An Alternative Way of Extracting the Best Tractability and Performance from the Weber DCOE Carburetor

This is not intended to be a complete tuning guide. The information provided here supplements the official Weber Tuning Manual (PN 95.0000.54PM). That manual covers all the basic aspects of tuning that I've not discussed. This is a white paper to show professional tuners and folks with a high degree of engineering skill an alternative way to tune these carburetors.

1. Introduction

Changing parts on Weber DCOE carburetors is easy, interpreting how these changes affect the state of tune is more difficult. Each individual change can have such a subtle effect that it cannot be detected by traditional seat-of-the-pants tuning methods. Eliminating problems like the dreaded midrange flat spot (~2000-3000 rpm) requires making a number of small changes in a particular order; only then are the carburetors tuned to the utmost. One must have a wide-band O_2 air-fuel meter to do this type of tuning. I use the LM-1 and LMA-2 units from Innovate Motorsports. Spark plug cuts only tell you if something is grossly wrong- they're hopeless for fine tuning.

This guide assumes that all other components of the engine, other than the Weber carburetors themselves, are in perfect working order. This includes the engine itself (i.e. compression), the cooling system and the ignition system. Many problems that seem to be carburetor related are actually caused by a faulty ignition system!

All air leaks in the intake and exhaust systems must be sealed. Air leaks in the induction manifold impair the proper functioning of the idle and transition circuits. On early carburetors, air can also leak past the threads of the idle mixture screws, causing an excessively lean condition on overrun. Grease the threads or place an o-ring or a short length of rubber hose underneath the screw head. Leaks in the exhaust system cause readings from the air-fuel meter to fluctuate wildly (this may be the only symptom if the leak is small) and also may cause popping on overrun.

2. Fuel Level

Begin by setting the fuel level. If the fuel level is not set correctly, it will have an adverse effect on the ultimate state of tune you will be able to achieve. I'll explain why it is so crucial later when discussing the main jet circuit. The standard procedure involves gapping the floats to the top cover. Unfortunately, this method is error prone. The floats are buoyant in a pool of fuel and should be measured as such in-situ. Construct a simple optical gauge (Figure 1) for this wet level measurement. This tool works much like a dipstick. The split nylon sleeve clamps gently onto the acrylic rod, this allows it to slide freely along the rod but not slip. Rest the sleeve on the top surface of the well (Figure 2) and slowly push the acrylic rod down. When the bottom end of the rod just touches the fuel it will make the top end look dark (look carefully!). When it does, measure the tip to sleeve distance. Ideally, this should be done while the engine is idling and level. If the engine is in a poor state of tune and shuddering severely it can be done within sixty seconds after shutting off the engine. The desired level is predetermined by the design of the DCOE carburetor. The passageway that connects the well to the auxiliary venturi is 23mm below the mating surface of the cover plate. The fuel level must be 2mm below that point or fuel will spill into throat when accelerating or braking. Therefore, the ideal fuel level is 25mm +/-1mm.

Figure 1: Optical Fuel Level Gauge

Figure 2: Using the Optical Gauge to Measure the Fuel Level

3. Transition Circuit

The cornerstone of the Weber DCOE carburetor is the transition circuit. It operates over a fixed rpm range designed into the carburetor, defined by the placement of the progressive holes relative to the throttle plate. Essentially, this range is nonadjustable- we must tune around it. This has two practical consequences for the tuner. One, it defines a required idling rpm so as not to create an off idle stumble. Two, it defines a transition rpm at which the main jet system must be activated to eliminate a flat spot.

To measure the true air-fuel ratio (AFR) of the transition circuit, we must disable the main jet circuit by temporarily removing the emulsion tubes. If the floats are set correctly (see Section 2) the fuel level will remain 2mm below the passageway leading to the auxiliary venturi. Consequently, no fuel should flood into the carburetor via the auxiliary venturi, so this shouldn't be a safety issue. With the emulsion tubes removed, fuel will continue to flow and the engine will run normally on the idle and transition circuits as long as the throttle plates are not opened past the last progressive hole. This occurs at approximately 10% of the pedal's full travel. Driving the car with the emulsion tubes removed provides a baseline for how the transition circuit was designed to perform. Be careful when doing this test because you will be lacking about 90% of normal engine power to get out of harms' way.

Drive the car gently at a steady speed on level ground and note the AFR measured by the air-fuel meter. Don't move the throttle while taking a reading- the accelerator pumps will shoot fuel and make the AFR reading inaccurate. Moving the throttle plates past the last progressive hole will kill the engine so just don't do it. Swap the idle jets until the AFR is approximately 12.5:1.

