

engine, we are really talking about a mixture of fuel and oil. If you richen the pre-mix ratio (20:1 as opposed to 30:1), there is more oil and less fuel in the same volume of liquid, which effectively leans the air-fuel ratio. This fact gives the clever tuner one more tool to use when the correct jet is not available or when none of the standard jets are exactly right. You can richen the jetting by slightly reducing the pre-mix ratio (less oil). You can lean the jetting by increasing the pre-mix ratio (more oil). Changes in the pre-mix ratio affect the jetting over the entire throttle-opening range, but the changes in ratio must be small to prevent excess wear from lack of lubricating oil or fouled plugs from too much oil.

Pre-mix oils are formulated for a fairly narrow range of pre-mix ratios. You should examine the oil bottle for the oil manufacturer's suggestion on the pre-mix ratio. All production two-stroke dirt bikes have a sticker on the rear fender suggesting that you set the pre-mix ratio to 20:1. That sticker is put there for legal purposes. Always refer to the oil manufacturer's suggestion on pre-mix ratios. In general, small-displacement engines require a richer pre-mix ratio than do large-displacement engines because smaller engines have a higher peak rpm than larger engines. The higher the engine revs, the more lubrication it requires.

TUNING GAUGES

There are three types of gauges that professional tuners use to aid carb jetting:

1. Relative-air-density (RAD) gauge
2. Air-fuel (AF) ratio meter
3. Exhaust-gas-temperature (EGT) gauge

The following is a description of how each gauge functions and its advantages.

RAD Gauge—A RAD gauge is the best choice for dirt bikes because of the convenience, but the gauge is no good unless you get the jetting perfect. The RAD gauge provides you with an indication of how much the air density changes, helping you compensate for the effects of changes in the air temperature, altitude, and barometric pressure.

The gauge is calibrated in percentage points. Once you set the jetting with the ride and feel method, you can set the calibration screw on the gauge so the needle is pointing to 100 percent. When the air density changes, the RAD gauge will show the relative percent of change. Using a calculator, you can multiply the percentage change shown on the RAD gauge by the jet size and determine the corrected jet size for the air density. The pilot/slow and main jet have number sizes that correlate with the RAD gauge, but the needle clip position can only be estimated. Normally for every two main jet increments, the needle clip must be adjusted one notch.

AF Ratio Meter—The AF meter measures the percentage of oxygen in the exhaust gases and displays the approximate air-fuel ratio of the carb. The gauge displays AF ratios from 10:1 to 16:1. The optimum AF ratio for a two-stroke engine is 12:1. The AF gauge utilizes a lambda sensor that is inserted into the center of the exhaust stream, approximately 6 in. from the piston in the header pipe of a four-stroke and in



The number one cause of stuck throttle condition is a bad throttle cable. Improper routing caused this cable to fray above the carburetor. The cable should route through the center of the head-stay brackets.

the baffle cone of a two-stroke engine. A permanent female pipe fitting (1/4 in.) must be welded to the side of the exhaust pipe in order to fasten the sensor. The weld-on fitting setup is also used on the temperature gauges, and the fitting can be plugged with a 1/4-in. male pipe fitting when the gauge is not in use. This gauge is ideal for four-stroke engines.

EGT Gauge—The EGT gauge measures the temperature of the gases in the exhaust pipe by means of a temperature probe fastened into the exhaust pipe, 6 in. from the piston. This type of gauge enables you to tune the carb jetting and the pipe together, taking advantage of the fact that exhaust pipes are designed with a precise temperature in mind.

An exhaust pipe is designed to return a compression wave to the combustion chamber just before the exhaust port closes. Most pipes are designed for a peak temperature of 1,200 degrees Fahrenheit. Most dirt bikes are jetted too rich, which prevents the exhaust gases from reaching their design temperature, so power output suffers. Sometimes just leaning the main jet and the needle-clip position makes a dramatic difference.

Digitron is the most popular brand of EGT gauge. It measures both EGT and rpm. The gauge is designed for kart racing and is not suited for wet weather conditions. It is designed to mount on the handlebars so the rider can focus in on it. Once you perform the baseline jetting, send the rider out on the bike with the EGT. The rider observes the EGT to give you feedback on the necessary jetting changes. Once the jetting is dialed, use the tachometer to check the peak rpm of the engine on the longest straight of the racetrack. For example, if the peak rpm exceeds the point of the engine's power-peak rpm, change the rear sprocket to a higher final-drive ratio (rear sprocket with fewer teeth) until the rpm drops into the target range. An EGT gauge is ideal for dirt track bikes and karts, where peak rpm temperature is critical.

TWO-STROKE TOP-END REBUILDING

Top-end rebuilding is the most frequent and costly service routine on two-stroke dirt bikes. Every year, dirt bike riders waste loads of money on top-end parts that didn't need to be replaced, or they make costly mistakes while performing repairs. This section provides the dos and don'ts to easy top-end rebuilding, plus some tips that aren't printed in your factory service manual.

BEFORE YOU START

Thoroughly wash your bike because dirt stuck to the underside of the top frame tube could break loose when servicing and fall into the engine. Use a stiff plastic brush and hot soapy water to clean off the grit and grime around the base of the cylinder, on the carburetor and intake boot, and especially underneath the top frame rail. Degreaser can be used on metal surfaces, but take care not to leave it on rubber or gasket surfaces.

TOOLS

You'll need at least some 3/8-in.-drive metric sockets and box wrenches (open-end wrenches will round off the edges on the cylinder or head nuts and shouldn't be used for top-end rebuilding), needle-nose pliers for removing circlips, and a gasket tool to scrape the old gaskets away. For soft tools, get some shop towels, aerosol oven cleaner, a Scotch-Brite pad, a locking agent such as Loctite, a gasket scraper, a brush, and a bucket of soapy water. You'll also need a compression tester, a feeler gauge, and a digital vernier caliper.

COMPRESSION TESTING

A compression tester is a useful diagnostic tool, readily available from Sears

or auto parts stores. Buy the threaded type, and make sure the kit comes with an adapter that matches the spark plug threads of your engine.

Performing a compression test is simple. Start by removing the spark plug, threading in the adapter, and holding the throttle wide open with the kill button on. This prevents any spark and enables the engine to draw in maximum airflow. Then kick-start the engine several times until the needle on the pressure gauge peaks. The pressure reading depends on two main factors: the compression ratio and the altitude at which the engine is tested. The compression ratio will also depend on whether or not the engine is equipped with exhaust valves and the condition of the valves. When the exhaust valves are in the closed position, the compression ratio will be greater than if the valves are carbon-seized in the open position. The difference may yield a pressure reading of 25 psi. The quality of compression testers varies greatly. The main thing that a compression tester can identify is a change in condition. Whenever you rebuild the top end, take a compression pressure reading and mark it down. When the pressure changes 20 percent, check the condition of the piston and rings. Pistons usually last twice as long as rings.

CRANKCASE PRESSURE TESTING

The crankcase of a two-stroke engine is sealed off from the tranny. It's important that the two crankshaft seals are in optimum condition. One side of the crankshaft uses a dry seal and the other a wet seal. The dry seal runs on the magneto side and the wet seal runs in oil on the tranny side. When the dry seal wears, the crankcase sucks in hot

air, causing the mixture to run lean and overheat the engine. When the wet seal wears, the crankcase sucks in tranny oil, causing the engine to run rich and eventually wet-foul the spark plug.

A crankcase pressure test involves the use of a vacuum pump with spark plug adapter and rubber plugs to block off the intake and exhaust manifolds of the cylinder. The piston must be positioned at BDC to allow the transfer ports to be wide open, linking the bore and the crankcase. The hand pump produces vacuum pressure up to a standard setting of 5 psi. The normal bleed-down pressure loss is 1 psi per minute. Cylinders with complicated exhaust valve systems can be difficult to block off air leaks and harder to test. Crankcase pressure testing kits are available from Morion Pro.

If I suspect that an engine has an air leak in the crankcases, I do a visual test. Start by power-washing the engine clean. Then remove the magneto cover. Spray the magneto clean with an aerosol can of brake cleaner. Make sure to use a non-chlorinated cleaner. Sprinkle baby powder on all the suspect areas of the engine. Sprinkle the powder on the crankcase around the magneto, at the crankcase seam line, the cylinder base, and the reed valve. Run the engine for a while; the white baby powder will highlight any fluid or air leaks on the engine. The baby powder test is much better than the alternative test of blowing raw propane gas at different areas of a running engine and listening for a change in the idle rpm. That is dangerous because it involves flammable gas and a hot engine with random electrical shorts.

DISPLACEMENT	80 cc	125 cc	250 cc	500 cc
TEAR DOWN AFTER	5 hours	10 hours	20 hours	40 hours



When you do a top-end job, check the condition of the cylinder head. The top-end bearing of this bike started to break apart, and the needle bearings smashed between the piston and head, causing damage to both. The head was refinished on a lathe.

MAINTENANCE AND INSPECTION

A thorough top-end rebuild requires removing the reed valve, cylinder head, and cylinder. You should tear down your top end periodically and inspect the reed valve, cylinder head, cylinder, piston, and so on. Use the following chart to determine when you should tear down your bike:

Note that air-cooled bikes should be inspected more frequently. Also, you may want to inspect more often if you are riding in fine sand or lots of mud. When you tear down the engine, inspect each system and look for the following trouble signs:

REED VALVE

Check the reed petals for open gaps between the sealing surfaces. In time, the reed petals lose their spring tension, and the backflow can cause a flat spot in the throttle response. Stock nylon reeds tend to split at the edges on bikes that are constantly over-revved. Expert riders find that carbon fiber reeds last much longer.



Most cylinders use alignment pins to locate the cylinder on the crankcase. If those pins get tweaked or rusty, it may be difficult to bolt the cylinder to the cases. Sometimes, stress fractures will occur on the cylinder or the case. Check out this hairline crack in the cases below the cylinder bolt.

CYLINDER HEAD

Check the head at the edge of the chamber for erosion marks—a sign that the head gasket is leaking. If the head or top edge of the cylinder is eroded, it must be turned on a lathe to be resurfaced.

CYLINDER

All cylinder bases use aligning dowel pins around two of the cylinder base studs. The pins are made of steel, and after heavy power-washing, they get corroded. That makes it difficult to remove the cylinder from the crankcases. Never use a pry bar. That will damage the cylinder. Instead, use a plastic mallet to hit upward on the sides of the cylinder at a 45-degree



There are two ways to install the top end. You can install the piston assembly into the cylinder, and then lower the piston and cylinder onto the connecting rod to pin it. The conventional way is to install the piston assembly on the rod and lower the cylinder onto the piston. Never twist the cylinder or rings when sliding the cylinder and piston together. The ring ends can get trapped in the ports and be prone to cracking.

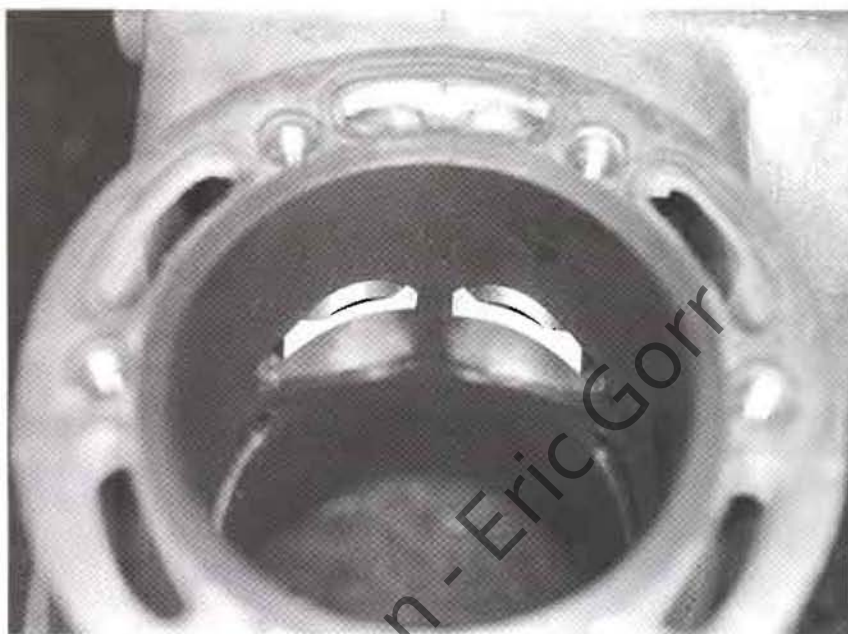
angle. Alternate from left to right sides to lift the cylinder up evenly. After you remove the cylinder, stuff a shop towel into the open crankcases to prevent debris from entering the engine.

THE DIFFERENT TYPES OF STEEL-LINED AND PLATED CYLINDERS

There are two types of cylinder bores used on dirt bikes: steel or cast-iron sleeves or those with plating on the aluminum. Most dirt bikes made after 1989 have plated cylinders. You can check the cylinder type with a magnet. If the magnet sticks to the bore, it is a sleeve. If it doesn't stick, it is plated.



This is a view looking down the exhaust pipe. Notice how carbon buildup has reduced the diameter of the pipe, which can make the bike lose power and run hotter. If your bike ever breaks a piston, power-wash the pipe to flush out the debris.



Whenever the cylinder is overbored, check the exhaust valve clearance to the bore. These valves protrude too far into the bore and need to be ground for a piston clearance of 1 mm.



Some big bore kits have pistons larger than the hole in the crankcases. Clearance grinding is necessary and can be performed with careful taping and the aid of a vacuum cleaner.

There are three types of plated cylinders: Kawasaki Electrofusion, hard chrome, and nickel silicon carbide. There are several variations of the nickel silicon carbide process, but the most common trade name is Nikasil. The nickel-based processes have many advantages over hard chrome, Electrofusion, and sleeving. Nickel attracts oil and is an excellent carrier material for silicon

carbide particles, a wear-resistant material that carries the load of the piston. The material is electro-plated right on to the aluminum cylinder for the optimum thermal efficiency. Nickel can be honed with diamond stones, which leave distinctive peak-and-valley scratches in the cylinder wall that retain oil and provide a certain bearing ratio between the running surfaces of the bore.

It's possible to rebuild a plated cylinder by fitting it with a sleeve. However, you can expect to pay more for bore maintenance over the life of the bike and lose thermal efficiency and horsepower. Plated cylinders are harder and last longer than sleeved cylinders. Kawasaki cylinders with the original Electrofusion coating or hard-chromed cylinders can be repaired with nickel plating or sleeving. Steel or cast-iron sleeves cannot be nickel-plated unless they are separated from the aluminum cylinder. The pretreatment for the plating would disintegrate the aluminum. There are four companies that re-plate cylinders in the United States. The average cost to re-plate a cylinder is about \$200.

THE PISTON

Some unfortunate guys do more damage replacing the piston than the actual wear on the piston. Remove the circlips with small needle-nose pliers and throw them away. It is a common mistake to reuse circlips, but the cheap spring-steel wire clips will fatigue and break if you install them for a second time.

After removing the circlips, you have to remove the piston pin. Never use a hammer and punch to remove the pin. That will damage the connecting rod and needle bearings. Instead, use one of the pin-extractor tools available from your local franchised motorcycle shop. You can also grasp the piston with one hand and use a 3/8-in. socket extension to push the pin out with your other hand.

Too many people replace their pistons too often. The exact service interval for your bike depends on how hard the bike was run, for how many hours, the quality of the lubrication, and the amount of dirt or other debris in the intake air. Bikes that are run hard with dirty air filters may wear out pistons in only six hours, while bikes that are ridden easy with clean filters and adequate fuel octane may last 60 hours.



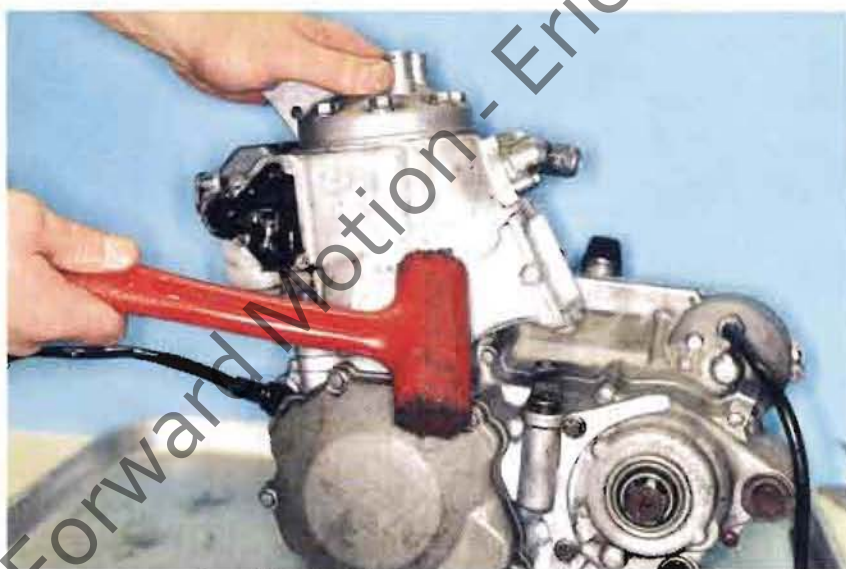
This Motion Pro piston pin extractor saves you from hammering on the rod to remove the piston.



Never use a chisel to break the cylinder loose from the crankcase.

MEASURING THE PISTON

It is best to measure the piston with a caliper. Digital calipers cost about \$100 at industrial tool companies such as Enco or Harbor Freight. A digital caliper is easy to use and gives accurate measurements on the piston diameter and cylinder bore. Measure the widths of the piston (front to back) just above the intake cutaway—this is the widest point of the piston. Check the maximum wear specs in your service manual. Check the piston for derotation marks in the crown, cracks in the skirt, or seizure marks. Look at the underside of the piston crown for a large black spot. The spot is burnt oil deposits that adhered to the piston because the piston crown temperature was too hot. This is an indication that the carb's main jet needs to be richer.



Use a plastic mallet to rock the cylinder up evenly. Damage to the cylinder gasket surface might cause it to leak.

LETTER DESIGNATIONS ON CYLINDERS AND PISTONS

The Japanese manufacturers use a letter designation system for paired cylinders. They intend for you to order replacement pistons based on the letter designation printed or stamped on the cylinder. In mass production, you can't guarantee that all parts will be exactly the same size. The size variance is based on an acceptable level of quality. Tool bits become dull, temperatures of machine tools change through production runs, and machine operators have inconsistent performance. The Japanese manufacturers have two to four different-sized pistons and cylinders, normally labeled A, B, C, and D. If they only had one size, the piston-to-cylinder wall clearance would vary between 0.001

and 0.006 in. In the standard Japanese alpha-labeling system, "A" denotes the smallest bore or piston size, and every letter after that is slightly larger, usually in increments of 0.0015 in. If you try to put a D piston in an A cylinder, the piston-to-cylinder wall clearance will be so tight that a seizure might occur.

Measure the piston at the bottom, from front to back. Pistons are cam ground and tapered specially for engine running conditions. A \$30 caliper is good enough to get an accurate measurement of the piston.





