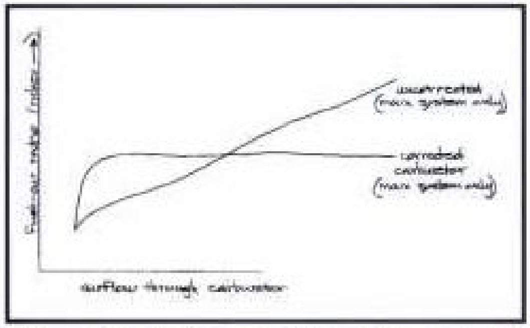
Chapter 6

CARBURETION

A Jet Kit. Bike manufacturers sometimes overdo it when they strive to meet emissions standards, resulting in marginal performance such as lean stumble and weak acceleration. Jet kits came into being to correct this, but are now also made to correct your carburetion to specific pipes and other mods. *Dynojet*



Airflow vs. Mixture in Carburetors. What we'd like is a nice, flat curve that shows constant mixture as airflow increases. But with an uncorrected carb, the natural trend is to enrich. Air correction systems exist to prevent this. Typically, the air jet is the one located at six o'clock as you look at the carb bellmouth, and it bleeds air into the needle jet to mix with fuel before emerging into the intake airstream.

I watched a friend having trouble starting his drag bike. It was obvious that the throttles were out of synch, and that there might be other problems. I suggested that he might benefit from standard tune-up procedures. "That stuff's irrelevant," he replied, with a dismissive wave of his hand. "The moment the last yellow starts to fade, I'm on full throttle all the way."

When I offered to do the tune-up myself, he grudgingly got out his 7-mm wrenches and began to synch the carbs. Then he checked the timing and reset it. Then he installed a clean set of plugs.

The next run was almost half a second quicker. Why? When he brought the revs up as the tree came down, all cylinders came up together, and quickly. When it was time to leave, all those cylinders kicked up to peak-torque revs without hesitation or popping, and the engine turned the tire and left. Seems that something important does happen between idle and full throttle.

My point is that lots of bikes run poorly, and their riders, having got used to it in small stages, don't even notice it. A careful, standard tune-up would give them free horsepower and make their bikes much easier to ride. As I also note in chapter 2, taking excess slop and friction out of cables, and readjusting hand and foot controls to comfortable heights and angles can make your bike easier to ride well.

Not all bikes of a given production run have identical carburetion requirements. Most will be at least a bit lean off the bottom, and a good many will hesitate if the throttle is moved smartly. This results from manufacturers' zealous compliance with emissions standards. Some riders have recently moved to Denver, at 5,000-foot altitude, from some lower point, so their bikes are now drowning rich. My point is that standard carb settings can often be improved upon.

Years ago, you made these improvements by buying a range of main jets, needle jets, and pilot jets, and you changed one thing at a time to come up with improvements that were often well worth the effort. It is quite common to widen a stock powerband by hundreds of revs by carefully tailoring carburetion to that engine's special needs.

When Supersport racing began in earnest in the 1986–87 period, CV-carb tuning became a critical element in success. At Daytona in 1987, the paddock-area public address system was constantly barking, "Will Mark Dobeck please go to garage 36." Dobeck's Dynojet Company was a pioneer in the jet-kit field, and there are more today.

Today, custom carburetion has become an industry, in the form of jet kits, each made to correct the problems of a particular model or, in the case of pipe/jet kits, to make a given model carburetor with a particular aftermarket pipe on it. You will know that you need a jet kit when your machine, despite having had a recent and competent tune-up, will not accept throttle, hesitates, or accelerates poorly.

A rack of smoothbores for a 1025 Superbike engine. All carbs for multi-cylinder engines are rack-mounted because it simplifies slide synch, controls carb vibration, and it reduces throttle-spring tension. *John Owens Studio*

The basis of jet kits is to enrich part-throttle carburetion from lean stock settings. This is done either by replacing the stock carb needles with others of subtly different shape, or in some cases by raising the stock needles with tiny, thin washers. The changes are small, but the effects can be large, which is why jet kits are so popular.

Tiresome but Predictable Warning on Safety

Being a father of three boys, I feel obligated here to remind you that gasoline is, when vaporized, an energetic explosive, easily ignited. Do not, please, ever become casual about working with fuel. Old man Yoshimura was badly burned in a dyno fire, and others have been killed in fuel explosions and fires. I'll never understand the dad who washed paint off his children with gasoline while he smoked a cigarette.

Further, gasoline contains ring-structured aromatic compounds which have bad effects on living organisms. Prolonged breathing of gasoline vapor or skin contact is not a good habit. Neither is washing parts in the stuff. That's what low-volatility parts-washer fluid is for—it will burn, but does not readily form an explosive vapor.

How Carburetors Work

It was old Bernoulli who noticed that air lost pressure as it speeded up. This makes sense because, as air rushes to fill a vacuum, the energy to accelerate it has to come from somewhere. This energy can't come from the vacuum, which has no energy at all. It therefore comes from the pressure of the air itself.

You can think of it in terms of conservation of energy; pressure energy in the still air is converted into velocity energy as it accelerates. When the air decelerates again—when it arrives inside an engine's cylinder, for instance—the velocity energy is converted back into other forms, pressure and heat.

A carburetor is a fancy piece of pipe placed in an engine's intake stream, designed to apply Bernoulli's Principle. As the engine pulls air through the pipe, air pressure inside the pipe falls. We poke a hole in the bottom of the pipe, stick a straw through it, and submerge the lower end of the straw in a bowl of fuel. One end of the straw is at air-pipe pressure (low), and the other end is in the fuel, which has atmospheric pressure pushing down on it (higher). This pressure difference causes fuel to flow up from the bowl, through the "straw" (main jet and needle jet), to spray out into the low pressure at the carburetor throat.

The basic principle is that simple. All the remaining complication of a carburetor is concerned with making sure that the fuel delivered is actually in correct proportion to the airflow, with maintaining a constant fuel level in the bowl, and so on.

Description of Carburetor Systems

All carbureted sportbikes are delivered with CV (constant-vacuum) carburetors, so I'll cover those first.

