Chapter 16 – Ignition

16.1 Introduction

Ignition timing in two-stroke engines can seem like a mystery, especially when you don't understand its fundamentals. However, when you understand its concepts in depth, you begin to understand why it behaves so differently from four-stroke engines, using more advanced ignition timing at low RPM and less advance at high RPM.

like combustion chambers, with no squeezing. Therefore, the flame's reach is enormous, requiring ignition advances of around 50 degrees, even in the highest torque zone. This would be disastrous in a two-stroke engine.

We must first remember that two-stroke engines achieve their peak power when creating and receiving the shock wave. At lower RPMs, the shock wave arrives too early, and at high RPMs, it arrives too late. It makes sense to think that if we could change the speed of the shock wave, we could improve power, right?

However, to change the shock wave speed based on RPM, we would need to change the exhaust length in real time, but this is somewhat difficult to do in practice.

We also know that the speed of sound (the speed of the shock wave) is constant. But we also know that it can vary with temperature. The hotter the gases, the higher the speed, and the colder the speed, the lower.

So how can we change the wave speed? That's where varying the ignition timing comes in!

It's important to understand that gases can reach and even exceed 2,000 degrees Celsius inside the combustion chamber. But immediately after combustion, as the piston descends and the gases expand, the temperature drops dramatically, reaching a fraction of that temperature when the exhaust port opens. An advanced ignition timing causes the mixture to ignite earlier and, of course, cool earlier.

A later point occurs later, storing energy (heat) and cooling later as well. What happens in both cases is that an earlier point sends cooler gases to the exhaust, and a later point reserves more heat for the exhaust.

This is how we can change the speed of the shock wave inside the exhaust, changing the temperature of the gases. This is why we use an earlier timing at low RPM, cooling the exhaust and creating slower shock waves. And we also use a later timing at high RPM to heat the exhaust and create faster shock waves.

It's important to note that a more advanced ignition timing heats the engine more, while a later ignition timing cools it down. This is where the temperature plays out, shifting heat back and forth to the benefit of supercharging.

The combustion chamber has a strong influence on flame speed. A squished combustion chamber has a squish band that creates a centralized area, allowing the flame front to reach the entire area more quickly. The squish band compresses and accelerates the mixture toward the center, generating turbulence, which also accelerates the flame front.

So, if we want a faster flame front, creating a 50% crush band with a lot of speed, for example, we'll be benefiting power at low RPM, since we're burning this mixture faster. If we burn it earlier, this means we'll be sending less heat to the exhaust, consequently cooling our pipe and generating slower shock waves.

On the other hand, if we use a 40% crush band and low speed, we will be slowing down the flame front, which has a larger area to travel, and accelerating the mixture less, reducing turbulence.

This reduces the flame front speed, diverting more heat to the exhaust, which in turn will return faster shock waves and benefit high RPMs. We can then modify our combustion chamber according to where we need more power, whether at high or low RPMs.

Another point to consider is that the higher the RPM, the greater the atomization (mixing of fuel and air) in the carburetor due to the increased air velocity passing through the carburetor venturi. This accelerates the flame front. The faster the burn, the less ignition advance is required.

16.2 Early/late point

We shouldn't confuse the term "delayed timing" with timing after TDC, more than 0 degrees, or negative. A two-stroke engine always operates with the ignition timing before TDC, and we'll never see timing angles of 0 degrees or less. Unless the intention is to "brake" the engine from X RPM.

Normally we will see, in the best power zone, angles close to 15 degrees with small variations depending on the engine and the construction of the combustion chamber when the fuel is gasoline.

Fuels with a high RON tend to have a greater resistance to ignition initiation and will require more advance. We typically see 4 to 7 degrees more for ethanol and methanol, depending on a few factors.

But what needs to be clear is that a point ahead or behind will always be before TDC. A clear symptom of ignition after TDC is the famous "shot" or fire coming out of the exhaust, which occurs when an engine refuses to start. This occurs because the fuel burns too late, and the exhaust port opens while combustion is still occurring.

16.3 MSV x Ignition Point

By FOS:

MSV = Maximum Squish Velocity

There is a relationship between crushing speed and combustion speed. But, strictly speaking, there is no flame front. Turbulent combustion doesn't move smoothly from point A to point B to point C.

Turbulent combustion can be compared to a forest fire, where the wind carries burning leaves to remote areas, where they start their own fires long before the "main" fire has reached those areas. Squish does the same thing: it throws clouds of burning mixture throughout the combustion chamber, making combustion many times faster than a laminar flame front.

