familiar with thinking about port heights. A 30mm-high port, for example, in a 50cc engine has a low caliper, but those same 30mm in a 300cc engine will have an extremely high caliper. But whenever we talk and think about caliper, regardless of engine size or displacement, 160 degrees will always be a low caliper, and 190 degrees will always be a high caliper. It's important to know that changing the crankshaft stroke, increasing or decreasing the number of gaskets, or altering any cylinder or piston height will affect the caliper.

Chapter 7 – Cylinder: Exhaust Port

7.1 Introduction

The exhaust port's importance and function are poorly understood. It controls the exhaust gas output, directly impacting power and how it's delivered. As we'll see in this module, the choice of opening shape, type, graduation, and size will largely dictate the behavior of two-stroke engines.

Here we'll cover a wealth of theory drawn from many textbooks on the subject, as well as the conclusions and expertise of this writer. This means you won't find anywhere else the learning you'll get here. I'm convinced that a major shift will occur in your mind, and many things will begin to make sense from this module onward.

Of course, the exhaust port isn't isolated in terms of importance or engine behavior; as I've already explained, everything is interconnected. But we need to look at this part like we would look at a spark in a fire. Here, we'll talk a lot about shock waves, and it's from the exhaust port that they originate. How they're created and emitted answers many questions about the mysteries of these engines.

7.2 Concepts we need to understand:

Whenever the exhaust port opens, a pulse of energy is released and travels through the exhaust. Many people confuse the exhaust of burnt gases with this pulse, called a shock wave. In the image to the side, we can see the shock wave, which is separate and much faster than the smoke. The exhaust of burnt gases and the energy pulse are distinct things. This pulse drives all the engine dynamics. It's responsible for drawing mixture from the crankcase, returning it, and even supercharging the engine, increasing volumetric efficiency.

The pulse has supersonic speed (greater than the speed of sound) when it leaves the exhaust port due to the high temperatures of the gases. When it returns, the speed is subsonic, as the exhaust temperature drops dramatically and deceleration occurs.

The timing and shape of this pulse is controlled by the escape port. That's right, we can not only define the timing (which everyone knows) through the window's graduation, but also shape the shape of the energy pulse (which I believe few know). The pulse is shaped by the shape of the top of the escape port. If the escape port opens gradually, as in the image below, the pulse splits and lengthens as the port is uncovered by the piston. This means the pulse doesn't suddenly exit; it's elongated and split into a long, but weaker, pulse.

In the image below, we see a square exhaust port that opens 100% of its entire length. This generates a strong, short pulse as the piston uncovers the port, suddenly opening a very large area.

For better understanding, it's as if we had a cylinder full of air and tried to empty it by lowering the piston and uncovering the exhaust port. The port with an oval opening would allow us some control over the air outlet, allowing it to exit gradually and continuously until it's empty. A port with a flat opening, on the other hand, wouldn't allow this control, allowing the air to escape quickly and with greater force.

This explains why engines with very open top ports leave the cylinder in poor low-end performance, as the pulse is concentrated strictly in a very specific, typically higher, RPM range. A gradually opened port, on the other hand, spreads the torque band across several

RPM ranges, including the lowest and highest peak power ranges.

That's why we have to carefully consider its shape to ensure it fits the project. A gradually opening window will never deliver the most power, but it spreads the torque band across several rpms, which pairs well with engines with gearshifts and direct drives.

The flat-port exhaust delivers plenty of power, albeit in a narrow range. It's well-suited to CVT transmissions. However, even with this type of transmission, caution is needed, as some designs don't have a CVT system capable of accepting adjustments for this exhaust port. Keep in mind that the power band will be at high RPMs, while some CVT systems operate at low RPMs.

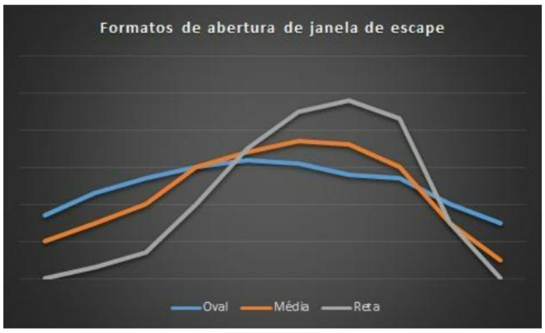
In short, when we look for peak power as in the graph represented by the gray line, we use an exhaust port with a flatter top.