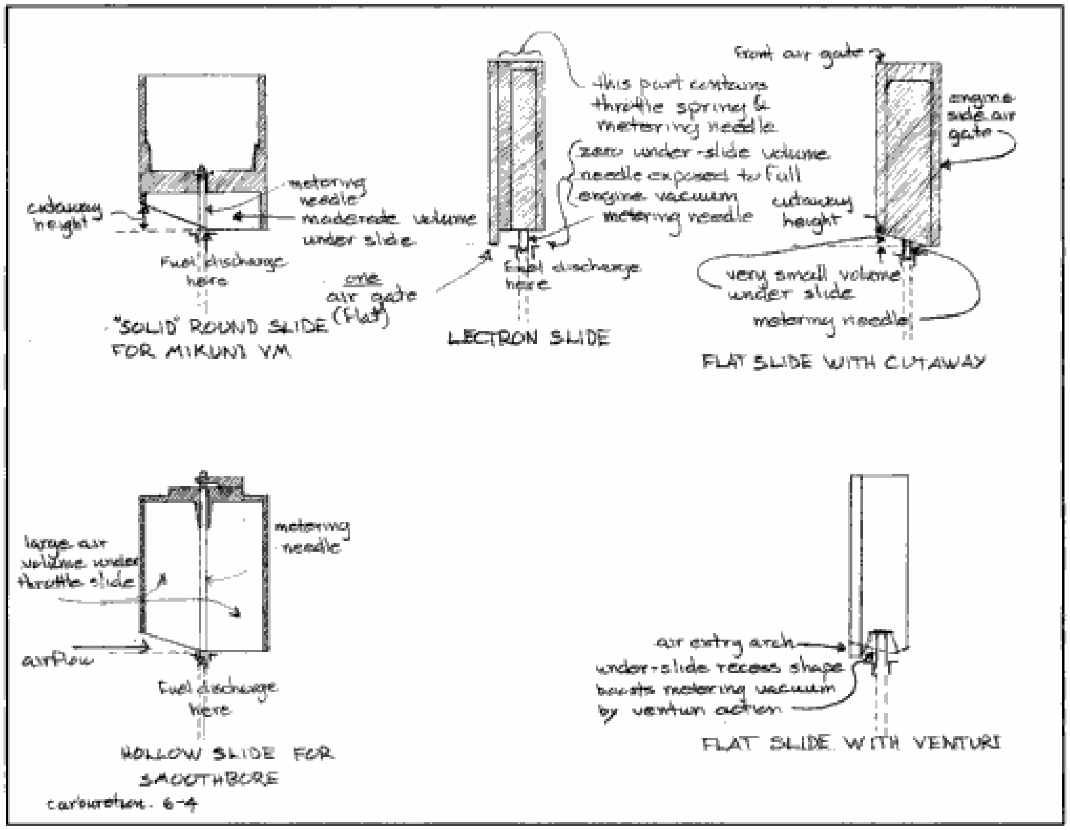
Beginning at the engine side of the carburetor, there is a butterfly throttle that rotates on a shaft, connected to the throttle cables. A spring returns this butterfly to the nearly closed position, set by a stop screw. The small airway remaining supplies air to the engine at idle, and the stop screw controls how much air is delivered. In the fully open position, the butterfly is parallel to the airflow, offering minimum resistance. This part of the carburetor is of large diameter to prevent the presence of the butterfly and its shaft from reducing airflow.

Right at the edge of this butterfly, in its nearly closed position, you will see a series of tiny holes. These supply fuel and progression air for idle, and off-idle operation. Fuel for these passages is supplied through a pilot or idle jet (PJ), screwed into the bottom of the idle fuel passage, submerged in fuel in the fuel bowl. Air to these passages is controlled by the idle-mixture screw (AS, for air screw).

Just upstream from the butterfly, the carburetor bore decreases, and entering the bore from the top is a vacuum-controlled throttle piston. This piston in its lower position does not completely close off the bore, but leaves a space beneath, where the shape of the underside of the piston forms a convergent/divergent venturi through which air can pass.

Hanging down from the center of this throttle piston is a tapered metering needle, called the jet needle (abbreviated JN in carb specs). It sticks down into a tube, whose bottom end is submerged in fuel. This tube is the needle jet (NJ). Into the bottom of the passage feeding this needle jet is screwed the main jet (MJ).

As the vacuum piston lifts, it pulls the tapered jet needle higher in the needle jet, making the fuel supply orifice larger, keeping fuel delivery in proper proportion to airflow. When the



Evolution of Carb Slides. Because people were fixated on wide-open airflow, smoothbores evolved first, but their large under-slide air volume limited the strength of the metering signal, making part-throttle performance sluggish. The "solid slide" type improved off-idle response by reducing under-slide air volume. Lectron changed everything by locating the needle in full engine vacuum. The cutaway-type flat-slide, with minimum under-slide air volume, was Japan's response. Later types contour the slide's underside to act as a venturi, creating maximum signal at the metering needle.

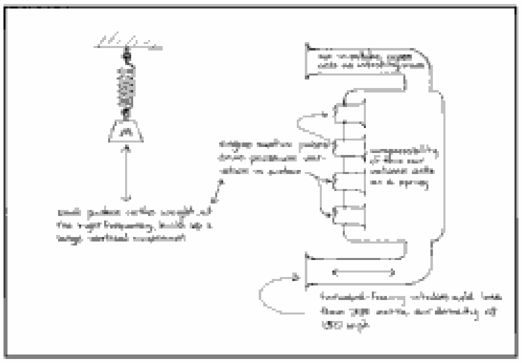
vacuum piston is fully lifted, fuel delivery is controlled by the main jet, rather than the needle and its jet.

The vacuum piston's motion is controlled by venturi vacuum applied above a thin, flexible rubber diaphragm located under a cap atop the carburetor. The piston lifts because the area of this diaphragm is larger than the area of the piston. A control orifice feeds venturi vacuum to the space above this diaphragm. What this system does is maintain a constant vacuum above the needle jet. If airflow decreases, venturi vacuum decreases a bit, which in turn causes the slide to fall. This causes vacuum to increase back to the original value, and so on.

Why bother with this complication? The reason is that fuel is 600 times heavier than air, by volume. If the rider controlled the throttle piston directly, and jerked it upward, air would rush into the engine, leaving behind the much heavier fuel. The momentary result would be very lean operation, with misfiring and a big stumble. But with the rider controlling only the butterfly, when he snatches open the throttle, it takes time for venturi vacuum to act on the vacuum piston, through the control orifice. The piston rises, but at a rate that keeps airflow under it moving fast enough to pick up the correct amount of fuel. The result—when everything is adjusted right—is snappy throttle response without stumble or misfire.

This relatively simple picture is complicated by a number of details. Fuel enters the fuel bowl through a float valve (FV), controlled by a pair of molded-foam or hollow, soldered-brass floats. As fuel rises in the bowl, the floats rise with it, closing the float valve. As the engine uses fuel, the level falls, causing the float valve to open, and so on.

If the fuel system is gravity feed—no fuel pump—there is little pressure to push fuel into the bowl, so the float valve is relatively large (usually its size is stamped into it somewhere, in mil-



Mass-on-Spring Analogy to Resonant Airbox. Everyone assumes airboxes work because their intakes face forward, but the ram effect is worth only 3 percent at 160 miles per hour. The real value of the airbox lies in the large resonant pressure variation that can build up inside it, driven by intake pulsing. If the engine takes air only on the positive side of each cycle, it receives a useful supercharge across a range of a few hundred rpm. This can be used either to boost top end or to fill in a hole in the powerband elsewhere.

limeters, such as 2.5). Recent bikes usually have electric fuel pumps, which supply a lot more pressure. Consequently, their fuel valves must be much smaller to prevent pump pressure from overcoming the floats and causing pressure flooding. These typically use smaller FVs, in the 1.5-mm range.

The mathematics of carburetor operation calls for fuel to stand just below the outlet of the needle jet, so that very little venturi vacuum is needed to get it flowing. But the reality of vibration, lean angles and such makes it necessary to set it lower than this.

