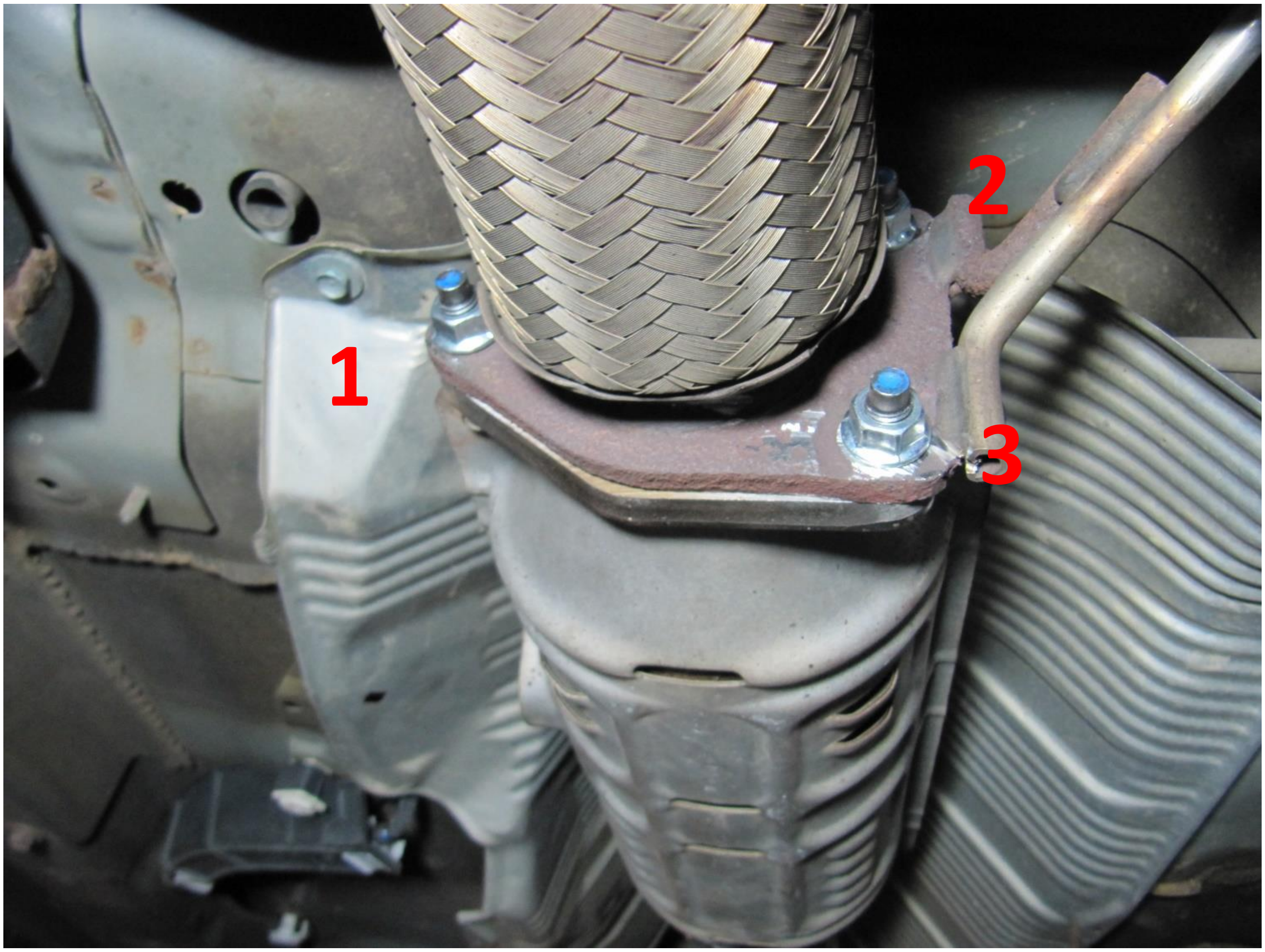
With a bit of the gasket bent up, I was able to pull it out with a pair of pliers:



Install the new gasket in the end of the flex pipe:

And pop in the new cat:

The Honda service manual recommends the following tightening sequence. Both the front and rear should be torqued to 33Nm and should use new locking nuts.

