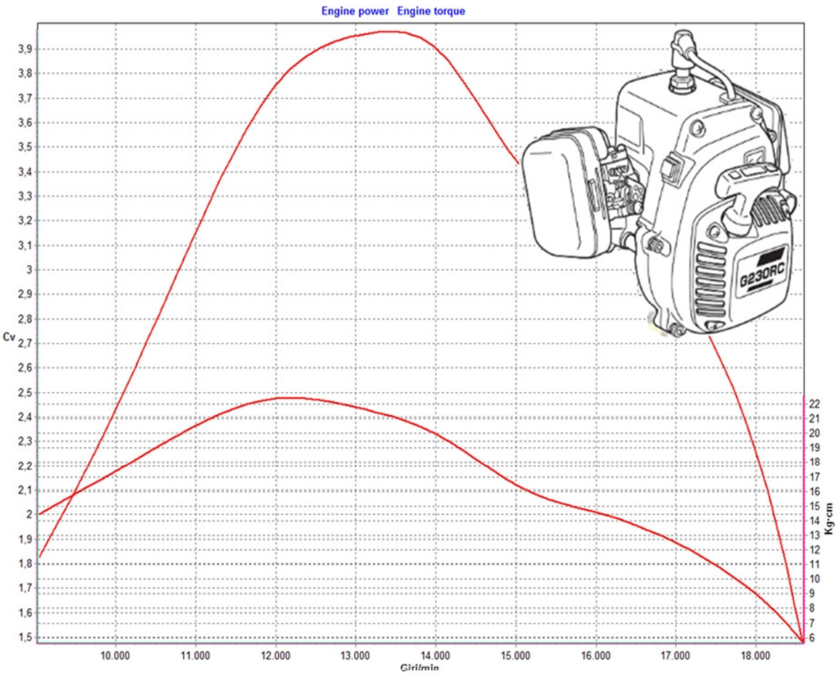
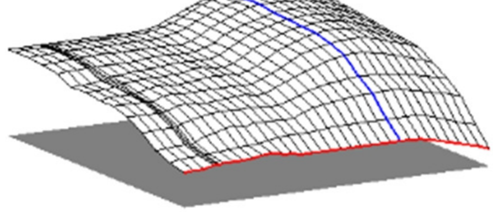


Guide for developing advance maps

EcuPlus TC-I

Version 1.2

English



Release

EcuPlus
ITALY

Last update, 04 October 2017
EcuPlus does not assume any responsibility about incorrect or missing content or damage resulting from this guide.
Moreover it is underlined that the information in this document is subject to change without notice and has not to be interpreted as obligation on EcuPlus side.
We are grateful for references to mistakes or for improvement proposals in order to offer an even better product in the future.

List of Contents

1 Conventions and used terminology

The following table describes the conventions used in this guide about the symbols used.

⚠ WARNING	Dangerous operation for your safety
🚫	Operation not allowed
ℹ	Relevant information
⚠	Pay attention

- **TDC**
  Piston Top Dead Center

- **BDC**
  Piston Bottom Dead Center

- **Gap** spark plug (distance between electrodes of the spark plug)

- **Ignition Timing**
  means the advance angle in degrees of crank or displacement millimeters of the piston respect to TDC and it is the time when the ignition system fires the spark of the spark plug. Timing can also be delayed respect to TDC.

- **Ecu** (Engine control Unit)
  In reality the EcuPlus TC-I is not an engine control unit, in fact, the primary management of the phase is delegated to the IKEDA-D coil, it is an additional unit for the correction of the ignition timing and for the control of the engine operation.

- **Fixed advance of shrink**
  The fixed advance is the measure, in degrees (but may also be measured in millimeters) of the advance with which the spark of the spark plug fires respect to the point 0 ° (TDC), and that if not modified by other factors, has the same value for every RPM of engine operation.

- **EGT**
  Exhaust Gas Temperature

- **CHT**
  Cylinder Heat Temperature

- **Run**
  It is the session considered since the start of the engine until is is switched off. Every time you start the engine then starts a new one.

- **Calibration**
  Ecu Plus setting file containing the information of the ECU operation and management along with the phase correction maps for the engine in use.

- **FlyWheell/Air Gap**
  It is the distance between the rotor and the stator (ignition coil)

- **Map**
  Two-dimensional representation (Rpm x Ignition Timing) of the advance correction management map. Maps (8) are contained within the calibration file.

- **Engine Management Tool**
  It is the software developed for the complete Ecu management and compatible with all Windows OS.

- **Over-rev**
  Revving engine. In practice it is used for the progressive increase of the speed allowing spacing the opponents maintaining the same speed ratio.

- **Range**
  Shall mean variation range or variability interval between a minimum value and a maximum value.

- **Setup**
  Is the set of operations required to set up the system according to a certain configuration.

- **Squish**
  Describes the phase in which the piston at TDC compresses the side areas of the combustion chamber, conveying the mixture into the center of the head dome, which would otherwise have difficulty taking part in the combustion process.

- **Tuning**
  The term tuning means changing a system in accordance with the series production standards in order to adapt it to your fancies or to their specific needs.

2 Objectives of this guide

The purpose of optimizing the ignition timing is to generate the maximum torque during a given period of revolutions. It is quite easy to get close to this result, but for obtaining the best results it is required an understanding of the various effects of any single modification.
A part of the rpm range of a high compression 2-stroke engine, requires sufficient ignition advance to operate at the limit of detonation, while a part of the operating range requires the ignition delay in such a way as to change the temperature of the exhaust gases, with consequent reached over-rev. There is also a part of the rpm range at any point of the zone in the middle between the two previously described parts, where other chaotic events can happen, such as harmonic resonance or events that last a very short intervals of time for which you may need to delay the advance.
In the ignition system originally installed in the Zenoah engines, the value of the advance ignition is fixed and common to all schemes. Therefore, the system is not able to adapt the advance to the various conditions of the engine such as rpm, throttle opening of the carburetor, engine temperature etc. and the engine thus works with an advance value which is generally a compromise between the various needs. With this limit, the maximum level of performance obtainable is limited

to the advance value previously chosen, but it must be reminded that in the case of official competitions, this is the only manner permitted by sports federations of the area.

With systems with variable advance instead, as a general rule, you can give the correct advance for any given condition and functional configuration of the engine. Obviously, the more complex the system is, the more it will take account of various operating parameters, thus ensuring the management of the timing, in a greater number of conditions.