Pro-X piston kits come in increments of 0.0005 inch for most modern Japanese dirt bikes. LA Sleeve distributes Pro-X and more individual top-end engine components than any company in the world.

PRO-X OVERSIZE PISTON KITS

Pro-X is a marketing company that sells surplus pistons from the Japanese company ART, which makes all the cast pistons for the Japanese motorcycle manufacturers. These pistons are the same quality as the OEM pistons, and they are available in sizes larger than the alpha pistons available from franchised dealers. The Pro-X pistons are usually priced lower than OEM pistons. If the cylinder bore is slightly worn (up to 0.005 in.) with only a small area of bare aluminum exposed, you can install a Pro-X oversize piston. The Pro-X pistons are graded oversize in smaller increments than Wiseco pistons, but a wider range than the OEM pistons. For example, Wiseco pistons are sized in 0.010-in. increments and Pro-X pistons are sized in 0.001-in. increments. Before attempting to order a Pro-X piston, you must measure the cylinder bore at the smallest point and allow 0.002-in. clearance between the piston and cylinder.



Wiseco pistons are ideal for overboring and electroplating. The Wiseco rings are compatible with all types of nickel coatings.

MEASURING THE RING GAP

Measure the ring end gap to determine if the rings are worn. Place the ring in the cylinder and use the piston to push it down about 1/2 in. from the top, evenly spaced. Now use a feeler gauge to measure the width of the ring gap. Normally, the maximum gap is 0.018 to 0.025 in.

CYLINDER AND EXHAUST VALVE CLEANING TIPS

Does your cylinder have burnt-on mud on the outside, heavy brown oil glazing on the cylinder bore, or goopy oil on the exhaust valves? If so, there is a way to clean those parts without flammable cleaners. Go to the grocery store and get a can of aerosol oven cleaner. This stuff is great for cleaning the carbon from the exhaust valves without completely disas-



Boyesen Precision Porting makes trick circlip installation tools for 125- and 250-cc dirt bikes. The device has a plunger that installs circlips without the stress caused by pliers.

sembling them. Caution: Oven cleaner attacks aluminum; don't leave it on the cylinder for more than 20 minutes. Oven cleaner can be used on both steel and plated bores.

The oven cleaner will help loosen the oil glazing on the cylinder walls. Then, you can use a Scotch-Brite pad to hone the cylinder walls in a criss-cross pattern. Wear rubber gloves when you use oven cleaner and flush the cylinder afterward with soapy water to neutralize the acid in the oven cleaner and break the molecular bond of the oil, so the debris can be rinsed away. Sleeved cylinders (especially Kawasaki cylinder bores with Electrofusion coating) are vulnerable to corrosion after cleaning. Spray some penetrating oil on the cylinder bore to prevent it from rusting.

Caution: Certain types of cylinders corrode quickly after the cleaning process, so spray the bore area with penetrating oil to displace the water.

HONING THE CYLINDER BORE

Many people e-mail me with questions regarding honing cylinder bores. If you want to buy a hone to deglaze bores or polish off small scratches, a ball hone is the best choice. Ball hones are manufactured by Brush Research in Los Angeles, under the brand name Flex-Hone. These hones are available under different labels and are most easily available from auto parts stores. Buy a size that fits in the range of the actual bore size. Hones are available in several different materials and grits, but the profile that best suits both steel and plated cylinders is aluminum oxide or silicon carbide 240 to 360 grit.

A ball hone cannot remove material from the cylinder bore, especially on hard, nickel-plated bores. However, a ball hone can polish down the peaks of the original hone scratches and increase the bearing ratio. In other words, the piston will be touching a greater percentage of the bore. Sometimes that



A centrifugal governor mechanism converts rotary motion from the crankshaft and turns it into linear motion to vary the exhaust port's effective stroke matched to rpm. The four steel balls travel in channels on a ramp. The higher the rpm, the farther the balls travel up the ramp, overcoming the force of the spring.

makes the piston wear quicker, but if you have to ball hone the bore to remove scratches, it's a compromise. Never use a spring-loaded finger hone on a two-stroke cylinder. The sharp edges of the stone will snag the port edges and most likely damage the hone and the cylinder.

TOP-END ASSEMBLY

1. Install one of the circlips in the piston with the opening facing away in the 6 or 12 o'clock position.
2. Grease the cylinder-base alignment pins.
3. Set the exhaust valves in the closed position.
4. On cylinders with reed valves, leave the intake port open because you will need to reach in through the port to push the piston-ring ends back in place.
5. The best way to slip the piston into the bottom of the cylinder is to rotate the rings toward one side of the locating pins and squeeze the rings with your middle finger and thumb. That will leave your other hand free to position the cylinder.
6. There are two methods used to assemble the top end. The first method is to attach the piston to the connecting rod and lower the cylinder on to the piston assembly. The second method is to install the piston assembly into the cylinder and lower the cylinder and piston on to the connecting rod. The second method

is easier but involves pinning the piston and installing one circlip with a minimum amount of free space.

7. Take care to align the exhaust valve control mechanism as the cylinder is bolted to the crankcases.

GASKET HYGIENE

The oven cleaner you used to clean the cylinders will help loosen the old gasket material enough to remove it. Carefully scrape the gasket off with a gasket scraper. Never use a flat screwdriver to remove the old gaskets because the aluminum surfaces of the head, cylinder, and crankcases are easily gouged. If these surfaces are gouged on your engine, they should be draw-filed flat to prevent air or coolant leaks.

Never reuse paper gaskets; always replace them with new gaskets, and spray sealer on the paper gaskets, so they will seal better and will be easier to remove the next time. The new-style steel gaskets can be cleaned and reused a few times, but you'll need to spray the gasket with a sealer such as Permatex Spray-A-Gasket or copper-coat.

KEEP A LOGBOOK

Keep a logbook that tracks the number of riding days and the periodic maintenance. From reviewing the log, you will learn how often you need to service the top end if you record the measurements of the ring gap and the piston diameter. A logbook also gives you greater leverage when you try to sell your used bike for a premium price.

BIG BORE KITS

One of the best ways to increase horsepower is to increase displacement by overboring the cylinder. This can be ideal for play or vet-class riders, where the increased displacement won't be illegal for your race class. When done right, a big bore kit can give you more power everywhere rather than an increase in only the top or the bottom of the powerband. Such increases are typically more usable and give you more power where you need it.

Piston manufacturers such as Wiseco make oversize piston kits for popular model bikes. These kits boost the displacement of the cylinder to the limit of a racing class or to a larger displacement class, for example: 80 cc to 100 cc, 125 cc to 145 cc, 250 cc to 265 cc or 300 cc, and 495 cc to 550 cc.

Riders competing in the AMA veteran class can ride a bike with any displacement. Riders competing in hare scrambles and enduro can race the 200 cc class with a 125 converted to any displacement. AMA motocross and enduro racers can make the 250 cc bikes legal for open class by increasing the displacement a minimum of 15 percent (to 286 cc). Also, you should at least consult with an expert before tackling a big bore kit. To get the most from an overbored engine, you need to make sure the carburetion, exhaust, porting, and timing are all adjusted to suit the larger bore. There are several companies specializing in alternative displacement kits involving both overbores and crankshaft stroking.

PORT TIME-AREA

Port time-area refers to the size and flow range of the intake and exhaust ports, relative to rpm. The ports enter the cylinder bore at angles. When the cylinder is overbored, the transfer ports become lower and wider. The same thing happens to the exhaust port. This effectively retards the port timing and reduces the total degrees of duration. When the displacement of the engine increases, so does the demand for more port time-area.

If you just overbored and plated a cylinder, it would have much more low-end power than stock, but the top-end power would suffer. Normally, tuners have to adjust the ports to suit the demands of the larger engine displacement. The proper dimensions for the ports can be calculated using a computer program from Two-Stroke Racing (TSR). The program, "Port Time," enables tuners with limited math skills to run strings of formulas for determining the optimum dimensions of the ports. Generally speaking, if the ports in the overbored cylinder were raised to the same heights as the stock cylinder, it would make the port timing sufficient to run with stock or after-market exhaust systems.

CYLINDER HEAD

After overboring the cylinder, the head's dimensions must be changed to suit the larger piston. First, the head's bore must be enlarged to the finished bore size. Then, the squish band deck height must be set to the proper installed squish clearance. The larger bore size will increase the squish turbulence, so the head's squish band may have to be narrowed. The volume of the head must be increased to suit the change in cylinder displacement. Otherwise, the engine will run flat at high rpm or ping in the midrange from detonation.

EXHAUST VALVES

When the bore size is increased, the exhaust valve-to-piston clearance must be checked and adjusted. This pertains to the types of exhaust valves that operate within close proximity of the piston. If the exhaust valves aren't modified, the piston could strike the valves and cause serious engine damage. The normal clearance between the exhaust valves and the piston should be at least 0.030 in. or 0.75 mm.

CARBURETOR

The larger the ratio between the piston's diameter and the carb's size, the higher the intake velocity. Overbored cylinders produce higher intake velocity, which

draws more fuel through the carb. Of course, a larger engine will need more fuel. Normally, when you overhore an engine 15 to 20 percent, the slow jet will need to be richened and the main jet will need to be leaned. Start with the stock jetting and make adjustments after you ride the bike.

IGNITION TIMING

The ignition timing has a minimal effect on the powerband. Retarding the timing reduces the hit of the powerband in the midrange and extends the top-end overrev. ("Overrev" is a slang term that describes the usable length of the powerband at high rpm.)

The scientific reason for the shift of the powerband to extremely high rpm is because the temperature in the pipe increases with the retarded timing, and that enables the pipe's tuned length to be more synchronous with the piston speed and port timing of the cylinder.

Advancing the timing increases the midrange hit of the powerband, but makes the power flatten out at high rpm. The relatively long spark lead time enables a greater pressure rise in the cylinder before the piston reaches TDC. This produces more torque in the midrange, but the high pressure contributes to pumping losses at extremely high rpm.

PIPE AND SILENCER

Because only the bore size is changed, you won't need a longer pipe, only one with a larger center section. FMF's Fatty pipes work great on engines that have been overbored.

HEAD GASKET

Increase the bore diameter of the head gasket to the dimension of the new piston. If the head gasket overlaps into the cylinder bore more than 1 mm on each side, it could contact the piston or be susceptible to pressure blowouts.

11 TIPS FOR REBUILDING A TWO-STROKE TOP-END

1. Before you begin, power-wash the engine and the rest of the vehicle to

reduce the risk of dirt and debris falling into the engine. Once you remove the cylinder, stuff a clean rag down into the crankcases.

2. The cylinder and head use alignment pins to hold them straight in position from the crankcases on up. The pins make it difficult to remove the cylinder from the cases and the head from the cylinder. Sometimes the steel alignment pins corrode into the aluminum engine components. Try spraying penetrating oil down the mounting studs before attempting to remove the cylinder and head. Never use a flat-blade screwdriver, chisel, or metal hammer to remove the cylinder. Instead, use this technique: buy a lead-shot plastic mallet, swing it at a 45-degree angle upward against the sides of the cylinder. Alternate from left to right, hitting the sides of the cylinder to separate it from the cases evenly. Clean the steel alignment pins with steel wool and penetrating oil. Examine the pins closely. If they are deformed, they won't allow the engine parts to bolt together tightly, which can cause a dangerous air leak or a coolant leak. The pins are about \$2 each. Replace them if they're rusty or deformed.
3. Never reuse old gaskets. Remove them with a razor blade or gasket scraper. Don't use a drill-driven steel wool pad to remove old gaskets because the wool pad can remove aluminum from the cylinder and head, which will cause a gasket to leak.
4. Always check the ring end gap on a new ring by placing it in the cylinder between the head gasket surface and the exhaust port. The gap should be 0.012 to 0.024 in.
5. Always install the circlips with the opening facing straight up or down; that way inertia will hold it tight into the clip groove. Place one clip in the groove before installing the piston on the connecting rod. It's easier to install a clip with the piston in your hand than on the rod. There is also less chance that you'll drop the circlip in the crankcases.

6. Always install the rings on the piston with the markings facing up. Coat the rings with pre-mix oil so they slide in the groove when trying to install the piston in the cylinder.
7. Always install the piston on the connecting rod with the arrow on the piston crown facing toward the exhaust port.
8. The traditional way to assemble the top end is to install the piston assembly on the connecting rod, compress the rings, and slide the cylinder over the piston. That can be difficult with larger bore cylinders or if you're working by yourself. Try this method instead: Install one circlip in the piston, place the piston in the cylinder with the pin hole exposed, install the piston pin through one side of the piston, position the cylinder over the connecting rod, push the piston pin through until it bottoms against the circlip, and install the other circlip. It only takes two hands to install the top end this way, and there is less chance that you'll damage the rings by twisting the cylinder upon installation.
9. On cylinders with reed valves and large oval intake ports, take care when installing the piston assembly in the cylinder. The rings are likely to squeeze out of the ring grooves. Use a flat-blade screwdriver to gently push the rings back in the grooves so the piston assembly can pass by the intake port.
10. For steel head gaskets, place the round side of the "bump" facing up. Don't use liquid gasket sealer; use aerosol spray adhesive sealer instead. For hybrid fiber/steel ring head gaskets, place the wide side of the steel rings facing down.
11. When you initially start the engine after a rebuild, manipulate the choke to keep the engine rpm relatively low. Once the engine is warm enough to take it off choke, drive the vehicle around on flat, hard ground. Keep it under 2/3 throttle for the first 30 minutes. Two common myths for proper engine break-in are: A) Set the

engine at a fast idle, stationary on a stand. B) Add extra pre-mix oil to the fuel. When the engine is on a stand, it doesn't have any air passing through the radiator and can run too hot. When you add extra oil to the fuel, you are effectively leaning the carb jetting. This can make the engine run hotter and seize.

TROUBLESHOOTING PISTON FAILURES

Examining a used piston can give a mechanic helpful information on the condition of a two-stroke engine. When engine failure occurs, the piston is likely to take the brunt of the damage. Careful examination of the piston can help a mechanic trace the source of a mechanical or tuning problem. This is a guide for the most common mechanical problems.



1. *Perfect Brown Crown*

The crown of this piston shows an ideal carbon pattern. The transfer ports of this two-stroke engine are flowing equally and the color of the carbon pattern is chocolate brown. That indicates that this engine's carb is jetted correctly.



2. *Black Spot Hot*

The underside of this piston has a black spot. The black spot is a carbon deposit that resulted from pre-mix oil burning onto the piston because the piston's crown was too hot. The main reasons for this problem are overheating due to lean carb jetting or coolant system failure.



3. *Ash Trash*

This piston crown has an ash color, which shows that the engine has run hot. The ash color is actually piston material that has started to flash (melt) and turn to tiny flakes. If this engine had been run any longer, it probably would've developed a hot spot and hole near the exhaust side and failed. The main causes of this problem are too-lean carb jetting, too-hot spark plug range, too-far-advanced ignition timing, too much compression for the fuel's octane, or a general overheating problem.



4. Smashed Debris

This piston crown was damaged when debris entered the combustion chamber and was crushed between the piston and the cylinder head. This engine had a corresponding damage pattern on the head's squish band. The common causes of this problem are broken needle bearings of the connecting rod, broken ring ends, or a dislodged ring centering pin. When a problem like this occurs, it's important to locate where the debris originated. Also, the crankcases must be flushed out to remove any leftover debris that could cause the same damage again. If the debris originated from the big end of the connecting rod, the crankshaft should be replaced along with the main bearings and seals.



5. Chipped Crown Drowned

This piston crown chipped at the top ring groove because of a head gasket leak. The coolant is drawn into the combustion chamber on the downstroke of the piston. When the coolant hits the piston crown, it makes the aluminum brittle and eventually cracks. In extreme cases, the head gasket leak can cause erosion at the top edge of the cylinder and the corresponding area of the head. Minor leaks of the gasket or O-ring appear as black spots across the gasket surface. When an engine suffers from coolant being pressurized and forced out of the radiator cap's vent tube, it is a strong indication of a head

gasket leak. In most cases, the top of the cylinder and the face of the cylinder head must be resurfaced when a leak occurs. Most MX bikes have head-stays mounting the head to the frame. Over time, the head can warp near the head-stay mounting tab because of the forces transferred through the frame from the top shock mount. It's important to check for warpage of the head every time you rebuild the top end.



6. Shattered Skirt

The skirts of this piston shattered because the piston-to-cylinder clearance was too great. When the piston is allowed to rattle in the cylinder bore, it develops stress cracks and eventually shatters.



7. Snapped Rod

The connecting rod of this engine snapped in half because the clearance between the rod and the thrust washers of the big end was too great. When the big-end bearing wears out, the radial deflection of the rod becomes excessive and the rod suffers from torsion vibration. This leads to connecting rod breakage and catastrophic engine damage. The big-end clearance should be checked every time you rebuild the top end. To check the side clearance of the connecting rod, insert a feeler gauge between the rod and a thrust washer. Check the maximum wear limits in your engine's factory service manual.



8. Four-Corner Seizure

This piston has vertical seizure marks at four equally spaced points around the circumference. A four-corner seizure occurs when the piston expands faster than the cylinder and the clearance between the piston and cylinder is reduced. Also common, a single-point seizure on the center of the exhaust side of the piston occurs only on cylinders with bridged exhaust ports. The main causes of single-point seizure are too-quick warm-up, too-lean carb jetting (main jet), or too-hot spark plug range.



9. Multi-Point Seizure

This piston has multiple vertical seizure marks around the circumference. This cylinder was bored to a diameter that was too small for the piston. As soon as the engine started and the piston started its thermal expansion, the piston pressed up against the cylinder walls and seized. The optimum piston-to-cylinder wall clearances for different types of cylinders vary greatly. For example, a 50-cc composite plated cylinder can use a piston-to-cylinder wall clearance of 0.0015 in., whereas a 1200-cc steel-sleeved cylinder snowmobile set up for grass drags will need 0.0055 to 0.0075 in. For the best recommendation on the optimum piston-to-cylinder clearance for your engine, look to the specs that come packaged with the piston or consult your factory service manual.



10. Intake Side Seizure

This piston seized on the intake side. This is very uncommon and is caused by only one thing—loss of lubrication. There are three possible causes for loss of lubrication: no pre-mix oil, separation of the fuel and pre-mix oil in the fuel tank, water passing through the air filter and washing the oil film off the piston skirt.



11. Composite Flaking

Most two-stroke cylinders used on motorcycles and snowmobiles have composite plated cylinders. The composite material is made of tiny silicon carbide particles. The electro-plating process enables the silicon carbide particles to bond to the cylinder wall. The particles are very hard and sharp; they don't bond to the ports so the manufacturer or reconditioning specialist must thoroughly clean the cylinder. Sometimes the silicon carbide "flaking" breaks loose from the ports and wedges between the cylinder and the piston. This causes tiny vertical scratches in the piston. This problem isn't necessarily dangerous and doesn't cause catastrophic piston failure, but it should be addressed by thoroughly flushing the cylinder and ball honing the bore to redefine the crosshatching marks.