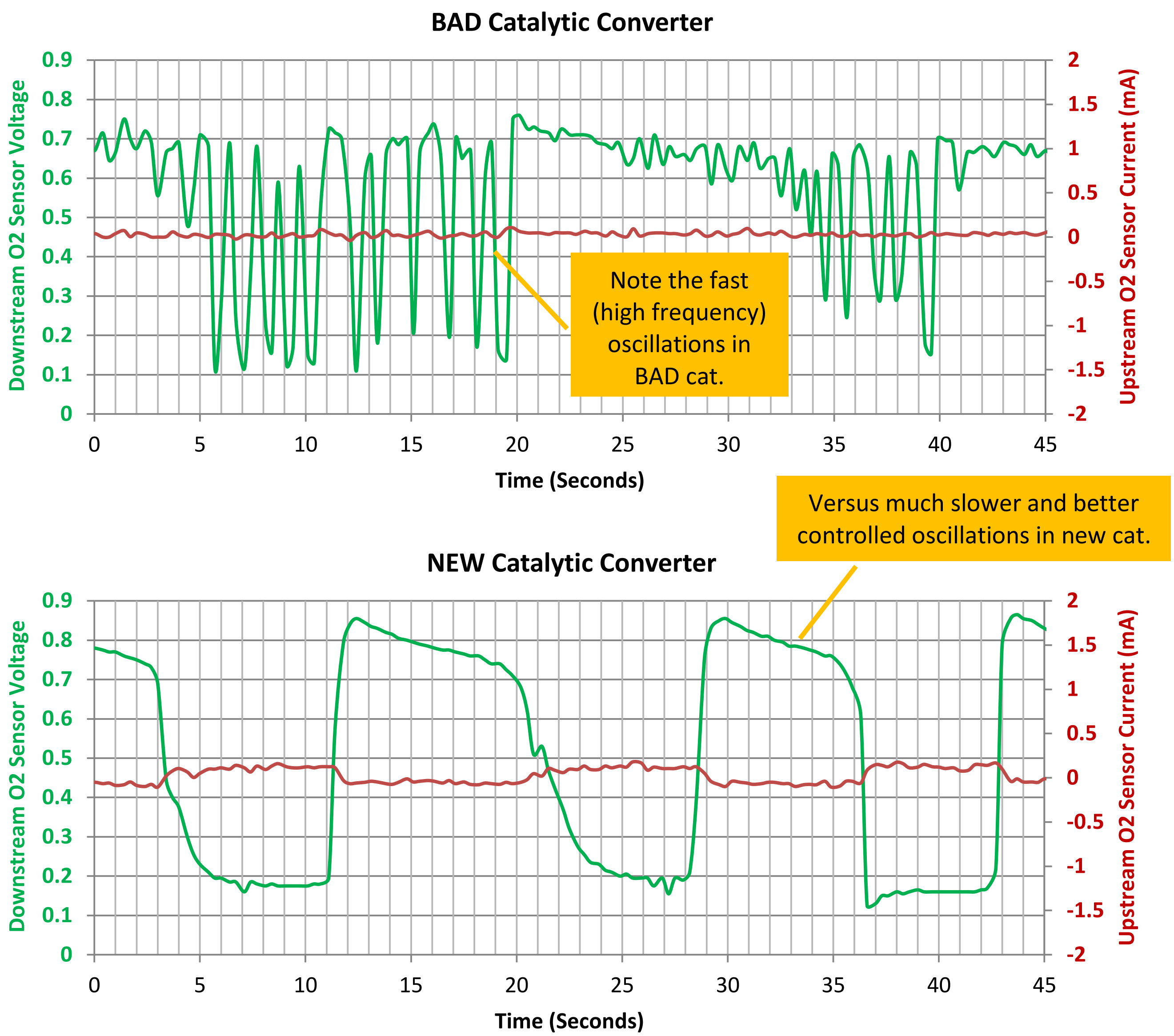


Don't forget to re-install the downstream O2 sensor (44N-m Torque):