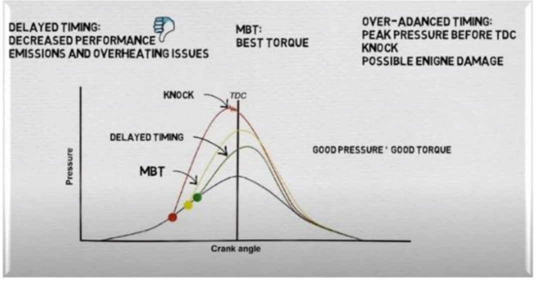
Rapid combustion has the same effect as advancing the ignition timing: combustion will complete sooner after top dead center, leaving more time for the burned gas to expand before entering the exhaust. During this expansion, the gas cools, and its lower temperature lowers the exhaust system's resonance frequency. In short, more squish or more ignition advance (or a higher compression ratio) reduces the maximum engine speed the engine will reach.

One thing to keep in mind: the turbulence generated by crushing also tends to push ionized gas molecules apart between the spark plug electrodes, stretching the conductive path between them and increasing the required spark voltage. In other words, the higher the Maximum Squish Speed , the stronger your ignition should be. This is why you can have too much MSV for a given engine. The fault isn't the MSV itself, but the ignition, which can't handle it.

16.4 The correct point

We need to understand that the correct timing for a two-stroke engine depends on several factors, as we've seen so far. Combustion chamber size, squish speed (turbulence), fuel type, fuel atomization, stoichiometric ratio, engine operating RPM, among many other factors.

The ideal ignition timing isn't an easy question to answer, as multiple variables create conditions for a rule to exist. What we do know is that the best ignition timing will be the one that generates maximum chamber pressure a few degrees past TDC, between 8 and 12 degrees.



What changes the ignition timing:

Fuel octane rating

Rich or lean fuel mixture

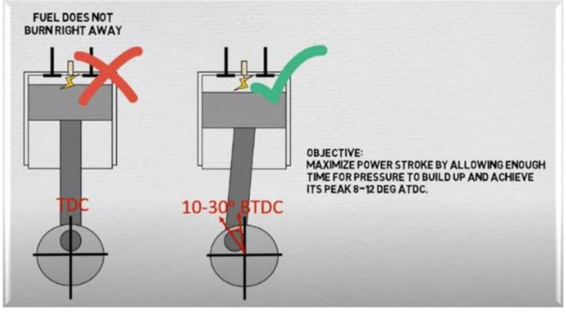
Engine temperature

RPM

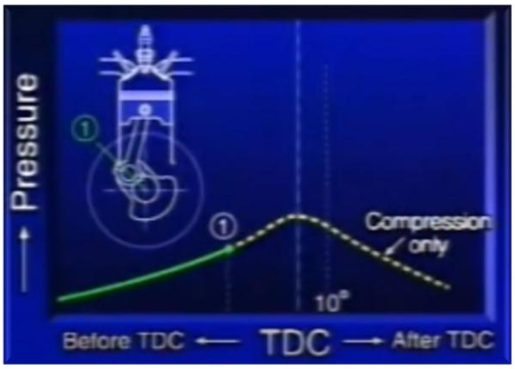
Engine load

But how do you find the engine's optimal ignition timing? This is another difficult question, since the engine will deliver maximum power under these conditions, but small variations will hardly be noticed during test drives on the street.

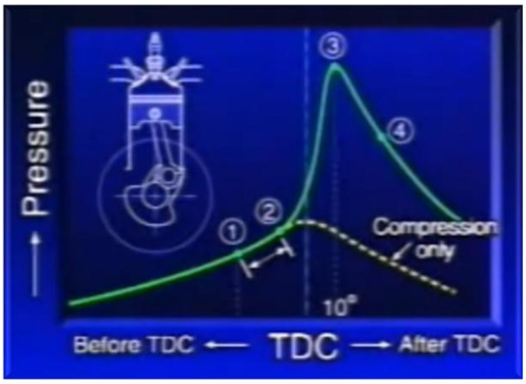
Only a dynamometer can tell us the best ignition timing, which is the one that generates maximum power just before detonation occurs. If detonation occurs, the timing needs to be retarded to avoid this condition, and we'll then have the engine's optimum timing.



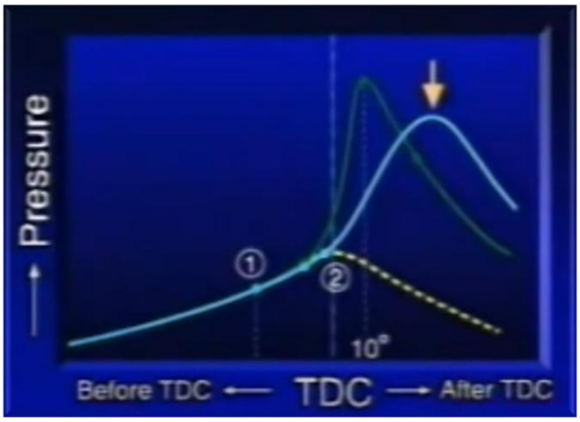
But first, let's understand a little about how timing affects cylinder pressure and, consequently, power. In the figure below, we see an engine compressing a mixture without a spark. What we see is the increase in pressure due to the piston compressing the combustion chamber.