This type of problem can also be caused by a leak in the air intake system. Debris such as sand or dirt can cause the same type of tiny vertical scratches in the piston skirt and cylinder wall.

However, the main difference is the color of the piston crown and spark plug. Dirt will leave a dark stain on the piston and sand will make it look shiny, like glass. That's because melted sand is essentially glass. Normally, you will need to replace the piston kit because the scratches will reduce the piston's diameter beyond the wear spec.



12. Burnt-Out Blow-Hole

This piston overheated so badly that a hole melted through the crown and collapsed the ring grooves on the exhaust side. Normally, the piston temperature is higher on the exhaust side so catastrophic problems will appear there first. There are several reasons for a failure like this. Here are the most common: air leak at the magneto-side crankshaft seal, too-lean carb jetting, too-far-advanced ignition timing or faulty igniter box, too-hot spark plug range, too-high compression ratio, or too-low-octane fuel.



13. Blowby

This piston didn't fail in operation, but it does show the most common problem, blowby. The rings were worn past the maximum end-gap specification, allowing combustion pressure to seep past the rings and down the piston skirt, causing a distinct carbon pattern. It's possible that the cylinder wall's crosshatched honing pattern is partly to blame. If the cylinder walls are glazed or worn too far, even new rings won't seal properly to prevent a blowby problem. Flex-Hones are available at most auto parts stores. They can remove oil glazing and restore crosshatch honing marks that enable the rings to wear to the cylinder and form a good seal. If you purchase a Flex-Hone for your cylinder, the proper grit is 240 and the size should be 10 percent smaller than the bore diameter.

14

**14. Shattered and Scattered**

This piston was allowed to run way past its service life. Too much clearance between the piston and cylinder wall caused stress cracks to form at several points. Amazingly enough, this piston shattered and the engine quit without causing any significant damage. Most of the debris was deposited in the exhaust pipe. I flushed the crankcase, replaced the crank seals, bored the cylinder, and fitted a new piston.

15

**15. Bridge Point**

This piston has a deep wear mark in line with the exhaust bridge. Two different things can cause a problem like this. The most common problem is that the right-side crankshaft seal is leaking, causing tranny oil to enter the bore. The ionic charge of the friction present at the exhaust bridge and the oily debris cause an attraction. The oily debris works like an abrasive media to accelerate the wear at the exhaust bridge. Another common problem is a lack of proper relief clearance on the exhaust bridge. When a cylinder is repaired or overbored, the exhaust bridge must be ground for extra clearance over the bore size because the exhaust bridge gets hotter than other areas of the cylinder. The extra relief clearance compensates for expansion. The normal relief clearance is 0.001 to 0.003 in. Generally speaking, the wider the exhaust port in relation to the bore size and the narrower the bridge, the less relief needed. Too much bridge relief will cause the rings to flex the exhaust port and break.

16

**16. Piston Bounce**

Do you notice the distinct circular line located near the outside of the piston? It was caused by contact between the piston and the cylinder head's squish band at TDC (top dead center). There are several causes for this problem, ranging from worn connecting rod bearings to an improperly modified cylinder head. The optimum clearance between the piston and head at TDC is 0.040 to 0.080 in, depending on the displacement of the engine. The larger the displacement, the greater the clearance required.

17

**17. Arrow Forward!**

This piston was installed backward, meaning that the arrow on the piston crown was pointing to the rear of the bike. The ring end gap was aligned with the exhaust port and the rings expanded out of the groove into the exhaust port, causing them to shear off in the exhaust port. This engine suffered catastrophic damage and required a new cylinder and piston.

Piston manufacturers use the standard of stamping an arrow on the crown that points toward the front of the bike or the exhaust port. Another indication of the correct piston position is to have the ring centering pins facing the intake side of the cylinder. There is only one motorcycle I've ever known that opposes this rule—the early model Kawasaki KDX 175. That model has a piston with ring centering pins aligned on both sides of the exhaust port.



18. Four-Stroke Contact

This piston is from a modern big bore chumper. The cam chain tensioner failed, allowing the cam chain to jump a few teeth on the camshaft which allowed the exhaust valves to contact the piston. This can also be caused by any other problem that allows for valve float or a slack cam chain. For example, the chain guides can wear out, the chain can wear, the cam or crank sprockets can wear, and automatic cam chain tensioners can fail abruptly. Valve float can occur when the engine is over-revved or the valve springs break. Most times this happens when an aggressive camshaft is installed without stiffer valve springs.



19. Reading Piston Burn Patterns

Reading the burn patterns that naturally form on the crowns of pistons can give a tuner insight into several aspects of the engine's performance and condition.

The color and arrangement of the burn patterns and the location with regards to the different types of ports provide insight into what types of changes will make the engine run its best.

The piston shown here is from an RM125. The bike was running a bit weak throughout the rpm range. These are some of the observations of the burn patterns and how they relate to the engine's condition and carb jetting.

1. Outer edge: The light gray color indicates lean carb jetting. Mocha brown is the optimum color, but some oils, such as Yamalube R, have additives that prevent carbon from forming on the piston crown.
2. Front edge: The two black spots align with the sub-exhaust ports and indicate exhaust blowback when the sub-exhaust port valves are closed. If the exhaust valves were carbon-seized and stuck closed, the carbon patterns would be much larger.
3. Rear edge: The two small black spots are above the ring alignment pins. The black spots show pressure leakage, possibly from excessive ring-end gap, which enables the combustion gas to escape past the ring gap and leave a carbon trail in its wake.
4. Rear band: The intake side of the squish band has some light brown patterns. That is the appropriate color for the center pattern when the carb jetting is right. If the color were dark brown, it would mean that the engine is running on the rich side or that the engine doesn't run at the right temperature.
5. Center: The center pattern shape can explain how the engine is running. This pattern is shaped like a heart, showing the flow patterns through the transfer ports. Notice the left side is slightly larger, which indicates that the flow rate of the right-side transfers is greater than the left side. That means that the area and timing

of the left-side transfer ports need to be adjusted to match the right side.

TWO-STROKE EXHAUST VALVES

Three words sum up exhaust valve maintenance: spooney, gooey, and grungy. If two-stroke exhaust valves didn't have such a dramatic effect on the engine's powerband, I'm sure mechanics would remove them and beat them to bits with a hammer in frustration. There is little information given by the manufacturers on how to diagnose and repair the exhaust valve systems on well-used dirt bikes. This section provides a guide to characteristic mechanical problems that occur in exhaust valve systems of dirt bikes and covers tips on how to re-time exhaust valve systems.

How Exhaust Valves Work

An exhaust valve system is designed to increase the engine's low-end and midrange power. There are three different designs of exhaust valve systems. The first-generation design uses a variable-volume chamber mounted to the head pipe to change the tuned length of the head pipe. A butterfly valve separates the surge chamber and the head pipe. At low rpm, the valve is open to allow the pressure waves in the pipe to travel into the surge chamber, effectively lengthening the pipe and reducing the pressure wave's magnitude when it returns to the exhaust port. This design was primitive and not very effective on 125-cc dirt bikes. Honda and Suzuki used this type of exhaust valve system in the mid- to late-1980s.

The second-generation design features valves that control the effective stroke and the time area of the exhaust port. These valves are fitted to the sub-exhaust ports and the main exhaust port. The main exhaust-port valves operate within close proximity to the piston to control the effective stroke of the engine. The effective stroke is defined as the time from TDC to when the exhaust port opens. At low rpm, the engine needs a long effective stroke, which results in a high compression ratio. At high rpm, the engine needs a

shorter effective stroke, longer exhaust duration, greater time-area, and a lower compression ratio. Yamaha used this system starting in 1982 on the YZ250. Honda's HPP system is similar and was used on the 1986 to 1991 CR250 and 1990 to current-model CR125.

The third-generation design of exhaust valve systems attempts to change the exhaust-port velocity, effective stroke, exhaust-gas temperature, and compression wave pressure. Yamaha and Suzuki started using these systems on their 125s in 1995. Both companies employed a venting system to the outside atmosphere. This is very complex because they are attempting to affect the temperature and pressure of the returning compression wave to synchronize it with the piston speed. Two oval wedge valves that enter the exhaust port at a 45-degree angle control the exhaust-gas velocity and the effective stroke. The wedge valves partially block the exhaust port, thereby boosting the gas velocity. Kawasaki's KIPS system uses wedge valves in the main exhaust port to control the effective stroke, drum valves in the sub-exhaust ports to control the time area, and a surge chamber to absorb the excess compression-wave pressure at low rpm.

A centrifugal governor mechanism opens and closes the exhaust valves. The governor is mounted under the right side cover and is gear-driven by the crankshaft. As the engine rpm increases, the governor spins, increasing the angular momentum of the four steel balls encased in the governor. The steel balls fit into an angled ramp-and-cup arrangement. A spring places tension on the steel balls. When the momentum of the steel balls overcomes the spring's tension, the balls force their way up the angled ramp. A spool attached to the ramp enables it to change its linear position with changes in rpm, and the spool is attached to a linkage system that operates the exhaust valves in the cylinder. Factory race teams have different combinations of springs, ramps, and balls to tune the exhaust valve operation and enhance the powerband.



This is a layout of the CR125 HPP 1990 to 1999. Rectangular guides position the exhaust valves that slide in and out to vary the exhaust port. If the clips come off the ends of the valves, the valves could fall into the bore and hit the piston. The 1998 model uses an L-shaped guide that prevents the valves from wearing and contacting the piston. The 1998 model valves are less expensive than previous models and fit back to model year 1990.

EXHAUST VALVE TIPS AND TUNING

Although exhaust valves use the same essential principles, the implementation is different with each manufacturer and each type has its own flaws and fixes. The list below gives you tips on how to install and service the most common exhaust valves, as well as some tuning tips.

HONDA HPP

Honda's HPP system started as a butterfly-operated canister mounted between the cylinder and pipe. It served to control the volume and length of the exhaust pipe. It had little effect on the power, and most aftermarket pipes eliminated the canister. The butterfly was prone to carbon seizure and required frequent maintenance. The next-generation HPP was used on the 1986 to 1991 CR250. This system featured two sliding valves that operated within close proximity of the piston and effectively varied the exhaust port time-area in accordance with rpm. The square valves moved

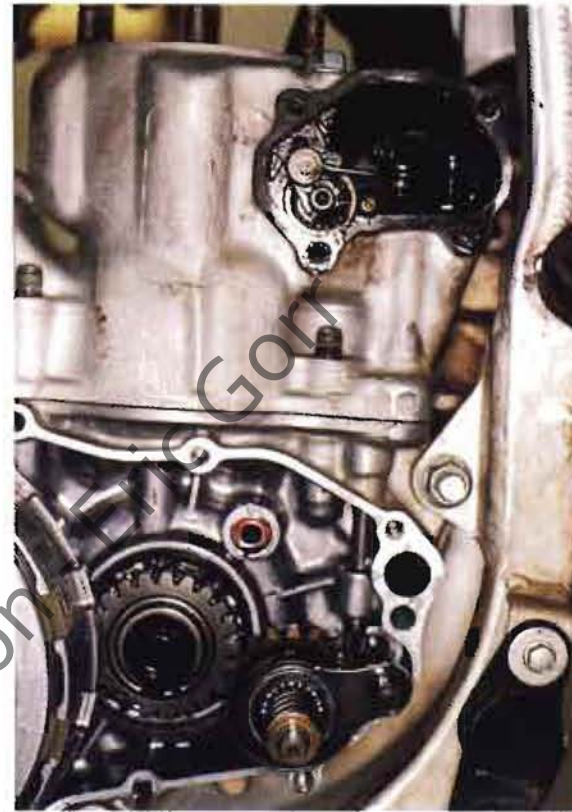
horizontally through a valve guide. The system was plagued with a mixture of design problems and misinformation on how to service and re-time the complicated exhaust valve arrangement. This section lists some common problems and some tips for timing the system, installing the cylinder, and engaging the HPP mechanism.

Common HPP Problems

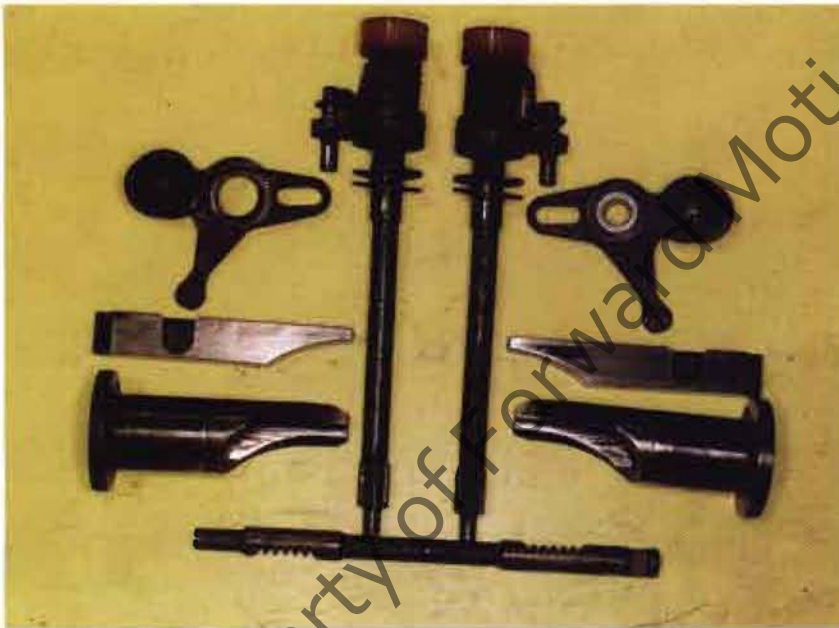
Two main problems plague the HPP system: carbon fouling and rack-and-cam-spindle damage. The square shape of the valves contributes to the accumulation of carbon in the corner of the valve guide (stationary part) that is directly in the exhaust gas stream and this causes the valve to become carbon-seized. Chamfering the corresponding edge (1 mm) of the valve will eliminate this problem. The rack-and-cam spindles are easily damaged when the cylinder is installed incorrectly or the HPP mechanism is engaged incorrectly. See the photos for examples of damaged rack-and-cam spindle parts.



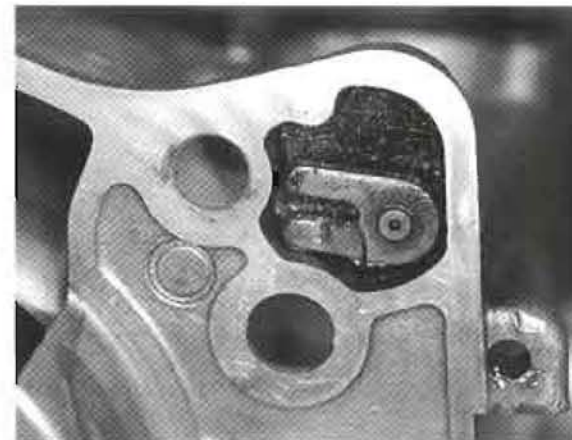
This is the CR125 2000 exhaust valve system. It's similar to the design proven on Honda's line of road racers and two-stroke sport bikes in Japan. Two main valves are actuated from a single pivot to accurately vary the exhaust port's width and effective stroke. This system has a chronic problem of carbon seizing, so you can't remove the shaft from the valves to service them.



This is the late-model CR250 1992 to 2000. Unlike earlier models, there is no manual engagement bolt. However, there is still an actuating rod in the cases and cylinder, which must align properly.

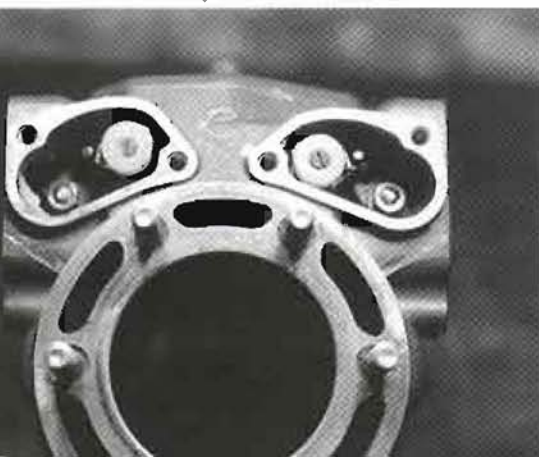


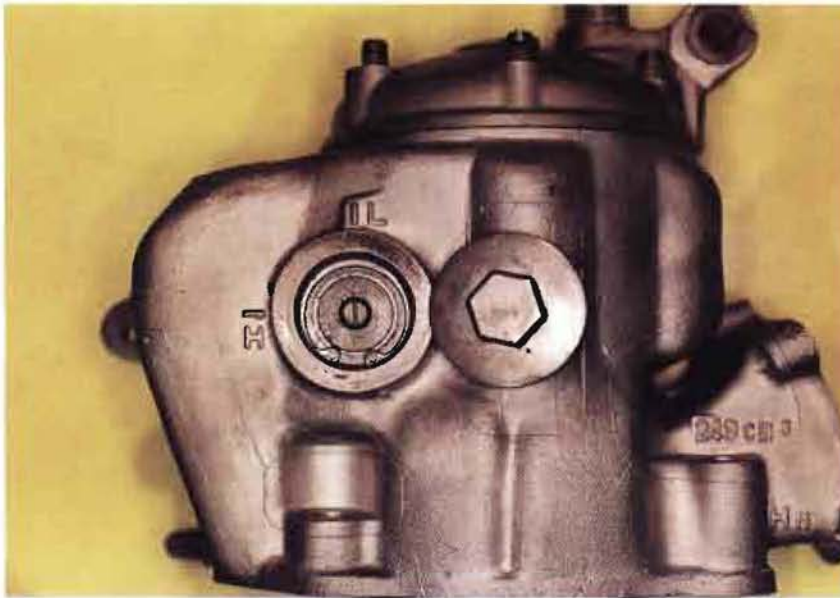
This is a layout of the CR250 HPP 1986 to 1991. This system uses a complicated rack-and-pinion linkage to control the rectangular valves of the left and right exhaust ports. The cylinder and crankcase actuating joint have to be engaged simultaneously with controls on the cylinder.



This is a view of the forked actuating rod from the bottom of the cylinder. Notice that it is cracked. That happened because the cylinder was tightened down with the actuating rods out of alignment. This part needs to be replaced.

This is the correct position of the 1988 to 1991 Honda CR250 HPP pinion shafts when the cylinder is seated on the cases correctly.





You can quickly check the operation of the HPP system of a late-model CR250 (1992 to 2000). Remove the 17-mm cap bolt from the left side of the cylinder. The L and H marks stamped on the cylinder indicate the low- and high-rpm positions of the valves. The line carved in the center rod is the left HPP valve's. You can run the engine with this cover removed to check the valves, but don't let it get exposed to dirt.



This is a layout of the CR250 1992 to 2000 HPP system. The center valve pivots from one end, and a rod through the front center of the valve links the two sub-exhaust valves. The center valve tends to get caked with carbon, hindering its operation. Clean the valve with a wire brush, and pay special attention to the center of the valve that controls the full open and full closed position of the side sub-exhaust valves. You can use a small-diameter round file to remove the carbon from the center valve.