3. Comparing Performance of New Cat to Old Cat

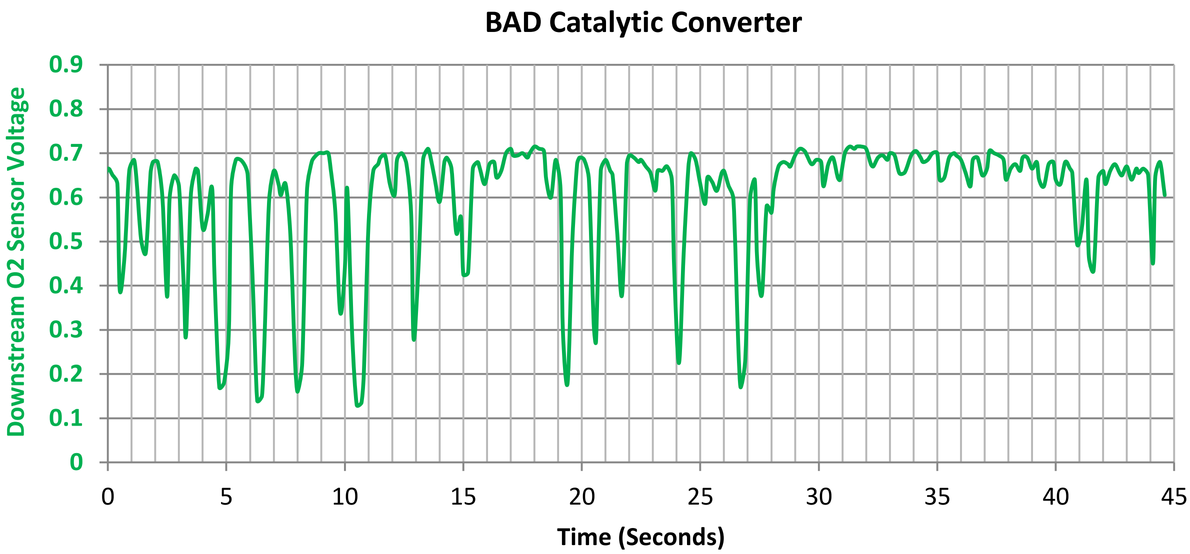
Installation of the new catalytic converter solved the problem (no DTC codes after ~1000 miles now, and I passed inspection). I was curious to look at the LAF and O2 sensor signals for the new cat and compare them to the old cat to see if the rapid oscillations in the downstream 02 sensor signal were indeed an indication of a bad catalytic converter. Here's what I found:

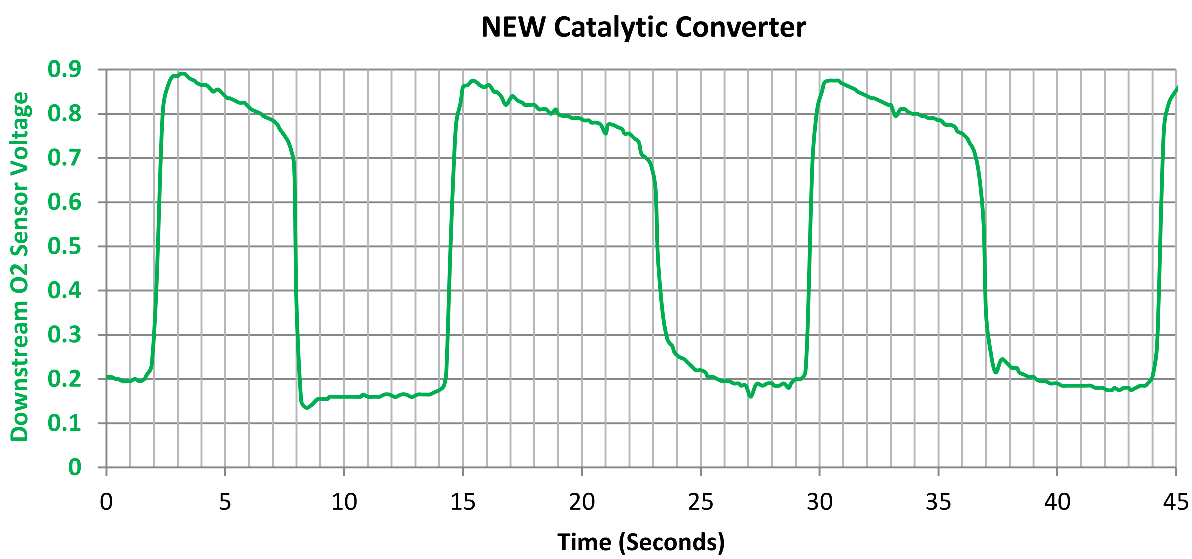
Comparison #1 – Hot Engine, Parked, Held at 2000 RPM