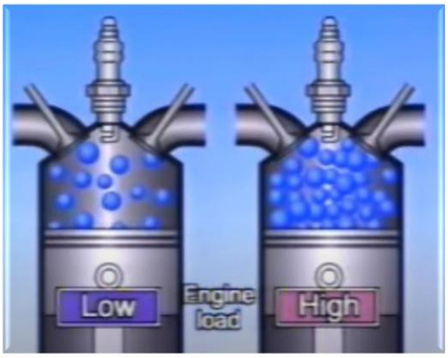
Below, the same engine with a spark trigger that ignited and increased cylinder pressure. Maximum pressure occurred 10 degrees after TDC, which would be ideal. From point 1 to point 2, we see the delay the mixture takes to receive the spark and actually initiate the flame front. This is why we advance the timing, and each fuel has its own specific timing.



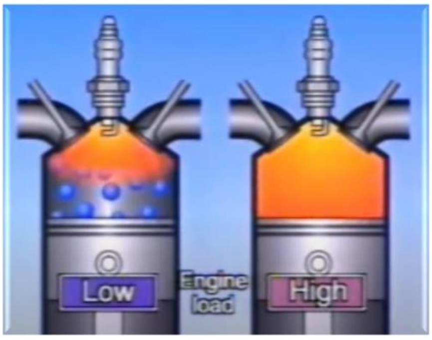
As we increase RPM, the delay time remains constant, but the engine spins faster, resulting in a delay in ignition timing, which occurs later. The maximum pressure peak will occur after 10 degrees of crankshaft rotation and result in a loss of power. In this case, the timing should be advanced to compensate for the higher speed at which the cycles are occurring. This is what happens in a four-stroke engine, but as we've seen so far, two-stroke engines use retarded timing despite this phenomenon. The only drawback is that, despite the delayed ignition timing , it will heat the gases more and shift the return stroke of the shock wave, increasing supercharging. This automatically increases the engine's volumetric efficiency, which will generate even more cylinder pressure.



Another point to consider is that at low RPM the volumetric efficiency is lower, that is, the cylinder filling is lower and less fuel ends up in the combustion chamber.

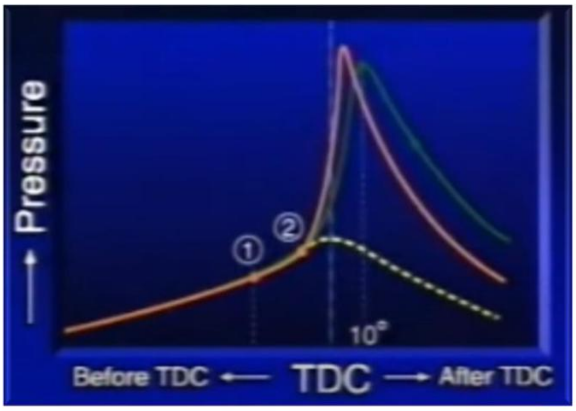


Less filling reduces chamber pressure and reduces the number of molecules present. Pressure helps increase velocity, and fewer molecules delay the flame front because there's a greater spacing between them, slowing the combustion process. Therefore, lower RPMs require more advanced ignition timing, while higher RPMs require fewer.



Just as cylinder filling is affected by RPM, throttle position also plays a role. We might have high RPM but little throttle, which would result in low cylinder filling, requiring more timing. This is why we see injection maps with a correction factor not only based on RPM but also on throttle position. This also explains why some carburetors have an opening position sensor.

Below, we can see a timing point that's too advanced, increasing cylinder pressure and occurring at the wrong time. This causes stress on the entire moving assembly, damaging the cages and connecting rod. If the timing is advanced further, we'll see signs of detonation and further damage to the crankshaft.



16.5 Types of ignitions

We can find 3 types of ignitions, those with fixed point, variable map depending on RPM and programmable.

Fixed -point ignitions are typically the oldest and don't provide the timing correction a 2-stroke engine needs. They can be equipped with a platinum or CDI without an advance curve. Ideally, we should avoid this type of ignition, as it will only allow the timing to be adjusted for the engine's optimum power range, which will be at higher RPMs. Consequently, this engine won't have timing correction at low RPMs, resulting in a loss of power under these conditions. This results in an engine with poor acceleration, meaning it struggles to rev up.