HPP Timing Procedure

Use the following procedure to time the HPP system.

1. Install the HPP valves and levers, and tighten the pivot nuts. Place the washer on the stud first, then the lever (marked left and right), and then the flanged center hushing with the flange side facing up.
2. Turn the cylinder upside down. To position the rack correctly, slide it to the left until it stops; then move it right 2 mm. Rotate the rack so the square notch faces you. Now the rack is in the correct position to install the pinion shafts. Carefully turn the cylinder right-side-up without changing the position of the rack.
3. Close the valves and install the left pinion shaft with the screwdriver slot facing the 1 o'clock position. Install the right pinion shaft with the screwdriver slot facing the 11 o'clock position (see photo for correct positions). A simple way to determine if the pinions are mistimed to the rack is to look at the screwdriver slots. The wrong position is with both slots facing 12 o'clock.

Installing the Cylinder and Engaging the HPP Drive

After timing the HPP mechanism, the cylinder is ready to be installed on the crankcases. Here are some tips for installing the cylinder and engaging the HPP drive mechanism.

1. Make sure the reed valve is removed from the cylinder. CR250s have such large intake ports that the rings tend to slip out of the ring grooves during installation of the cylinder. This takes the spring pressure off the cam spindle. Turn the engagement bolt 1/4 turn clockwise. You should feel it positively lock into a groove and stop. Remember that the HPP engagement bolt is a spring-loaded detent not a threaded bolt. Slide the cylinder down onto the piston and rings; use a screwdriver to push the rings back in the grooves until the rings clear the intake port.

2. The HPP mechanism should be engaged while the cylinder is being installed, just to keep the cam spindle in position. The cylinder will stop about 3 mm from the crankcases because the cam spindle and the rack are misaligned. Disengage the HPP mechanism by turning the engagement bolt 1/4 turn counterclockwise. Grasp the right-side valve lever and wiggle it; the cylinder should then drop evenly onto the crankcases.
3. Bolt the cylinder down tight. The best way to engage the HPP mechanism is to insert a screwdriver in the right-side pinion shaft and turn it counterclockwise. Now turn the engagement bolt clockwise. You should feel the engagement bolt lock positively in position. If you try to rotate it too far, you will bend the cam spindle and the system won't work at all, so don't be a hammer-head. The best way to check the HPP system is to remove the left-side valve cover from the cylinder, start the engine and warm it up, and then rev the engine. The valves should be fully closed at idle and fully open when the engine is revved.

In 1992, Honda introduced the HPP system currently used on the CR250. The system features a center valve for the main exhaust port and two rotating drum valves to control the flow of the sub-exhaust ports. The system also features a return of the old resonator as used on the mid-1980s model. The resonator improves the throttle response and mellows the powerband at low rpm. A thin rod links the valves together, and the whole system is mostly self-scraping to prevent carbon buildup. The inside of the center valve has an elongated passage where the tie rod travels. This elongated passage is prone to carbon buildup over time (one to two years). The carbon limits the range of movement in the valves. The carbon is easily removed by using a small-diameter rat-rail file. The sides of the center valve and the drum valves interface, and that area is prone to

carbon buildup as well. A wire brush or file is an effective tool in cleaning the exhaust valves. Here is a simple way to check the operation of this system: On the left side of the cylinder there is a 17-mm cap bolt that exposes a straight-line mark in the left drum valve. There is a corresponding mark on the cylinder. The "L" mark denotes the low-speed position of the valve, and the "H" denotes the high-speed position. To check the HPP, start the engine. At idle, the valve should align with the "L" mark. Then rev the engine; the valve should align with the "H" mark. If the angle of the mark on the valve is slightly off, the valve probably needs to be decarboned. The system is very easy to disassemble and can only fit together one obvious way so I won't waste space on that procedure.

There are some aftermarket parts to adjust the performance of this system for different types of dirt biking. Pro-Racing in England makes a spacer for the right-side valve cover. It serves to add volume and length to the resonator part of the system. This is especially suited for enduro riding where a smooth transition to the midrange is important for better traction. ESR (Eddie Sanders Racing) in California makes a replacement HPP system that holds the valves wide open. The center exhaust valve is thinner, which enables tuners to raise the exhaust port. The ESR system is primarily used for dirt track or kart applications where low-end power is of no consequence.

Whenever the cylinder is installed on the bottom end after top-end rebuilding, the valves need to be put in the closed position. Otherwise, the HPP cam spindle that connects the actuator in the cases to the cylinder will get damaged when you tighten down the cylinder. That will also make the valves inoperable. Always check the HPP valve operation after you assemble the top end by using the inspection cap on the left side of the cylinder.

The CR125 HPP system was redesigned in 1990. Honda chose to use a system similar to the 1986 to 1991

CR250, featuring horizontally sliding valves. This system has been plagued with problems over the years. The valves are prone to carbon seizure because the critical square edges face the exhaust stream. If the clips that fit on the ends of the valves vibrate off, or if the valve wears too much, then the valve can tilt on an angle and strike the piston. Another common related problem happens when tuners widen the exhaust port during porting and neglect to grind the valves at the outer corners for piston clearance. There again, the valves strike the piston because they protrude into the bore.

In 1998, Honda made a modification to the valves; they added an L-shaped rib that prevents the valves from angling in and contacting the piston. The problem of clearance between the top of the valve and the guide was eliminated, and the new-style valves provide more low-end power. The valve and guide sets from the 1998 to 1999 models fit the CR125 models back to 1990.

In 2000, Honda redesigned the CR125 engine and adapted the exhaust valve system used on the RS250 road racer. Honda also used this system on several dual-sport and street bikes sold in Asia and Europe. The new system is simple and effective. It is a wedge-shaped valve that pivots at one end, similar to the CR250. The valve is much thicker and can vary the exhaust port's effective stroke, time-area, and duration over a wider rpm range. It's a self-scraping setup, so maintenance should be greatly reduced over previous models.

KAWASAKI KIPS

Kawasaki's KIPS exhaust valve system has gone through steady design refinement. Kawasaki uses a different system to suit the needs of the different model bikes. The earliest KIPS design used two drum-shaped valves to control the flow of the sub-exhaust ports. Opening the ports gave the exhaust port more time-area. The main exhaust port was relatively small with modest timing and duration. A rack-and-pinion setup

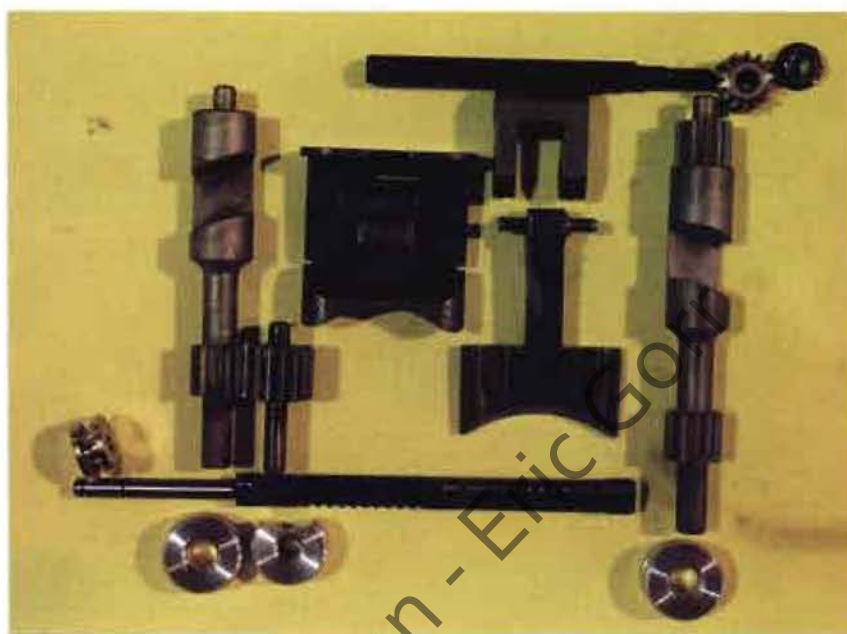


This is a common problem for all KX and KDX models that use aluminum drum valves—the gear teeth tend to shear when the valves become carbon-seized.



All KX250s use a yoke lever like this to transfer the linear motion of the centrifugal governor into the actuator rod. If your bike starts running poorly, unbolt the plastic cover on the lower right side of the cylinder and make sure that the actuator rod is moving in accordance with rpm. If not, the yoke lever is probably broken.

controlled the drum valves, opening them at about 6,000 rpm. Kawasaki used the rack-and-pinion design in all of its KIPS systems except the 1998 and later KX80-cc and 125-cc models. The 1992 KX125 and KDX used the next-generation KIPS, which featured a center-wedge valve with two side-drum valves engaged to a rack-and-gear actuating system. The system is very



This is a typical KIPS system for the following models: 1992 to 1997 KX125, 1995 to 2000 KDX200, and 1993 to 2000 KX250. As you can see, there are a lot of moving parts. The two racks must be timed with gears to link the main center valves and the drum valves. This valve system performs well, but it requires a lot of maintenance.

complicated with all its moving parts. The top and bottom racks have to be synchronized through the left drum valve, which has two drive gears molded in it. The drum valves are made of aluminum. When the drum valve becomes carbon-seized, the steel teeth on the rack shear off the aluminum teeth on the drum valve, rendering the drum valve inoperable. Check the condition of the gear teeth every time you do a top-end service, because if one gear fails the whole system runs out of sync. On the late-model 80-cc and 125-cc KXs, the KIPS is relatively simple, relying on a wedge valve and flapper. The system is self-scraping, so it requires little maintenance.

In the first year of operation (1998), the KIPS system was plagued with failures such as the pin breaking on the flapper, the valve receding into the cylinder and contacting the piston, and over-extension of the valve causing cock and jam. Pro-Circuit made an aftermarket valve cover with a full stop that prevented over-extension and, in 1999, Kawasaki changed the wedge valve and flapper

design for more rigidity, which solved all the reliability problems.

The drum valves on the 1988–1992 KX250 and 1990–2000 KX500 are aluminum but have a hard-anodized coating that resists wear. However, the drum valves eventually wear at the drive channels for the center wedge valve, and the sloppy fit between the wedge and drum valves prevents the center valve from fully opening. That is why the bikes get noticeably slower as they get older. There is no preventive cure or aftermarket fix. You just need to replace the drum valves when the drive channels wear out.

The 1993 KX250 was the first year for the KIPS system used through present-day models. The system uses a single wedge and flapper valve for the main exhaust port and two drum-shaped valves for the sub-exhaust ports. The valves are linked together with two rack-and-pinion units on the right drum valve and a steel gear on the upper rack linking the wedge valve. A left-hand-thread nut retains the gear to the rod that actuates the wedge valve. Check the



This is the new-generation KIPS system used on the 1998 and newer KX80, 100, and 1998 to 2002 125 models. There are three pieces: a stationary guide, a sliding valve, and a pivoting flapper. This design is mostly self-cleaning and should be checked every time you service the top end. It's normal for a large amount of sludge to accumulate under the valve cover.

nut periodically; if the nut loosens, the wedge valves become inoperable. The KX250 KIPS also features two large cavities to allow for dissipation of the compression wave that travels back up the exhaust pipe at low- to mid-rpm. It's important that the two valve covers on the cylinder are sealed with gaskets, and it is normal for large amounts of black sludge to accumulate under those valve covers. It takes years for the sludge to accumulate to the point of adversely affecting performance. The only way to clean out the sludge is to have the cylinder hot tank cleaned at an automotive rebuilding store.

The 1993–2000 KX250 wedge valve tends to form burrs at the outer edges that face the piston. The burrs prevent the wedge valve from opening fully, and the thin flap that comprises the exhaust-port roof hangs out into the exhaust-gas stream, producing a shock wave that closes off the exhaust port. File the burrs until smooth and check the wedge valve through the full range of movement. The valve pocket in the cylinder gets worn too. Aftermarket cylinder rebuilders such as Max Power Cylinders apply a hard coating to that area to reduce wear and build up areas that have worn down from the moving wedge valve.



The 1998 to 2005 KX80, 85, and 100 use this clumsy pinion lever to actuate the KIPS valves. The easiest way to service the top end is to start by removing the bolt that retains the pinion shaft and lift the shaft off with the cylinder. To install the cylinder, close the valves and align the dot on the shaft with the open bolt hole or the valves won't work because they won't be timed correctly.

Another characteristic problem of the KX250 KIPS is broken governor levers. The lever that transmits the movement from the centrifugal governor to the right-side case lever tends to break in half. The piece is located under the right-side cover. If your KX250 suddenly loses top-end power, it's probably due to a broken actuating lever or the carbon-seizure of the KIPS valves.

1988–1992 KX250 and 1990–2000 KX500 KIPS Timing Procedure

The explanation of this procedure, as written in the Kawasaki service manual, is confusing. It requires you to time the upper and lower racks at the same instant. My method of timing the exhaust valves uses simple steps that enable you to check your work as you go. The 1988–1992 KX250 and KX500 use the drive-channel system to actuate the center valve. Here is the best way to time the KIPS on these models.

1. Set the cylinder upside down on a bench.
2. Install the center valve but don't bolt it in.
3. Install the side drum valves and align the drive channels on the drum

valves with the center valve, but don't bolt it in.

4. Lift up the drum valves so the bottoms of the gears are flush with the cylinder base. Take care not to disengage the center valve.
5. Slide in the rack from either side of the cylinder. Position the rack by installing the seal pack and pulling the rack out until it bottoms against the seal pack. This is the full-open position.
6. Drop the drum valves onto the rack so the valves are in the full-open position. Don't pay attention to alignment dots or marks on the valve or rack; just remember that the valves should be open when the rack is pulled out and closed when the rack is pushed in.

1992–1997 KX125 and 1993–2004 KX250 KIPS Timing Procedure

The system on the KX125 and KX250 uses both wedge and drum valves with racks. This is the best exhaust valve system for performance but the most difficult to maintain. Here are some tips for retiming this KIPS system.

1. Install the wedge valves in the cylinder and the actuating rod and lever. Squirt some pre-mix oil on the parts.
2. Pull the wedge valve into the full-open position, place the gear on the end of the rod, and rotate the gear counterclockwise until the rack butts against the stop plate. Thread the nut on the rod and tighten it counterclockwise; it is a left-hand-thread nut.
3. Place the drum valves into their respective cavities until the top of the gears are level with the cylinder base. Now push the lower rack into place and bolt the seal pack on the rack into the cylinder.
4. Pull the rack out until it stops and push it in 1 mm; now it is in the correct position to install the drum valve. Before you push the drum valves down, make sure the wedge valve and drum valves are in the full-open position.
5. Push the drum valve down with the two gears first; it must engage the



The most common problem with Suzuki exhaust valve systems has to do with the actuating lever spring. On the top right side of the cylinder, there is a shaft that the valves are linked to. If you remove the actuating lever, the spring may snap loose and cross ends. The spring ends should always be parallel in order for the valves to move.



upper rack and lower rack simultaneously. Take care and be patient. You may have to wiggle the wedge valve yoke to get everything to fall into place. Never hammer the drum valves! Push down the right drum valve and

install the idler gear. Now install the bushings and check the system. The valves will bind and stick if you try to move the valves without the bushings installed or if the cylinder is facing upside down. Test the KIPS in this

way: pull the rack outward until it stops, and then look through the exhaust port from the pipe side. The valves should be in the full-open position. On cylinders where the base has been turned down more than 0.010 in., the drum valve bushings will also need to be turned down to prevent the valves from binding when the cylinder is tightened.

SUZUKI ATEV

Suzuki first used exhaust valves in 1985, using a drum valve that uncovered a cavity in the head or cylinder to add volume and length to the exhaust pipe, strictly at low rpm. In 1987, they employed a system that featured two large valves that had multiple functions. The system was used on the 1989–2000 RM80, 1987–2000 RM125, and 1987–95 RM250. The wedge-shaped valve was positioned at about a 45-degree angle over the exhaust port. The ATEV system is designed to regulate the effective stroke exhaust-gas velocity through the exhaust port, and on 1995 and later models, it controls the exhaust-gas temperature. The ATEV system is self-cleaning in that carbon is scraped off the valves every time they move. Some of the early RM models suffered from broken exhaust valves when the stem would detach from the cylindrical wedge. That problem was cured in 1991 when the radius between the stem and valve was increased. The two common problems that occur with the ATEV are caused by two errors in assembling the system.

1. Too much preload on the spring. On the left side of the cylinder there is a dial that controls the spring preload for the exhaust valve system. The preload doesn't have a great effect on the engine's powerband, but too much preload will prevent the valves from opening, which causes a lack of top-end power.
2. Crisscrossed spring. A centering spring on the right side of the cylinder, located on the rod, actuates the valves. This spring is commonly installed incorrectly. The spring tabs



This is a typical layout of the valves used on the following models: 1989 to 2005 RM80 and 85, 1988 to 2003 RM125, 1989 to 1995 RM250, and all RMX models. The cylindrical valves are comprised of a stationary guide and a sliding valve. A knob mounted on the top left side of the cylinder provides spring tension. It's common for the left spring to get twisted in half from turning the knob too much or in the opposite direction (counterclockwise).



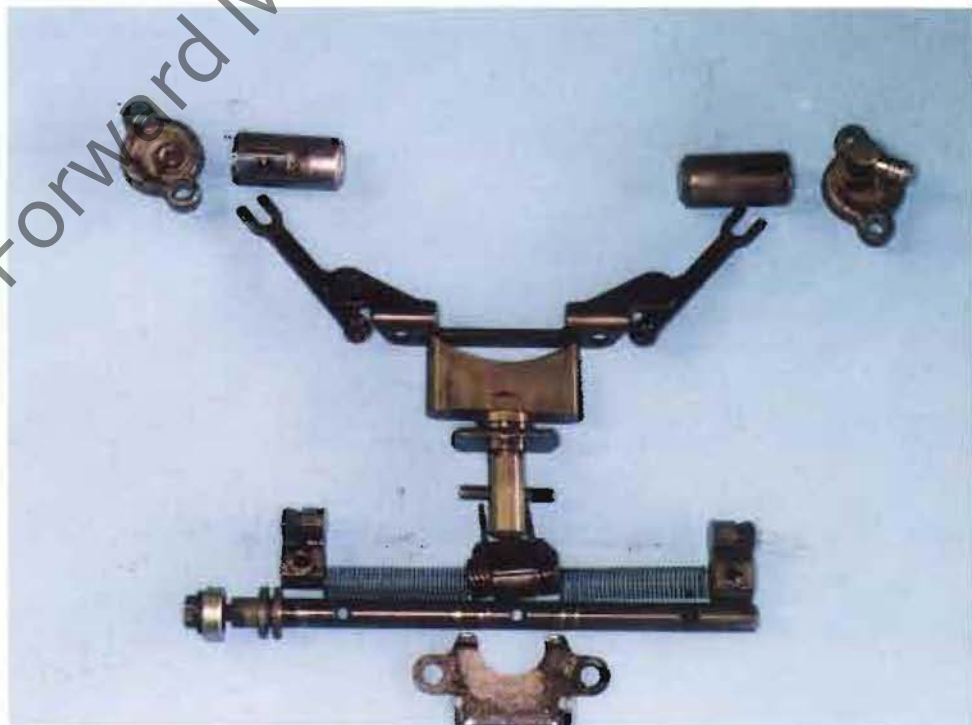
Starting in 2001, Suzuki changed its exhaust valve system every year until 2004 on the RM250, fiddling around with everything from electronic solenoids to cam levers and other components. Finally, in 2003, Suzuki settled on a copy of Yamaha that sidestepped its patent. My advice is: If the valves move through their operation, don't attempt to disassemble and clean them.