It's quite common, after carburetors have been dry on the bench for rejetting, for one or more to overflow when the fuel is turned on again. The cause is a stuck float. A sharp whack on the fuel bowl with a plastic screwdriver handle usually stops this.

Idle System

Fuel enters the pilot jet, and air from the air screw mixes with it there to form an emulsion. This emulsion is lighter than raw fuel, so vacuum at the edge of the throttle butterfly can lift it more easily. The emulsion sprays out on the downstream side of the butterfly, mixing with air leaking past its edge.

As the rider begins to open the throttle, the edge of the butterfly begins to move, uncovering more tiny holes—or a thin slot—causing them to flow fuel. This is the so-called progression system.

Main System Begins to Flow

Meanwhile, the increased airflow is also moving under the vacuum piston, creating more vacuum there. This does two things. One, it lifts fuel from the needle jet, and two, it begins to apply vacuum to the upper side of the vacuum-piston control diaphragm.

As the edge of the throttle butterfly exposes all the progression holes, fuel delivery from the needle jet begins. If it did not, fuel delivery from the progression holes would rise to a maximum, then fall as further movement of the edge of the butterfly cut down on the local vacuum created there. As fuel flows from the needle jet, vacuum acts on the vacuum piston diaphragm, causing the throttle slide to lift, supplying more airflow. The engine accelerates.

Note that this process of progression from idle system to main system has a lot of overlap. It's not as though the idle system stops and the main system starts up. What happens is that the idle system tails off as the main system chimes in.

Effect of Vacuum Piston Lift Speed

Above I noted that venturi vacuum is fed to the space above the vacuum piston's diaphragm through a control orifice. Let's consider what happens if that orifice is made larger or smaller. If we make it larger, the slide lifts faster, and airflow may accelerate faster than fuel flow, leading to a lean condition. If we make it smaller, the slide lifts more slowly, fuel flow keeps up better with airflow, and mixture gets richer.

Once the vacuum piston stops moving—either because it is fully open, or because the engine is now running at some constant speed—the mixture is controlled only by the orifice formed between needle and needle jet, or—at wide-open throttle—by the main jet itself. Thus, the speed of slide lift, controlled by the slide lift vacuum orifice, gives sensitive control over mixture during acceleration, not during constant-speed running.

Air Correction

Once the vacuum piston is fully lifted, mixture control is handled by the main jet, but there is a problem. Air is elastic but fuel is not. As air moves ever-faster through the venturi, it loses pressure, becoming less and less dense. The fuel does not. This causes the air-fuel mixture to become richer as the engine pulls more and more air through the carburetor. This requires some kind of correction, or the engine will drown itself in fuel as it revs up.

The usual answer is to bleed a small amount of air into the fuel as it rises in the needle jet. The jet controlling this bleed air is called, appropriately enough, the air jet (AJ). As the venturi vacuum increases with rising engine revs, not only more fuel, but also more bleed air, will be pulled into the needle jet. The result, if the air jet is correctly sized, will be constant proportion between fuel and air, delivered to the engine. This air jet is usually located at six o'clock as you look into the carb intake.

Air-jet tuning is usually not undertaken by many because it's a bit complicated, but it's nice to know that there is a way to change the slope of the air-fuel curve; a bigger AJ causes the curve to go leaner as the engine revs up, and vice versa. The complexity arises because a change in AJ also requires a change in main jet.

Cold Starting

Engines require a much richer mixture for cold starting, because the cold engine can only evaporate a small fraction of the fuel. To get a rich enough fuel vapor to fire, the engine must be given lots of fuel. In car carburetors, this is accomplished with a choke butterfly, which acts like putting your hand over the carb intake; unable to get enough air, the engine sucks in a lot of fuel.

Most motorcycle carburetors use a different system. Cold enrichment is performed by a sub-carburetor, cast in unit with the main carb body, with an air passage that bypasses the slide and butterfly. Its "throttle" is a cable-operated piston, and it has a very

Throat of a Smoothbore Carburetor. The slide and needle have been removed from this carb, but you can easily see the thin slits in which the hollow cylindrical slide rises and falls. Thanks to this construction there is little disturbance to airflow on full throttle—hence the name—smoothbore. Part-throttle carburetion is not this type's strong suit. *John Owens Studio*

A Fast By Gast Lectron Carburetor. This flat-slide carb meters all its fuel from one point—where the needle disappears into the needle orifice. There is no idle system, so there is no idle-to-main system transition. Lectrons are famous for good part-throttle carburetion and the ability to vaporize fuel even in cold engines—something that's important to drag-racers. *John Owens Studio*

rich "main jet." In order for this starting carburetor to flow maximum air, the main throttle butterfly must be closed, so opening the throttle as you try to start a cold engine defeats the effect of the cold-start circuit.

Traditional Slide Carburetors

Although some racing CV carbs have been built, most racing carbs employ throttle slides directly controlled by the throttle cable. Carburetion works a bit differently in these units.

Idle System

Idle holes are located at the bottom of the throttle bore, right at the engine-side edge of the throttle slide. They are served, as in CV carbs, by a pilot jet and air screw.

Because slide carbs lack the CV carb's self-regulating constant-vacuum feature, transition from idle to main systems involves more tunable parts. The first of these is the throttle slide itself.

The problem is to create a vacuum under the slide that will pull the appropriate amount of fuel from the needle jet. The strength of this vacuum is controlled by the shape of the slide. In the case of a cylindrical slide, the edge closer to the engine closes almost completely, but the intake-side edge is higher than this. The lower the intake-side slide edge is made, the stronger the vacuum beneath the slide becomes, and the sooner the main system begins to flow fuel. The higher it is made, the weaker the vacuum. The height to which this edge of the slide is cut is called its cutaway (CA), usually measured in millimeters. Thus, a 2.5 slide cutaway is richer than a 3.0 (the number is stamped at the bottom of the slide).

Oval, flat, and rectangular-slide carbs employ variations on this idea—but always the intent is to create just the right degree of vacuum beneath the slide as it lifts, to bring in the main system smoothly.

Why Different Slide Designs?

Why the variety of slide types—solid round, hollow round, rectangular, and so on? The round slide came first because it was easy to machine, and was copied from European models. Later came rectangular, oval, and other gate-like slide designs.

Here is why carb design has taken this route. When the engine's suction pulse hits the carburetor, it must sneak under the engine-side edge of the slide, then pull air out of the space under the slide fast enough to create a vacuum there, strong enough to pull fuel.

A round slide has quite a lot of volume under it, so this requires a pretty strong suction pulse to pump all that volume down enough to pull fuel. A rectangular slide's engine-side and intake-side edges are closer together, so the volume under the slide is smaller. Consequently, the rectangular design can flow fuel in response to a weaker engine suction pulse. This makes this type of carburetor more responsive, able to continue to form a mixture even in powerband regions in which engine suction pulsing is weak.

In more recent slide designs, the underside of the slide is carefully contoured to form a venturi with the bottom of the air passage, which itself may have a special contour. This produces an even stronger vacuum, able to pull fuel in response to the weakest engine suction pulses. GP tuner Erv Kanemoto was once told by a Honda technician, "Whatever you do, don't mess with that shape. It took us six months' work to get it right."

