Timing The Animal

By Bob Markiewicz

The spark inside your race engine is pretty simple, high voltage is used to jump a gap and create the heat needed to get combustion started. The spark itself is pretty simple, but getting everything to happen just right isn't that easy. Spark timing is one of the most critical tuning agents we have to maximize power. If it isn't right within a degree or two, power can be down. With the stiff competition of today's racing, a loss of power because of bad tuning is unacceptable. We work too hard for every tenth of horsepower to have it lost from what could easily be avoided.

Our ignition systems are pretty simple, just a handful of components carry out the tough job of getting your mixture lit. The flywheel, coil, spark plug wire, and spark plug are the major components we have to work with. These components are very reliability, and as long as we get the engine timed right, the set it and forget it theory applies.

The purpose of the ignition system is to start the burn of the air/fuel mixture inside the combustion chamber at the perfect time. This allows the fuels energy to be converted to heat, which ultimately expands and pushes the piston down the bore. It is critical that this process is started at the correct time, otherwise this expansion process will happen too late or early and the piston descending down the bore will not be able to utilize its maximum energy. When the spark plug lights the air/fuel mixture it doesn't cause an explosion. It actually causes the start of a controlled burn that starts out slow, rapidly increases to a fast burn rate, and then slows again before it burns out. Maybe it is easier to picture as a pile of wood that has started on fire, it takes a while to get going, burns like crazy once the fire has spread across the logs and then slows down as the last little bit is burned off.

Getting away from the thought that the mixture inside your engine is exploding can greatly help you develop horsepower and better understand ignition timing. By understanding the mixture burns at a slow rate, compared to an explosion, and knowing that by increasing this burn rate you can increase power output, you can use this to help maximize power.

Figure 1

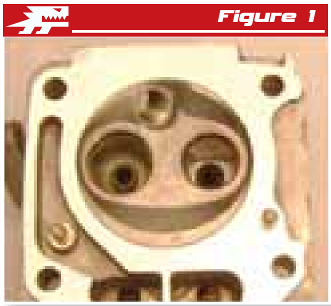
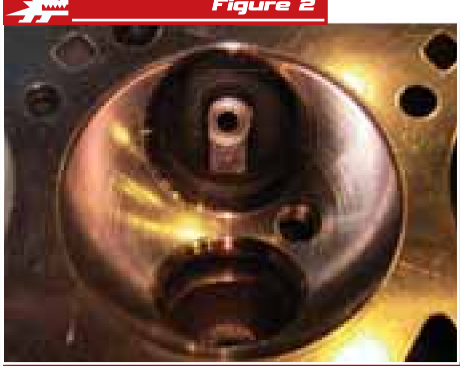


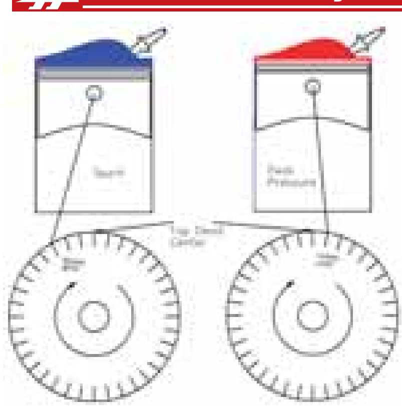
Figure 2



Figures 1 & 2: The location of the spark plug has an effect on ignition timing. The head design normally dictates where the plug can be located. By having the plug closer to the center of the bore it allows the timing advance to be reduced or retarded because the burn rate is increased. Notice how the head on the right allows the spark plug to be located closer to the center, the head on the left must be offset more.

Getting the mixture inside the chamber to burn faster increases the pressure rise in the chamber and makes better use of the expanding fluid. How do you increase the burn rate? Think of a forest fire on a calm day, though it burns, it doesn't spread very fast. That is until the wind picks up, then the flame spreads uncontrollably fast. Now compare this to the air/fuel mixture burning inside your engine. The intake charge enters the bore and the valve closes, if the mixture is completely still when the spark occurs it will burn slowly out to the cylinder wall. Now picture the intake charge coming into the bore swirling around the bore axis. As the piston comes up the bore, the mixture between the flat part of the chamber and the piston get squished out towards the spark plug. Because of thoughtfulness in the design, the mixture motion in this example is very high. Now when the spark plug lights the mixture inside this small hurricane a new meaning is given to the name wild fire.