Variable Timing - Variable timing ignitions have a map, that is, an advance curve based on engine RPM. We'll see more advance at lower RPMs, and as RPMs rise, the timing decreases. Each ignition has its own specific curve, and you'll need to consult the manual to find it. Several manufacturers, such as Seletra, PVL, MVT, Motoplat, Hitashi, and others, have internal rotors, without a coil to power the headlight or battery. This type of ignition also has an external rotor, or magneto, as it's called. The latter usually comes pre-installed with the engine and has a light coil.

Programmable - Programmable timing ignitions give us the freedom to adjust the timing according to each engine's needs. However, it's important to understand that adjusting this type of ignition is more complex, since we're starting from scratch. My experience with this type of ignition is that when faced with a blank map, we're tempted to research existing curves. In this case, the freedom we had with the ability to adjust the best timing is limited to a generic ignition curve.

Before opting for this type of ignition, be aware that the curve needs to be perfectly tailored to the engine for the option to be worthwhile. But unless we have the tools and knowledge to optimize this curve, the investment will have been in vain.

Therefore, it is preferable to choose an ignition with a standard curve if we do not have a dynamometer to calibrate the engine.

16.6 Optimum point adjustment

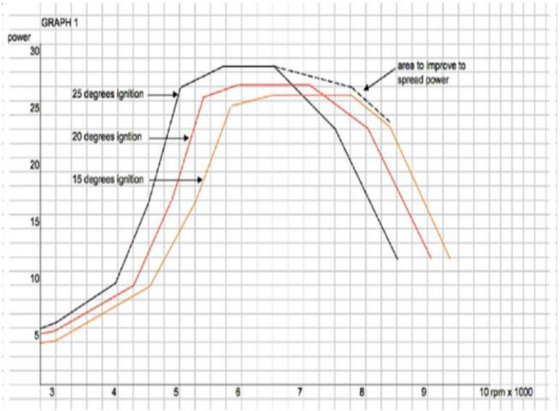
As I mentioned earlier, to perfectly adjust the point we will need a dynamometer or some software that simulates this function, such as applications that measure the acceleration from one point to another as a function of elapsed time.

Fixed-map point adjustment: The fixed point, as the name suggests, doesn't vary. If the manufacturer opted for a stable curve of 17 degrees, for example, the engine will operate at that point regardless of the RPM. What you can do is rotate the table or rotor/magneto clockwise or counterclockwise to match the point with the engine's best power range, especially when modifying something.

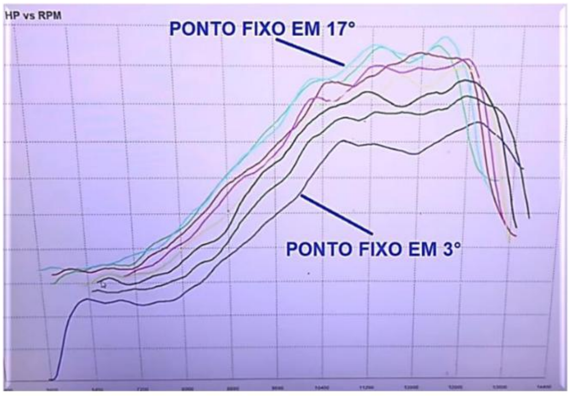
Timing adjustment with variable map : The variable timing has a curve where we cannot adjust it. It is usually a ramp, decreasing advance as engine RPM increases. In other words, more advance at low RPM and less advance at high RPM. What we can do is move the curve so that it operates at the RPM that provides the best possible benefit. Typically, we will adjust the curve to generate maximum efficiency in the engine's best power range. To do this, we must move the table or rotor/magneto clockwise or counterclockwise in 2-degree increments until we find the point where the engine produces the most power. The low RPM point will be a consequence of the curve created by the ignition manufacturer.

The timing should be advanced until the power output has stabilized or declined at peak power, which indicates that detonation may be occurring. In this case, retard the timing by about 2 degrees to avoid this problem. This would be the optimal timing with a variable ignition map.

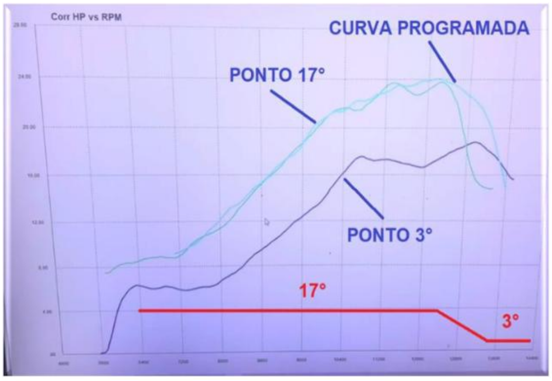
Timing with a programmable map: Here we'll understand how an ignition curve is created specifically for a two-stroke engine, taking its needs into account. To do this, we must select some fixed points and run them on the dynamometer. Below, we can see the curves for three fixed points: 25, 20, and 15 degrees. It's clear that 25 degrees performs best at low RPM and 15 degrees at high RPM. The idea here is to compare the curves and connect them, as shown by the black dotted line, creating an ignition curve that meets the needs of this engine.