The next test measures the transition rpm at which the main jet system must be activated. Shift the car into high gear and slowly increase the engine rpm until the engine dies. The maximum rpm at which the transition circuit keeps the engine running while in high gear is the transition rpm to which you MUST tune the main jet circuit to begin providing fuel. Typically, this target rpm is about 1400 rpm in high gear. The main jet circuit must be contributing fuel at this transition point without the AFR deviating from the desired 12.5:1 value. Any gap in fuel delivery between these circuits produces the classic and much dreaded flat spot! At part throttle cruise in the higher gears the main jet circuit is actually providing all the fuel so concentrating on fine-tuning its low rpm performance is crucial to achieving the best tractability possible.

4. Idle Theory

The "BEST LEAN IDLE ADJUSTMENT" method universally touted through the years happens to be the worst tuning procedure possible, typically resulting in an AFR of about 22:1. This extremely lean mixture produces a number of undesirable results. It burns slowly and causes spitting and misfiring at idle. The slightest opening of the throttle plates causes a stumble. Furthermore, when the throttles are opened abruptly the slow burning lean charge ignites the fuel vapor in the induction manifold, causing a backfire out of the carburetor. On overrun, the AFR will rocket to even leaner values and the chance of a total or partial misfire is very likely; unburned fuel will collect in the exhaust system resulting in backfiring or popping.

Avoid all these usual pitfalls by setting the idling AFR to 12.5:1. This should be done with a wide-band O_2 air-fuel meter. To start, set the idle mixture screws as per the "BEST LEAN IDLE ADJUSTMENT" procedure to get all the same lean AFR contributed from every screw. Reduce the AFR to 12.5:1 by opening all the idle mixture screws by an additional equal amount of twist for each. A good indication that the AFR is equal on every cylinder is that the shuddering motion of the engine on its compliant mounts is at a minimum.

5. Airflow Balancing

If the amounts of air entering the combustion chambers are unequal, the combustion strengths will also be unequal and the engine will rock back and forth on its rubber mounts. Measurement of the airflow must be done with a high quality, calibrated gauge. I use and recommend the synchrometer made by STE. If the airflow is balanced correctly you should be able to place a brimming cup of water on the engine and slowly increase the rpm via the idle speed screw to above 3000 without spilling a drop. Older carburetors might require small holes to be drilled through some of the throttle plates to balance the airflow to the throat with the highest rate of flow. The Weber Tuning Manual describes how to drill these holes. Newer carburetors have an adjustable air bypass bleed screw. The airflow synchronization between carburetors via the linkage is reserved for the cruise throttle condition at about 15% power so the engine pulls smoothly while in a cruise driving mode and this adjustment is done first. This cannot be done while in motion so raise the engine revs to where the engine shudders about worst and do the synchronization via the linkage there to smooth out the engines' torque reaction force. Next procedure is adjusting the airflow at idle of all the others to match that of the cylinder with the highest flow.

One last word of advice: Do not twist the throttle spindle to balance the airflow past the pair of throttle plates. The factory made an extremely fine adjustment of the throttle plate edge to first progressive hole when the carburetor was first assembled. Close inspection may show that one of the first progressive holes has had additional metal scraped away downstream to make it even with its other paired hole. Twisting the spindle just makes the preset idling rpm less effective and increases the likelihood of an off-idle stumble.

6. Idling RPM Determination

The Weber manual states that the DCOE was designed to idle at 1000 rpm. Slowly speed up the revs by a few hundred rpm via the idle speed screw and listen for a stumble. A stumble is caused by a lean condition; you can confirm this with the wide-band O_2 sensor. If there isn't a stumble then either it's okay or the fuel is being supplied by the first progressive hole. To test for the latter, close each idle mixture screw in turn and confirm that the cylinder cuts out and misfires from a lack of fuel. If it does not stumble and the cylinder cuts out like it should then that idle speed setting is correct.

7. Lazy Idle Syndrome

An engine that does not quickly return to the set idle speed after a blip of the throttle has the classic “lazy idle” syndrome. My theory is that on overrun, the additional air sucked past the throttle plates draws fuel from the first progressive hole when the induction manifold vacuum is highest. Both additional air and fuel is necessary for this fault condition to happen. This is a self-feeding situation that normally slowly decays away after several seconds. To eliminate a lazy idle, reduce the idle speed until these symptoms vanish thus moving the throttle plate away from the first progressive hole.