Figure 3



The picture on the left illustrates the crank position at the point of spark ignition. The picture on the right shows the general location where peak pressure inside the cylinder should occur. This helps illustrate how retarding or advancing the ignition timing can change the point where peak pressure occurs in the cylinder.

Head porters have known about the importance of this swirl, tumble, and squish along with other tricks to increase burn rate inside the chamber. Unfortunately, for stock class racing their isn't much we can do to increase this outside of what the engine manufacturer has supplied us with. For some of the open class racing, this is something that should be considered in the overall design of the intake port and chamber.

The spark plug location also has the effect of changing the burn rate inside the chamber. By locating the plug closer to the center of the bore the burn can go in all directions. This greatly increases the burn rate when compared to a spark plug that is located closer to the cylinder wall. (Figures 1 and 2). Four valves per cylinder engines do a great job of getting the spark plug centrally located because the 4 smaller valves allow for this. Two valve per cylinder engines normally don't allow this so the spark plug location is always a compromise. This means that you can normally run less spark advance, which helps maximize power, with the more centrally located spark plug.

The fuel we run also can affect the burn rate inside the engine. Fuels with higher octane than standard pump gas and fuels like methanol or nitro methane have slower burn rates. Because of this, the ignition timing may have to be advanced to compensate for this slower burn.

The reason this is all important to ignition timing is because the burn rate inside your chamber is directly related to the timing you put into your engine. Pressure inside your cylinder needs to reach its peak around 10 deg. after top dead center for maximum performance. This means that the spark has to happen before the piston has reached top dead center to allow enough time for the mixture to burn and reach its peak pressure at the correct time. If it reaches it early, too much energy is being used while the piston is coming up the bore on the compression stroke. This is because the pressure will actually start to push on the piston on the way up, which is negative work, instead of pushing it down after top dead center, which is positive work. On the other side, if the peak pressure happens too late then pressure can't be optimized to put force into the piston and energy will be wasted. And, because the exhaust valve opens before the bottom of the power stroke, pressure that could have been used for power now goes right out the exhaust pipe. (Figure 3)

After an engine is built, little can be done to change when this peak pressure occurs. The main adjustment we have is our

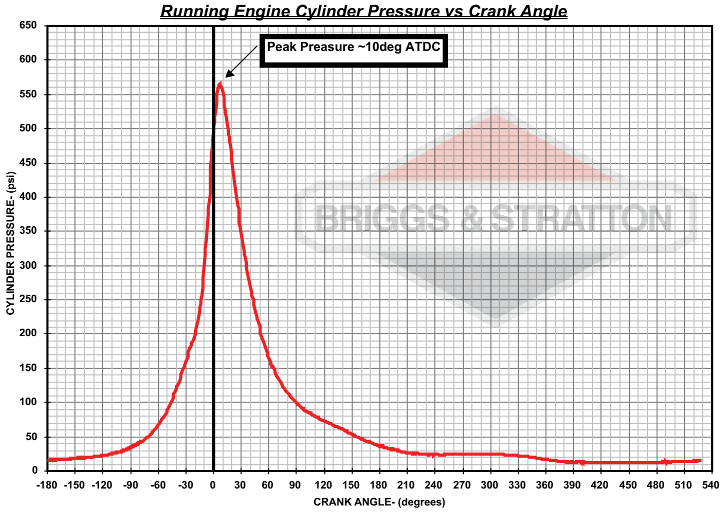


Figure 4, Above

This is a comparison of the pressure inside the cylinder vs the crank position. Notice how it starts out slowly, rises fast, and slowly burns out. The peak pressure, occurs right around 10deg after top dead center for best performance.

timing, and by advancing or retarding it we can make sure peak pressure ends up right where we need it. Most have probably never heard of measuring for peak pressure, but it is possible. Big manufacturers use pressure sensors inside of the chamber and compare this pressure output to the crank position. Figure 4 shows how an average pressure trace looks from this type of measurement. Unfortunately, this equipment cost tens of thousands of dollars which is out of reach for most kart shops.