There is certainly a very significant difference in the downstream O2 sensor with the new cat, but interestingly even with the new catalytic converter there are still lean/rich oscillations (which is interesting because this is not the case in vehicles with an upstream O2 sensor). However, with the new cat, the oscillations are much more controlled and of a MUCH longer duration (18 seconds versus about 1 second). I certainly can't say why there are always oscillations in the downstream O2 sensor (even with a good cat), but possibly it is due to the ECM modulating fuel/air ratio to maintain sufficient oxygen storage in the cat especially under such light load conditions (note that this vehicle DOES use the secondary O2 sensor signal to adjust fuel trims). However, whatever their cause, it does seem that the frequency of these oscillations might be a good indicator of the state of the catalytic converter (oscillations becoming more frequent in the failing cat, possibly due to its decreased oxygen storage capability).

Comparison #2 – Hot Engine, Parked, Held at 2000 RPM

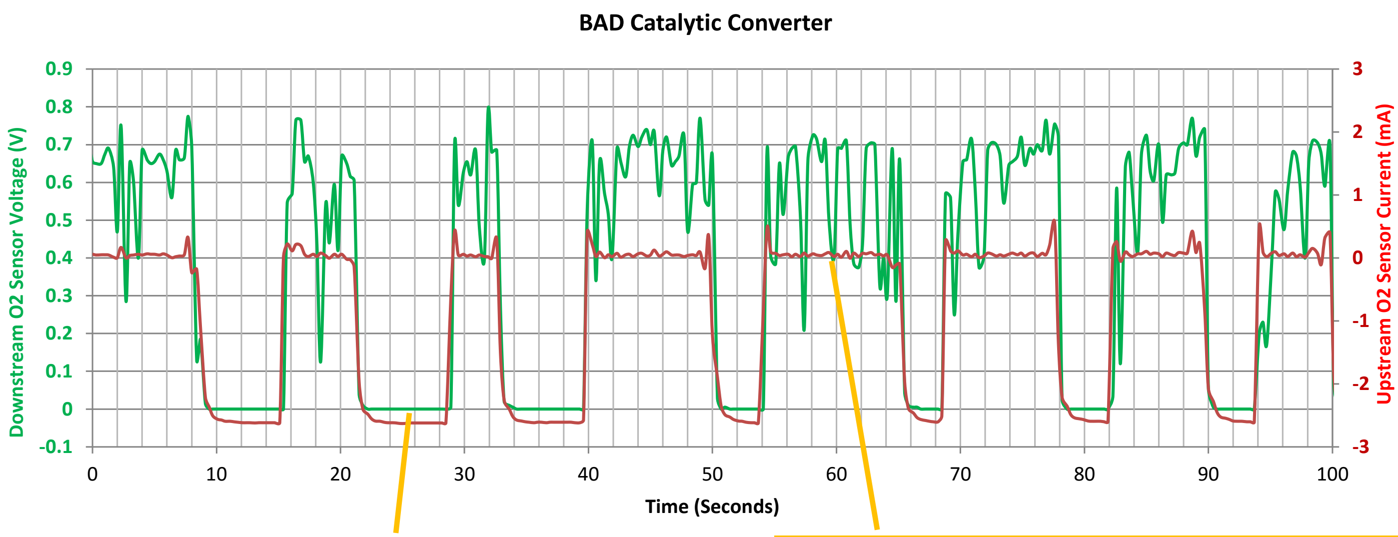




This is simply a second trial to show that the results seem quite consistent. From these results, it seems that the appearance of high frequency oscillations (one high/low ripple per second or so) might be a good way to diagnose a marginally failing catalytic converter (but I don't want to draw too much of a conclusion from this one case).