8. Main Jet Circuit Theory

Now we get to the toughest part, understanding and tuning the main jet circuit. Since the available vacuum energy to operate this circuit is so tiny a number of factors impact its adjustment. As described in Section 2, the preset fuel level is 2mm below the well passageway leading to the auxiliary venturi. The force to lift the fuel up these 2mm is derived entirely from the auxiliary venturi vacuum signal. Typically, the total amount of vacuum of the combined auxiliary venturi and main choke assembly of a 40 DCOE at 6000-rpm with a 30mm main choke (1600cc Lotus Twincam) is only able to lift a manometer column of fuel about 4mm. This 4mm value was measured without an air corrector jet and the test facilities could not accommodate going to WOT at redline. Therefore this value may change and get slightly bigger when better testing procedures are employed. Since an air corrector jet introduces an additional air leak the total vacuum achievable is always going to be a bit less.

At first, it seems that there is not enough force to drive the main jet circuit. True, if the vacuum were acting on the dense liquid fuel alone the system would be inefficient and the AFR could not be maintained at a precise value like 12.5:1 over the entire operating range. Remember, however, that the vacuum signal does not act upon liquid fuel at the float bowl level with most of the popular emulsion tubes installed. Instead the fuel once sucked up to adjacent the passageway in the well stays there due to its' surface tension properties. Gasohol containing ethanol exhibits an even higher surface tension tendency than neat gasoline and seems to make tuning a bit more difficult as a result. Even if the fuel level falls in the float bowl by an additional 13mm the adhesion of the liquid fuel to cling to surfaces of the emulsion tube and the well is enough to hold the column of fuel up. Breaking this adhesion appears to be the dominating factor that dictates the fuel flow behavior at low airflow rates through the auxiliary venturi. Further study is required to understand this process well enough to devise a satisfactory solution for all fuel types. The cohesion property of the fuels' surface film also resists the penetration of the small bubbles emitted from the air bleed holes of the emulsion tube. This provokes no flow of air until a certain air pressure threshold is reached and then a burst of bubbles will be emitted from any emulsion tube air bleed holes which are located below the top of the fuel column. There appears to quite a bit of variation to that threshold which makes the low airflow tuning tricky depending on the emulsion tube chosen and many other factors.

The behavior of fuel-air emulsions under various conditions is described by "two-phase flow"- a fascinating, but extremely difficult area of fluid dynamics. It suffices to say that the Weber DCOE utilizes air corrector jets to create a two-phase flow to a small degree. By the time the emulsion has been sucked several millimeters into the passageway leading to the auxiliary venturi the bubbles have burst and the fuel trickles down the wall mostly under the influence of gravity at that point. When this system is set up properly it is possible to maintain an AFR of 12.5:1 under ALL CONDITIONS.

9. Air Corrector

The size of the air corrector jet is crucial for two reasons. First, it determines the onset of flow from the main jet circuit in conjunction with the chosen auxiliary venturi and main choke. An oversized air corrector jet weakens the vacuum signal substantially, delaying activation of main jet circuit past the transition rpm (~1400-rpm). This is the cause of the classic mid-range flat spot. Second, it introduces an air leak and reduces by diluting the highest attainable vacuum signal from the auxiliary venturi. By not introducing to big an air leak at low flow the largest size of auxiliary venturi and main choke can be selected to provide enough vacuum signal for the WOT mode without overly restricting the air consumption needed at the redline for maximum power output.

Ultimately, the air corrector keeps the load-slaved vacuum signal proportional to the fuel flow rate at low airflow consumption of the engine, thus keeping the AFR constant. Once the airflow through the auxiliary venturi is fast enough to generate a vacuum that creates sufficient liquid fuel pressure gradient across the main jet to meter the fuel flow, at that point the primary role of the air corrector jets is completed. The air corrector jets are no longer important or required for the emulsion tube assembly to provide the AFR at the higher rpms and loads. Consequently, the air corrector jet is not to be used to lean the air-fuel mixture out at high rpm. That is the function of the main jet and the fuel level.

Choosing correctly sized auxiliary venturi, main chokes and air corrector jets is paramount to getting the best, smooth, tractable performance from the main jet circuit. Arriving at the best combination is a trial and error process, but can be achieved by performing two simple tests.

First, check to see if that the main jet circuit is fully functioning just prior to transition rpm measured in Section 3. To test if the main jet circuit is flowing at the transition rpm, drive the car in high gear at that target rpm and suddenly go to wide open throttle (WOT) and hold it open for about five seconds. At first, the car will lunge forward slightly because of the accelerator pump shot, but then if the engine continues to run (even if it obviously lugs) that indicates the main jet circuit is active. If it is not, then the engine will die, just as if the ignition was switched off. This is the “WOT Main Jet Flow Test”.