We can measure horsepower and because power output is all that matters to us this method works just fine for finding the correct peak pressure location. So the answer to the question of how do we find if peak cylinder pressure is happening at the right time? We do power tests. Notice how I said peak pressure should be about 10 deg after TDC, power tests still need to be ran to find what works best for a particular engine, even with sophisticated equipment, because it may end up being ~8-15 deg after TDC.

If an engine has a slow burn rate it will require more advance in the timing, or the combustion started earlier to get the peak pressure to fall at the right time. If the engine has a faster burning charge the timing can be retarded or happen later. The second scenario is better for performance because this means that less negative work was done to get the peak pressure to fall at the right time.

By adjusting the timing and measuring the power we find what timing the engine works best at. The engine probably won't like the same timing throughout the RPM range that it is ran at. If we run the engine from 4000rpm to 7500rpm

Figure 5, Below

This chart shows the measured timing of the test engine vs engine speed. Notice how the timing retards as the engine speed increases. This shows that when checking the timing with a timing light it must be done every time at the same speed. Otherwise, the value will change every time it is checked making tuning nearly impossible.

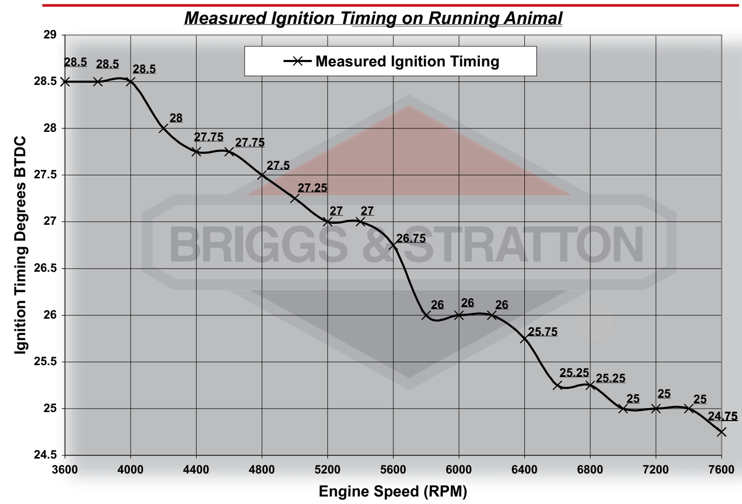


Figure 6

Adjustable flywheel courtesy of JR Racecar used to change timing during dyno testing.

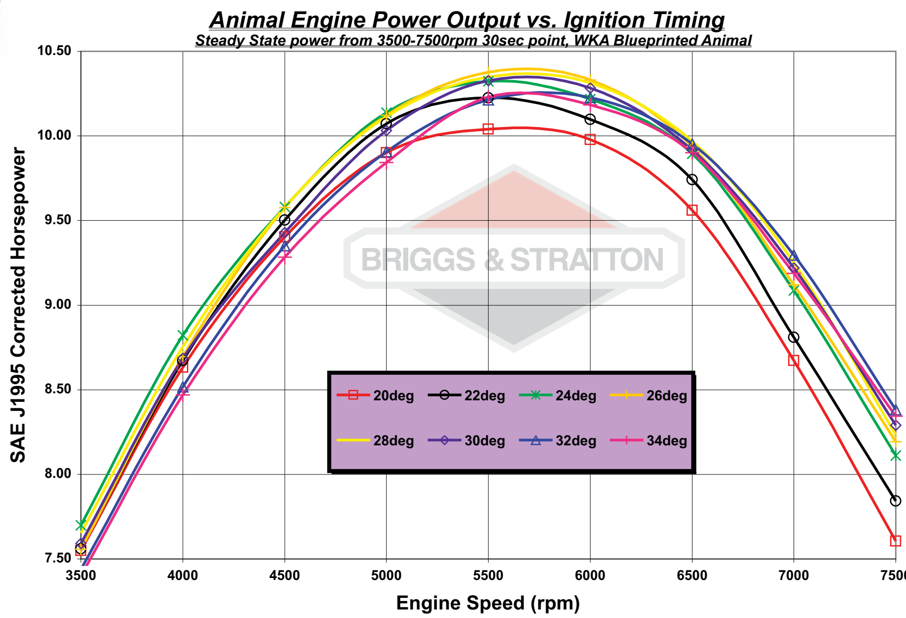
chances are it will want more timing at the higher engine speeds. This is because the burn rate doesn't normally increase as fast as the engine speed, so once again to get the peak pressure to fall at the right time the burn must start earlier in the bore otherwise it will fall behind with speed.