Most of this slide development has occurred in motocross, where extreme responsiveness is essential to make use of every instant the rear wheel has traction. (Listen to the engine go "burp-burp-burp" as a bike hammers through the whoops, every time there's traction, the rider gives the engine a shot of throttle.)

Some of these slide designs cannot be used on GP road race bikes, precisely because they are *too* responsive. The slightest touch on the throttle in mid-corner and the engine barks strongly to life, possibly destroying rear wheel grip. Earlier carb types give a less-sudden power onset.

Some Superbike carbs have roller-equipped slides. In the early days, engine suction pulled standard carb slides hard against the engine side of the carb, making it very hard to pop the slides up from the closed position. This caused many an ungainly corner exit, as the rider twisted the grip harder and harder until, finally, *BLAMMO!* the slides popped loose and opened much farther than intended. The rollers ease the roll-on.

What are Smooth Bores?

Many years ago when carburetors were a lot less responsive than they are today, much smaller bore carburetors had to be used. Such small carburetors (How about the 15/16-inch—24-mm—carbs on Vincent 1,000-cc twins?) created considerable flow loss, so engineers thought about ways to make them slicker inside.

One idea was to put the metering needle in a side chamber (this was done on AMAL RN and GP carbs), thus getting it out of the airflow. Another idea was to make the throttle slide like an inverted bucket, open on the bottom, sliding in and out of the carb bore through a round, narrow slit. When this slide was fully open, the carb bore was perfectly smooth—save for the slit.

AMAL GP and RN carbs are museum pieces today, but in the first Superbike era (1976–83), smoothbore carbs were still considered the ultimate. The classic Japanese smoothbore is the Keihin CR, made in several sizes. Unfortunately, the hollow slide of the smoothbore makes its throttle response inferior to that of later designs, which in turn means that it must be used in smaller bore sizes.

What Is a Powerjet?

As I note in chapter three, engines need a correct mixture for part-throttle operation, but need an enriched mixture for acceleration and maximum power. One way to achieve this selective enrichment is with a so-called powerjet. There is nothing exotic about the concept—even VW Beetles had powerjets!

In a slide carburetor, a tube is hung down from near the 12 o'clock position, just upstream of the slide. The tube is fed through a jet, and there is a passage (often just a hose) leading to the fuel bowl. As the engine runs, the powerjet does nothing so long as the slide is closed enough to prevent fast-moving air from generating a vacuum near the end of the powerjet tube. But as the slide rises higher, high-speed airflow does rush across this tube, generating a vacuum that lifts fuel from the fuel bowl, draws it through the powerjet, and sprays it out of the tube, into the airstream. As the air velocity past the powerjet increases, so does the fuel flow.

Powerjets are tricky. Get them just right and you have a responsive mid-range with adequate enrichment for strong top-end. But make the powerjet too big and your engine will drown as it revs up. One solution to this exists in the solenoid-controlled powerjets used on current Yamaha TZ250 road racers. The ignition computer turns on the jet only when needed—in the TZ's case, this is below and above the rpm range where the exhaust pipes pump strongly.

Carb makers and others offer powerjet kits, but not every carburetor needs one. Some, in fact, actually benefit from high-speed lean-out.

Other Carburetor Types

A place of honor belongs to the U.S.-made, Edmondston-designed Lectron carburetor, for its radical design stimulated a lot of later developments from Japan. Lectrons are still available, and they are the preferred carburetor in certain drag-racing classes.

The unique feature of the Lectron is that it is a single-point metering device. There is no idle system—all fuel flow is controlled by a nontapered, hard steel needle, working in a closely fitted hole in the carb body. There is no main jet. The needle has a flat ground on it at a very slight taper, and is installed with the flat side facing the engine. The throttle slide is a simple gate—there is no cutaway. Because the needle and fuel orifice it works in are on the engine side of the throttle gate, they are subject to full engine vacuum at all times. This gives them maximum metering signal.

The great strengths of the Lectron are:

1. Excellent part-throttle response. This accounts for their initial popularity in road racing in 1977–81.
2. The ability to form a good mixture even when the engine is cold. This is what makes them attractive for drag racing. Drag racers run cold because cold engines induct more air than hot ones.
3. They are easy to tune, because mixture strength is controlled by screwing the needle up or down, or by changing to a needle with a richer or leaner flat ground on it. You need no boxes of jets and slides.

Older Lectrons had no air correction system, so they enriched as revs rose. Today they are offered with an air-corrected powerjet that compensates for this lack.

Fuel Injection

Most motorcycle fuel injection systems are of the mapped type, in which the computer measures two basic variables—rpm and throttle angle—then looks up the corresponding correct mixture information in a stored "map," in the form of an EPROM chip or other such device. In addition, the system monitors other variables such as atmospheric temperature and pressure and engine temperature. The aim is to create a system that not only gives the correct mixture today and here, but which will also automatically deliver it in tomorrow's different weather, and continuously as we ride up to Denver's 5,000-foot altitude, and down to below sea level in Death Valley.

The injection on Honda's RC45 has its little box with four mysterious knobs, but all other FI systems are computer-accessible only or require EPROM replacement for mixture adjustment. The basic idea is to plug in a laptop or some dedicated device to the FI's CPU, download the fuel mixture curve, and then enter changes in the area of concern, or to simply replace the map with another of suitably different specification. This leads to the social problem of certain teams who "can't get the good chip."

Fuel injection can simplify the mystery of carburetion drastically. Mick Doohan's crew chief Jeremy Burgess says that the on-board detonation counter not only totals the counts per lap (Honda's spec calls for no more than X), but shows under what specific throttle and rpm conditions they occurred. Then they enrich the fuel map in the area of concern. The end.

Automotive fuel injection systems place the nozzle close to the engine, aimed to shoot the fuel spray onto the backs of the hot intake valves. This assists its vaporization—and fuel injection needs it. Fuel-particle size from carburetors is usually smaller, surprisingly, than it is from injection, and this can cause problems. In an econobox, proceeding at legal speed up the freeway, the engine is turning around 2,000 rpm, so there is all the time in the world for the fuel to vaporize.

But in higher revving engines, there is less time for this, and to compensate, the injectors are repositioned farther away from the valves, to give longer evaporation time. Ferrari, on one of its F1 engines, had the injectors on little movable trolleys that moved up and down the intake stacks with rpm—close to the valves at lower revs, farther away at higher. Currently, at least two Superbike engines use two injectors per stack—one low down, the other hovering over the open end of the intake stack.

Intake Length Effects

As I noted in the discussion on cam timing, when one cylinder's intake process begins, a suction wave travels out the intake valve and up the intake pipe and carburetor. It is reflected from the open end with its sign reversed—the suction wave becomes a pressure wave—and it returns toward the engine. If this positive wave—or any positive wave resulting from multiple reflections—arrives just at the end of intake, as the intake valves are closing, it will stuff extra air into the cylinder and increase torque. The bad news is that at other speeds, it is a suction wave that arrives just at intake valve closure; this sucks out some of the charge and causes a minor flat-spot in torque. The positive and negative effects can be quite large—as much as a 10 percent torque boost has been observed.