This is the original power valve design that Yamaha patented in 1972. The system is used on YZ125s from 1982 to 1993 and YZ/WR250s from 1981 to 1998. In the early years, Yamaha designed the valve with plenty of clearance from the piston. In 1990, Yamaha added a stop plate on the left side of the cylinder and positioned the valve closer to the piston for better performance. The problem is that the stop plate and valve wear, and the valve eventually contacts the piston, causing a total top-end failure. The best remedy is to grind the valve face for more clearance to the piston in the closed position. You lose a little power but save \$500 or more in the long run.

should be parallel when coupled to the lever and rod. If the spring tabs are crisscrossed, the valve travel will be limited and won't open fully.

In 1996, Suzuki redesigned the RM250 engine, going back to a design reminiscent of the 1987 model RM250. For this model, Suzuki modified the Honda HPI design used on the late-model CR250. However, a problem plagued this system. Instead of pivoting the center valve, Suzuki chose to slide it in a passageway of the cylinder. The added mechanical friction made the system prone to binding in one position: half-open. This causes the engine to run flat. The shape of the valve was also a problem. The leading edge that faced the piston was too square and sharp. Even when the valve was in the full-open position it caused a shock wave that impeded the outgoing exhaust flow. Grinding the edge smooth reduced the low-end power but helped improve top end. In 1997, Suzuki redesigned the center valve, choosing steel and splitting the valve into two sections, a major and minor valve. Suzuki also added a two-stage spring



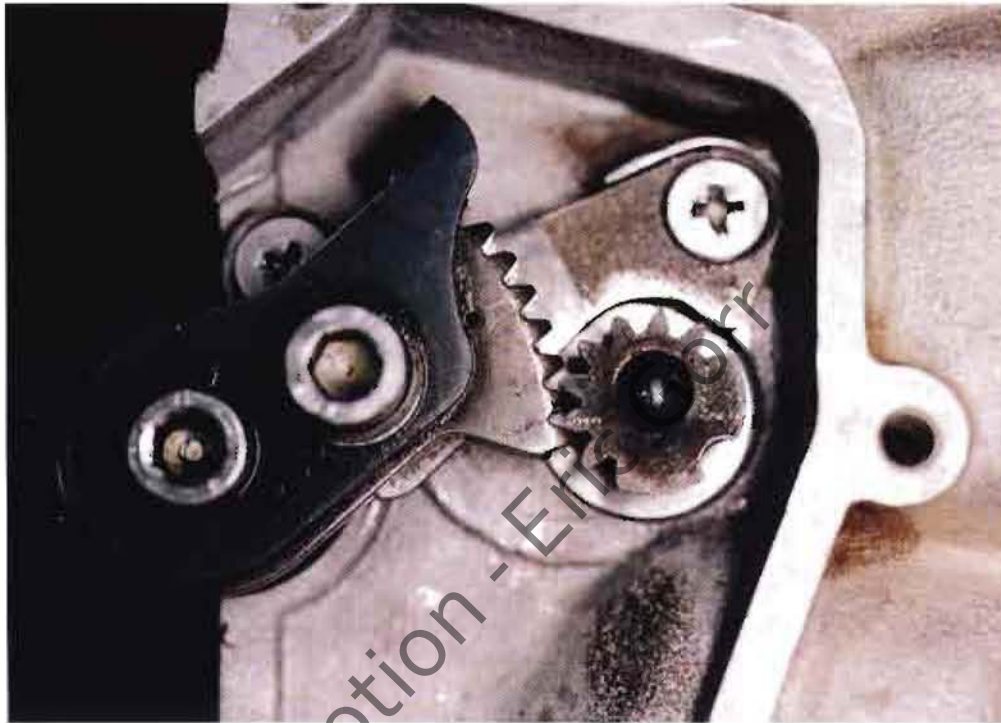
This is the power valve from the 1999 to 2005 YZ250. It's a two-stage system mounted to a single drive shaft where the center valve opens first and the sub-exhaust valves open later, based on the ramp angle of the drive lug. The sub-exhaust valve cam levers aren't marked left and right, so it's common for people to install them backward, which makes the powerband run flat. It's also common for the mounting plate for the center valve to crack, allowing the valve to contact the piston.

system. With some simple grinding to match the valve to the exhaust port when fully open, this setup was a winner. Suzuki chose to redesign the 1997 system design for the 1998–2000 models. The thought was that the steel valve damaged the valve pocket in the cylinder, although simply extending the nickel silicon carbide bore material into the valve pocket would have solved the problem. In 2001–2004 models, Suzuki added many more successive designs of moving parts such as linkages and pins. It's a very difficult system to assemble and requires a factory service manual.

YAMAHA POWERVALVE

Yamaha was the first motorcycle manufacturer to adapt exhaust valves to two-stroke motorcycle engines. Yamaha's simple design uses a cylindrical valve that rotates 1/4 turn to vary the height of the exhaust port and requires little maintenance. The system was used on the YZ250 from 1982 to 1998 and on the YZ125 from 1983 to 1993. Occasionally, you'll need to replace the seals and O-rings to prevent exhaust oil from drooling out of the side of the cylinder. In 1989, Yamaha added a stop plate to limit the travel of the power valve, primarily so mechanics couldn't install the valve in the wrong position. The stop plate is located on the left side of the cylinder. The valve has a small tab that bumps up against the stop plate to limit the fully opened and closed positions of the valve. This design enabled Yamaha to position the valve closer to the piston to make it more effective at varying the exhaust-port timing. Unfortunately, the soft aluminum tab on the valve gets worn, allowing the valve to rotate farther in the fully closed position. Eventually (after about three years' use), the tab wears enough that the valve strikes the piston, causing damage to the piston. Yamaha's exhaust valve is cheap to replace. I recommend replacing the valve when the tab wears more than 0.030 in. (0.7 mm).

In 1994, Yamaha changed the engine design of the YZ125 and included the next generation of exhaust valves. This

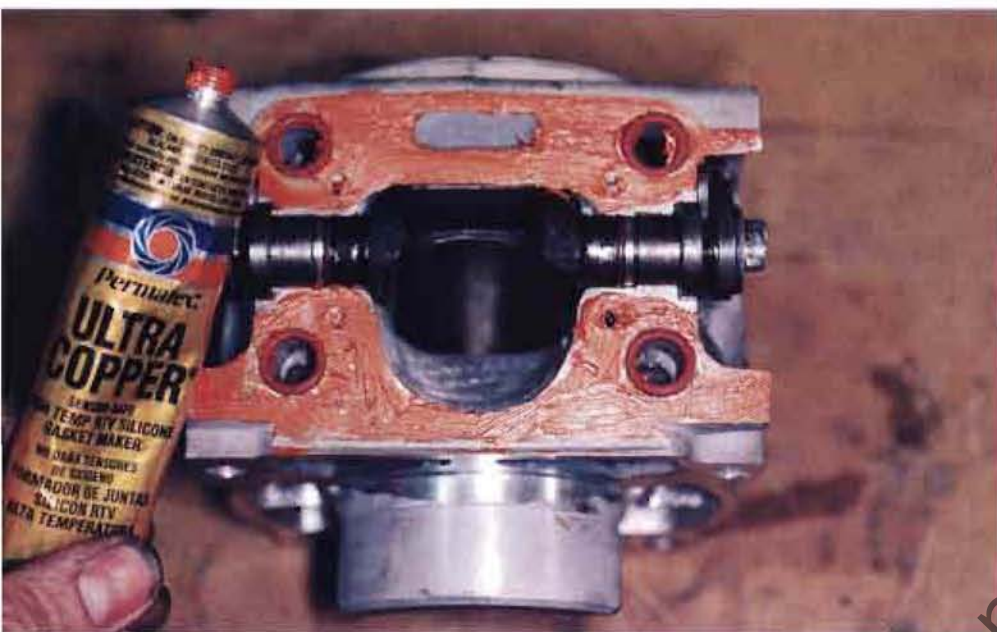


This is a view from the left side of the cylinder of the KTM exhaust valve system used on the 1986 to 1997 125s and on all 250s, 300s, 360s, and 380s. The main shaft has a gear plate that turns the side drum valves. Scribe marks show timing alignment. The stop plate with the two Allen bolts controls how far the main exhaust valve closes in distance from TDC. In the KTM manual, the stop plate is referred to as the "Z" dimension. If you turn it too far, the main valve will contact the piston and damage it. The stop plate loosens and the valve breaks the rings and piston crown, causing catastrophic engine damage. Whenever I service a KTM cylinder, I grind the valve face 1 mm to prevent this problem.

system used two oval-shaped wedge valves, positioned at a 45-degree angle over the exhaust port. The system is similar to the one employed by Suzuki. Yamaha experimented with resonator cavity volume and vents for pressure bleed-off and temperature control. Overall, this is a very reliable system. Occasionally, the pins that fit through the ends of the valve to interface with the actuator lever vibrate out, causing the valve to strike the piston. Those pins are a press fit but you can add some Loctite Instant Adhesive to the pins for added protection. Yamaha has added springs to the valves to control high-rpm valve flutter, but future innovations could include a positive seal between the valve and the cylinders' valve pocket.

In 1999, Yamaha redesigned the YZ250 engine and exhaust valve

system. The model features a power valve that marks a significant design change from the company that pioneered the use of exhaust valves on two-stroke engines. Looking more like a Rube Goldberg device, the new power valve has separate valves for the main (center) and sub-exhaust ports (sides). The whole assembly is controlled by one actuating rod, but the side valves open after the main exhaust valve. The side valves are controlled by two wedge-shaped ramps that resemble the shift drum from a transmission. The ramp design offers versatility in tuning. By changing the shape of the ramp, the duration and timing of the sub-exhaust ports can be changed to match a rider's ability or the demands of the terrain. So far there are no aftermarket companies making these ramps but you can



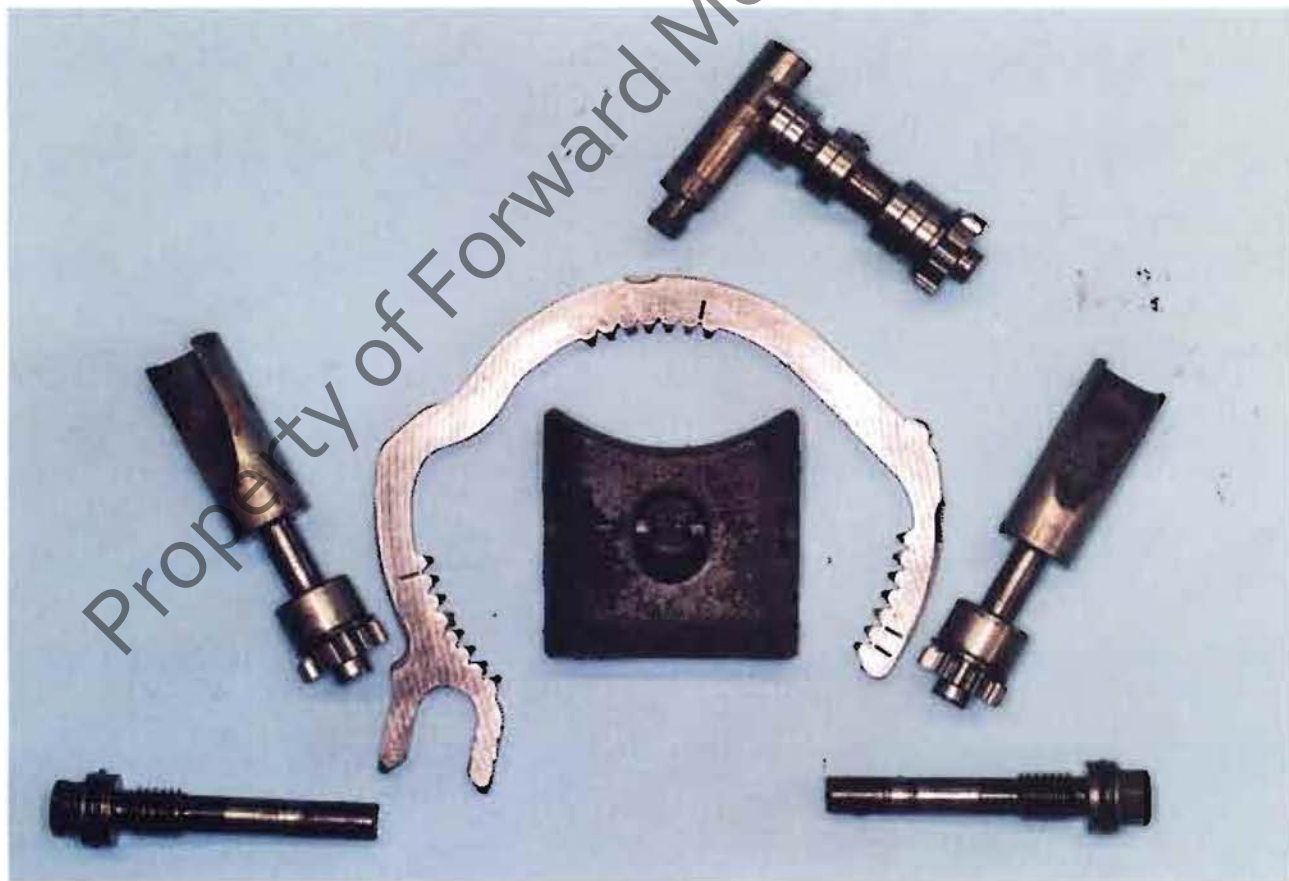
Use RTV Ultra Copper silicone sealant on the front exhaust plate of the KTMs.

bet that the factory teams are experimenting with them.

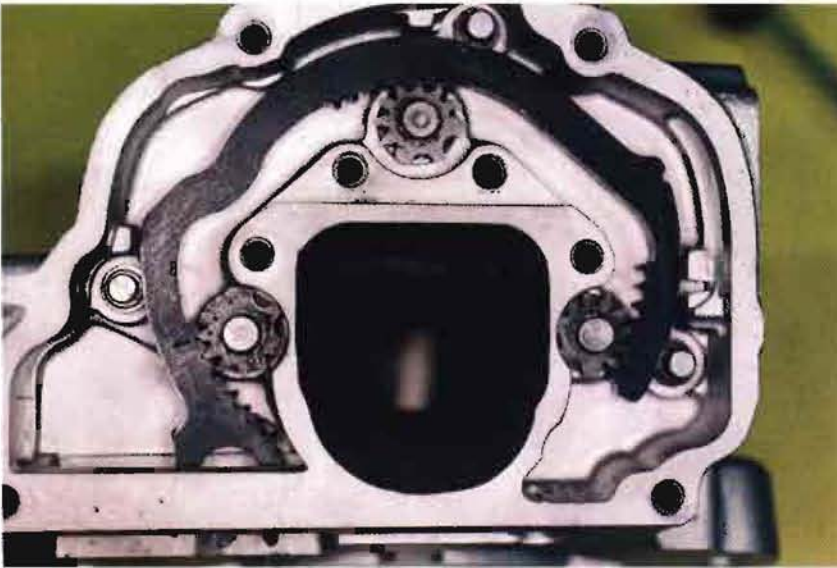
The stop plate of the center valve tends to crack, allowing the valve to contact the piston. Look for cracks in the plate right around the two retaining bolts.

KTM 250, 300, 360, 380 1990-2004

KTM uses two distinct designs of exhaust valve systems. The earlier model uses one large center valve with the actuating rod cast together. Two drum valves control the sub-exhaust ports, and steel gears interface the main and minor valves. The effective stroke can be adjusted by altering a stop plate on the left side of the cylinder. The governor control in the right-side case has an inspection cap that allows tuners to add thin washers and increase the spring preload to effect a change in engagement rpm. The system is prone to carbon-seizure of the steel valves (sub-exhaust



This is the exhaust valve system for the 1998 to 2005 KTM125 and 200 models. Overall, the system is very reliable and performs well.



The KTM system is easy to align, with dots on the valves aligning with lines on the rack.

ports). Also, there are rubber O-rings that prevent oil from leaking out the sides of the actuating rod that eventually wear out. In order to service this exhaust valve system, you need to remove the cylinder. The main valve and all its hardware can remain bolted together. There is an access cover on the front of the cylinder, and four bolts fasten the cover to the cylinder. There is no gasket for the cover; it seals with a non-drying liquid gasket like RTV silicone. The main valve pulls straight out.

The drum valves are held in place by two plates with two tapered, panhead Phillips screws. There is a specific procedure for removing these screws. Start by heating the screw heads for two minutes with a propane torch to break down the locking agent on the threads. Then use a hand impact with a No. 2

Phillips tip. If you strip the heads of the screws (most people do, including me!), use a tapered-point punch to spin the screws out. It will destroy the screw, but you should replace the Phillips with a tapered-panhead Allen bolt. Take care when handling the stop lever on the left side of the main valve. Before you loosen the two Allen bolts, scribe a line to reference the position of the plate relative to the gear plate. It is possible to adjust the stop plate so far that the valve rotates past the fully closed position and contacts the piston. That will destroy the piston.

The 1998 and newer KTMs have an exhaust valve system that makes use of the resonator concept. The system is so complex that you would need the factory service manual in order to service it.

TWO-STROKE LOWER-END REBUILDING

Rebuilding the lower end of a two-stroke engine is the procedure that is most often put off until next race/month/season. When you start hearing the engine make a strange knocking sound, it's time to shut it off and tear it down. Don't pin the throttle wide open and hope it will just go away! The normal service interval for lower-end rebuilding is once a year on engines under 200 cc and once every two to three years for 250 and larger engines. While rebuilding the lower end, you should replace the ball bearings that support the crankshaft and the transmission shafts, plus the rubber seals. In most cases, the crankshaft will need to have a new connecting rod, pin, bearing, and thrust washers installed. Some manufacturers (Honda) don't sell parts for their crankshafts, only the entire part. However, there are companies that offer high-quality replacement parts (Hor Rods) to rebuild modern Japanese cranks and vintage Spanish cranks. Although some aspects of lower-end rebuilding are very specific to a particular model engine, this section gives you an overview of the general process.

THE RIGHT TOOLS

Engine rebuilding is nearly impossible without the right tools. Some guys try to use the "caveman" method—big hammers and chisels. They usually end up doing some stupid thing that ruins expensive engine components.