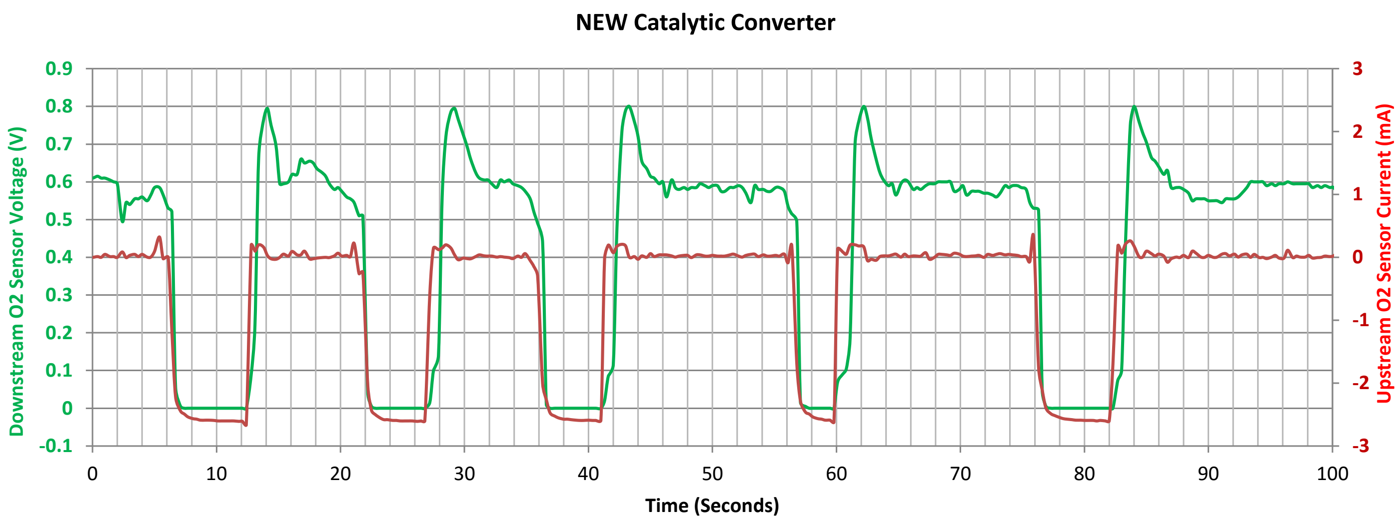
Comparison #3 – Hot Engine, Repeated Throttle "Snap" at Highway Speed (~65MPH)

In this case, I was driving on the highway at ~65MPH and alternating between hard throttle and coasting (completely off the gas). I was wondering if I might be able to see a delay between the upstream and downstream sensor as a measure of oxygen storage in the catalytic converter (similar to the propane enrichment test used for cat testing), but I didn't see any significant delay even in the new cat. However, it is interesting to note that with the new cat, the secondary O2 sensor holds very steady at 0.6V during highway driving (the high segments of the waveform) while the old cat showed significant oscillation under the same conditions. Therefore, it is possible that oscillations in the downstream O2 sensor while driving at highway speeds might be another indicator of a marginally failing catalytic converter.



These segments are for periods of deceleration, when the mixture goes lean and both sensors show high oxygen content (in fact during these durations, the ECM can't maintain closed loop operation and goes into Open Loop Drive.