On some World Superbike engines, a two-length intake system has been used. One length—the shorter of the two—is used to boost top-end. An added piece of intake stack is snapped into place by a servo-motor to give a boost at some lower rpm. In F1 car racing, continuously variable intake-length systems have been used. Back when Honda was running the RC30 V4 Superbike, they machined back into the heads to make the intake length shorter, to boost peak revs.

The reason I mention this is that so-called "velocity stacks" are still sold for a variety of carburetors, and many riders put them on simply because the name sounds racy and/or they like the look of the shiny aluminum or plastic things. If you change intake length, evaluate the result on the dyno or drag strip! Extra intake length will lower the rpm at which intake effects boost torque; you may or may not like the result. Customizing may be a lot of fun (I haven't tried it—maybe in my next life), but don't let it determine your performance bike's intake length.

Carburetors and Vibration

People today are spoiled, because the only carbs they have ever seen on bikes are rubber-mounted. It wasn't always so. I mention this not because the past is coming back, but because you may not be familiar with the effects of vibration on carburetion.

It occasionally happens that a carb or carbs are mounted in such a way that they can make hard contact with metal parts of engine or chassis. The resulting vibration can cause frothing of fuel in the bowls, allowing air to pass into main jets, leading to lean-out. I have seen fuel climb up the sides of transparent fuel bowls as engines were revved up, leaving the main jet hanging in fumes. This is not a likely problem with rack-mounted carbs, but can easily affect single carburetors.

The Airbox and What It Does

Early bikes had open carb intakes. Then filters were added to prolong engine life. Finally, when new noise standards proved impossible to meet without some kind of intake silencing, airboxes came into being.

Sporting riders have always hated interference with the purity of their engines, so one of the first acts on buying a new bike was to trash the ugly, molded-plastic airbox concealing those beautiful, functional carburetors. What can be more beautiful than a row of carburetor bellmouths, like trumpets upraised? Everyone knew that this raised horsepower because it eliminated the restriction of the filter and the (usually) tiny entry leading into the box. Those who wanted filtration added sporty-looking individual "sock" filters to each carb. It was cool to have jutting, bare carburetors.

Then just after the mid-1980s, riders got a terrible surprise. When they trashed their airboxes, their reward was not more power, but less. Powerbands that had been chubby and full suddenly turned lumpy—even with careful rejetting. The problem was especially severe in Supersport road racing, the one year when airboxes and filters were made optional. So people grudgingly put their airboxes back on, and the power came back. Something new was happening.

That something was airbox resonance. Everyone has hummed or whistled across the mouth of an empty bottle. At just the right frequency, the air in the bottle resonates in step with the tone being hummed or whistled. This is just like a weight, hanging on a spring, bouncing up and down. The spring is the compressibility of the air in the bottle. The weight is the slug of air in the bottle's neck.

If a suitable volume is connected to an engine's intake stacks, it can resonate in this same way, within a certain rev range. When the box is resonating in this way, its pressure is high just as one cylinder begins its intake stroke, and this drives more air into the engine. As the engine takes air, box pressure falls, but more air is on its way in through the box's intake snout.

If everything is sized correctly, box pressure is high again just as the next cylinder's intake stroke begins, and so on. The net result is a substantial boost—like free supercharging—within a particular rev range. This can amount to 10–15 percent more power. There are always weak areas in any engine's torque curve, so engineers have tuned airboxes to strengthen those weak areas: presto—a stronger, smoother torque curve.

This is why current sportbikes—and all World and AMA Superbike racers—have sealed airboxes. They are very well sealed—with rubber gaskets and quarter-turn fasteners—because any serious leakage destroys the resonance, just as a leaking valve pad stops a saxophone from playing a note. They are rigidly constructed, too, because a "soft" airbox would also kill the resonance, just as a rubber trumpet cannot be played.

Ram Air and Hot Air

Most people assume sealed airboxes exist just to create gains from forward-facing air intakes (I did). This is considered hot because racebikes have very visible snorkels, scoops, or other SR-71-looking air-intake hardware up front. Sadly, even if the energy of moving air could be completely converted to pressure, at 150 miles per hour the pressure gain is only 3 percent. This is fine on a

PLAYING WITH AIRBOX RESONANCE

Making an airbox work is a trial-and-error process, but the basic formula describing Helmholtz resonance shows us how to get what we want.

$$\text{Resonator frequency} = 5{,}300\sqrt{\frac{\text{Total Area of Intake Pipe(s)}}{[\text{Air Box Volume}] \times [\text{Length of Intake Pipe}]}}$$

If you have two intake pipes, the length in this expression is the length of one, not the total of two. Area of intake pipes is total area; that is, if there are two intake pipes, each of two square inches area, the total is four square inches.

Looking at the formula, you can see that increasing intake pipe area raises the resonant frequency, and vice versa. Increasing box volume or making intake pipe length greater both lower the resonant frequency.

The basic facts about sealed and/or ram airboxes are these:

a. There are two basic kinds of intakes. One type is cut into a flat or slightly curved fairing surface, perpendicular to the direction of motion. Locating intakes at the sides of fairings will take in lower pressure air that is speeding up to flow around the bike's shape.

The second type, the "rocket launcher," consists of a forward-facing tube or tubes that project forward several inches from any surface. This puts them in undisturbed airflow. You have seen these, made in black carbon fiber, on Honda NSRs and the Roberts KR3. The proper name for this device is a Kuchemann diffuser, and every subsonic jet engine uses one.

b. The total area of the intake pipes must be significantly greater than the total carb area.

c. The intake pipes must enlarge gradually as they approach the box, not enlarge suddenly from a small diameter. Sudden enlargements waste a lot of the ram pressure. The angle of the enlargement should not exceed 10 degrees.

d. The box must be truly sealed, meaning a rubber gasket compressed between box and cover, and each carb bell sealed to the box positively—not just shoved through a hole. There can be no leaking holes for frame members, cables, or hoses. Preferably only the carb bells are in the box, because this eliminates sealing all those items individually.

e. All float-bowl vents and the fuel tank vent must be connected to box pressure. Otherwise, at maximum speed there will be carb lean-out.

f. The box volume, and the intake length and cross-sectional area must be chosen according to the Helmholtz formula. Check your work via track or dyno test to put the box resonance in the desired frequency range.

Factory race parts made for Superbike racing sometimes include an airbox and intake parts. Unfortunately, this material is usually hideously expensive—even Muzzy didn't buy Kawasaki's carbon-fiber airbox one year. If you decide to make your own, study production or racing airboxes that work. There is a lot more to them than just a box with some white pool-supply flex tubing running to holes in the front of the fairing. Factory airboxes are good-sized; when you see one on the bench, it looks like something made by Samsonite.

Superbike racer, where it might give an extra 3 to 4 horsepower near top speed.