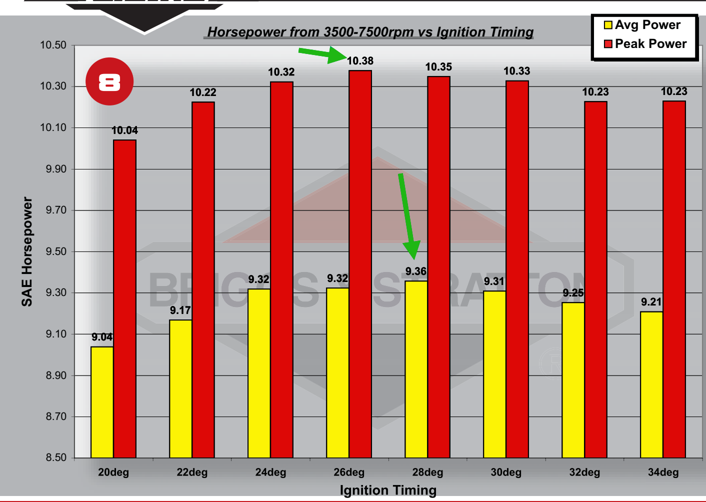
Most of what we do is limited to the standard straight curve timing that is integrated into the coil itself. I say straight curve because that is how we normally discuss our timing; 29deg, 30deg, etc. The reality is the electronics inside the coil take time to "think" they also can fall behind with engine speed. Figure 5 shows the curve off of the test engine using the standard Briggs and Stratton coil part 557040 and flywheel part 555625 (JR Racecar). The points were taken every 200 rpm, and as you can see the timing retards throughout the curve. When someone states they are running 29deg of timing advance, your question to them should be at what engine speed? Because, 29deg at 4000rpm is not the same as 29deg at 7000rpm, I like to check my timing at the middle of the powerband which is about 5000rpm. I do this with a Flaming River timing light and a billet degree wheel made to spin this high. Whenever you check your timing on a running engine make sure the manufacturer of your testing equipment has approved your testing method.

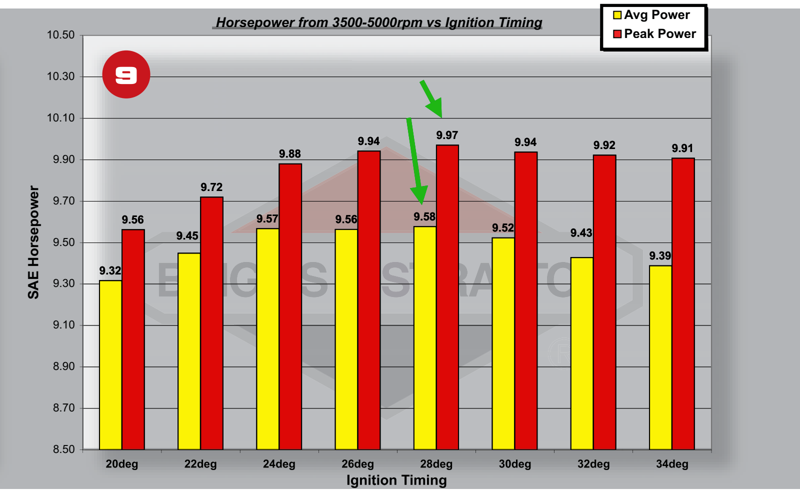
To recap, the purpose of setting the timing is to get the peak pressure inside your cylinder to occur at the proper time. Depending on the airflow, fuel used, and burn characteristics of your engine, this may

Figure 7

Notice how when the timing is changed the power curves also change. When the timing is advanced the power increases until it reaches a point where it must be a compromise between bottom and top end power output.







Figures 8-11

FIGURE 8: This shows what timing produces the best average and peak power when comparing the speed range. At 26deg the best peak power occurred and 28deg the best average power was seen.