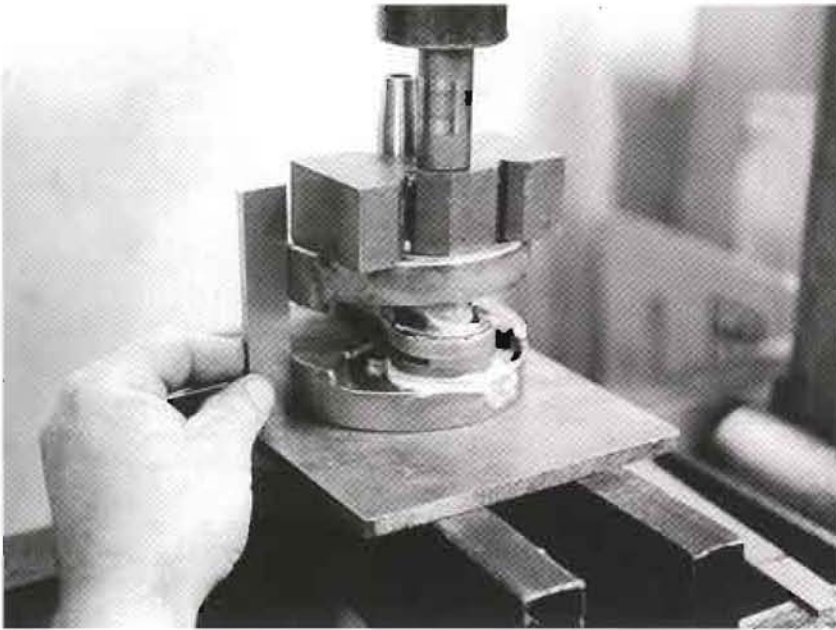
To properly rebuild the lower end, you will need the following tools from the manufacturer: a service manual for torque specs and disassembly/assembly techniques specific to your model engine, a flywheel puller, a clutch-hub holder, a crankcase splitting tool, and a crankshaft installation tool—but I'll show

you techniques for removing the clutch and installing the crank so you can save money on those tools. You will also need: an air- or electric-powered impact wrench to remove the nuts that retain the flywheel, clutch, countershaft sprocket, and primary gear; a parts washer with solvent to clean the engine parts; a hydraulic press to remove and install the bearings (a hammer will only damage them); a propane torch to heat and expand the aluminum crankcases to remove or install the bearings; because they have an interference fit (meaning that the bearing is a slightly larger diameter than the hole that it fits into); a digital caliper to measure certain engine

parts and compare them to the minimum wear specs listed in the service manual; a variety of wrenches and sockets; and soft tools such as brake cleaner, thread-locking agent, penetrating oil, seal grease, and gasket sealer. To hold the engine while you work on it, make an open square box from wood blocks. A universal box for any engine can be made from 2x4-in. blocks with the dimensions of the box being 5x10 in. CC Specialty makes a ball vise for \$100 that is convenient if you plan to rebuild engines frequently. To permanently remove the temptation to use steel hammers when rebuilding engines, buy a plastic mallet. Snap-on makes a



These are the basic tools that you'll need to rebuild the lower end of a typical dirt bike engine. Starting from the left, this is a crankshaft installation tool that draws the crankshaft into the left case half. The three-point tool in the top center is a crankcase splitting tool. Just below that is a wedge tool that prevents the crankshaft from slipping out of parallel alignment when pressed into the right case half. The tools are available from Kawasaki and fit all two- and four-stroke dirt bikes. The small device in the top right is a flywheel extractor. The long T-shaped tool is a piston pin extractor.



Once the rod is pressed into one crank half, install the rest of the rod assembly, including the bearing and washers. Place a machinist's square alongside the crank halves to align the free half before pressing in on the rod. At the final stages of pressing the crank together, insert a feeler gauge with the minimum rod clearance dimension between a crank half and the rod. Then press the crank together and prepare for final and-error aligning, which requires a jig with live centers and a dial indicator.

pressure to assemble the crank. He then uses the square to align the scribe lines on each flyweight so the crank is assembled very close to true.

4. As the crank is pressed together, the technician uses a feeler gauge to monitor the clearance between the connecting rod and the thrust washer. The proper clearance is listed in the service manual. The manual also lists an overall crank width spec that can be measured with a caliper.

Truing the Crank

1. During the truing process, the technician supports the crank between live centers.
2. Knife-edged bearings must be used if the machined centers of the crank ends are damaged. Dial indicators are used to measure the runout of each crank end and the side runout of the flyweights.
3. If the crank has side runout, the flyweights aren't parallel and must be adjusted before the crank ends can be

trued. This is accomplished by hitting the wide side of the flyweights with a large brass hammer and then wedging the flyweights apart at the narrow side with a large tapered chisel and hammer. It sounds very caveman-like, but this is the way the pros do it. Of course, the crank must be removed from the jig before the runout can be adjusted; otherwise the dial indicators and jig centers will be damaged. The crank ends have runout because the flyweights aren't parallel and must be rotated about the crankpin. This is accomplished by striking the flyweight at the exact point of the greatest runout with a brass hammer, while holding the opposite flyweight in hand. It doesn't take much force to rotate the flyweight into true.

Now you can understand why we must be careful how the crank is installed into the crankcases during engine assembly. It is very easy to throw the crank out of true if you bear the hell out of it and the cases during assembly!



This is the RCE crankshaft assembly jig. This excellent tool features a sturdy jig frame and bushings to align the crank halves and press the crankshaft together true.



CHAPTER EIGHT

TWO-STROKE ENGINES

Changing the powerband of your dirt bike engine is simple when you know the basics. A myriad of aftermarket accessories is available to tune your bike to better suit your needs. The most common mistake is to choose the wrong combination of engine components, making the engine run worse than a stock engine. Use this section as a guide to inform yourself on how changes in engine components can alter the powerband of your bike's engine. Use the "Tuning Guide to Performance Modifications" section to map out a strategy for changing engine components to create the perfect powerband.

TWO-STROKE PRINCIPLES

Although a two-stroke engine has fewer moving parts than a four-stroke engine, a two-stroke is a complex engine with different phases taking place in the crankcase and in the cylinder bore at the same time. A two-stroke engine completes a power cycle in only 360 degrees of crankshaft rotation, compared to a four-stroke engine, which requires 720 degrees of crankshaft rotation to complete one power cycle. Two-stroke engines aren't as efficient as four-stroke engines, meaning that they don't retain as much air as they draw in through the intake. Some of the air is lost out the exhaust pipe. If a two-stroke engine could retain the same percentage of air, it would be twice as powerful as a four-stroke engine because it produces twice as many power strokes in the same number of crankshaft revolutions.

The following explains the basic operation of the two-stroke engine:

1. Starting with the piston at top dead center (TDC, 0 degrees), ignition occurs and the gases in the combustion



This is a view inside a cylinder. A right-angle grinding tool machines the timing edges of the transfer and exhaust ports—this is real porting. Straight tools are used to texture surfaces and polish a port, which is considered metal finishing and doesn't make much of a difference in power.

- tion chamber expand and push down the piston. This pressurizes the crankcase, causing the reed valve to close. At about 90 degrees after TDC, the exhaust port opens, ending the power stroke. A pressure wave of hot expanding gases flows down the exhaust pipe. The blow-down phase starts and will end when the transfer ports open. The pressure in the cylinder must blow down to below the pressure in the crankcase in order for the unburned mixture gases to flow out the transfer ports during the scavenging phase.
2. Now the transfer ports are uncovered at about 120 degrees after TDC. The scavenging phase has begun, meaning that the unburned mixture gases are flowing out of the transfers and

merging together to form a loop. The gases travel up the back side of the cylinder and loop around in the cylinder head to scavenge out the burnt mixture gases from the previous power stroke. It is critical that the burnt gases are scavenged from the combustion chamber, to make room for as much unburned gas as possible. The more unburned gases you can squeeze into the combustion chamber, the more power the engine will produce. Now the loop of unburned mixture gases has traveled into the exhaust pipe's header section.

3. Now the crankshaft has rotated past bottom dead center (BDC, 180 degrees) and the piston is on the upstroke. The compression wave reflected from the exhaust



Case-reed engines can benefit from crankcase porting and cylinder matching more so than cylinder-reed engines. Case porting is a metal finishing task that serves to match the crankcase and cylinder transfer ports and polish surface imperfections.

pipe packs the unburned gases back in through the exhaust port as the piston closes off the port to start the compression phase. In the crankcase, the pressure is below atmospheric producing a vacuum, and a fresh charge of unburned mixture gases flows through the reed valve into the crankcase.

4. The unburned mixture gases are compressed and, just before the piston reaches TDC, the ignition system discharges a spark, causing the gases to ignite and start the process all over again.

HOW TO CHOOSE A POWERBAND

By making changes in engine components, nearly every Japanese dirt bike has the potential for two types of power. The engine can be tuned for midrange and high-rpm power or for low-end and midrange power. The midrange and high-rpm bike will have little or no low end, hit explosively in the midrange, and have an abundance of top-end power that can be over-revved. This kind of power can put you out front in the straights, but it is harder to control and will tire out the rider more quickly.

Expert outdoor riders tend to use engines tuned for high-rpm power.

An engine tuned for low-end and midrange power will have plenty of power down low, a hefty midrange, and a flat top end. Supercross and enduro riders favor this kind of power. It is easy to use and gives the rider confidence. Most riders can see faster times and have more fun with more low end and midrange.

With tuning, you can change your motorcycle's powerband to somewhere between one of these extremes. Only a few riders use the extremes. Professionals on outdoor tracks—especially 125-cc European Grand Prix bikes—use engines that are almost all high-rpm power. These machines are extremely fast and require highly talented professionals to make the most of them. Enduro riders in extremely slippery, technical conditions use bikes tuned for lots of low end. Trials riders use bikes that are tuned for nothing but low end.

Generally speaking, the higher the powerband peak (both in horsepower and rpm), the narrower the powerband. Conversely, the lower the power peak, the wider the powerband. Sometimes you can get the best of both worlds. Exhaust valves systems have made the biggest

difference in widening the powerband. Innovations in exhaust pipe design and ignition systems have also contributed to making two-stroke engines as tractable as four-stroke engines.

Riders should choose a powerband according to their skill levels, terrain obstacles, and maintenance practices. Here are some tips on how to select the right powerband.

SKILL LEVEL

Generally speaking, beginning riders need low to midrange powerbands, while expert riders can benefit from top-end powerbands. There are exceptions, though. Supercross bikes have low to midrange powerbands because the steep, far-spaced jumps are positioned so close to the turns. Keep in mind that low-end to midrange powerbands are typically easier to use. In conditions where traction is minimal and the terrain is particularly technical, low-end power will allow you to keep the bike under control and ultimately go faster. Also, "torquey" bikes are more fun to ride casually. Expert and top-level riders need high-end power to be competitive, but the extra juice can slow down lesser riders even in good conditions and is a handicap in slippery, difficult conditions.

TERRAIN OBSTACLES

This term describes a variety of things ranging from the soil content to elevation changes and the frequency of jumps and turns on a racetrack. Low to midrange powerbands work well on soils such as mud and sand. Tight tracks with lots of off-camber or difficult corners will favor low-end to midrange power. Smoother, broader powerbands work well for enduro or trail riding over a variety of terrain and soil conditions. Midrange to top-end powerbands work best on terrain with loamy soil, long fast uphill, and fast sweeping turns.

MAINTENANCE PRACTICES

Generally speaking, powerbands designed for low to midrange require less engine maintenance than powerbands designed

TUNING FOR SPECIFIC POWERBANDS

This chart is designed to give you some general guidelines on different powerbands and the changes required to the individual engine components. For specific recommendations on your model bike, refer to the chapters on tuning tips.

COMPONENT: Cylinder Head

LOW TO MIDRANGE: 9.5:1 compression ratio, squish band 60 percent of bore area

MIDRANGE AND HIGH RPM: 8:1 compression ratio, 40 percent squish

COMPONENT: Cylinder Ports

LOW TO MIDRANGE: Exhaust port 90 ATDC, transfer ports 118 ATDC

MIDRANGE AND HIGH RPM: Exhaust port 84 ATDC, transfer ports 116 ATDC

COMPONENT: Reeds

LOW TO MIDRANGE: Dual-stage or 0.4-mm fiberglass petals

COMPROMISE: Thick carbon fiber petals

MIDRANGE AND HIGH RPM: Large area 30-degree valve

COMPONENT: Carburetor

LOW TO MIDRANGE: Smaller diameter or sleeved down carb (26 mm for 80 cc, 34 mm for 125 cc, 36 mm 250 cc)

MIDRANGE AND HIGH RPM: Larger carb (28 mm for 80 cc, 38 mm for 125 cc, 39.5 mm for 250 cc)

COMPONENT: Pipe

LOW TO MIDRANGE: Fatty or Torque

MIDRANGE AND HIGH RPM: Desert or rpm

COMPONENT: Silencer or Spark Arrestor

LOW TO MIDRANGE: Short, small diameter

MIDRANGE AND HIGH RPM: Long, large diameter

COMPONENT: Ignition Timing or Advance Timing

LOW TO MIDRANGE: Stock timing

MIDRANGE AND HIGH RPM: Retard timing

COMPONENT: Flywheel

LOW TO MIDRANGE: Add weight

COMPROMISE: Stock flywheel

MIDRANGE AND HIGH RPM: PVL internal flywheel

COMPONENT: Fuel

LOW TO MIDRANGE: Super-unleaded 93-octane

MIDRANGE AND HIGH RPM: Racing fuel 105-octane

for high rpm. High-rpm powerbands usually require frequent use of the clutch to get the engine up into the rev range where the powerband is most effective. An engine that sustains high rpm requires more frequent replacement of parts such as piston and rings, reeds, crankshaft bearings, and clutch plates. Also, the carb

jetting becomes more critical. If the main jet is one size too lean, the piston can seize. High-rpm powerbands have high compression ratios and fuel selection is critical. Most tuners recommend racing fuel because the specific gravity of these fuels doesn't vary with the season like super-unleaded pump fuel.

TUNING GUIDE TO PERFORMANCE MODIFICATIONS

Before you begin modifications, you need to decide what you want from your engine. What kind of riding do you do? What level of rider are you? How much money do you have to



The cylinder on the left is ported and the cylinder on the right is stock. Porting is a metal machining operation that includes general smoothing and matching of the ports with port timing changes made at the intersection of the port windows and the cylinder bore.

spend? Remember that you need to bring the bike to peak stock condition before you add aftermarket equipment.

This section lists each performance mod and describes how to modify each system for the performance you want.

CYLINDER PORTING

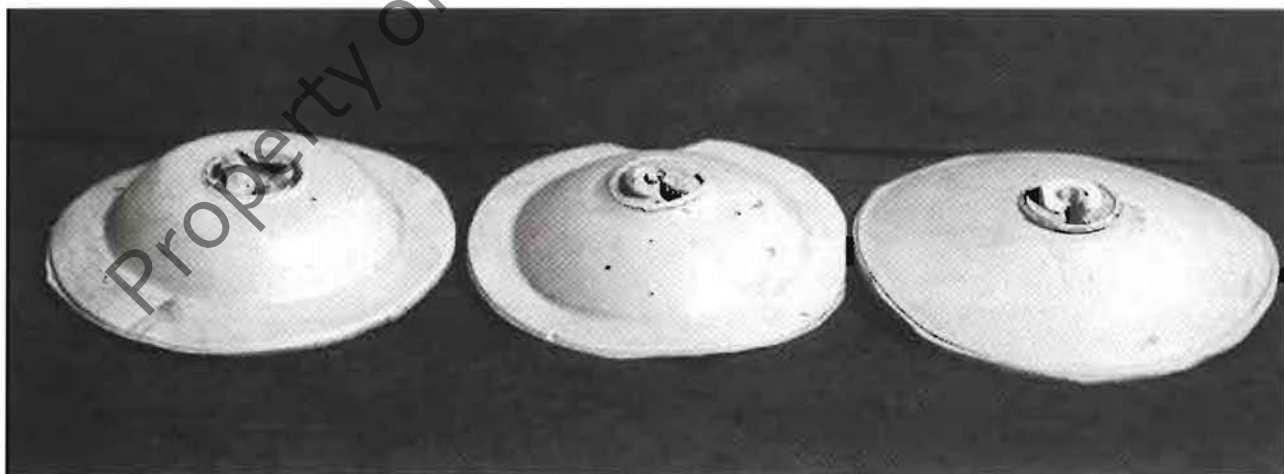
The cylinder ports are designed to produce a certain power characteristic over a fairly narrow rpm band. Porting or tuning is a metal machining process performed to the cylinder ports (exhaust

and transfers) that alters the timing, area size, and angles of the ports to adjust the powerband to better suit the rider's demands. For example, a veteran trail rider riding an RM250 in the Rocky Mountain region of the United States will need to adjust the powerband for more low-end power because of the steep hillclimbs and the low air density of higher altitudes. The only way to determine what changes to the engine will be necessary is to measure and calculate the stock engine's specifications.

The most critical measurement is the port time-area, the calculation of a port opening's area and timing in relation to the displacement of the engine and the rpm. Experienced tuners know what exhaust and transfer port time-area values work best for different purposes (motocross versus enduro, for example).

In general, if a tuner wants to adjust the engine's powerband for more low to midrange, he will do the following two things.

1. Turn down the cylinder base on a lathe to increase the effective stroke (distance from TDC to exhaust port opening). This also retards the exhaust port timing, shortens the exhaust port duration, and increases the compression ratio.
2. Narrow the transfer ports and reangle them with epoxy to reduce the port



These are silicon molds of popular combustion chamber designs starting from the left: flat top, domed, and hemispherical designs. Flat-top chambers are good for motocross and off-road because of their quick throttle response and use of lightweight flat-top pistons. Domed chambers are better for thermally loaded, high-rpm engines. Most factory 125s use domed pistons. Hemi chambers are used for road racing and shifter kart applications.



The latest performance trend in cylinder head design is the two-piece head. The water jacket housing and combustion chamber are separate pieces bolted together on the cylinder. Bronze combustion chambers are used because the material transfers heat efficiently and is more resistant to detonation damage. Chamber designs and compression ratios can be quickly changed for different applications.

time-area for an rpm peak of 7,000. The rear transfer ports need to be reangled to oppose each other rather than pointing forward to the exhaust port. This changes the flow pattern of the transfer ports to improve scavenging efficiency from 2,000 to 5,000 rpm.

For both of these types of cylinder porting changes to be effective, other engine components need to be changed as well.

CYLINDER HEAD MODIFICATION

Cylinder head shape also affects the powerband. Generally speaking, a cylinder head with a deep, small-diameter combustion chamber and a wide squish band combined with a high compression ratio is suited for low-end and midrange power. A cylinder head with a wide, shallow chamber and a narrow squish band and a lower compression ratio is suited for high-rpm power.