From these considerations, it is clear then, that to get the best performance from the engine, it is necessary to have a system with variable advance freely programmable in accordance with the performance requirements and types of set-up.

The additional control unit ECUPlus TC-I by reason of its nature, is designed to provide a correction of the ignition point of the mixture only in relation to engine speed and it does it during the operation of the engine according to the values set in the advance maps contained in the ECU. It does not directly drives the ignition so the results obtained in terms of the amount of change of the ignition timing, are not the same that you can get with an Ecu able to drive at will the ignition point. The choice of the operating modes of the TC-I, is explained by the fact that the original ignition system (IKEDA-D) is strong enough to ensure a good spark, it is compact, reliable and cheap. Currently the TC-I works only with this type of system but probably in the future it will also be available an additional ECU for other types of systems (DTA type) on the market.

With it you can then change the ignition point for the operating range 7500 <-> 23000 RPM and with an excursion of advance that starts from the maximum advance value statically set up to a limit delay value determined by the ignition system in use.
In all cases, however, the range of operation obtained by matching the original system + EcuPlus TC-I, make possible the adaptation of the ignition timing to a number of different engine configurations. This allows obtaining the primary objective of the TC-I which is to improve the performance, to ensure the right operating conditions of the engine, increasing the reliability and longevity.

In addition, if properly programmed, the TC-I improves fuel consumption, as well as being useful to tune the engine (only the advance) to different environmental conditions. The EGT / CHT or other temperatures also monitored and acquired from the TC-I, do not contribute to the management of the advance.

All these and other not mentioned requirements, are well known to the "calibrator" (which is a real profession anything but simple and finds application where the motors and electronic control units are much more complex), and require knowledge, passion for combustion engines and time, so you can not become calibrator simply reading a bit of documentation and particularly this one, which aims to describe the subject without getting too specific.

However this guide will allow you to get the necessary skill to program your EcuPlus TC-I in order to experience a significant improvement in performance of your engines in a reasonable time, and especially avoiding the occurrence of unpleasant failures.

The engine research and development by EcuPlus continues and in the future calibrations more efficient or suitable for new solutions but not yet loaded into your ECU may be available. You should therefore verify any availability in the official website before undertaking any calibration activity.
But before starting to look for the best timing setting, it is necessary to have a clear understanding of the negative effects that a bad adjustment may cause. The lack of knowledge of the possible effects

caused by a wrong adjustment, almost always leads to significant failures, therefore it is strongly recommended to read this guide.
In the following chapters then, together with the role of the main engine components as well as methods of tuning the advance, will be also mentioned the causes and actions to prevent the occurrence of unpleasant failures.
Obviously, to obtain the best results in terms of performance, it is necessary to have an engine in good health conditions. It is also very important to organize at best on how to perform the tests.
In fact, the methodical approach to testing, allows to obtain conclusive results that if properly interpreted, does not leave room for assumptions or uncertainties or useless duplication, but rather will guide you to obtain the best performance.

3 Overview of mechanical and their influences

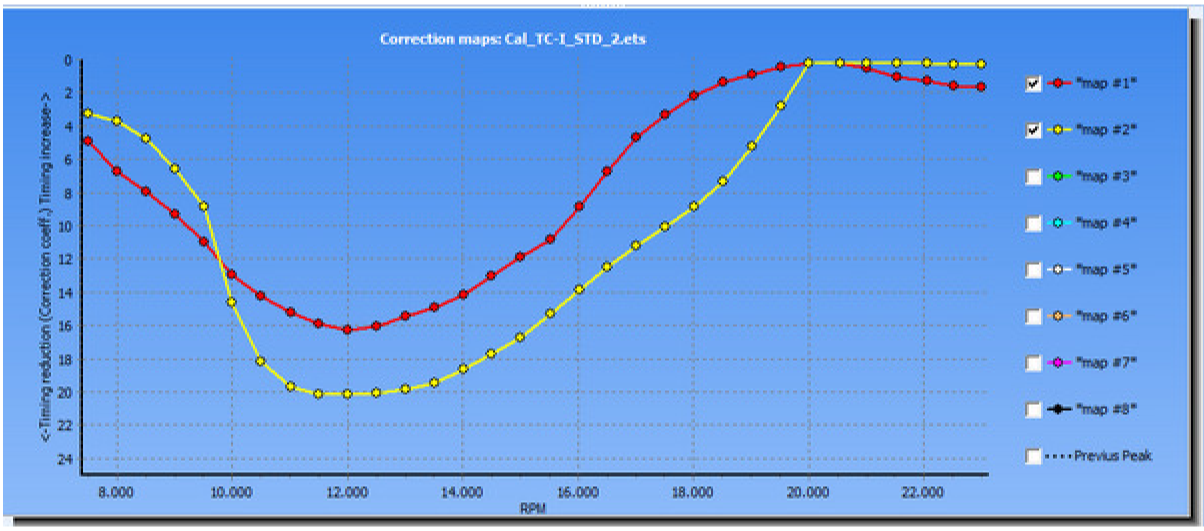
The timing of the transfer ports and exhaust systems, are designed to achieve a high peak power in a narrow range of rpm. There are various known events that determine the basic setting of the mapping of ignition timing, but there are also several unknown chaotic events that must be considered and that with this guide we aim to illustrate.
As well as the time of each cycle changes related to RPM, the exhaust valve timing and the muffler characteristics, also should change according to the system, so as to always be tuned. Unfortunately in these engines the timing is fixed and also the muffler is fixed so as is known, the design of the exhaust system has a huge impact on the 2-stroke engine power.
So the ignition timing can be used to compensate a bit this limit. Increasing a bit the delay at higher speed, you get more heat to the exhaust, and the highest temperatures simulate a shorter exhaust pipe. This works as for the sound speed (the key factor for the acoustic characteristics of the exhaust) that increases with increasing of temperature.
The balance between the added heat in the exhaust pipe and the loss of efficiency due to a delayed spark, may determine the extent of the usable range (over-rev) of more than 500 rpm.

There are also some chaotic events that can occur to a certain number of rpm. Typically some mufflers have an harmonic resonance that can occur at high rpm (16200-16250 RPM) or even higher, causing sometimes a richer mixture. In this case a bit more advance (steeper) can compensate this problem. In other cases a muffler can have a resonance point at 14,550 to 14,650 RPM, which may require a slight delay in this range. Fortunately, as will be described later, these events have short duration and therefore we will be able to neglect them almost always.