One determines the smallest air corrector jet by reducing the jet size until the engine stalls momentarily when the throttles are held open, while briskly cornering at about 15-30 mph on an uphill incline of at least a 5% grade. The cornering must be in the direction opposite that the air trumpets point out. If the carburetors are oriented so they point forward or aft then I don’t know how to find the lower AC size limit.

I don’t think this effect is caused by fuel starvation from the liquid sloshing around in the float bowl. If the engine stalls I think the fuel droplets in the constantly density changing emulsion having traveled to the carburetor throats are simply too large so they weigh enough that they are flung out of the trumpets during cornering. In other words, under that operating mode there is not enough air bubbles in the emulsion to sufficiently reduce the droplet size and therefore the AC jet is too small. Going up in diameter by two (100 microns) to four (200 microns) incremental sizes should cure the problem.

10. Main Jet

The goal here is to achieve a steady AFR over the entire rpm range, particularly at WOT at high rpm. Finding the smallest jet that maintains the correct AFR it is the key to winning the tuning game!

The main jet has two forces acting upon it. Both forces are small but combined they exert the highest possible pressure gradient across the main jet. The vacuum force has already been discussed in Section 8. The other force is the “hydrostatic” force provided by the dynamic fuel level in the float bowl; it is about half the total combined force acting upon the main jet. Lowering the fuel level actually does two things. It reduces the hydrostatic force acting upon the main jet and increases the distance the vacuum signal must lift the fuel in the well to be mixed via the emulsion tube into the emulsion. Manipulating the hydrostatic force is how the rate of fuel flow at WOT should and must be controlled. Let me emphasize: The target AFR is adjusted via the float bowl fuel level and the main jet hole size and not by diluting the vacuum signal by installing an oversized air corrector jet. This is why the emulsion tube only impacts the AFR at partial throttle and has little affect at WOT. At WOT and high air induction velocity there is enough vacuum signal strength to pull even unmixed raw liquid fuel into the engine.

11. Emulsion Tube

Changing emulsion tubes or altering its' air bleed holes allows you to achieve the desired AFR at partial throttle steady cruise. So far, I've only experimentally tuned with F11 tubes. The large expense of purchasing all the available type of tubes has prevented me from conducting more tests.

I've learned that adjusting the amount of air flowing through the bleed holes above fuel level alters the AFR quite a bit. You may have to add several additional air bleed holes to lean out the AFR at part throttle cruise. You may also have to plug up several of the air bleed holes to fatten up the AFR. Experimenting has shown these modifications will shift the AFR by a little more than +/- "one part of air" from the stock configuration. The alteration required can only be determined by testing with the air-fuel meter.

12. Main Jet Circuit Tuning Procedure

With all this information in hand the procedure to find the best components is actually rather simple. First, find the diameter of air corrector jet that gives the ideal emulsion. Second, find the diameter of main jet that provides the desired AFR at WOT full load. DO NOT change the size of the air corrector jet to change the AFR. Last, select and tweak the emulsion tube to optimize the cruise AFR.

13.Accelerator Pump Theory

The accelerator pump provides a specific amount of fuel for a specific time interval with a sudden application of WOT. The pump shot needs to be adjusted such that the desired AFR creates a flat line in the wide-band O2 data graph at the engine's shift points when at racing speeds. This will provide a little too much fuel and produce an overly fat (rich) AFR when the pump is actuated at less then a racing performance level, but this is perfectly normal and expected. You may be able to alter the bleed back hole size on the quick gulping, one-way check valve that supplies the pump to lessen this effect.

When doing WOT runs to find the main jet size at a starting rpm well below the racing shift points, the first 3 seconds of the data graph contain the contributions from the accelerator pump; this data should be ignored. To truly dial in this parameter it must be done on the racetrack under 10/10s operating conditions.

The Weber Tuning Manual states that, under some conditions, the pump circuit will continue to contribute fuel after the shot is expelled. I have not seen this effect first-hand on the few stock sports car engines I've tuned. This may be dependant on the air flow restriction of the induction manifold. A race engine that breathes well and revs up high enough just might cause this type of fuel flow.

14. Conclusion

These tuning principles should apply to all racing or road car applications and all the different brands of carburetors that share a similar design to the Weber DCOE. Using these tuning principles should yield excellent results in a few hours of effort. Most of this information provided has been derived from actual testing and is easily reproduced. I strongly suggest you do your own testing before being convinced one way or the other.

15. Disclaimer

Use this information at your own risk. If you lack expertise dealing with these units then don't attempt to correct the faults based solely on this article. A full understanding of all the issues covered in the official Weber Tuning Manual is also required. Carburetors and the fuels are inherently dangerous. Heed the warnings and use common sense.

I will discuss this topic for awhile at: http://autos.groups.yahoo.com/group/sidedraft_central/