When we want a smoother engine with power in other RPM ranges besides the maximum, as demonstrated by the blue line, we use a gradually opening exhaust port.

We can also have an intermediate window, with a smaller arch than the oval window, but not as flat, creating a curve similar to the orange line.

However, as mentioned earlier, the exhaust port works in conjunction with other engine components.

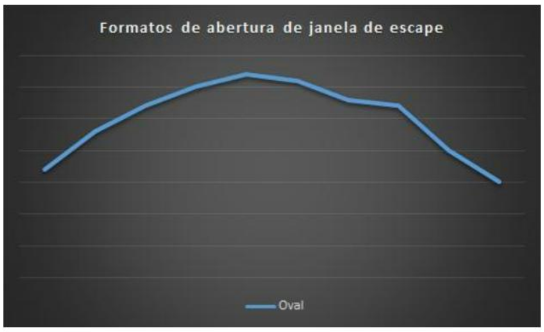
The final exhaust cone, called the baffle , as we'll see in the exhaust section, helps us form the return wave we seek. But how it forms is a function of the exhaust port.

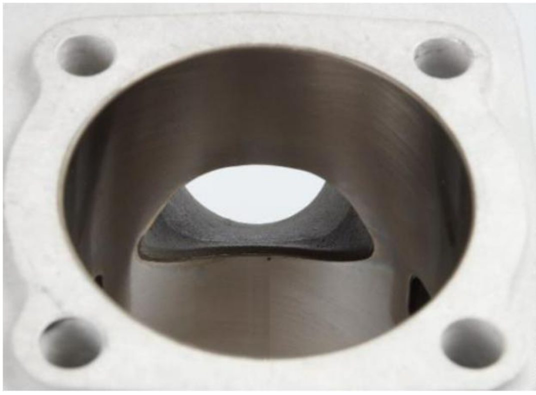


7.3 Types of escape window

Oval – The oval or round exhaust port is the most common and most widely used. It's the easiest to build and meets all engine requirements for daily use and doesn't require performance. It's typically small, and because it has an arched opening, it causes less wear on the rings.

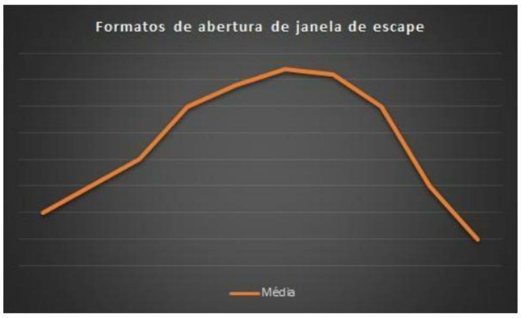
As we saw earlier, the shock waveform it creates is long and weak, making it well suited to various designs. And the graph demonstrates the type of power curve .


Formatos de abertura de janela de escape
Oval

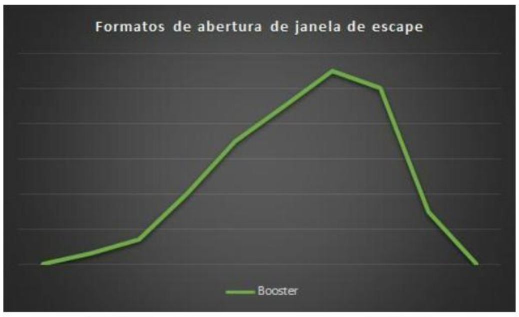


Square – The square exhaust port, because of its flatter roof, creates a stronger and narrower shock wave. It's used when we want to increase the power of an engine that already had an oval port, and our design allows it to lose power at low RPM.

If used in an engine with a geared transmission, it's important to check for gaps between gears. It's common to find engines with a dead zone between fourth and fifth gear. In this case, fourth gear needs to be stretched significantly to allow fifth gear to reach an RPM that provides torque and maintains the speed increase. In the exhaust section, we'll learn how to correct this by changing the shape of the baffle (the last cone).



Oval with Booster – Here we get into the types of racing cylinder ports. The booster exhaust port is undoubtedly the most efficient. It doesn't generate the most power, but it is the safest among racing ports . As long as the 70% diameter limit is respected when constructing the main port, there will usually be no problems with ring breakage or premature wear. It is possible to use more than 70% opening, but the risk of ring damage increases considerably. We'll look at this in more detail when preparing the exhaust port. The boosters (side holes) increase the width of the exhaust port where it's most needed, at the top of the port, helping to quickly drain gases, creating a strong, rapid pulse.