Below, we see several power curves in search of the best point for an engine in a real test. The ignition is programmable, and the test consists of passing the engine through various fixed points from 3 to 17° of advance. Alongside, we see tests at 3, 5, 7, 11, 13, 15, and 17 degrees. We can see that 17 degrees provides more power at lower RPMs, but dies at higher RPMs. And that 3 degrees is where the engine has the greatest RPM range. However, between 17 and 3 degrees, we can see that other ignition points complete what would be an ideal power curve.



Now we can see the curves created by the fixed points 3 and 17° separately and a third programmed curve that combines the two, extracting maximum power from the engine. It's worth noting that this engine has a power valve, so it didn't require as much timing at low RPM, as the valve adjusts power based on the exhaust port timing. Engines without a power valve will require 20 to 30 degrees of advance at low RPM because there's no exhaust port adjustment.



By FOS

Crossings:

Any reasonably healthy engine can idle at 16° ignition. With this fixed value, we perform a test bench measurement, and a power curve emerges. Then, we set the ignition to a fixed 12° and measure again. Let's say the 16° power curve is best up to 10,000 rpm, while the 12° curve is best from 10,000 rpm. At 10,000 rpm, the two curves intersect; therefore, they perform equally well there. We can then say: at 10,000 rpm, 16° is too early, while 12° is too late. 14° could therefore be the ideal value for 10,000 rpm. So, we adjust the point to 14° and create a power curve again. For example, this 14° curve intersects the 16° curve at 8000 rpm and the 12° curve at 11000 rpm. So, we can conclude that 15° is optimal at 8000 rpm, 14° at 10000 rpm, and 13° at 11000 rpm.

16.7 The point in practice

Platinum: Platinum is an old form of ignition that works like a key that opens through a cam located on the crankshaft axis and opens at the moment the spark must be generated.

Therefore, its timing is fixed and should be adjusted to the engine's optimum RPM range. Typically, two-stroke engines will "like" 15 degrees at higher RPMs, so we should adjust the breaker to open close to this advance, assuming that the engine with this ignition system has no priming.

To make the adjustment, we must rotate the crankshaft 15° before TDC, opposite the direction of rotation, and with a 0.10 feeler gauge, check if the platinum is already starting to open. This would be the correct way to adjust the timing with the platinum system.

Fixed-point CDI: Fixed-point ignition is very similar to platinum ignition, but the timing and spark generation are generated electronically through a CDI. Some have a pulser that tells the exact moment the spark should be generated, while others use the magnetic field generated by the magneto's coils and magnets.

should be adjusted to the engine's optimum RPM range. Likewise, the platinum ...

Just like the platinum, we will look for a standard point of 15 degrees for this type of ignition and, if this engine goes through a dynamometer, calibrate the best point for it.

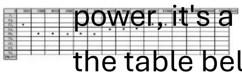
Variable Timing CDI: This is where we come across more modern ignition systems that have pre-programmed ignition timing advance and retard curves. In other words, we can't change the curve itself, only the RPM at which this curve affects the engine by rotating the table or rotor/magneto.

This type of ignition is manufactured with several curves, depending on the manufacturer or engine for which it was designed. They can be built with flywheels, which cover the vast majority of original engines, or they can be manufactured with internal rotors, which provide less inertia when increasing engine RPM. Magneto ignitions require a timing gun to be adjusted, and with external markings between the table and the flywheel, we check the curve of that CDI.

Rotor ignitions are mostly manufactured as replacements for original flywheel ignitions. These are adjusted by rotating the crankshaft in the opposite direction to the rotation and measuring the piston's height. This value is always provided by the manufacturer.

Let's start by adjusting the timing using the internal rotor ignition system. This type of ignition is manufactured by PVL, MVT, Seletar, Hitashi, Motoplat, Ital, and many others. The internal rotor is typically made of aluminum with magnet plates attached to it, while the stator (coil) is external. There's a marking on the stator and another on the rotor, indicating the point at which the spark is fired. Each manufacturer has created a specific curve, and we need to research the advance and retard timing and at what RPM this occurs. This isn't always easy, but if you don't know, you can find your own ignition map using a spark gun. Simply install the ignition by connecting the two marks and placing the piston at TDC.