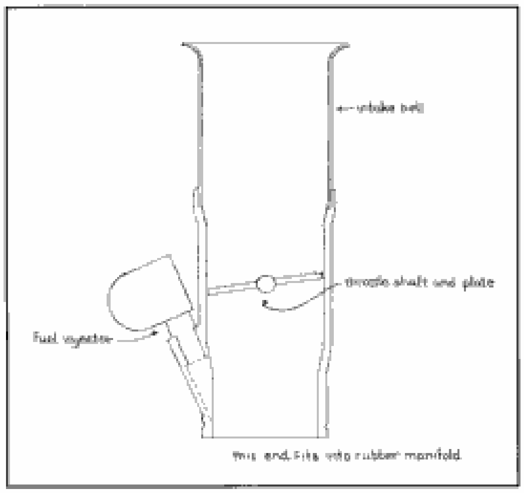
But this "ram-air intake" is a velocity-squared effect; if you double the speed, you get four times the pressure. Conversely, if you halve the speed to 75 miles per hour, you get only 1/4 the effect, or 3/4 of 1 percent. This is a horsepower or less on a big engine. Not much.

Rad-looking scoops sell bikes, but forward-facing intakes have one real purpose at less-than-race speeds. That is to prevent hot air from radiator, cooling fins, or hot exhaust pipes from entering the carburetors. Air loses density as it is heated, so hot air gives less power than cool air. Forward-facing airbox intakes exclude all hot air. Another thing they do is to point intake noise in the opposite direction to exhaust noise. This is as useful in meeting noise standards as the time-honored trick of putting one exhaust pipe on each side of the bike—the noise meter can only be in one place at a time.

There may also have to be means of correcting mixture for the higher air density in the box, but this is really a race-only problem, as relatively few street riders spend much time at maximum speed. It's important to note that, as pressure in the airbox rises at very high speeds, it reduces the pressure difference across carburetor mainjets, causing lean-out. If airbox pressure rose high enough, it would push the fuel right back down into the float-bowls and blow bubbles!

The simplest compensation for high-speed lean-out is to vent the float-bowl breather lines into the airbox (which is done by the factory on most modern motorcycles). Even with this, a 3-percent density increase will still lean out an engine, just as will a 3-percent rise in the barometer. But we're talking about legal speeds here, so we'll ignore this one.

While on the subject of venting things into the airbox, I should mention the gas tank breather. As your engine takes fuel from the tank, an equal volume of air must enter the tank through the tank breather to take its place. The breather on production bikes is usually incorporated into the filler cap. On some modified bikes, it has happened that the tank breather was too small for the bike's new ap-



Fuel Injection Throttle Body and Injector. This unit has a butterfly throttle but some employ flat gates. The injector is an electromagnetic valve, opened by electric current. Instead of figuring fuel flow in terms of jet sizes, fuel injection figures it in "on time"—the number of microseconds that the injection valve is held open at a particular rpm and throttle position. Sometimes more than one injector per cylinder is used; at lower rpm, an injector close to the intake valves is used, switching to one located farther up the stack (or even hovering over the open bellmouth) to give the fuel more time in which to evaporate.

petite, or got covered up by the cap gasket or such, causing mysterious lean-out only at high speeds, when fuel demand is highest.

If you have any weird symptoms like this, think about restrictions that may exist in the tank breather or in the fuel lines and petcock. I once had a bike that revved up to 9,500 down the Daytona back straight, then cut dead, coasted down to 8,500 revs, cut back in again, and so on. It turned out to be fuel starvation, caused by carb float valves a bit too small, in-line gas filters, and fuel-line quick-disconnects. All this restriction was causing the fuel bowls to run dry. Once I had provided enough flow capacity, the problem obediently went away. This applies mainly to bikes with gravity fuel feed. Electric fuel pumps are another story.

Some tank petcocks leak, and so do some carburetor float valves. The combination of these two with an open intake valve, given time enough, can result in a cylinder full of fuel. Ever see those World War II airplane movies, in which two or three ground crewmen pull the prop blades around before starting up a big radial engine? They did that to be sure no cylinder was full of oil—radials have many cylinders below the crankcase—so the starter could safely turn the engine without "hydraulic-ing" a con-rod. Fuel in a cylinder is just as incompressible as oil. Just one more little thing to think about.

Tuning Slide Carburetors

Carbs are complex because of their overlapping systems and their many parts. It's easy to feel it's all too complicated and just give up. But no, there's a step-by-step method. This was taught to former Kawasaki team rider Hurley Wilvert by a craggy old Australian speedman, and Hurley taught it to me.

Assume that the machine is in good running order, that the carbs are properly mounted, with consistent float levels, and all have the same tuning parts in them. Set all idle airscrews to the same setting, such as 1 1/2 turns open.

Set any idle-speed adjusters to let the slides close completely, then synch the slides to lift simultaneously. Some people will tell you to synch to make all slides reach fully open together. This is wrong, for it's much more important to have smooth power off the bottom. Since you have to do this with the gas tank off, remember that when you replace the tank, it may disturb the lie of the cables; making a cable bend tighter lengthens the housing. Recheck synch with the tank in place.

Race-only machines are not set up to idle, so their slide carbs are synched for simultaneous opening. Street machines have to idle, and for setting this there is the method of connecting vacuum gauges to each carb and thereby equalizing all carbs' airflows.

Start the engine and warm it up. Have a friend hold it at a constant idle, as low as possible. Note the rpm and have your friend keep an eye on the tach. Now turn each idle airscrew open 1/4 turn more. If rpm falls, turn the screws back to the starting point, then 1/4 turn inward. If idle rpm again falls, the original setting is good and you can go on to the next stage.

But if idle rpm continues to climb as you adjust the idle air screws, keep going until either of two things happens: (1) You find the peak rpm setting, in which case leave it there and proceed to the next tuning step. (2) Max idle rpm requires that the idle screw be less than 1/2 turn open, or more than three turns open. If number 2 occurs, you must change pilot (idle) jets to a different size. If the best idle setting is smaller than 1/2 turn open, install richer idle jets. If the best setting is more than three turns open, install leaner idle jets.

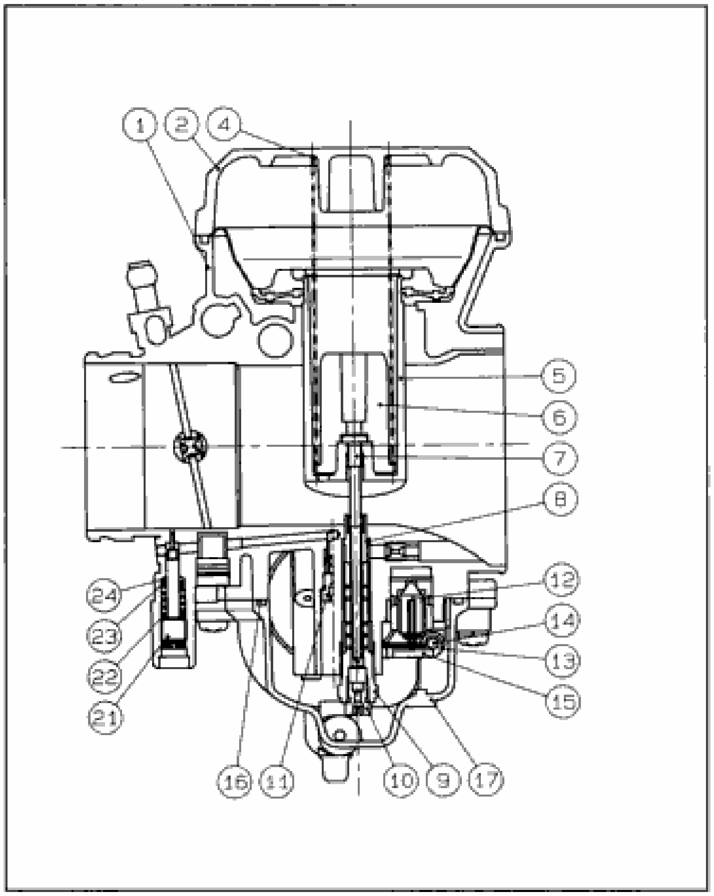
Continue this process until you achieve an idle-airscrew setting that gives peak rpm, and lies within the range between 1/2 turn open and 3 turns open. If this is a street-ridden bike, you can now set the idle speed.