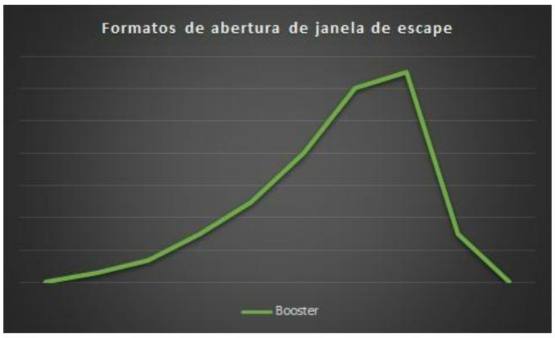
Boosters may already be included in a special cylinder or may be constructed from a cylinder with a simple port. We'll never see the boosters above the main port; at most, they'll be aligned with it. It's important to understand that flow has inertia, and the part we open first tends to be the main flow channel. Therefore, it's preferable to open the main port one or two notches before the boosters. This way, the flow will be concentrated through the main port, which is usually larger. One cylinder is the exception. Kawasaki's KR150 has boosters above the main port, but they contain the power valves, similar to Yamaha's YPVS and called KIPS (Kawasaki Integrated Power- Valve System). Here, the boosters open after a certain RPM to increase power, unlike the YPVS, which opens the single central port to increase the scaling and generate more power.

In the original Ninja KR150 cylinders, there are two holes where two rods are fitted and open and close the boosters.. In the modified cylinders, the Thais remove this system, leaving the boosters always open, and raise the main exhaust port so that the three ports are level. This way, they achieve a very strong pulse, as we saw previously.

This window isn't the one that generates the most power because between the main window and the boosters, there are two dividers that normally can't be too narrow, as they risk expanding due to heat. These dividers prevent the pulse from escaping when the window is fully open.

Dual or bridged – The dual exhaust port generates the most power of all. As we saw earlier, the booster exhaust port has two dividers at the opening, but the dual exhaust port has only one in the center. However, this is the most problematic exhaust port. This is because the beam that prevents the ring from jumping into the window is located precisely on the window.

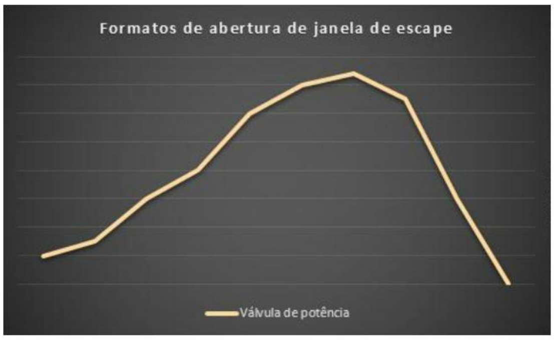
where most of the gas escapes. This causes the gas separator to heat up and expand. Two things typically occur: 1. It expands and pushes against the ring and piston, causing damage to all parts. 2. As the piston rod heats up, the oil film that should lubricate and reduce friction between it and the ring evaporates, leaving only metal on metal.

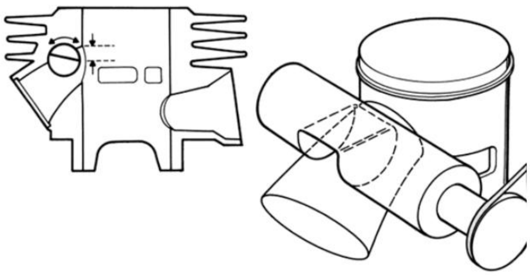


It's common to see evidence of wear on the cylinder and ring. The ring leaves a mark where it has worn down and stopped making contact with the cylinder. The wider the port, the greater the problem, since what prevents the ring from exiting the exhaust port is the bar. This is why we should avoid this type of port, especially in daily or constant use. To minimize the problem, sand the bar to prevent it from projecting against the piston. Another solution is to drill 1.2 to 1.5 mm holes in the piston aligned with the bar to lubricate and cool it. However, these are stopgap solutions that don't always solve the problem permanently.