When we start the engine, we'll use the ignition gun to determine the timing at that RPM and write it down. We need to increase the RPM by 1,000 rpm and note the timing at that point until the engine's highest RPM. With this data, we can record the ignition curve and check if it suits the engine. Again, only the dynamometer can determine the optimal timing, so if this is the case, we should advance the timing until we feel the engine is performing in its best power range, then return (retard) it a few degrees. If there's a loss of power, it's a sign of detonation. I'm providing a PDF with the table below so you can create your own maps.



Initially, we can use the manufacturer's advance indication, but be aware that it will not be the best curve for the engine, since, as I said, the variables are too large for there to be a standard point.

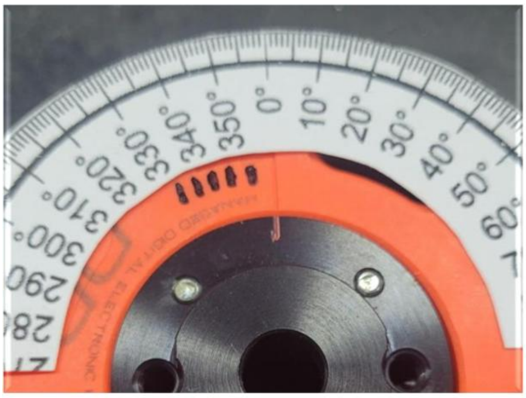
Some manufacturers, such as MVT, recommend using 0.35 mm for a 42 mm crankshaft stroke. Let's assume this manufacturer has a lot of experience in this area, and their recommendation is certainly very close to the ideal. Therefore, in the absence of a dynamometer, we'll base our calculations on the manufacturer's recommendations.

The adjustment method for this ignition is the same as for all other ignitions where the manufacturer's indication is given in millimeters before TDC.

But how do you measure the piston height in relation to TDC?

Using a dial indicator screwed into the cylinder head instead of the spark plug, place the piston at TDC and reset the dial. MVT recommends a 0.35 mm piston advance before TDC. This means turning the rotor in the opposite direction to the engine speed until the dial indicates the 0.35 mm of piston movement.

If we want to find the exact point, simply mark the angle with a graduated disc on the stator and, using the gun, check the map correctly.



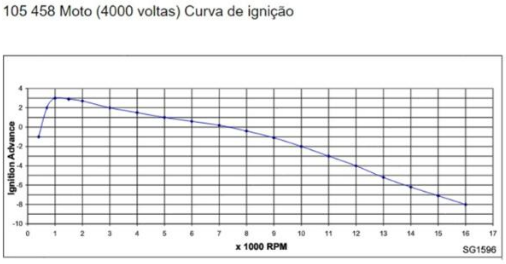
You can also find the piston height with a caliper, but it's not as accurate. Simply insert the tip of the caliper and make sure the base is flush with the spark plug thread. Place the piston at TDC and zero the caliper. Then, rotate the crankshaft until the piston recedes 0.35 mm and rotate the crankshaft so that the mark aligns with the stator mark. In other words, the two marks must be aligned while the caliper is showing 0.35 mm.

Even assuming we don't have access to a dynamometer, but we know the ignition curve we're using, whether from the manufacturer's website or measured ourselves, we can set the 15° point for the engine's best torque range at the highest torque RPM, which we've already learned to calculate using the adjusted exhaust length. From my experience and the ignition timing readings I've been doing for a long time, the 15° point meets the requirements of most gasoline engines. It's known that ethanol and methanol require around 4 to 7 degrees more advance.

Therefore, if we know that an engine's peak torque is at 10,000 RPM, we need to adjust the ignition timing to be 15 degrees within that RPM range. Using a tachometer, we can accelerate the engine to 10,000

RPM and use the ignition gun to measure the ignition timing at that moment.

If it isn't, simply rotate the stator or rotor to calibrate the ignition to the desired RPM. If 15° isn't ideal for the engine, we're very close, and the small error won't cause damage.



Now that we know how to adjust the timing of internal rotor ignitions, let's do the same for flywheel ignitions. This type of ignition isn't adjusted by piston height relative to TDC and is typically secured with a keyway that prevents the timing from changing. Depending on the manufacturer, we can determine the original timing, but if we don't know or want to double-check, we can use a timing gun.

The process is basically the same as we saw previously, which consists of marking the angle every 5 degrees on the table using a graduated paper disc and an overhead projector pen. Cut the graduated disc to the same diameter as the magnet to avoid scale distortion. Remember to mark the TDC on the table and the magnet for a reference point to align the disc marking with.