FIGURE 9: This histogram shows the percentage of time the engine spends at each engine speed for one lap at a local sprint track. This came off of my Mychron 3 data logger and is a good way to break down how much time is spent at each rpm so you can best optimize your timing.

FIGURE 10: At the lower engine speed the peak and average power both occurred at 28deg.

FIGURE 11: At the mid to upper engine speed the peak and average power was the same as when compared to the entire speed curve.

FIGURE 12: At the top of the engine speed, the timing shifted to the more advance position to achieve the best average power. This proves the speed the engine is run at most can change what timing will work best for your application.

change when the optimum timing should occur. By measuring horsepower on a dyno and adjusting the ignition timing we can find the correct setting for our particular engine.

To show this in practice I set up an Animal engine on the dyno and did power tests with different timing settings to find what worked best for my particular engine. The engine was a slightly blueprinted WKA Animal. It still retained the standard bore and piston. The exhaust was a Robertson Candy Cane. The timing was changed by using an adjustable flywheel courtesy of JR Racecar. The flywheel was allowed to turn on the center hub rather than the crank to adjust the timing. This made for more accurate timing settings; rather than having to remove the flywheel for every test. The engine was steady state power tested from 3500-7500rpm and the timing was varied from 20 to 34deg in 2deg increments. Two tests were run at each point to verify accuracy. The timing was set at 5000rpm using a degree wheel and timing light. (Figure 6 - adjustable flywheel)

Figure 7 shows the results of the testing in graph form. As you can see, the power varies greatly as the timing is changed. This graph is pretty cluttered and makes it hard to see what is clearly going on. But, if you look closely you can see the effects of the different settings. Notice how when the timing is too low the power is down everywhere. As the timing is increased the bottom end power increases until it hits its peak and then it starts to fall back down. The top end of the curve still increases as the timing is raised right up to 32-34deg. This shows how the timing choices we have end up being a compromise between bottom end and top end power.

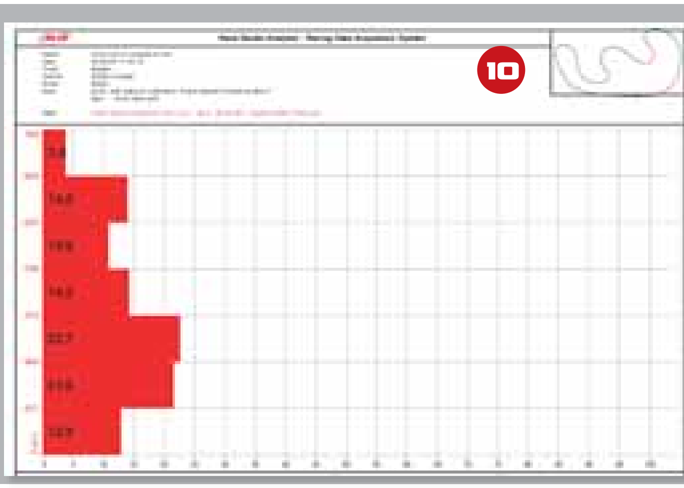
To show this clearer, I broke the graph down into a bar chart that tells the story much easier. The average and peak power were compared at 3500-7500rpm to represent the full curve, 3500-5000rpm to represent the low end, 5500-7000rpm to represent the mid to top end, and 6500-7500 to represent the top end. The ignition timing is called out at the bottom of each bar.