4 Advance curves – typical operational areas and their analysis

Graphically viewed, a correction of the advance curve is a set of points that divides the operating speed of the engine.

The following picture shows advance curves (correction) of two Zenoah engines with different set up.



As described above, to obtain the best engine performance, the crank advance must vary in accordance with the desired performance and the set up types. From now on we will speak about advance curves to show the topic in a general way, but we remind you that EcuPlus TC-I corrects the advance and not the direct managing of it.

To better understand the tasks of each part of the advance curve, it is convenient to divide it in the following areas:

Idle area (not present in the chart as not handled by the EcuPluc TC-I).

This area includes the functions that have no effect on performance, therefore those not used on track, but that are advantageous to obtain a good start and a regular operation at idle engine speed.

It is divided in:

- Starting area
- Idle area

Transition area

This area is where the curve has an effect on low engine speed and on the beginning of the most important area for performance.

It is divided in:

- RPM ramp
- Transition point

Crucial performance area

It is the area with most of the emphasis, and then determines the maximum achievable performance.

It is divided in:

- Critical area
- Over rev

Therefore the map must be developed around the three main ignition areas but as described in par. 2.0, the TC-I is able to manage the last two areas.

4.1 Idle area

4.1.1 Area of cranking engine speed

If the ignition system is the original one, the spark advance in this area of operation for microengines intended to model 1:5, corresponds to the fixed value chosen during the installation. The choice of the correct value determines the good engine start without jerks and the advance value at this stage also corresponds to the maximum advance value on the entire excursion of RPM just without a slight delay proportional to the RPM, due to the electrical characteristics of the ignition system IKEDA-D.
So the chosen value is the result of a compromise between a value that allows a good start and the next idle operation, and obtaining the highest possible performance but only at certain engine speed. As described above, the TC-I is able to implement only the delay correction; so by mapping it is possible to set the total amount of advance to the desired value in accordance with the limits imposed by the ignition system.

In practice the actual value at start appears to be reduced by some degrees due to the electrical characteristics of the IKEDA ignition system at low RPM, but it moves to the base value as soon as you reach approximately 3000 RPM.

Start is considered from 0 RPM up to 4500 RPM in case of pull starter. In this area of operation the EcuPlus TC-I is only powered up and prepared for operation, but does not give corrections to the ignition timing, in fact it starts correcting the advance from 7500 RPM thereafter.

4.1.2 Operation area at idle

In this area, there are the same rules mentioned in the previous paragraph with the difference that the range of concerned RPM is between 3500 RPM and 4250 RPM.
Change the timing different than the basic settings does not offer important advantages in this area but it does in other areas as explained in the previous paragraph. The advance in this area (which therefore corresponds to the fixed value of keying) helps the normal engine operation by ensuring the stability of the idle speed especially during first period of cold operation.

4.2 Transition area

4.2.1 RPM ramp

It goes from the idle increased by 300 RPM until the engine speed related to maximum torque reduced by approximately 75%.

The importance of the RPM ramp in the engine operation is crucial at standing start, so in all those cases where it is requested to the engine to increase RPM starting from the idle speed. It then defines the operating range for lower engine speed in race conditions, and it is considered a transition area.

For example if the engine gives the maximum torque at 14500 RPM, the highest limit of the transition area is about 10900 RPM.

From this point onwards, the advance generally decreases and the curve slope is function of the engine characteristics and is identified as transition point.

4.2.2 Transition point

The transition point is the value of RPM where generally begins the descent of the advance curve.

The different timing of exhaust/intake ports as well as the different characteristics of mufflers have an important role in the research for the optimal transition RPM and therefore for the optimal point of the advance of ignition.

We recommend that you do some research about this area in order to fully optimize the advance.

The choice of the right advance value, greatly improves the engine output and consequently the entrance in the critical zone. This area is then the first on which intervening to make more or less mild the engine in case of slippery tracks.

Remember also that this is the area where clutches generally close.

4.3 Crucial performance area

4.3.1 Critical area

It is a range from about 75% up to 110% of maximum torque RPM.

Example: if the engine develops maximum torque at 14250 rpm, this would be between 10650-15670 RPM approx.

Also in this case the values of port timing and mufflers characteristics affect the specific value, but this method to define the critical area can be considered a good reference for the majority of engines.

Generally, the resulting advance curve is a flat line between these points, the slope of which generally tends to reduce the advance in a progressive way although there may be variations in order to find the maximum optimization.

The design of the muffler in fact plays an important role in these variations that are essentially due to:

- Angle of the walls of convergent cone

Steeper angles, produce high reverse pressures to the number of RPM for which they are tuned and then you get more effect from the muffler which in turn requires less spark advance.