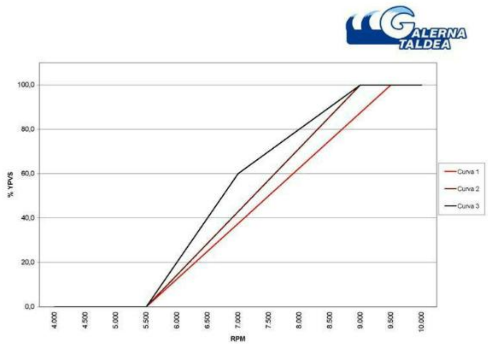
Power Valve – The power valve window, better known as YPVS, after Yamaha's name, is the most versatile. The acronym stands for Yamaha Power Valve System. Other manufacturers also adopted this technology, which is still used in some engines today.

It varies the height of the window, changing the graduation according to RPM. The adjustment is made with an electromechanical system that changes the window timing. At low RPM, the system closes the top of the window, emitting slower shock wave pulses, and raises the height to emit faster pulses as the RPM rises. This makes the power curve more complete, with low and high torque.

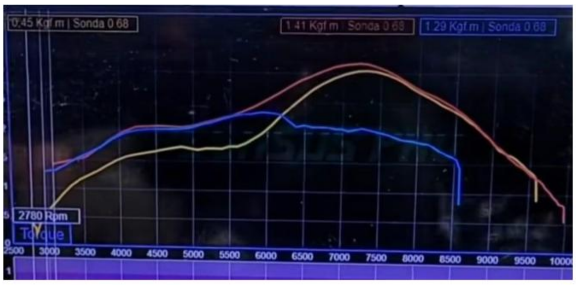




Interestingly, it's possible to alter the original power valve opening curve when the actuator is electromechanical. Here we see a graph showing the opening as a percentage versus RPM. Curve 1, for example, has a linear opening that starts at 5500 RPM and opens 100% at 9300 RPM. It's also possible to stagger the opening. By doing this, we can better match the YPVS opening to the exhaust's peak power.



I tested an off -road motorcycle with the same Yamaha Lanza DT230 engine, running it on the dynamometer with the valve module turned off. I first ran it with the valve fully closed, as shown in the graph below and represented by the blue line. Then I opened the valve fully, and we obtained the yellow curve. Finally, I turned on the module, and with the valve operating correctly, we were able to connect the two curves with the red line. See the importance of an exhaust port with a properly functioning power valve.



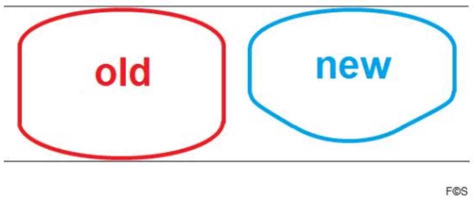
At the blue line, low-range power delivered power at low RPM, but didn't go beyond 8500 RPM. At the yellow line, with high-range power, low-range power was weak and high-range power was very powerful. This is what the exhaust port power exerts on a two-stroke engine.

Poop Escape – The poop escape is a work of art by our friend Russo, who works with Jeff Moby Custon here in Brazil. These guys are so funny, it's impossible not to laugh when they're around you.

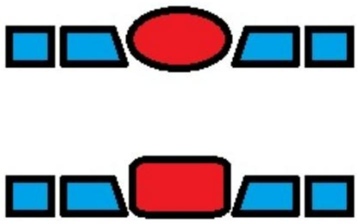
The poopy exhaust has its roots in gradually opening the window and spreading the poop zone, or rather, torque. According to them, this engine is still running today.

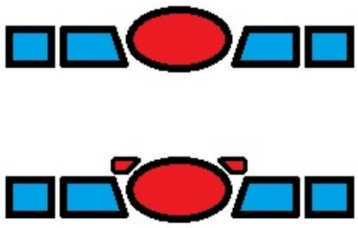
Still on the subject of exhaust port shapes, the drawing on the side was suggested by Fritz Overmars . Note that in the blue drawing, the bottom of the exhaust port is arched. This means that the opening after the transfer opening level no longer matters when considering performance.

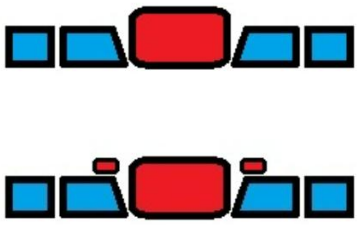
He's probably more concerned with avoiding loss of mixture to the exhaust than with any flow improvement. It also saves rings, as camber helps push the rings back into the cylinder more smoothly. Yes, the rings protrude from the port, and that's why we can never have a 100% flat port. Minimal camber and not-so-tight corner radii are necessary. So, don't worry if the piston covers part of the exhaust port when it's down.