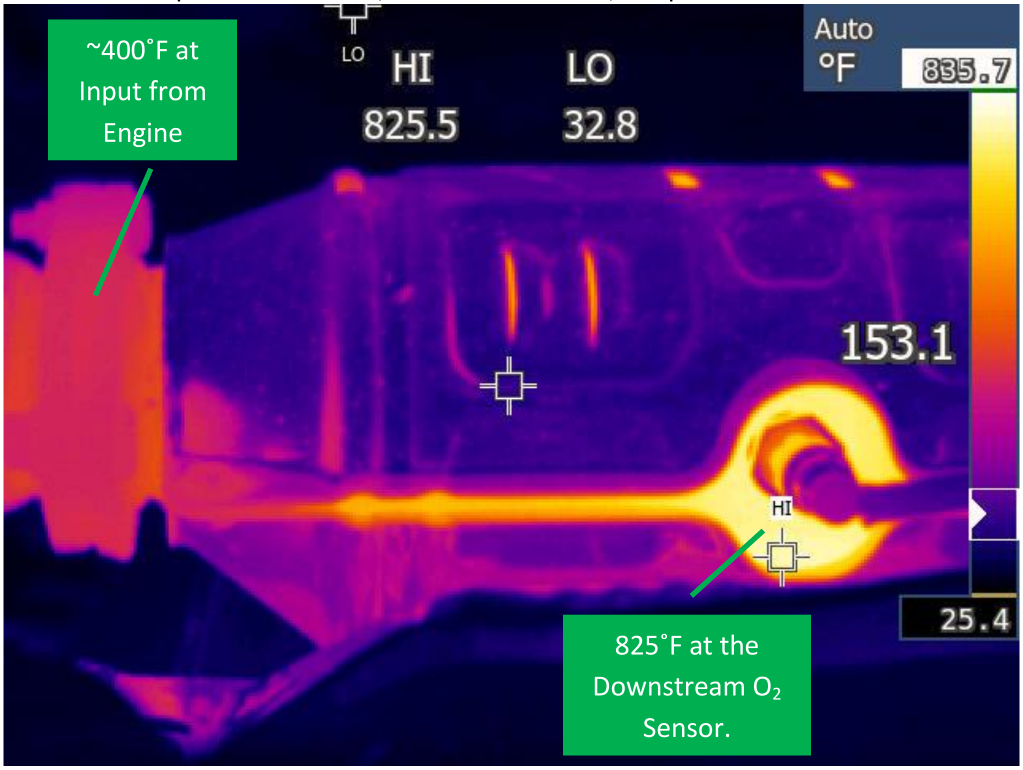
The "high" segments of the waveform are for normal driving (somewhat heavy throttle) conditions. Note that the bad cat still shows significant oscillations in this region of operation in comparison to the new cat (below).



Finally, just for good measure, I compared the temperature of the new catalytic converter with the bad one. Overall, the temperatures were quite comparable. Again, I suspect that this is probably due to the fact that in my case, the catalytic converter was only marginally failing but was not completely nonfunctional. I believe that this does show that the temperature test is not a very good test to diagnose a P0420 code.