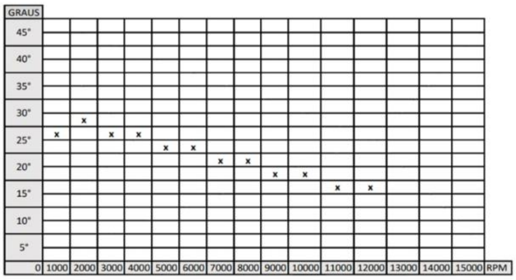

MESTRE
EM 2 TEMPOS
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
350°
340°
330°
320°
310°
300°
290°
280°
270

With the TDC and timing markings every 5 degrees before TDC, we can start the engine and, using the timing gun, begin the measurement. Most guns don't have an advance, so we need to create the degree scale with the markings we made. My gun has an advance, but for 1 spark per revolution or 1 spark every two revolutions. In the case of the engine I measured, an AV-10, the original ignition has a lost spark, which is nothing more than 2 sparks per revolution. One above and one below. In this case, we have 2 sparks per revolution, and the gun doesn't recognize this pattern. Be careful with this, as the measurement will be inaccurate if the gun doesn't correctly match the number of sparks the engine generates.

In my case, I left the gun at zero degrees, meaning no advance, and started the measurements. Note the photo below with the magnet point at the first mark.

With the engine running, I measured it at idle, which showed something like 25 degrees. Accelerating to 2,000 or 3,000 RPM, the point rose to 27 degrees, and whenever the RPM increased, the point decreased linearly. Accelerating to maximum RPM, the point dropped to 15 degrees and remained stable there.

Below is the plotted curve that I measured.



Low RPM measurement:

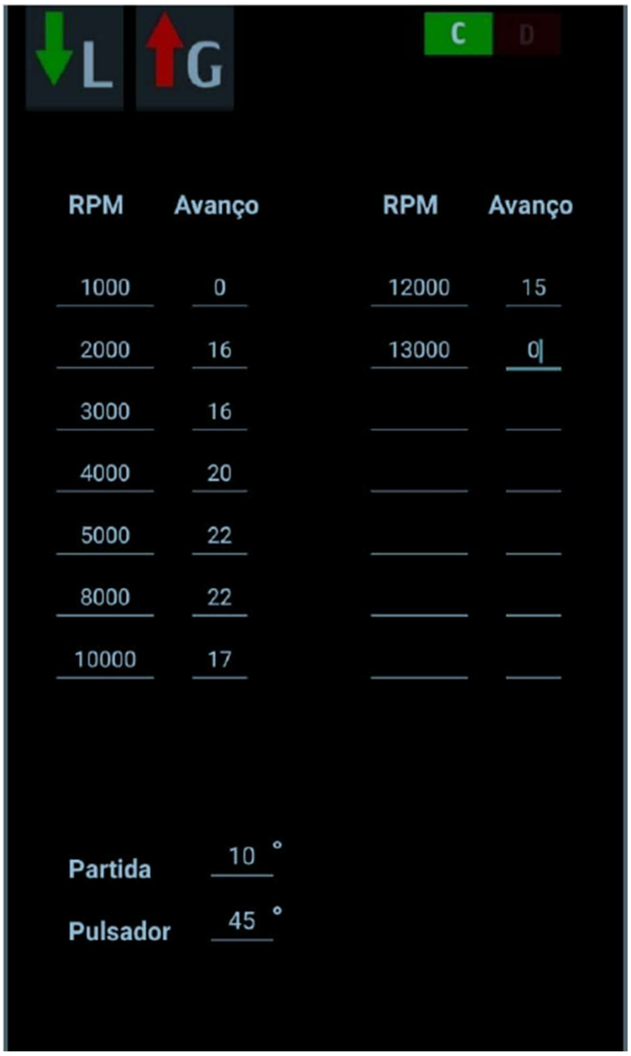
Photo with measurement at 11400 RPM

Programmable Timing: Programmable timing allows flexibility in creating the timing map. However, as mentioned above, a dynamometer is needed to create this curve, extracting the best from the engine.

Installation and adjustment are simple, just assemble the map according to the desired RPM as shown in the photo alongside.

This ignition has a flywheel with a pushbutton to indicate the crankshaft position, and this angle is entered as data. They eliminate the need for coils, as they are powered by an external battery. The ignition timing is also displayed at the time of starting.

This type of ignition typically has the highest spark output of all ignitions, allowing for very large gaps in the spark plug. It's recommended to validate the timing with the ignition gun, as the pulsator may be at a different angle than the one indicated. This ensures that what's displayed on the screen is accurate.