- Length of exhaust pipe

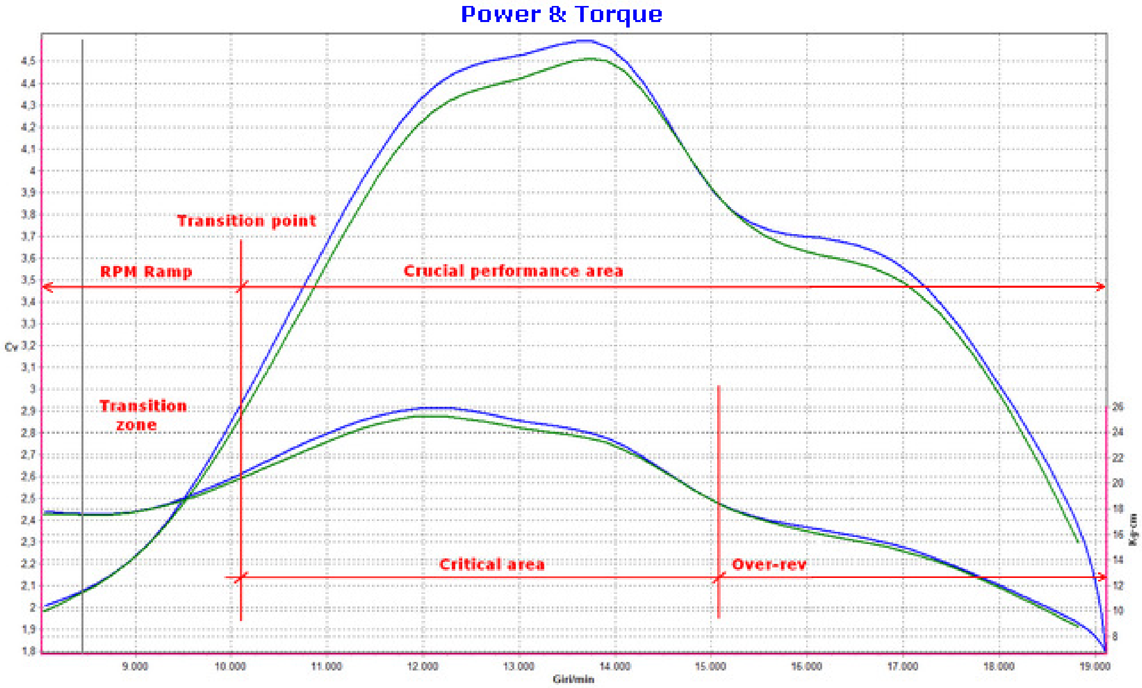
By changing the length of the exhaust system including manifolds, gaskets sleeves jointing and various silencers, great results are achieved. The shortening of the length will result in raising the maximum power and vice versa.
As already mentioned, there are other functional exceptions that suggest to modify the ignition timing, for example, harmonic resonances of the exhaust or not optimal carburation in some point of the operating range of the engine.
There are too many things to be able to predict the behavior, but generally these anomalies are short-lived (just over 100-200 RPM) and acting on the advance (almost always with a slight increase) it is possible to minimize the abnormal behaviour.
Generally, however, for the use on track it is not worth and the important thing, instead of these functional exceptions, is that they do not lead to detonation because otherwise it will become necessary to delay the ignition all over the critical area in order to avoid risk of breakage.

4.3.2 Over-rev

This is a range that begins over 110% of maximum torque RPM. Keeping the delayed advance beyond the critical area will extend the usable power range throughout the power curve.
This can allow the use of a lower transmission ratio and provides a wider power range without loss of maximum torque and top speed.
In many cases the slope of the advance curve in the over-rev area is very similar to that of the critical area; however, there are no detonation issues in this area and then it is also possible to increase the advance in case the engine is quite empty.

The over-rev extension result in rising EGT (Exhaust Gas Temperatures). In some configurations, this will be tolerable, but not in all cases. You will therefore need to verify or establish the correct safety standards relating to the EGT limit value typical for each configuration (mufflers, carburetors, thermal units etc).
The K type thermocouple for temperature measurement is very useful to search the maximum performance and to adjust the carburation, so it is recommended to always use it during the development of the maps.

Below are highlighted the typical intervening areas relating to the engine performance.



5 Effects on advance alteration due to engine tuning

When replacing the important details of the engine, almost always you are in the position of having to change the ignition advance.
Manufacturers of modified components such as thermal units, mufflers etc., do everything is possible in order that it is sufficient to install the new component without changing anything else, but this is not always possible and in such cases they indicate which additional changes are needed to be done in order to achieve the expected conditions. So in general it should be noted that following the replacement of one or more constituent parts of the engine, it is necessary to retune the carburation and the advance.
If the muffler is replaced with a more powerful one, you will certainly need to modify the carburation, as well as the ignition timing, and the same thing also applies to thermal groups and everything that involves the combustion process.
If you increase the engine displacement (by increasing the diameter of the piston) the ignition timing generally requires to be delayed so as to improve the over-rev, in fact when the displacement is increased, the engines are generally "flat" at high RPM.
Also the characteristics of the crank mechanism influence the choice of the correct ignition advance, in fact the connecting rod length and stroke determine the movement speed of the piston, and consequently the increase of pressure in the vicinity of TDC can cause detonation. Therefore also important for the squish choice is the fact that longer connecting rods also have as result an increase of the time that the piston spends in the TDC.
Here are summarized the effects that generally are found following the change of the advance:

- Increase the ignition advance determines a curve of power delivery steeper in the central part but flatter closer to the maximum engine speed. In fact the increase of advance, provides a flame front within the combustion chamber that advances faster thereby determining a sudden increase of pressure. The fast increase of pressure generates a real shot in the area of maximum power and in some cases the increase of pressure can be so huge as to cause a metallic noise from the engine. With the increase of RPM, however, the pressure in the cylinder becomes such as to cause a loss of pumping to the piston and this is the reason why too engines too advanced or with a compression ratio too high, they become flat at high RPM.

- Delaying the advance instead, makes the power area flatter in the middle while makes it larger at high RPM. When the spark occurs closer to the TDC, the increase of pressure in the cylinder is not too large. This results in the transfer of heat from the cylinder to the muffler preventing the piston overheating at high RPM, but the best benefit is the effect that the heat has on tuning the muffler. When the exhaust gas temperature rises, the speed of the waves in the muffler grows and at high engine speed they cause a better synchronization of the system muffler-“exhaust valve timing” and this effectively extends the maximum peak of RPM.

6 Process of the analisys result

Let’s see how to apply the concepts described up to now in order to get the best results in the shortest possible time. Surely if you dedicate more time to the development you will get greater results also improving the feeling with your engine, but keep in mind that in a moment it will be time for maintenance...This is to emphasize the importance of developing a method of analysis that brings results in a reasonable time instead of a waste of time and an unnecessary engine wear.
Almost in every case, when it is possible to choose, the best time for the maps development is at the end of the break-in, when the engine is running at peak performance. It could also be done close to the maintenance so as to service it just after the map development, but in this case the normal wear of the mechanical parts and especially of the thermal system may lead to a significant variation in the thermal efficiency, which is not the best condition to search for the maximum advance value acceptable by your engine. Finally, as another option, if you have a piston used but in good condition, you can use it for development, and at the end of the activities replace it again in order to restart with the engine in condition as before the development.
The EcuPlus TC-I is supplied with 8 base curves already planned, and the management software contains the configuration of each of these curves, so you can begin the research of the best advance for your engine using curves *map #1* - *map #2* - *map #3* that provide an excellent general starting point keeping in mind that each of the areas of the advance map can be set up even with attempts tolerating possible errors to identify limits.