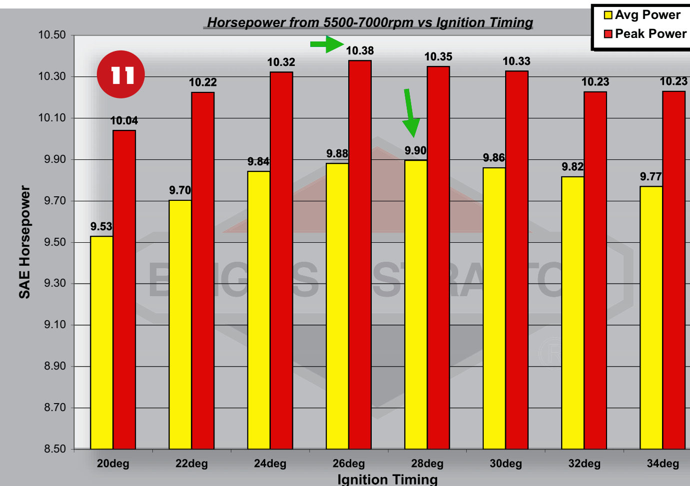
Figure 8 shows the power for the entire tested speed range. The bar graph easily shows what timing made the best peak power and the best average power. For this test 26deg was peak power and 28deg was the best average power. If your engine is going to be operated consistently across this entire speed range then this is probably your best bet. By this I don't mean that your engine will see 3500rpm at one spot on the track and 7500rpm at the other. Yes, you are using the entire engine speed range, but you are probably not using it the same amount of time. Take a look at Figure 10 (AiM graph). This shows the percentage of time spent at each engine speed at my local track taken off of my Mychron data logger. Looking at this you can see how even though time is spent at higher rpm, the majority of the lap is spent at the lower rpm. This means that maximizing the timing for the entire rpm range would not maximize the power where the engine spends most of its time.

Figure 10 shows the power for just the low end of the curve. The results are similar to the full curve comparison, but this particular test showed 28deg being best for both peak and average power.

Understand that all these values are negotiable because there is only a couple hundredths of a HP between them. The next engine may not be exactly the same, but this is what this engine measured.

Figure 11 shows the mid to upper section of the power curve. Peak power occurred at 5500rpm for all the tests, so this range represents the timing that gave maximum power. Much like the previous





illustrations, peak power fell at 26deg and the best average power was at 28deg. Most people I talk to set their timing at 29-31deg, which according to this seems too high. Two things must be noted here, first is how close the power output actually is from 24 to 32deg, we are only talking hundredths. Second, take a look at the next illustration. For circle track racers, the rpm range that is used is much shorter than sprint racing, sometimes only a couple hundred rpm. This means we can optimize our timing for the small range we run in.

Figure 12 shows the power at just the top of the curve. From 6500-7500rpm, now there is a significant change as to when the peak power occurs. Now the best peak and average power occur at 28deg and 32 deg, respectively. Now it makes more sense that most are setting their timing in the 29-31deg range. I personally set my engines up at 29degrees.

This was a lot of numbers but it was necessary to show how different engine speeds can affect your timing, studying the graphs will make it much more clear. It also gives a good reference for engine builders to work off. Ultimately, it showed that timing from 24 to 32deg is in the ballpark, but optimum power is going to be seen between 28-32deg depending on what type of racing is being done. I would set my sprint engines up for 26-28deg and my big oval track engines up in the lower 30's because of the time each will spend at these engine speeds.

Most probably know that by the time this reaches print Briggs and Stratton has released the new PVL digital ignition for the Animal and World Formula engine. This new system is an approved upgrade by WKA and should have advantages over the standard ignition. Next month, we will investigate and test this new system to help the racer with this transition.

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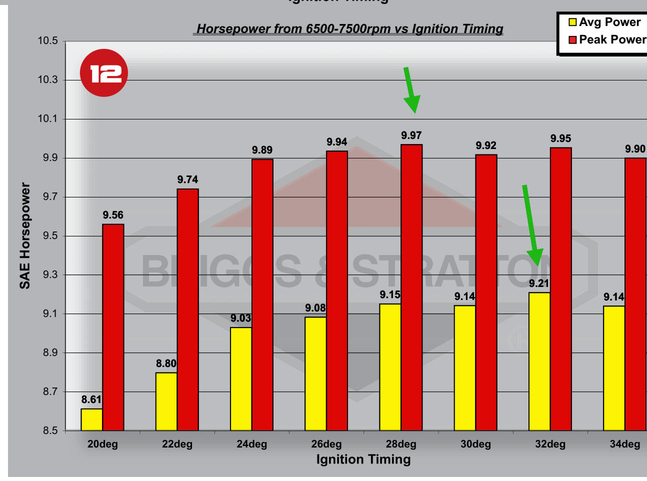

Next month we will take a look at the new PVL digital ignition system Briggs and Stratton has recently released.