We can not only prepare escape windows but also transform one window into another. Above, the original window, and below, the suggested prepared window. Below are some examples.







7.4 Preparing the escape window

Care must be taken when working on the exhaust port to avoid opening it so much that you lose torque at low RPM. Therefore, I always suggest starting by opening the port cautiously, millimeter by millimeter, until you gain experience and understand the transformation each millimeter brings to the engine. Most of the time, the cylinder of two-stroke engines is easy to remove and reinstall, which allows us to conduct tests and gradually open the exhaust port while conducting practical tests and learning.

With time and experience, we understand where and how to work the escape window. Remember, if you overdo it, there's no turning back.

We need to pay attention to two parameters: the height and width of the window. Height is directly linked to the graduation, and from experience, I can show you a path to follow by providing a table that we will see below. The second parameter, which refers to width, is more difficult to get wrong. But we need to know that increasing the width at the top of the window also affects low RPMs.

When we talk about flat windows, we're talking about some degree of arching. A window that opens at the same angle from end to end tends to have the ring sticking when the piston rises. Therefore, we'll never make a 100% flat window.

The minimum width of the exhaust port depends on the type of preparation we want, but a good starting point is 55% of the cylinder diameter. In other words, if the cylinder is 50mm in diameter, we'll calculate as follows:

50mm x 55% = 27.5mm (light preparation)

50mm x 60% = 30mm (more advanced preparation)

When considering light setup, always try to use exhaust ports with the maximum width indicated above and a gradual (arched) opening to avoid losing low-end torque. Once again, I emphasize that I'm giving you a guide, a starting point, so you have a place to start.

For street and track setups, we can carefully increase this aperture, reaching the 70% limit.

50mm x 70% = 35mm

A 70% opening of the main exhaust port will always be our limit when preparing safely. It's possible to use even more, otherwise there's a risk of ring breakage or premature wear.

The correct way to measure the opening is linear, not circular. To make things easier, I usually mark the desired opening on the piston, as shown in the photos below. Then I insert the piston into the cylinder, and we have the correct opening to mark on the window.

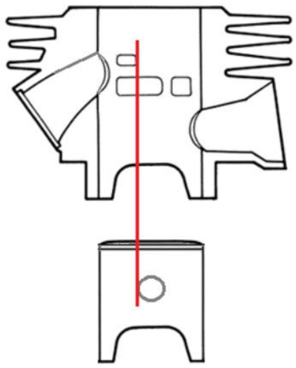
Knowing the limits of opening the exhaust port and also knowing that it can compromise engine usability or exceed the intended purpose, it's harder to make mistakes. I don't want to scare you when working with it, but I do want you to be as careful and confident as possible when handling the grinder. When in doubt, always open it less.

I usually spend hours, sometimes days, thinking about the objective and the best geometry and size for the escape port. If there's any place in the preparation that requires time and reflection, it's here. Measure, think, and reflect as many times as necessary to ensure you're confident in what will be executed.

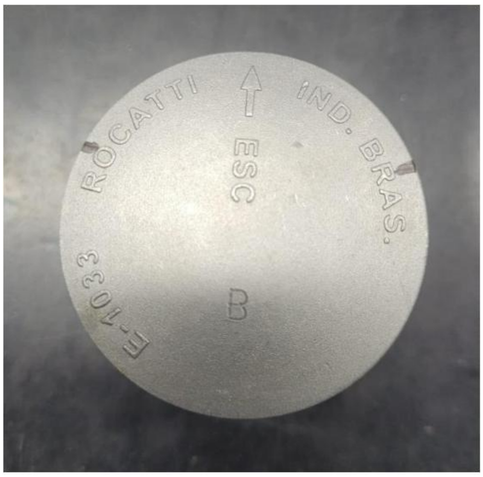
Never start working with the grinder before measuring and marking the area you want to open with an overhead projector. It's easy to get carried away and go beyond the intended opening. Therefore, the markings will guide you to open only what really needs to be worked on.

Later we will also see some techniques for using grinding to avoid stripping the nikasil or hard chrome from the cylinders, as well as how to chamfer all the windows to reduce premature ring wear.