Calibrations supplied with EcuPlus TC-I and downloadable from the official website, are specific to the EcuPlus engines, and developed with certain fixed advance values which are normally set at the time of preparation of the engine.
They take into account the different types and equipments of engines and, if nothing has changed, they pass safety tests avoiding the detonation risk. Please note that whenever you want to change the calibrations, the static advance timing must be properly set to the value suggested in the documentation that accompanies each calibration. The methods of set the fixed advance keying, are shown in the installation instructions. If your engine/set-up is not included in the list of available

calibrations the timing will be necessarily retuned, therefore the use of calibrations ready but not developed for engine configurations on which you intend to use them, most likely will not produce any benefit but could even be dangerous for your engines. If you want to experience the ignition curves in advanced way manipulating the fixed advance keying, you must be familiar with what the detonation is, which damages can bring to the engine, and how to identify it. These concepts are explained in detail in section 8.0. Even if it may seem boring reading several times "avoid detonation", this concept will be endlessly repeated in order to remember that the detonation in all its forms is the first absolute source of damages, often catastrophic, that your engine could face.

6.1 Preparation and tools needed

You can use the track or the power test bench to test the advance maps, but it is to be underlined that tests on track will allow more realistic data, so the test bench is very helpful but not necessary.

What is needed:

K thermocouple connected to EcuPlus TC-I to measure the temperature of the cylinder head and/or exhaust gas.

If you want to change the fixed advance value, then since it may lead to detonation, it is necessary to have also the following things:

- Some clean spark plugs with optimized gap between electrodes, without prior detonation experience, are definitely an added value for the good test execution.
- It is useful also a small flashlight to inspect the piston through the spark plug hole together with a magnifying glass (10X) to verify the absence of spots due to detonation.

Other things to do:

1) Prepare a sheet of record of the test configuration with the data reported in Table 1. Also, write all that is worthy of note and that somehow may lead to a different test outcome.

2) Use fresh fuel and oil: stale fuel facilitates the detonation as well as poor oil. Mixtures must be those normally used, or anyway maps must be specific for each type of fuel used.

3) Evaluate for few minutes the effects of each map available in EcuPlus TC-I, taking care to reach the normal engine operating temperature. Take care not to use different methods for result evaluation at each test.

4) Inspect the spark plug looking for detonation traces and in order to determine if the mixture ratio is correct.

5) Do not rush

Test record sheet			
Parameters	**Run1**	**Run2**	**Run3**
Fuel type			
Mixture Oil type			
% mixture oil			
Air temperature			
Relative humidity			
Barometric pressure			
Ignition system type			
Fixed advance (mm)			
Flywheel airgap			
Spark plug type			
Electrodes distance			
Calibration name			
Active map name			
CHT max temperature			
EGT max temperature			
Carburator type			
Screw reg. medium-low (L)			
Screw reg. high (H)			
Suction system type			
Squish			
Compression ratio			
Muffler			
Unloading phase time			
Lap time			
Test file name at Dyno			
After test inspection			
Spark plug			
Piston			
Notes			

Table 1: Tests notification sheet

Tests can now begin...

6.2 Performance analysis

Analyzing the test results of each map it is possible to deduce in which direction to go.
If for example, we see that map1 performs well in the transition area while map2 works better in the crucial area, the logical deduction is that you should create a new curve composed of the best areas of tested maps.
Then run a test with the new map always making sure to check the absence of detonation. From now on you can search the Top progressively increasing the advance up to 110% of the maximum torque RPM until obtaining the best but always without detonation.
Once found the limit (starting of detonation) it is convenient to reduce a bit the advance so as to avoid the chance of damages due to detonation. The difference between the start of the detonation (visible by inspecting the mechanical parts), and the necessary security, is about 2 - 3% less advance that in a fast track is roughly less than a tenth of a second per lap.
In summary, up to about 110% of the number of revolutions of the torque, let advance as possible.
With the most tuned engines, 110% is when the sound waves in the muffler can not keep up with the engine speed. This percentage may vary positively upwards depending on the discharge timing and the muffler characteristics, therefore there are no fixed rules but it is necessary to experiment ...

When you reach this point, the reward resulting from the increase of advance are offset by the loss of muffler efficiency.
If we let the combustion occurs only a little later we allow the best heat transfer to the muffler, which in turn will increase the propagation speed of sound waves so to obtain the torque a little more maintained. In most cases (but not all), we'll try a slight increase of the map tilt angle in the last 300-500 RPM of the operating limit now extended with the over-rev.

Once a satisfactory torque/power curve is found, the over-rev experimentation can be performed with the change of the slope angle in the bottom area of the map. During the test for the best over-rev, remember to check that values of exhaust and engine temperatures does not exceed the limit values. In all cases, it is better to run over-rev analysis on track.

7 Generation of final advance curves

Found the right map for your engine, here there are some useful information to correct the maps depending on the weather.

7.1 Influence of weather conditions on the advance

Assess data related to environmental conditions during the execution of the test and the conditions foreseen for the race day, can help you to decide which will be the most suitable map.
For the best engine performance you need the right air/fuel ratio; we all know that, unfortunately, temperature, pressure and humidity effects are often overlooked in determining the amount of oxygen available in the air, so the amount of fuel required to maintain the final mixture.

Most of us have noticed the change in performance in a cold morning or experienced the negative effects of high altitude on our engines.
These influences are clearly visible while testing on bench and most of the management software for test benches allow the compensation of the measured power value depending on the weather.
We must therefore consider that the variation of oxygen available will force us to change the fuel amount, if we want to avoid that the mixture is too thin or too fat.
Now it will be illustrated the effect of weather changes and what to do in order to correct the setup of the engine. My advice is to create a series of maps/calibrations for each different type of track and/or engine configuration. The same calibration for a single engine, may contain more aggressive and quieter maps for different mixtures etc .. This method will put you in a position of having a rich database where you will find the right map ready for any situation. To avoid confusion, however, you need to add more notes as possible to maps as well as their titles that must somehow be explicative.

7.2 Air Temperature

Higher temperatures reduce the air density and the amount of available oxygen. Hot days then require a leaning of the mixture.
Each 15° C of air temperature increase, it is advisable to increase the advance of one degree (3-4%) up until the start of over-rev and vice versa.
If you expect that in the middle of your race the temperature will be colder, it is recommended to delay a little considering the clearing of the air conditions that could also change.
Keeping the same slope across the path of the critical area, having roughly 0.8 degrees (-3%) less of advance is a good general rule.