The next tuning stage is selection of slide cutaway. Be sure that the engine is happy—not overheating and not fouling its plugs. With the engine idling, roll the throttle on very slightly. Does the engine follow willingly, or does it misfire or lag behind? If there is a problem, install a slide 1 or 1/2 mm richer (less cutaway). The cutaway numbers are stamped on the slide, or you can easily measure the cutaway by standing the slide on a flat surface (desperate tuners sometimes cut slides and don't change the stamped numbers!).

If the engine responds to the throttle better now, try slides that are richer yet. If the engine responds worse to the change, go the other way—install leaner slides, with more cutaway.

You may now ask if the engine is running on the needle now, and wouldn't it be appropriate to play with needle height. No, the shank of most needles is not tapered, so the first 10 mm of slide lift—a lot more than we are using in this part of the tuning process—is not on the taper. Therefore, mixture at these low throttle positions is controlled by: (1) the continuing but tapering-off effects of the idle system (2) the slide cutaway (3) the orifice between the needle's shank and the ID of the needle jet.

The rest of the test is best performed under way, on track or secluded road. You will now perform a series of roll-ons, as before to evaluate how the engine takes throttle.



Cutaway of CV Carb. These Keihins are very common on late-model sportbikes. The rider controls the butterfly throttle, but air pressure in the carb throat controls the air slide's lift. This—when everything is tuned correctly—makes it impossible for the air to get ahead of the fuel and cause acceleration stumble. *Keihin*

Carbureting from Zero

Occasionally, a rider may have to adapt carburetors to a machine not delivered with them, and so lack any starting point for such things as needle type, slide cutaway, and so on. One proper response is to call friends or others who may have more experience. Another is to call the carb manufacturer's importer and ask for help there. For common machines, importers often can supply carbs with at least approximate jetting for your bike, and you can use the above procedure to refine this.

If you have to do the job solo, all is not lost. Size the carburetors realistically to be slightly larger than the port ID at the head flange and begin with middle-of-the-road slides like 2.5, mid-range pilot jets, and a middling air screw setting like 1 1/2 turns. Start with some commonly used needles. What's common? The carb makers' catalogs list available needles, with diameter measurements given at a few points along the taper. Pick a type and begin. If the engine has a fuel pump, use small float valves. Otherwise, use something good-sized like 3.0. The tuning procedure will get you pilot jet, slide cutaway, and needle-jet sizes that work. Now all you need is to refine the choice of needle.

Test at other needle heights. If this by itself takes care of your mid-throttle-position running, you can proceed to main-jet selection. But if simple changes of needle position don't do the job, you may need to change to different needles. They are supplied in a dizzying array of tapers—single, dual, and even triple—with different shank diameters as well.

Whatever your on-the-needle running problem may be, you have to determine two things about it in order to correct it. The first is to identify the throttle position when the problem occurs. The second is to know whether the problem is richness or leanness.

One way to find out is to turn off the fuel to the carbs, and continue to run the engine until it has pulled the fuel level in the bowls down significantly. If, in this condition, your bike runs better in the problem area, you know it is rich there. Or try a little choke; if the engine picks up, it was lean in the problem area. With a little thought, you can devise a lot of little diagnostics like these.

Now identify the throttle position at which this problem occurs, and measure the needle diameter at the point that is just inside the top

PLUG READING

Reading spark plugs was long considered one of the tuner's black arts, but it requires more of a careful, methodical approach rather than crystal balls or chicken entrails. For plug reading, it is essential that you begin with clean, fresh plugs. A dark plug will not lighten to indicate a correct or lean mixture, so used plugs are useless for mixture assessment. Also, forget all the plug manufacturer's four-color advice sheets about chocolate-brown. That is the color a plug assumes in a street-driven bike with hundreds or thousands of miles on it. The color you are looking for in main-jet tuning is white. If you make a top-speed run of 30 seconds or so, and your fresh plugs come out brown, your engine is hopelessly rich.

The "reading" of spark plugs is based upon the fact that the insulator is a thermometer that can be read just like any other, except that it is not calibrated in degrees. The tip of the insulator is designed—provided you are running the correct plug heat range—to operate at a temperature high enough to prevent free carbon from sticking to it, but not hot enough to act as an ignition source on its own. As you travel up the insulator from its tip, toward the metal shell of the plug, the temperature falls until it is the same as the cylinder head metal into which the plug is screwed. That means that somewhere along the insulator, it will become cool enough that free carbon—if any—can exist on its surface.

Free carbon is an indicator of incomplete combustion, so if, at some point along the insulator's length, it is surrounded by a dark ring, this is proof that your engine is still rich. As you jet down, peak combustion temperature in the engine rises, the plug heats up, and the ring will recede up the insulator and finally disappear. You don't want no ring at all because maximum power is given at a slightly rich mixture (the physics of why is alluded to elsewhere). Nevertheless, good tuners are pretty ruthless in pushing that ring up the insulator.

They are also watchful for signs of oiling, which is usually evident in one cylinder first—the result of ring failure. Oil will darken the whole insulator, and there may also be odd colors resulting from metallic oil additives plating-out on the plug. Time—and experience—will teach you the difference.

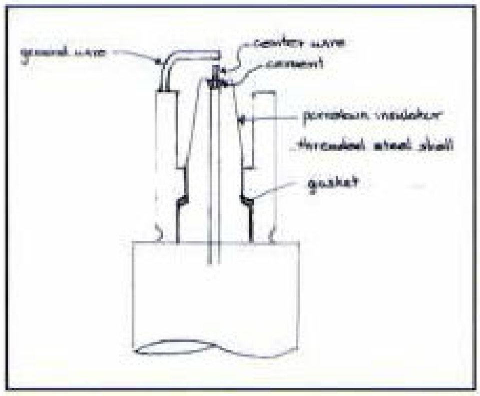
Gadgety little combination flashlight/magnifier things are made for plug reading, but almost always the battery is half dead and the light is feeble even with a new battery. You will do better with strong sunlight and an eye loupe or a little pocket magnifier like those sold by Bausch & Lomb.