When developing a booster or dual port with a very wide width, we need to pay attention to how wide we can open it. The side opening of the piston or pin can short-circuit. In other words, it can connect the exhaust port to the main transfers. Imagine that, when the piston is at half height, the pin bore passes through the side transfers. If the exhaust port is too wide, there will be a passage between the two ports, creating a short-circuit. This will cause vacuum leakage from the crankcase to the exhaust when the piston is ascending and compression when it is descending. This causes power loss. The limit is the red line.

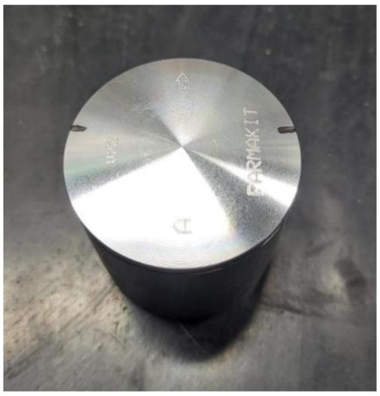


I usually mark the piston with an overhead projector, aligning the top of the piston with the side opening. This mark will give me the maximum opening I can transfer to the exhaust port.


ROCATTI
IND. BRAS.
ESC
B
E-1033


45.27
OFF
ON
ZERO
ROCATTI
IND. BRAS.
ESC
B

And now the marking with a piston that doesn't have a side port. In this case, the limit is the piston bore, which allows for a larger exhaust port. Whenever choosing a piston, be aware that those with a side port will limit the port opening. In the example below, we gain 3mm of additional port.

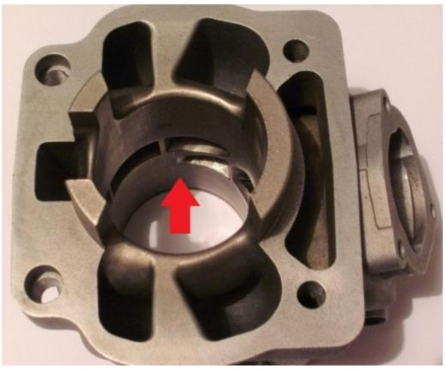


After marking the limits on the piston, we can transfer the marking to the cylinder and limit our exhaust port as shown below. Here, we're talking about maximum exhaust port sizes. We'll use this technique when we want to extract the full power from the engine.

Remember here, as we have seen before, that opening the exhaust port with a large extension at the top, throws the torque zone to higher RPM and generates power peaks.

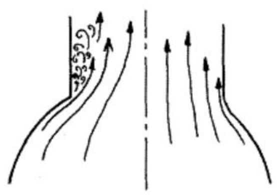
Interestingly, the Aprilia RSA used a piston with a cap in the piston pin bore. This cap was made of some type of polymer that could withstand high temperatures. Perhaps Teflon.

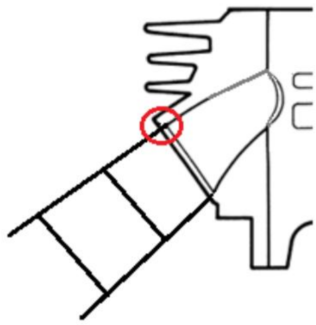
It closed the bore, allowing Aprilia to have the boosters project rearward, reaching almost the entire main transfer port. The idea was to have as much blowdown area as possible.



Now let's talk about the exhaust port's exit. It needs to be fluid, with no sharp edges from where the exhaust port exits the cylinder to the connection with the flange or nut that secures the exhaust. Whenever possible, smooth out the edges and level the steps. Due to the speed at which the pulse exits and returns, sharp edges generate turbulence and will reduce the pulse's efficiency.

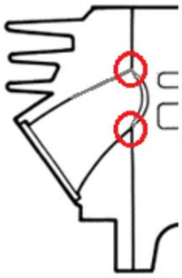
The finish from the channel to the exhaust port should be smooth, but it also doesn't require polishing. A sanded finish is more than sufficient.





Whenever we work on the escape port, we remove the original factory chamfer. This chamfer applies to all machined ports, including transfer ports. The chamfer serves to break the sharp corner and ease the entry and exit of the ring into the escape port.

It's also important to protect the cylinder coating, if present. Cylinders with Nikasil and hard chrome can chip when the ring scrapes against the window edge. Cast iron cylinders are uncoated and don't run this risk, but without proper chamfering, premature ring wear and even breakage can occur. I usually break the sharp edges with abrasive stones, working from coarsest to finest. Finally, fine sandpaper provides the final finish.