Cylinder heads with wide squish bands and high compression ratios will generate high turbulence in the combustion chamber. This turbulence is termed maximum squish velocity (MSV) and is

rated in meters per second (m/s). A cylinder head designed for supercross should have an MSV rating of 35 m/s, whereas a head designed for motocross should have an MSV rating of 25 m/s. The only way to accurately determine the MSV rating of a head is by measuring some basic engine dimensions and inputting the numbers into a TSR computer program called SQUISH. In the model tuning tips chapters, the SQUISH program was used to calculate the modified head dimensions.

Aftermarket companies such as Cool Head also offer cylinder heads that have different cartridges to give different cylinder head shapes. The various head cartridges have different combustion bowl shapes, compression ratios, and MSV ratings. The head cartridges are incrementally different, corresponding to powerbands ranging from extreme low end to high rpm.

CRANKSHAFT STROKING

Stroking refers to a combination of metal machining processes that relocate the center of the rod's big end in relation to the crankshaft center. A crank

can be stroked or de-stroked. Generally speaking, stroking refers to increasing the distance between the big end and crank center, and de-stroking refers to reducing the distance. Stroking increases the displacement of the engine, and de-stroking reduces the displacement.

PLAYING THE NUMBERS GAME

Certain combinations of cylinder bore size, crankshaft stroke, and connecting rod length produce ideal powerbands for certain applications. In 125-cc motocross, the accepted standard is a bore of 54 mm, a stroke of 54.5 mm, and a connecting rod length of 105 mm. In road race it's 56x50 and 110. A short stroke enables a higher rpm before critical piston speed is attained (4,500 feet per minute); that's why a shorter stroke is used for road racers. These engine configurations are termed "over-square" because the bore is greater



This is a Wiseco GP piston, designed for ported cylinders. It is a high-performance piston for a 125-cc engine. Unlike a stock piston, the Wiseco GP uses a nickel crown coating that reduces detonation, a moly coating on the skirt that is a dry film lubricant, lightening cutouts inside the piston for wider exhaust porting, and 50 percent of its mass is centered in the piston crown for better thermal efficiency. The ring is pinned on center to allow for wider transfer ports.

than the stroke. Conversely, the popular MX configuration is termed “under-square” or “long stroke.” Long connecting rods are commonly thought to produce more leverage, but the real advantage of a high-revving engine is that the piston dwells longer at TDC and allows for a greater pressure rise and hopefully more brake mean effective pressure (BMEP), or the average pressure per square inch in the cylinder from TDC to BDC.

The manufacturers fiddle around with bore, stroke, and rod combos all the time. The latest rage for the amateur class for 125s where the 80-over rule applies is a 55.5-mm bore and a 55.2-mm stroke with a 109-mm rod. Suzuki has determined that to be the winning combo and requires its support riders to have their engines modified to that spec. For the Kawasaki KX80, the magic numbers are 48.5x53x92. Kudos to Pro-Circuit for doing the legwork on that one!

So how does one find that magic combo? You could spend loads of time and money to try every possible combination, or you could use a simulation program such as Virtual Two-Stroke or Dynomation. There are a lot of things going on in a two-stroke engine. When you change one thing like the stroke, several other things change too, for better or worse.

WHAT HAPPENS WHEN?

These are the things that are affected when the stroke is changed.

1. The displacement increases.
2. The port timing advances.
3. The ignition timing advances.
4. The compression ratio of the combustion chamber and crankcase increase.
5. The reed valve timing advances and the reed lift increases.
6. The piston speed is greater at any given rpm.
7. The maximum piston speed is reached at a lower rpm.
8. The rod bearing wear accelerates.
9. The rod ratio decreases.
10. The bore-to-stroke ratio is altered.

WHAT THINGS MUST BE ACCOUNTED FOR?

The cylinder must be shimmed up or the head's squish band must be machined to compensate for the increase in stroke.

1. The port time-area must be increased to compensate for the stroke and displacement change.
2. The ignition timing may need to be retarded.
3. The combustion chamber in the head must be enlarged for greater volume.
4. The connecting rod bearing and piston pin bearing must be changed more often.
5. The crankcase diameter may need to be increased for rod clearance due to the greater offset of the rod.

FOUR WAYS TO STROKE A CRANK

There are four popular ways to change the stroke of a crank:

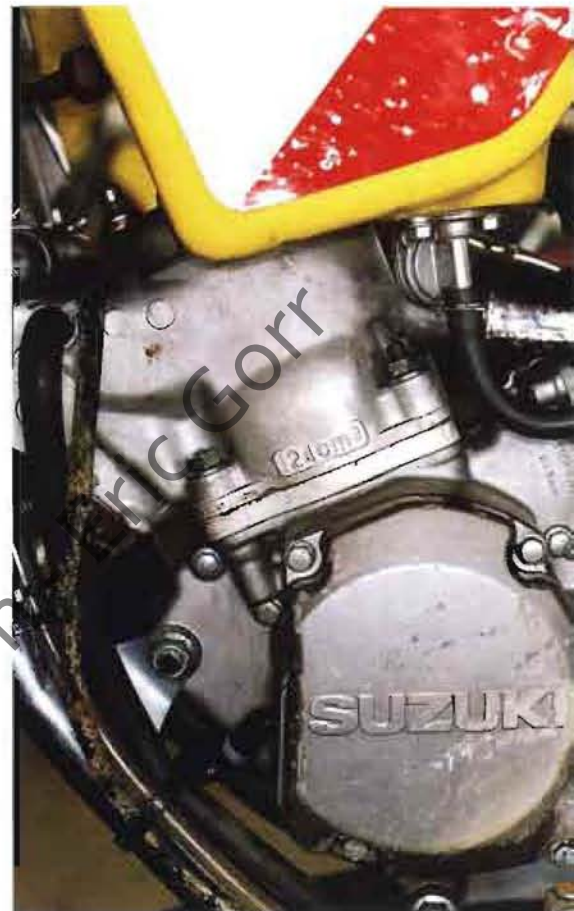
1. Manufacture new crank halves with the dimensions built in.
2. TIG weld the big end pin holes and drill new holes farther from the crank center.
3. Bore the big end holes larger and TIG weld eccentric flanges.
4. Precision grind an eccentric crankpin.

Manufacturing new stroked crankshafts is the most expensive choice and currently there are no aftermarket products of this type for modern dirt bikes.

Relocating the big end pin holes is the most logical and reliable choice. The crank is disassembled, the holes are TIG welded with stainless-steel filler rod, and the holes are rough-bored and finish-honed with the crank halves jigged together to ensure accuracy.

Eccentric flanges are manufactured by gun-drilling rod stock off center, and then turning the rod on a lathe into a flange shape. The crank's big end holes are bored oversize and the flanges are installed, indexed, and TIG welded to the crank halves.

Eccentric big end pins were popularized in Germany 20 years ago. The German logic is to avoid heating/welding material to the crank halves so as to minimize stress and distortion. Oversize rod stock is OD (outside diameter) ground to



Cylinder base shims are used for three reasons: to accommodate stroker cranks and long-rod kits or to advance the port timing.



This spacer plate was custom-made by Cometic Gasket Co. Average cost is \$50.



This is a view of the head, cylinder, and piston on an engine where the crank has been stroked. Notice how the piston crown extends over the top of the cylinder. The head's squish band recess gap has been increased so the piston doesn't contact the head.

form the three surfaces. However, the crank cannot be rebuilt by traditional means because of the difficulty with indexing the crank halves for the proper stroke dimension.

BALANCE FACTORS—THE MAGIC BULLET

Truing and balancing are often confused. Truing the crank refers to the process of aligning the crank halves about the big end pin, making the halves parallel to each other. Balancing refers to changing the balance factor, which is the ratio of the reciprocating mass to the rotational mass. The reciprocating mass consists of most of the connecting rod and the piston assembly. The rotational mass consists of the crank halves. Crankshafts are lightened at the top near the big end pin using a number of different methods. Sometimes there are holes drilled in the crank halves or lighter materials are substituted.

Crankshaft balance is important because excess vibration is converted to friction and heat, which spread throughout the crankcases and reduce the charge density. And that directly affects the peak power.

Altering the balance factor may

include adding weight of a denser mass to the bottom of the crank halves or lightening the halves at the top. Substitute materials for adding weight include Mallory, lead, and osmium.

FAQ: LONG ROD KITS AND SPACER PLATES

The terms "long rod kit" and "spacer plates" were popularized by the motorcycle press. Here are some frequently asked questions on these items and their effects on engine performance.

What is a long rod kit?

A long rod kit consists of a longer connecting rod and all the special parts that must be used with it. A longer connecting rod only changes the rod ratio between the stroke length and the rod's center-to-center length. Long rod kits do not change the displacement of the cylinder, only the crankcase.

How does a long rod kit improve the powerband?

The longer rod allows the piston to dwell at TDC longer for a greater pressure rise. Before the piston opens the exhaust in the middle of the stroke, the longer rod will have greater leverage. Near BDC,

the piston travels faster, causing greater intake velocity on piston port engines and greater reed petal lift and mass flow on reed valve intake systems.

How would the porting change with a longer dwell time?

The operating speed is about 8,000 to 11,000 rpm. The timing of the intake, transfers, and exhaust will change, even if the cylinder is spaced at the same distance difference as the longer rod.

Why don't all bikes in stock form have long rods? Do they work on all 125-cc bikes?

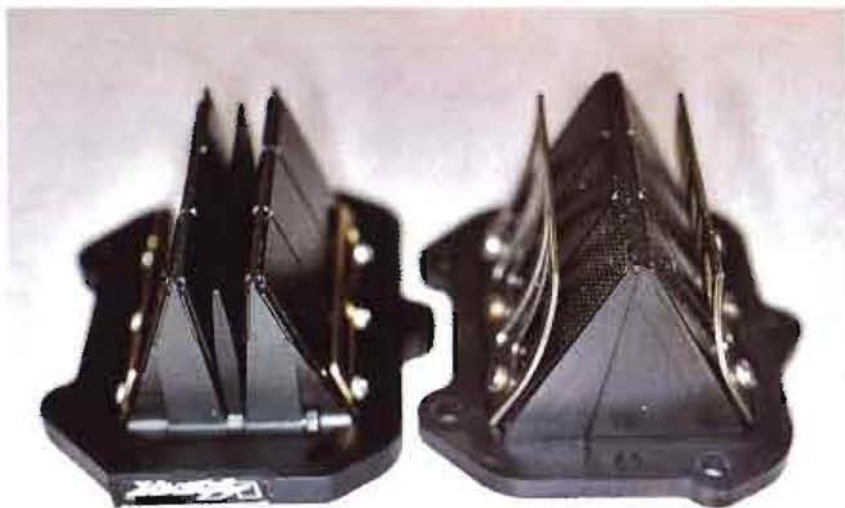
Two-stroke engine designers have to balance a number of factors when making an engine for a particular application. For example, a rod ratio of 4:1 is considered ideal for a road racer, while 3.75:1 is better for MX. On small engines, the greater the rod ratio, the lower the primary compression ratio. MX engines need a primary compression ratio of about 1.8:1 in order to have strong throttle response to clear obstacles.

Is there an ideal length or is longer better?

For a typical 54.5-mm stroke, the rod can range from 102 to 112 mm.

Why use a spacer plate and is there an alternative?

A spacer plate is like a thick base gasket, usually made of aluminum with a standard gasket on each side to provide some sealing means. The spacer plate serves to compensate for the difference in the extra rod length. In order to use a spacer plate, the cylinder base studs and the power valve linkage rod must be longer. The head-stay brackets must also be slotted, and the exhaust system brackets will need to be repositioned. The use of spacer plates enables the port timing to remain close to stock, which will help the midrange to top-end power. The alternative to a spacer plate is to machine the cylinder head's squish band and combustion chamber to accommodate the piston travel. This would also serve to retard the port timing due to the relative position of the piston.



Here is a comparison between a V-Force (left) and conventional stock reed cage (right). The V-Force has double the reed area but also double the angle. V-Force reed valves generally improve the low-end to midrange power.

CARBURETOR MODIFICATION

In general, a small-diameter carburetor will provide high air-mass velocity and good flow characteristics for a low- to mid-rpm powerband. A large-diameter carburetor works better for high-rpm powerbands. For 125-cc engines, a 34-mm carburetor works well for supercross and enduro, and a 36- to 38-mm carburetor works best for fast motocross tracks. For 250-cc engines, a 36-mm carburetor works best for low- to mid-rpm powerbands, and a 39.5-mm carburetor works best for high-rpm powerbands.

Recently, there has been an increase in the use of air foils and rifle boring for carburetors. These innovations are designed to improve airflow at low throttle openings. Some companies, such as Performance Engineering in Florida, offer a service to overbore the carb and include inserts to reduce the diameter of the carburetor. For example, a 38-mm carb for a 250-cc bike will be bored to 39.5 mm and two inserts will be supplied. The carb can then be restricted to a diameter of 36 or 38 mm.

Not every carb can be overbored. The maximum diameter of the carburetor cannot exceed the width of the slide or air will bypass the venturi and

the engine will run too lean. There are two ways to overbore a carb: by stripping it down and running it on a lathe (Keihin PWK and Mikuni round slide), or by milling it on a vertical mill using a rotary table. The rotary table method is necessary for carburetors where the needle jet cannot be removed (Keihin PJ and Mikuni TMX). Whenever a carb is overbored, the jetting must be richened to compensate for the loss of intake velocity.

AFTERMARKET REED VALVES

Like large-bore carburetors, bigger reed valves with large flow area work best for high-rpm powerbands. In general, reed valves with six or more petals are used for high-rpm engines. Reed valves with four petals are used for dirt bikes that need strong low-end and midrange power. Three other factors must be considered when choosing a reed valve: the angle of the reed valve, the type of reed material, and the petal thickness. The two common reed valve angles are 30 and 45 degrees. The 30-degree valve is designed for low-end to midrange power, and the 45-degree valve is designed for high-rpm power. Two types of reed-petal materials are commonly used: carbon fiber and

fiberglass. Carbon fiber reeds are lightweight but relatively stiff (spring tension) and are designed to resist fluttering at high rpm. Fiberglass reeds have relatively low spring tension to instantly respond to pressure changes in the crankcase; however, the low spring tension makes them flutter at high rpm, thereby limiting the amount of power. Fiberglass reed petals are good for low-end to midrange powerbands, and carbon fiber reeds are better for high-rpm engines. Regarding longevity, fiberglass reeds tend to split whereas carbon fiber reeds tend to chip.

Some aftermarket reeds, such as the Boyesen dual-stage reeds, have a large, thick base reed with a smaller, thinner reed, mounted on top. This setup widens the rpm range where the reed valve flows best. The thin reeds respond to low rpm and low-frequency pressure pulses. The thick reeds respond to higher pressure pulses and resist fluttering at high rpm. The Boyesen RAD valve is different than a traditional reed valve. Bikes with single rear shocks have offset carbs. The RAD valve is designed to evenly redistribute the gas flow from the offset carb to the crankcases. A RAD valve will give an overall improvement to the powerband. Polini of Italy makes a reed valve called the Supervalve. It features several mini sets of reeds positioned vertically instead of horizontally (as on conventional reed valves). These valves are excellent for enduro riding because they improve throttle response. Tests on an inertia chassis dyno show the Supervalve to be superior when power shifting. However, the valves do not generate greater peak power than conventional reed valves.

THE SECRET LIFE OF A TWO-STROKE EXHAUST PIPE

A pipe's job is to draw out the burnt gases from combustion along with some unburned gases, and then reflect a wave that plugs the unburned gases back into the cylinder before the piston closes off the exhaust port. The pipe is comprised of five distinct sections: header, diffuser, center dwell, convergence cone, and stinger. There are algebraic formulas for



FMF makes tailpipe silencers in three basic variations: short for low end, long for top end, and a spark arrestor for sound and fire safety.

the dimensions of each section of the pipe, but they are only a baseline for designers. The problem is that exhaust gas and outside skin temperature are variables to consider. Getting the temperature correct inside the pipe provides a greater tuning advantage than just swapping to a different hop-up company's pipe. The temperature inside the pipe is affected by the carb jetting, fuel formulation, and ignition timing curve. Cylinders with exhaust valve systems that employ large cavities or venting can also dramatically affect how the pipe works. Some of these things you can control, others you can't.

How Aftermarket Companies Design Pipes
You're fooling yourself if you think that the pipe manufacturers run comprehensive R&D programs on every model of



This is a comparison between two pipes for a 125-cc engine. The pipe on top is designed for a high-rpm powerband. It has a short tuned length and steep cone angles. The other pipe is designed for a low- to mid-rpm powerband. A long, tapered head pipe and shallow cone angles highlight the difference from the rev pipe.

dirt bike that they make a pipe for. They are challenged with bringing a large variety of pipes to market quickly and the way that they do it is simple. They start by doing a dyno run on the stock pipe. Then they decide which area of the powerband they want to improve. Next, they cut the front and rear cones off the pipe and weld spring loops. Then they interchange a selection of angled cones and make dyno runs. Some companies use the same cones on all their 125s or 250s since the Japanese manufacturers use nearly identical bore, stroke, rod length, and port timing. Once they are satisfied with the cone choices, they weld the cones permanently into place. Finally, they cut and rotate all the cones so the pipe forms a "C" shape. Then they cut off the header flange and the stinger. From there, the pipe goes to the die maker, who makes the aluminum casting of the pipe that becomes the press-die.

Torque and Rev Pipes

Pipes are stamped from sheet metal into a C-shaped pattern. Press-dies have a limited life span rated in the number of parts stamped. It isn't that they crumble

to pieces, but they do slowly wear. When the press-die wears, it changes the dimensions of a part. Dies start out larger than the target size and wear. The parts at the beginning and end of the die's life are different sizes. Pipes are fabricated by welding two C-shaped pipe shells together; then the sections are cut, rotated, and welded again. Every time the pipe is cut on the band saw, the length is reduced by the width of the saw blade and the amount of material that is sanded off the cut edges. Multiply that by the number of cuts and a pipe can shift its tuning range pretty quickly, especially if an overzealous worker sands too much here and there.

Manufacturers rate pipes by their length. A long pipe is a "torque" and a short pipe is a "rev." The engine manufacturers do the same thing with pistons and cylinders with the markings "A" and "B." The label is a dimensional representation of a finished manufactured part. Some manufacturers, like FMF, don't rate their pipes, but the pipes are still different dimensions. That's why you can buy two of the same model pipes from one manufacturer and they will perform slightly differently.

What's a Rocket Engine Doing in the Pipe?

When FMF introduced its SST pipe the manufacturer described it as a rocket engine in the pipe. Actually, it's a rapid convergence cone and it is shaped like the business end of a rocket engine. By constricting the outlet of the stinger before the silencer, it serves to raise the pressure in the pipe and the piston crown temperature. It has the greatest effect at high rpm. In shifter kart racing, RCE markets a pipe with a selection of tuning cones that feature different angles and diameters to adjust the tuning effect for different rpm ranges.