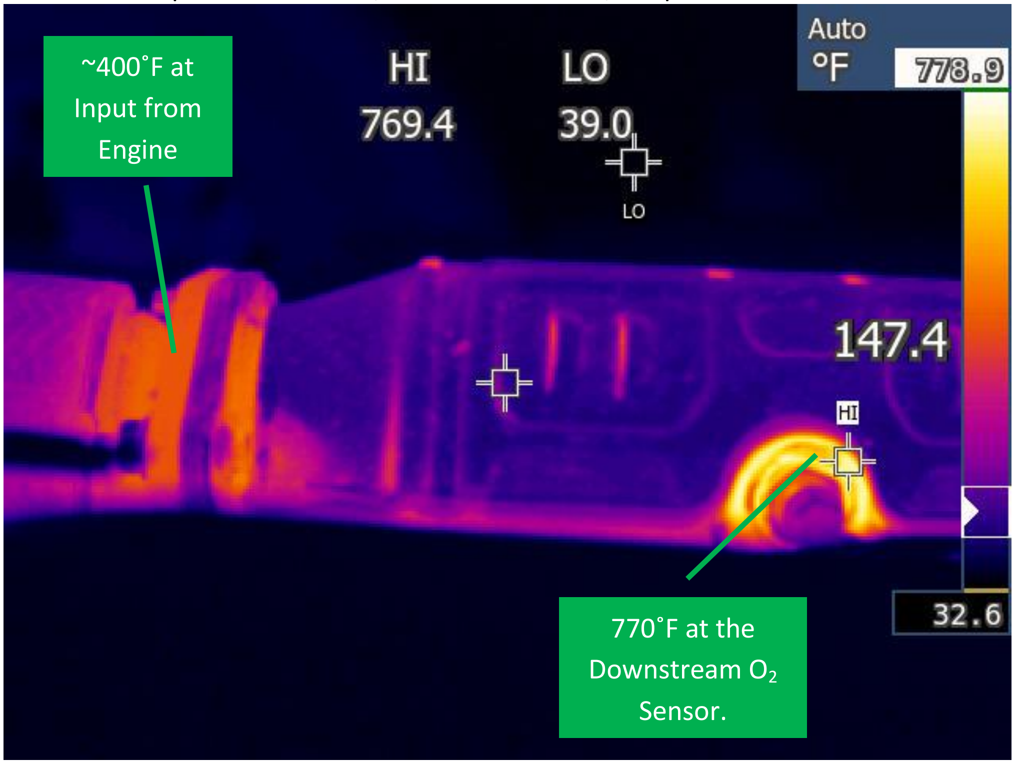
BAD Catalytic Converter

Input End ~= 400˚F, O2 Sensor = 825˚F, Output End ~= 565˚F



NEW Catalytic Converter

Input End ~= 400˚F, O2 Sensor = 770˚F, Output End ~= 520˚F



4. Conclusions

- Based on this experience, it doesn't seem that the catalytic converter temperature test is adequate to diagnose a marginally failing converter. (However, I assume it would detect a COMPLETELY FAILED converter).

- It appears that under unloaded (car parked) 2000 RPM operation, the secondary O2 sensor signal is NOT constant (even with a good catalytic converter and good O2 sensors), but instead varies back and forth between rich and lean in a controlled fashion. However, with a bad catalytic converter the oscillations between rich and lean occur very quickly (1 or 2 seconds) compared to a good catalytic converter (10 to 20 seconds). Presumably this is due to the improved oxygen storage capability of the new catalytic converter. Therefore, it appears that the presence of fast oscillations in the downstream O2 sensor might be a good indicator of a failing or marginal catalytic converter.

- At highway driving under load, the bad catalytic converter exhibited significant oscillations in the downstream O2 sensor (from ~0.7V to 0.4V or so). In comparison, with the new catalytic converter the downstream O2 sensor held very steady at approximately 0.6V under the same driving conditions. Therefore, another possible indicator of a failing converter is the presence of fast (1 to 2 second period) oscillations in the downstream O2 sensor under steady highway driving conditions.

Hopefully this information will be useful if you are trying to diagnose a P0420 code. It is however based only on this single case. If you find any errors or observe different findings, please let me know so I can correct/amend this document.

5. References

More information on Lean Burning (using a LAF sensor to operate leaner than the stoichiometric ratio for improved efficiency and reduced emissions):

https://en.wikipedia.org/wiki/Lean-burn
http://www.motor.com/magazinepdfs/091999_10.pdf

Page 64 of the following link has information on a Honda Civic Air Fuel Sensor used for lean burn:

http://www.lbcc.edu/attc/documents/Basic-O2-Sensors.ppt

A good explanation of wideband oxygen sensors:

http://tayloredge.com/reference/Science/oxygensensor3.pdf

Great video from Scanner Danner on diagnosing a cat with conventional O2 sensors:

https://www.youtube.com/watch?v=vyVnhCIMDnw

Great video from South Main Auto (I can't say enough positive about this great channel!) on O2 sensor failure:

https://www.youtube.com/watch?v=a19wkJ3bF2o