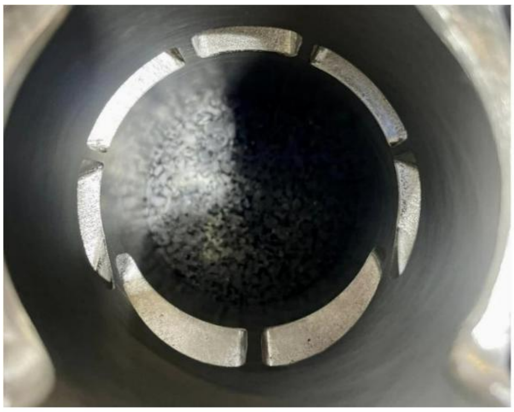
7.5 Case studies

Testarossa kit with bridge window

Kit 2 Fast with bridge window

Stage 6 Kit with Bridge Window

Kit with Bridge Window



kit with central window and booster

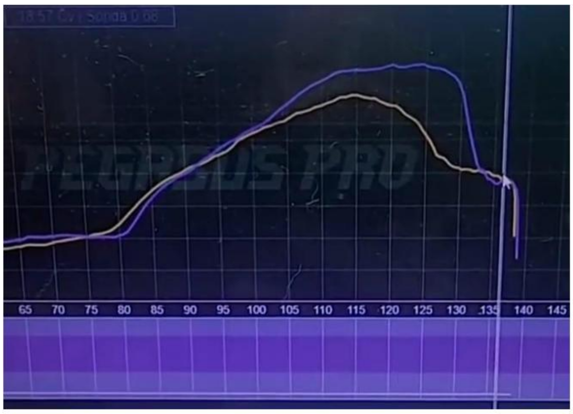
Kit 8.1 with central window and booster

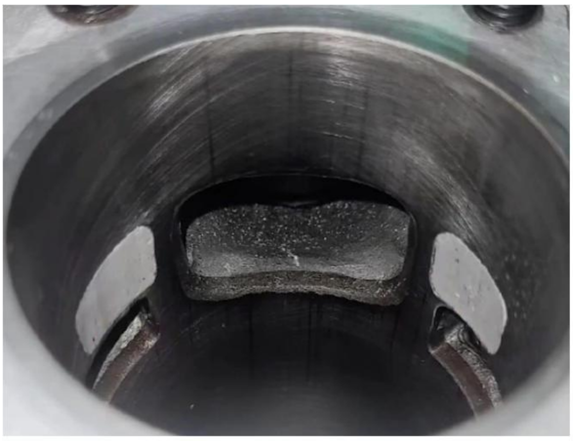
Roost Kit Havoc with bridge window and booster

Roost Kit Current Havoc with center window and booster

All of these cylinders are used in racing scooters, most with 90 to 100cc displacements, generating 40 hp in some cases. Note that they all utilize the two exhaust ports that generate more power.

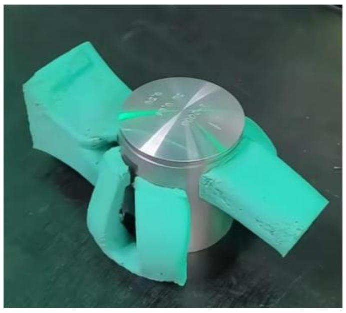
I conducted a practical test on a Yamaha RD135 cylinder, keeping the original exhaust port and adding boosters. I sealed them with epoxy glue and ran them on a dyno to compare their effect on the engine. Remarkably, there was no significant power loss at low RPM, but a significant gain at higher RPMs. This is because the boosters followed the rule of opening after the main exhaust port, creating a gradual opening. The yellow line shows the boosters closed and the blue line shows them open.





I made a model in molds so that I could visualize the internal holes of the exhaust window ducts as follows:

Original escape window, before preparation.



Exhaust port with boosters after final preparation. This 135cc cylinder produced over 40 hp at the wheel. The stock cylinder produces 17 hp according to Yamaha.

Chapter 8 – Cylinder: Transfer Window

8.1 Introduction

First of all, we need to familiarize ourselves with the nomenclature of transfer windows that the literature deals with.

We name the windows with letters and those closest to the escape window start with the letter A and continue with the letters B, C and D as they move away.