7.3 Atmospheric pressure

Lower air pressure (as with higher altitude) reduces the air density and the oxygen available. Altitude is an important factor and roughly each 300 meters of higher altitude there is a density drop of almost 4%.
The weather conditions can change very fast during the day, especially when a storm front is approaching.
Low pressure requires the leaning of carburetion and generally advance increase.

7.4 Relative humidity

The humid air is actually less dense. A certain air volume contains a number of molecules and since the water molecules are relatively lighter than Nitrogen and Oxygen content in the air, this means that more humidity corresponds to lower air density.
Higher humidity requires leaning of the mixture and has a profound effect on detonation, it usually decreases a bit the danger of detonation and is therefore necessary to consider it.
Each of these variables can have a large effect (in particular temperature and pressure), but it is when their influences are combined that knowing the density of the air becomes a very significant factor in order to obtain the maximum engine performance.
To facilitate the tuning process of the carburetor with changing weather conditions, there are tools on market able to measure the percentage of RAD (Relative Air Density). So RAD is calculated on the

basis of temperature, pressure and relative humidity, and thus allows to evaluate the deviation of the atmospheric conditions from those set as optimal for the engine operation, thus making easier the development of the mixture (at least theoretically).

7.5 Effects of carburetion on the advance

The ratio of air-fuel mixture, has a significant effect on the burning rate.
In a perfect world, it should be composed of 14.7 parts of fuel and one of air. To this we must add oil, some of which consume oxygen during combustion at a different rate, but the greatest impact is the need to integrate a bit more fuel for cooling. Most of the 2-stroke works best to a point just prior to seize!!!
On our engines we usually use the air-fuel ratio 12-13: 1.
The richer the mixture, the longer the time required to start and complete combustion; so if we optimize the ignition timing for a richer mixture (for example 12:1), and then we run it with value 13:1, this surely facilitate the detonation. Fat mixtures therefore require a bit more advance and vice versa.

8 Principles of Detonation

If the advance amount set for the engine is correct, we will have the maximum explosion pressure to about 10-15° after TDC. In this way, combustion is completed in the best moment and the transformation of pressure energy into mechanical energy, takes place in the best condition.
If the advance value is short, the combustion is completed in the exhaust system thereby reducing the thrust on the piston, while if the advance is too much, the combustion is complete before TDC and we can therefore have detonation (in addition to a considerable loss of power).
The damage to the engine components caused by the detonation are typically erosion and purplish discoloration of materials in contact with the combustion, breakage of the pistons and other parts of the crank mechanism therefore it must be avoided.
There are two forms of detonation and a third condition known as pre-ignition. For clarity it is called pre-ignition, but it should not be considered as a parameter of programmable ignition. The pre-ignition issues are due to factors not belonging to a controlled ignition system.

8.1 Pre-ignition

Pre-ignition is due to the spontaneous combustion of the mixture before the spark. High compression and hot spots are the major causes. For example a too hot spark plug, can generate pre-ignition.

8.2 Premature Combustion

The premature combustion is a form of detonation that occurs after the spark has struck and when combustion is completed a few degrees before TDC. This is a problem more common with engines with a compression ratio equal or lower than 13:1.
This is also the most serious in terms of damage as it can cause breakage of the piston skirt, or the collapse of the piston crown. Any engine can not withstand a significant number of premature combustion events that do not cause mechanical failure.

If the start of combustion occurs too early and the piston reaches the end of the compression stroke, a flicker can be perceived. When the piston travels in the direction of the TDC, the opposite side of the piston at the center of the crank pin is loaded heavier so that while the piston starts the descent stroke, the piston side is loaded in relation to the cylinder.
If there is a pressure excess due to the end of combustion before reaching the TDC, the thrust on the piston changes the contact side of the piston skirt therefore sufficient to cause a double slap (noise source) of the piston which can lead to the fracture of the piston skirt.
Premature combustion, if prolonged, may also determine the collapse of the piston crown and your race will end at that time ...

8.3 Detonation

A flame front regularly started by the stroke of a spark between the electrodes of a spark plug, advancing, compresses and heats up the fresh mixture that is in front of it. Since the latter is never perfectly homogeneous, neither in terms of temperature, nor composition, the reactions of pre-ignition may begin to grow with different speed in points of the charge not yet burnt. It may happen that one or more zones of the mixture will self ignite, and that, therefore, a large amount of energy is released locally, generating an abrupt pressure peak, which propagates at sonic speed and that also stimulates the ignition of other areas of the mixture.

The pressure waves are reflected repeatedly on the chamber walls, producing vibrations of the metal parts, which, in turn, are transmitted outside and are perceived in the form of a characteristic beat. The detonation is particularly insidious because at high RPM, masked by the general noise of the engine, can last for a long time. The pressure waves, in such situations, contribute to increase mechanical loads. These, combined with thermal stresses, may lead to the breakdown of some components (piston, piston rings, cylinder head gasket), and however, lead to not negligible losses of power.
The detonation is also the most difficult to monitor and detect, in fact weather changes can seriously affect the detonation. Higher humidity reduces the incidence of detonation in a nonlinear way, so it is a function of relative air density as well as the amount of fuel.

The detonation is favored by all those factors that reduce the ignition delay of the final charge part, i.e.:

- decrease of fuel octane number, i.e. increased chemical reactivity of the mixture;
- increase of compression ratio, which raises pressure and temperature of the charge;
- increase of the feed mixture temperature, which promotes the start of pre-ignition reactions;
- high advance at ignition, which makes the pressure in combustion chamber grow faster;
- bad cooling of the final portion of fresh mixture by the walls of the combustion chamber.

On the other hand, the detonation is also favored by those factors that delay the propagation of the flame front, i.e.:

- reduction of the turbulent motion of the fresh charge;
- increase of the path of the flame front needed to reach the farthest points of the combustion chamber;
- mixture ratio tending to thin which reduces the rise speed of the flame front.

The squish area has a considerable effect on the heat distribution creating turbulence around the perimeter of the head and maintaining a large dissipative surface available for trapped gases.

9 Detection methods of detonation and their characteristics

There are several methods for detecting detonation, ranging from the driver's ear (difficult since he is not in the vehicle...) and that even if he were it should be very trained, visual inspection of the parts affected by the detonation, parts temperatures, up to the use of electronic equipment for measuring magnitude and number of events of detonation.