The opposite of a rapid convergence cone is a rapid diffuser. A bulge in the junction between the convergence cone and the stinger was used on the Yamaha IT and YZ490 models of the mid-1980s. That shape prevents a backup of pressure in the stinger, mainly because those old bikes had a sharp bend in the pipe to compensate for. FMF uses a rapid diffuser in its four-stroke header pipes and calls it a "Power Bomb." A multi-phase resonator is commonly used on snowmobiles and it works differently on a two-stroke engine. (A rapid diffuser allows for less loss of energy when waves moving in opposite directions pass through each other. In the field of unsteady gas dynamics, that is called "super-position." A multi-phase resonator has a specific volume, length, and orifice size that allow the resonator to have an effect based on rpm and its position in the expansion chamber.)

What's a Titty Pipe?

I'm waiting to flip open a dirt bike magazine someday to read about "The Titty Pipe." I think the average teenager who reads these magazines could embrace the concept. Randy Nouis, an engineer at GM Racing, invented the multi-phase resonator, nicknamed the titty pipe. It looks like a bulging chamber that fastens to the pipe. Some modern Canadian snowmobiles and Italian trials motorcycles use them in production. Basically, the multi-phase resonator consists of an oval flask with an orifice that intersects with the edge of the pipe. It serves to add

volume and length to a particular section of the pipe. The orifice size determines the rpm at which the resonator will function. Honda used a similar device on CR125 and 250s on the 1985 and 1986 models. The concept was abandoned because the butterfly valve used to control the orifice of the chamber frequently clogged with carbon.

How the Ignition Changes the Pipe

Though it doesn't actually have anything to do with the pipe, an adjustable ignition can have a great effect. The ignition boxes have two timing circuits built in. A switch is provided to go from one circuit to the other. One timing curve has a steep advance for good low-end power and quick throttle response. The other circuit has a shallow advance curve with a high-speed retard circuit that times the spark close to TDC. This is called the top-end or hole shot switch. Essentially, combustion takes about 55 degrees of crank duration to occur. Retarding the spark causes more heat

from combustion to shift into the pipe and out of the cylinder. Raising the temperature in the pipe raises the rpm peak in accordance with piston speed.

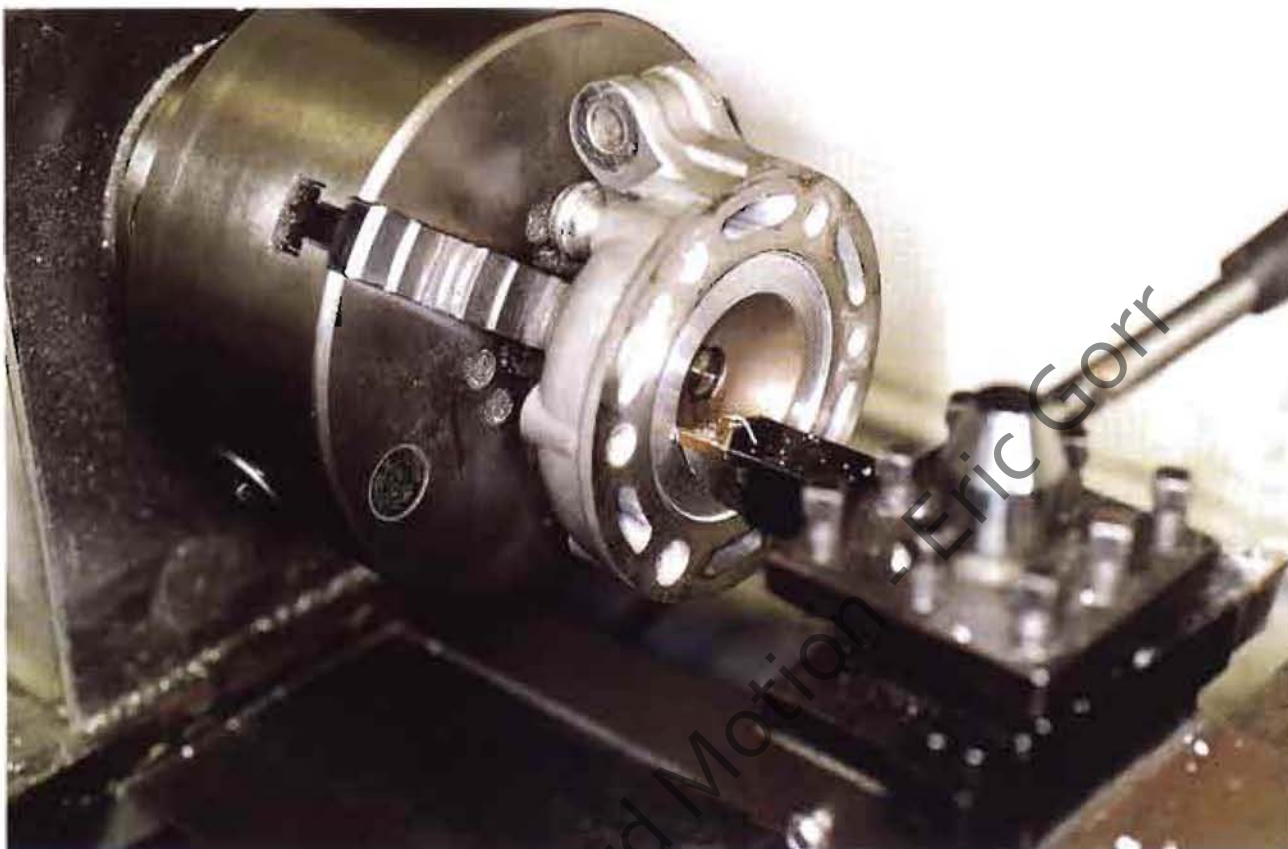
FLYWHEEL WEIGHTS

A heavier flywheel will smooth out power delivery. The flywheel is weighted to improve the engine's tractability at low- to mid-rpm. Flywheel weights are best for powerful bikes with decent low end and an explosive hit. The weight smooths out the hit and reduces wheel-spin, which will improve the drive out of corners. One common misconception of flywheel weights is that they increase low-end power. If an engine doesn't have enough low-end torque in the first place, it will actually be worse with the extra flywheel weight.

Stearhly manufactures thread-on flywheel weights that thread on to the fine left-hand threads on the center hub of most Japanese magneto rotors. Thread-on flywheel weights can only be used if the threads on the flywheel are in perfect condition.



This flywheel has been modified for a longer stroke length. The stock big-end pin is bored off center and a steel slug is welded in place and bored to size.



A centered spark plug head is threaded to a Goodson Automotive mandrel and installed in the three-jaw chuck of a lathe to facilitate tuning changes.

Modern bikes use external rotor flywheels. They have a larger diameter than internal rotor flywheels so they have greater flywheel inertia. PVT makes an internal rotor flywheel that gives quicker throttle response.

IGNITION TIMING

The ignition timing has a minimal effect on the powerband. Retarding the timing has the effect of reducing the hit of the powerband in the midrange and extending the top-end over-rev. "Over-rev" is a slang term that describes the useable length of the powerband at high rpm.

The scientific reason for the shift of the powerband to extremely high rpm is that the temperature in the pipe increases with the retarded timing because the burn cycle takes about 55 degrees of crankshaft rotation. When the timing is retarded, the burn cycle

starts later and continues into the pipe. Raising the exhaust gas temperature raises the velocity of the waves, making them more synchronous with the piston speed and port timing of the cylinder.

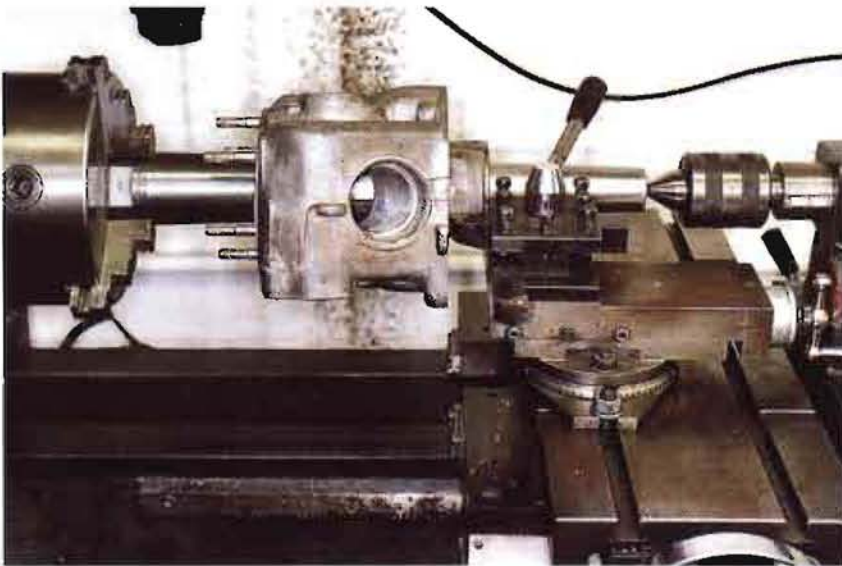
Advancing the timing increases the midrange hit of the powerband but makes the power flatten out at high rpm. The relatively long spark lead time enables for a greater pressure rise in the cylinder before the piston reaches TDC. This produces more torque in the midrange, but the high pressure contributes to pumping losses at extremely high rpm.

ENGINE MANAGEMENT SYSTEMS

Motorcycle engines have always been at the forefront of engine design. The next leap will come in the form of engine management systems that control the ignition system, power jet, exhaust valves, and resonator temperature and

pressure. Right now, we're seeing new products such as programmable or switchable ignition boxes. In the near future, we'll see a continual stream of products that will culminate in a direct-injected, two-stroke engine with a management system that coordinates the ignition, intake, exhaust, and ultimately the powerband with just a tweak of the thumb.

The Optimum GP Control package for the Suzuki RM250 is a kit that includes a handlebar switch, KX250 carburetor with pump and throttle position sensor, and a computer that fits under the seat on a hinged plate. The unit coordinates the ignition system with the carb's fuel pump. The handlebar switch offers 42 positions, and the jetting and ignition can be adjusted on the fly. There is also a separate bolt shot switch that provides smooth power delivery and better trac-



This cylinder is fastened on an expanding mandrel and mounted in a lathe. The cylinder base is being turned down to reduce the ports' duration, retard the timing, and increase the compression ratio. This machining operation serves to improve the low to midrange power of a dirt bike.

tion. You can program the control package with a PDA and change things such as the engine's ability to perform on less-expensive fuel. The Kawasaki Keihin electronic carburetor with throttle position sensor is ideal for computer control and coordination with things such as exhaust valve systems.

There are less-expensive aftermarket parts such as igniter boxes. FMF sells the Wolf brand igniter box that features adjust-on-the-fly timing. Products such as these offer a choice of an advanced curve for better midrange or one with a retarded curve for better over-rev. Normally, these products sell for about the same price as the OEM igniter box.

PERFORMANCE MACHINING TOOLS AND TECHNIQUES

MACHINE TOOLS

There are four different machine tools used for performance machining of motorcycle parts: lathe, vertical mill, horizontal or portable hone, and grinding or polishing tools.

Lathing

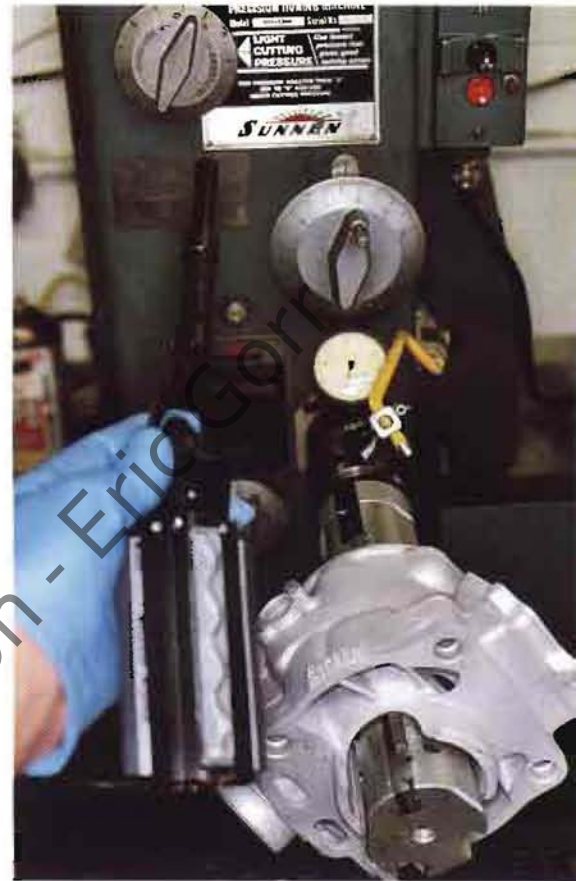
A bench lathe can be a handy machine in a motorcycle workshop. A 9x20-in.

bench lathe costs as little as \$995 new from mail-order companies such as ENCO and Harbor Freight. This simple lathe can handle most of the tasks needed to maintain dirt bikes. Common uses for a lathe include resurfacing two-stroke cylinder heads, boring cylinders and carbs, machining circular-ring grooves, turning cylinder bases, polishing axles, and checking the trueness of a crankshaft.

Tooling for lathing includes the cutting tools and the mandrels or fixtures needed to mount a work piece. For centered two-stroke heads, a threaded mandrel can be purchased from Goodson for \$25. For offset heads, you'll need to fasten and space the heads on bolts and pins on a face-plate.

To turn cylinders, expanding mandrels are the best setup. The mandrel's adjustable sleeve clamps on the cylinder bore. Precision Devices has the biggest selection of expanding mandrels, but mandrel kits can cost \$200 to \$1,000.

The most cost-effective way to buy cutting tools is to purchase a kit with five tool bit holders and replaceable tips. Considering that most machining tasks on dirt bikes will be performed on



Honing machines are either portable or stationary. The hone on the left is a portable tool that can be driven with a drill. Sunnen makes stationary honing machines with a wide variety of mandrels and stones. Diamond stones are required to hone modern plated cylinders.

aluminum parts, the TiN-coated tips work best because they resist buildup of aluminum on the cutting tip.

Milling

A vertical mill is like a lathe turned up on end. The main difference is that on a lathe the cutting tool is stationary and a mill spins the tool with the work piece mounted stationary. The uses for a mill include installing flywheel weights that use three Allen bolts, boring crankcases, removing broken bolts, resurfacing gasket surfaces such as crankcases, boring cylinders, and back-cutting tranny gears.

For my business, I chose a combination machine that enables lathing and



Cylinder heads with offset spark plug holes must be mounted to a face-plate for machining in a lathe. Three of the bolt holes are tapped to a 3/8-NC thread and spaced from the plate with wrist pins and washers.



This crankcase is being bored on a milling machine. Because the crankshaft was stroked for a 2-mm offset, the area where the connecting rod swings past the crankcase must be bored 4 mm larger for the proper clearance.

milling tasks. It's made by Smithy and is called Granite 1324. This machine sells for \$3,700 with a package of accessories, including lathe tool bits, end mills, collars, live center, boring/facing head, and a rotary table.

Honing

Honing is considered a finish machining process. The two types of hones used in the motorcycle business are a horizontal machine with a stationary mandrel and a drill-operated, portable honing mandrel. Common applications for honing include the cylinder bore, connecting rod, a cylinder head's cam and taper bore surfaces, crankshaft big end bores, and valve guides.

The biggest supplier in the world for motorcycle honing machines and supplies is Sunnen, headquartered in St. Louis, Missouri.

Grinding and Polishing

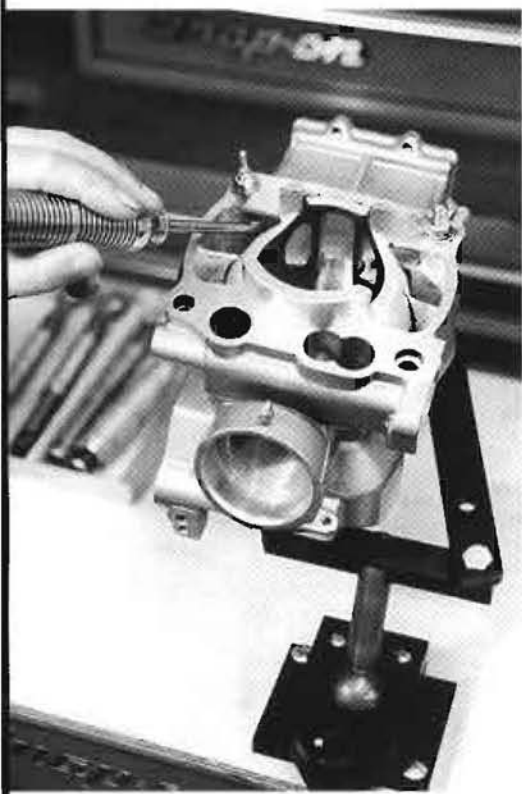
The two types of grinding tools are bench and cable-driven. Both a 6-in. bench grinder and a hand-operated setup like a Dremel can accept a variety of media ranging from rough stones to fine, rubberized abrasives.

In my porting business, I use a Dremel model 732. It has changeable tool handles in straight and right-angle configurations. There are hundreds of tool bits, varying in shape, size, grit, and material from felt to diamond.

The popular uses of grinding and polishing include cylinder porting, cleaning carbon from manifolds and pipes, leveling the wear grooves on clutch baskets, slicing the rusted bearing cages of swingarms and linkage, polishing carbon from power valves, and removing the molded rubber ears of two-stroke intake manifolds for V-Force reed cage installation.

Cylinder porting tool bits differ greatly for uses on nickel-plated and cast-iron-lined cylinders. Plated cylinders are harder and more brittle. It is a common mistake to chip the plating at a port's edge, which can lead to ring snagging and bore failure. Stones or diamond tooling cut through the hard nickel-plating, where traditional fluted carbide tool bits can take over the porting tasks. Virtually any tool bits can be used on cast-iron-lined cylinders because the material is much softer.

The biggest supplier of porting tools in the motorcycle industry is C.C.



Portable grinding tools have cable-driven and foot-operated electric motors with quick-change tool capability. They are used most often for cylinder and head porting tasks.



These are tool handles, straight and right-angle designs. These tools hold tool bits of different shapes, materials, and textures. Tool handles plug into cable drives. CC Specialty in Lawrenceburg, Tennessee, is the biggest supply company for porting tools, bits, and polishing supplies.

Specialty in Lawrenceburg, Tennessee. They sell everything from electric and air-driven tools to tool bits and polishing supplies. They even sell measuring tools and flow benches.

VALVE SEAT MACHINE TOOLS

The latest trend in performance machining is the multi-angle carbide cutter that floats in the valve pocket holding a concentric path. Serdi and Newen sell complete machines from bench-top micro to heavy-duty production machine tools. Goodson Automotive, a

mail-order supply company, markets an exclusive line of multi-angle cutters from famous tuners such as Tony Mondello. On four-stroke heads, much of the porting is accomplished by getting the right carbide cutter profile for the application and valve size. Goodson also sells a floating tool holder designed for the R-8 collets used in most vertical milling machines. The tool holder sells for \$900 and the carbide cutters for \$40 each.

There is hardly a need to resurface a valve because most of the hard coatings are applied during manufacturing.



This is a Serdi Micro multi-angle valve seat refacing tool. Multi-angle seats offer improved flow and longer valvetrain life.