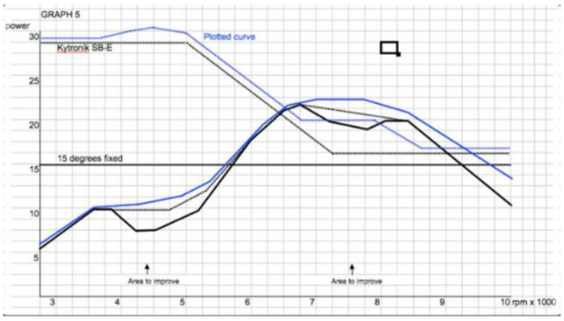


RPM	Avanço	RPM	Avanço
1000	0	12000	15
2000	16	13000	0
3000	16		
4000	20		
5000	22		
8000	22		
10000	17		

Partida 10 °
Pulsador 45 °

16.7 Case studies

Below, we can see three ignition curves and three power curves. The first is solid black and fixed at 15 degrees. The power curve in black has two holes at 4500 and 7500 RPM. The second curve, shown in dotted black, starts at 30 degrees and drops to 16 degrees at 7200 RPM. The generated power curve is already slightly improved, correcting the two holes. The third curve, in blue, raises the ignition timing in the gaps where the engine has depressions, and as demonstrated in the power curve, there was a significant improvement in its amplitude.



Aprilia RSA 125

Here we can see the Aprilia RSA's ignition curve. It used 30 degrees from 1000 to 8000 RPM. At 12500 RPM, where it had maximum torque, the ignition timing was 17 degrees. At 13000 RPM, where it had maximum power, the timing was 15 degrees.

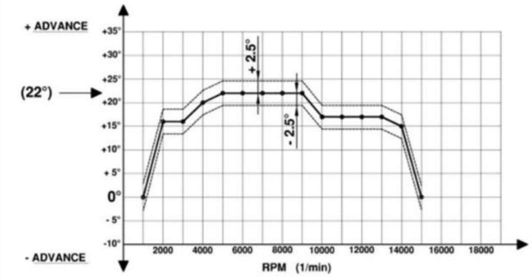
RSA used a racing fuel with characteristics similar to those of gasoline, but with a high octane rating, which allowed it to use a higher point at low RPM and a high compression ratio.

See below that this condition was 100% throttle. The RSA had a sensor in the carburetor that indicated the throttle position, and it altered the timing accordingly. It suffered from detonation in conditions of low carburetor opening due to high blowdown and because at low RPM the shock wave returned too early, pushing the mixture back into the crankcase, heating it and causing detonation. To correct this, the timing was retarded when there was low throttle.

Iame X30

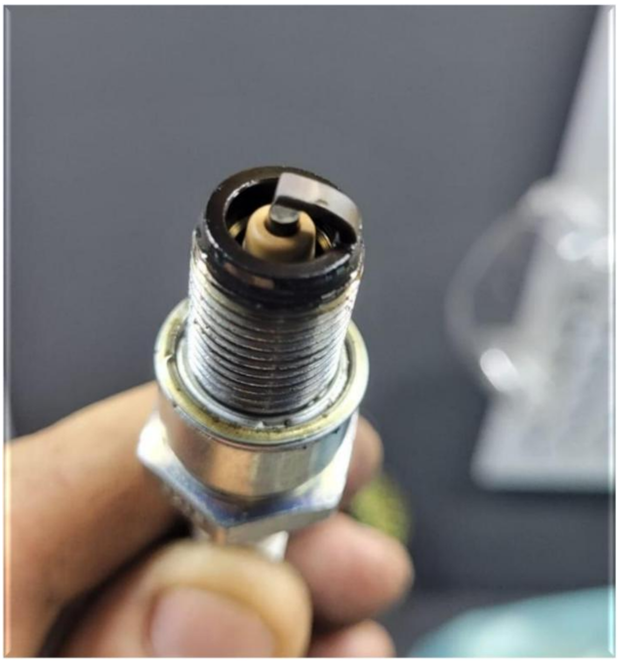
The X30 uses a PVL ignition with a typical gasoline curve. We can see a low point on the curve from 2000 to 3000 RPM and 22 degrees from 4000 to 9000 RPM. After that, the curve is flat from 10,000 to 13,000 RPM at 17 degrees, and at 14,000, we see the 15-

degree point. After that, the curve drops to 0 degrees at 15,000 RPM, undoubtedly to limit the RPM.



16.8 Candle reading

When we find the ideal spot, we'll see discoloration on the spark plug's ground electrode, reaching the center. However, this mark only appears when we're using the correct spark plug heat rating for the engine. If the heat rating is too hot, the entire electrode will change color. If the heat rating is too cold, the electrode won't burn, and we won't see this phenomenon. Furthermore, an incorrect heat rating doesn't create a standard tile color on the spark plug, as it doesn't get hot or too hot.



Chapter 17 – Conclusion

From recording and completing my online course, which provided the basis for this study, to the date I'm writing this book, I've accumulated so much new knowledge. Not only because I never stop reading and studying, but also because of my experience assembling and preparing new engines. Countless