9.1 Audible system

The audible method can be used but it should be noted that the acoustic sound of the detonation can only be perceived by the ear of an attentive and well-trained driver or by the preparer if the engine is tested on a dynamometer.

It is also possible to record the engine sound during testing and to listen it later the playback, but the audible difference between an engine running without detonation with one with detonation, is almost imperceptible especially if you do not have at least an audio system with quality comparable to CD. If we consider also that on board of the model there is a lot of noise due to transmission, actuators, rolling of the wheels, in addition to the engine itself, then it is very difficult to identify the presence of detonation without an appropriate filtering.

9.2 Visual inspection

With this system you can get a reasonable level of detection, but it is not possible to identify the RPM to which the detonation occurred. The detonation causes the pitting of the piston crown surface close to the external edge, in addition to the jag of the combustion chamber in the area of the squish band, and/or together with the upper part of the cylinder.

Generally the piston shows the majority of the detonation evidence, in fact, the surface temperatures are warmer and more susceptible to erosion. Because the metal of the piston erodes, some deposits are released on the spark plug insulating, so this is the first thing to check.

More details are visible with photographs depicting the damage to the pistons.

9.3 Head temperature

The increase of head temperature can be a useful tool for determining the presence of detonation and with some practice it can also indicate the RPM range where it is starting.

Using this system to develop the advance calibration is an art, but anyway even if you are not an expert, this method can be used to identify the intervals at which the detonation is occurring.

9.4 Poor performance

In presence of detonation, the engine shows a slight decline in terms of acceleration and RPM recovery, but it is not easy to detect it when you are not on board, so this system is not applicable.

9.5 Electronic detection systems

Devices for the detonation detection through the use of piezoelectric sensors are available on market. They essentially measure the intensity of engine vibrations that are much more pronounced and with different frequencies where the detonation occurs. Certainly this kind of system is by far the best available on market in order to evaluate the detonation.

These devices allow to check if the engine has detonation and at what speed in order to intervene selectively.
Because of their cost and also of their current size, these devices are not very suitable for the use on track but very suitable for the development with dynamometer.

9.6 Visual inspection of the parts

The inspection of the spark plug is able to provide the first clues about the detonation issues. It is essential to be sure that the carburetion is correct, and it is recommended the use of a new spark plug to make sure that there are no old traces.

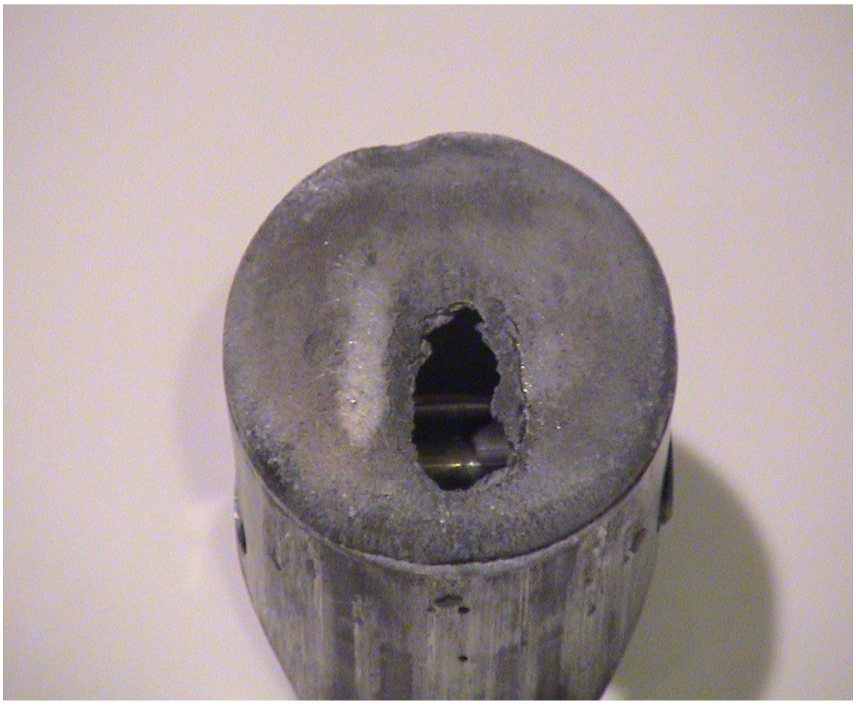
The erosion process of metal parts due to detonation, leaves small traces of aluminum deposited on the insulator of the central electrode. Traces on the spark plug only indicate that the detonation is present but they are not able to determine if the detonation is due to a too lean mixture. However it has to be considered that the detonation leaves traces only if it occurs for at least 5 seconds.
The spark plug check can then quickly reveal if during a qualifying session the engine operates under a detonation or not.
To better identify the presence of traces, it is recommended the use of a magnifying lens (10X).
The inspection of the piston crown through the spark plug hole can help to understand more about the detonation. In most cases it takes 30 seconds or more of the total detonation time in order to have a “readable” piston.
The position of the erosion damage will indicate whether the detonation is due to a lean mixture or it is cause or effect of a spontaneous ignition of the mixture.

Below some examples are reported to better identify possible anomalies.

Picture 1: Detonation

Picture 1: Detonation

This piston has suffered about 30,000 soft detonation events (which correspond to few minutes of operation). This detonation is due to a squish excess and to the addition of .05mm to the base gasket has allowed the elimination of detonation.



Picture 2: Detonation from lean mixture

Picture 2: Detonation from lean mixture

This piston started to erode the center of the piston crown near the spark plug. Once erosion starts, it can lead to other related problems and definitely catastrophic ones...

Picture 3: Lean carburetion and premature combustion

Picture 3: Lean carburetion and premature combustion

This piston lasted less than two laps and then it broke.
There also occurred damages to both the suction side and the discharge side, accompanied by strong beats close to TDC.
It should be underlined that with a mixture composed of 110 octane gasoline, the engine ran regularly for several laps, while gasoline used during the event of breakage, was of the type 98 octane. Gasoline is therefore important for the control of detonation.

Picture 4: Detonation

Picture 4: Detonation

This piston shows signs of a slight detonation.
It has been used exclusively for testing curves created for a specific engine and it has approximately one hour of usage.

Picture 5: Detonation caused by compression

Picture 5: Detonation caused by compression

This piston has been used about two hours with an advance curve very aggressive but that was in fact proved to be too advanced...