How can you know if your plug's heat range is correct? With a stock engine, plug heat range is determined by tests made with instrumented plugs. The goal is to achieve a desired range of operating temperature for the plug tip—the hottest thing in the engine. Look up the correct heat range in your manual. Plug makers can supply charts of equivalent heat-range plugs from the different manufacturers. For modified engines, the choice is up to you, guided by your vigilance and understanding.

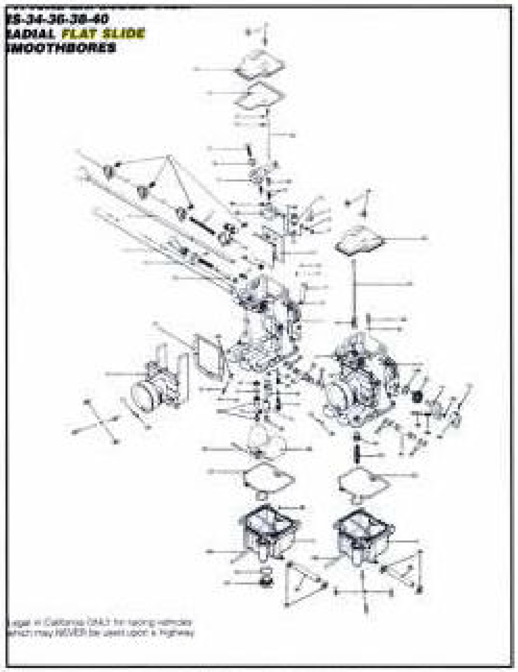
Obviously, if you boost your engine's power, it may need a colder plug by a heat range or so. With a 6X or so magnifier, examine the end of a fresh plug's center electrode—the wire that comes out the end of the central insulator, not the side wire. You will notice that it has been cut to length by some kind of shear, leaving the metal with somewhat distressed edges. If the center wire is getting too hot you will see that after hard use, the sharpish edges of the center wires appear to have softened—very much like the edges of a broken-off glass rod heated in a Bunsen flame in chemistry class. That's an indication you should move to the next colder plug.

This is also a diagnostic for excessive ignition advance, so ask yourself whether your engine's timing is correctly set. If you're sure ignition timing is OK and you are getting center-wire edge-softening after a bit of hard use—a number of pulls on the dyno, a few laps on the track, a few top-speed runs on your favorite, perfectly legal straight road—then you should try plugs a half or a whole heat range colder.

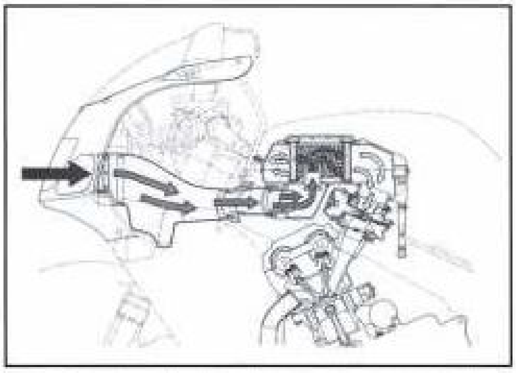
If an engine looks a bit rich on a given plug, it will look richer on a colder plug, and leaner on a hotter one. Don't get sucked into thinking you can correct your engine's mixture by changing plug heat range. Some people still believe it, but this is about as scientific as trying to change the weather by blowing into a low barometer.



Cutaway Spark Plug. The idea of reading spark plugs is to use natural thermometers that they present. One is the height of carbon on the insulator. Another is the presence/absence of deposits on the center wire. Yet another is any softening of edges at the center wire's end. On fine-wire plugs, a length of about one-and-a-half diameters at the tip will be deposit-free and shiny-bright when mixture is right.



Mikuni Radial Flat Slide. Slide carbs like these are the preference for pure race bikes, and sports machines whose users are willing to become carb experts. Don't expect smooth around-town casual use of big slide carbs. *Mikuni American*



Ram Airbox System. Air enters the system and is conducted to the intake resonator tube (vertical tube at bottom of air filter), through the filter, and into the airbox in which the carbs are sealed). Think of a resonant airbox as a guitar body, and the resonator tube as the sound hole in that body. Pressure variation in the airbox is driven, not by vibrating guitar strings, but by the engine's suction pulses. At the tuned rpm, the engine takes air from the box only when pressure inside it is positive. In the other half of the cycle, the box takes air through the resonator tube. *U.S. Suzuki Motor Corp.*

of the needle jet at this throttle position. Get out the carb maker's needle list and look for needles that are fatter in this area, but about the same elsewhere. If you have to jump to a needle with a different shank diameter, you will have to re-do the needle-jet selection as well.

From-scratch carb tuning can be a tricky process, but motorcyclists who want more performance are highly motivated, able to juggle tiny carb parts tirelessly and quickly. Or they can learn! As old Mack McConney—the second Triumph dealer in North America, who lived to be 99 years old—used to say, "The human mind has created this system, and the human mind should therefore be able to comprehend it."

Main Jet Selection

Some engines are quite sensitive to main jet size, while others don't seem to care too much so long as they are reasonably close. This kind of difference often has to do with an engine's combustion chamber turbulence. Highly turbulent engines are less sensitive because turbulence substitutes for flame speed; the richer the mixture, the slower the flame travel. An engine lacking in turbulence therefore acts as though its timing is retarded when it is rich.

The old stories about carburetion going completely off because the sun went behind a cloud describe a past era of bad carburetors and half-baked engines. Things are better now. But you will find that, as you make the carbs on a given engine bigger, carburetion becomes touchier. This is because engines don't run well unless they receive a fine fuel mist rather than a stream of blobs. Forming that mist depends on air velocity.

As the fuel shoots out of the needle jet into the air stream, the fuel droplets are beaten into little pieces by the impact of the air. Slow the air down by making the carbs huge and you get adequate fuel vaporization only way up there near peak revs. Suddenly, pulling away from the stoplight two-up becomes a nightmare of stalling and restarting while your riding buddies disappear into the distance.

Sure, big carbs look impressive and we know the factory Superbikes use fist-sized instruments. The truth is that smaller carbs are easier to tune and more likely to stay in tune. They are less fussy on the throttle and easier all around. But jump right in if you must, and try to put Daytona-style 41-mm slant-slides on your four-cylinder 750; it'll be an education.

Main-jet tuning methodology depends upon having someplace to run at full throttle, in top gear, long enough to perform a simple engine diagnostic (for slide carburetors), or long enough to color a spark plug (any type fuel system). The diagnostic is to slightly close the throttle, and note whether there is a slight gain in maximum revs. If there is, the engine is rich and should be jetted down.

Most tuners still rely on plug readings, but the ultimate truth about main jet size is not the appearance of the plug but the appearance of the tachometer. Jet for maximum speed, and do it in a place where it can be done in safety. Modern sportbikes are not touchy about main jet, and don't require endless fiddling to keep them right. Better to get on with the riding than to spend your time searching for perfect carburetion, surrounded by dismantled carburetors and the smell of drained fuel. There are a lot of fascinating points in tuning that invite us to become monomaniacs, but you have to remember that we all got into this because it looked like fun.