Note:

The piston is not the only point where the detonation erosion occurs. Erosion traces also must be checked on the external edges of the squish band in the cylinder head and on the upper part of the cylinder for a portion of approximately 3-4mm.

9.7 CHT – EGT temperatures measure

The measurement of the head temperature (CHT Cylinder Heat Temperature) at the spark plug base can be a very valuable method to help identifying when the detonation could be in place. The CHT shows a rapid and characteristic temperature increase during the detonation, but this method also has some limitations that need to be evaluated in order to be profitably used.

When the head temperature is between 120-140°, and the heat degree of the spark plug is right, as well as the carburetion, during the detonation gusts, the CHT typically measures about 30°-40° more and the CHT increases quick, with an increase of about 3°-5° per second.

The warning is that the CHT has even a slight delay in the response, then it is suggested to measure the exhaust gas (EGT).

Before you can interpret the temperatures acquired in this way, it is necessary to acquire the temperature during the normal operation so that you can compare them with those acquired during the maps development.

Keep also in mind that with the carburetor throttle fully open, it can be noticed that the increase of head CHT grows slower than on the spark plug, and it is only about 1°-2° per second.

Temperature measurement, is a valuable help in maps development, a method that is useful to confirm the suspicion of detonation detected by audible and visual inspection.

This method, however, is usable only if you have an acquisition system that records RPM and temperature, therefore, if you can not equip your model with such a system, then the only acquisition of the peak value reached during the run of map development is not enough to determine whether you are in the presence of detonation or not, but in all cases the maximum value acquired by EcuPlus TC-I is very useful to see if your engine is delivering maximum power or if the cooling is not sufficient.

Even if the engine seems to work well, head and exhaust gas temperatures must never exceed the suggested values, or you will damage the engine.

10 Spark plug reading

The spark plug is a key element in the 2-stroke engine. In fact it influences the performance, the combustion and also the polluting emissions. Since the spark plug is exposed to the combustion process, traces of it will remain impressed and once analyzed, allow us to guess the operating conditions of the engine. With the analysis of its appearance then, we can deduce the air/fuel ratio, if the chosen spark plug has the right heat degree and then you can also understand if the ignition timing is right or not.
Generally the required usage time for the spark plug to become readable is about 3-7min. If the reading is needed to establish the carburetion then after pushing hard the engine, turn it off immediately, this will avoid to distort the reading.

Below there is a list of the possible causes/effects.

10.1 Correct combustion

The insulator is normally polished, check where the insulation is joined to the metal body of the spark plug, if the carburetion is right on that point you should see a carbon deposits collar that extends for about 3 mm; if the collar is higher then the carburetion is fat, if the collar is not present then the carburetion is too lean. The central electrode has a sharp and chine edge.

10.2 Spark plug too hot

If the spark plug has a side electrode, it will appear as if it had been heated with the blowtorch, it will have a scaly appearance, the central electrode will be eroded, the insulation will be clear and polished but with the magnifying glass its surface will appear as grainy and porous as if it was mad of sugar. If the cause is only the mixture too lean it would only appear clear and polished, as evidence it will be sufficient to fatten the carburetion to see if it varies.

10.3 Spark plug too cold

If the spark plug appears covered in black and dry soot. Also when the fuel mixture is overly rich, the spark plug looks sooty but the deposit is often wet and almost velvety. Several people believe that it is safer to run with colder spark plugs, but it is wrong. They will never know if their carburetion is correct, as the spark plug fills with deposits and darkens so much that it is impossible to notice whether the fuel mixture is too lean, and this is how holes in the pistons are created.

10.4 Detonation

At the beginning some tiny dark spots are formed on the insulation; if the problem persists some small bead of molten aluminum begin to appear on all the exposed parts of the spark plug, the sealant around the electrode protrudes as if it was boiled.

10.5 Pre-ignition

When the fact is due to the too hot central electrode, it will appear corroded all along the edges, the end of the side electrode will appear overheated and scaly.

10.6 Excessive advance

Even after just a few minutes of operation it appears a slight erosion of the central electrode which assumes a bluish color, even with just two or three degrees too much. If the advance is greater than that, even bubbles appear around it.

10.7 Low sparking plug voltage

When the spark happens, a lighter point on the spark plug is formed; in case of a low voltage this point has a smaller diameter and jagged edges.

10.8 Distance between electrodes

Finally, please note that the electrode gap is a setting parameter of the spark plug and must be very precise because changing it you can have very different behaviors. In fact, the most important data for the determination of the gap is the discharge energy of the ignition system, where the greater the discharge energy and the greater will be the distance between the electrodes. The increased available energy, increases the combustion speed since in this way there is a larger electric arc whose consequence is to burn a greater amount of mixture at the moment of ignition that produces a faster combustion as a result, allowing to be able to reduce the ignition advance to all advantage of the heat efficiency.
To get the correct setting of the spark plug gap, you need to use a feeler gauge and check that the electrode gap is that one required or resulting from tests.

Listed below, find the effects of the spark plug gap adjustment:

- Too small gap:
  the spark may be too small to ignite the fuel mixture and it excessively consume/overheat the electrodes also determining a slight increase in the burning time.

- Gap slightly wider:
  the spark is stronger, allowing a better combustion.
- Too Wide gap:
  spark difficulties, leads to power reductions, especially at high RPM, with inevitable failure to reach the maximum RPM. With mixtures too fat you can even get to showy delivery holes due to contamination of the spark plug, especially in situations of large and sudden throttle

openings. Moreover in these conditions, the ignition system is pushed hard as the spark voltage increases significantly, and if isolation of coil, spark plug, spark plug cable and pipe is not perfect, the spark will go everywhere except in chamber...

11 Conclusions

We have reached the end of this guide and now it is necessary to put into practice the concepts that you know being different from theory !!!
In addition to highlighting the importance of structuring a method to carry out tests and analysis of results, I remind you that sometimes when comparing two seemingly identical engines, you may experience slight differences in performance. Every component of the engine has different characteristics so it is reasonable to accept this result. So for convenience you can use the same calibration on an engine considered identical, but in doing so, take into account that you may find different behaviours, moreover all the above rules are generally applicable to all high-performance two-stroke engines but sometimes some configurations of our engines, require mappings whose logics are not typically as per manual.

Have fun,

EcuPlus Team

Notes:

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