The following chapter is an excerpt from the book: Modern Advancements in Long Range Shooting. You can learn more about this book here: https://store.appliedballisticsllc.com/ProductDetails.asp?ProductCode=0004

Chapter 15: Measuring Muzzle Velocity

One of the most important things to know about your ammunition for long range trajectory modeling is the muzzle velocity of your bullets. Starting around 300 yards, you can see significant errors in predicted drop if you don't model the bullets muzzle velocity accurately.

Another reason it's important to understand muzzle velocity measurements is when you're developing handloaded ammunition or sampling factory ammo and you're looking for the most consistent muzzle velocity. The idea behind minimizing the spread in muzzle velocity is to minimize vertical dispersion at long range. Faster shots hit higher and slower shots hit lower. The more spread there is between the fastest and slowest shots, the taller your groups will be at long range.

A chronograph is an instrument used to measure muzzle velocity. There are several different kinds of chronographs which measure bullet velocity in various ways. They all have their pros and cons related to accuracy, precision, cost, ease of set-up, etc. There's a lot to know about chronographs, some of which is obvious and some is not so obvious. This chapter will provide you with information to select and properly use a chronograph for your application.

Two parameters we need to establish when talking about chronographs are: *accuracy* and *precision.* Accuracy is the ability of the chronograph to measure the true average velocity for a string of shots. This is most important when you're modeling long range trajectories in ballistics programs and need to know your bullets actual average muzzle velocity. Precision is the ability to resolve the true extreme spread and standard deviation of a string of shots. Precision is most important when you're looking at the *consistency* of ammunition.

It's possible for a chronograph to have high accuracy and low precision. It's also possible for a chronograph to have high precision and low accuracy. Extensive live fire testing was conducted which included 8 different brands of chronographs of various types. The performance of each chronograph will be characterized in terms of their accuracy and precision.

Before we get into the live fire, let's talk about the principles of velocity measurement as a baseline for understanding.

Principles of Velocity Measurement

There are different kinds of sensors used in chronographs. Most common are the optical sensors with sky screens. Other types of sensors are acoustic and electromagnetic. Regardless of the sensor type, all of them work on the same principle of measuring the *time* it takes for a bullet travel a known *distance.* In fact, that's the very definition of velocity; distance divided by time; feet per second.

The accuracy and precision with which a chronograph can measure velocity depends on the accuracy and precision of the sensors which measure the bullets position and the clock which measures time.

One rudimentary way to look at a chronographs potential precision is to consider the clock speed used in the processor. If a chronograph has an internal clock speed of 1 MHz, that means it's able to resolve time within 0.00000001 seconds. A bullet traveling at 3000 fps between two sensors spaced 1 foot apart would be measuring a time of 0.00033 seconds. A 1 MHz clock is able to measure this time within 0.3%. On a bullet traveling 3000 fps, that's 9 fps. Since the velocity calculation will round to the nearest time step, the effective error is ½ the time step, which is 4.5 fps in this example.

The idea of the above example is that the native resolution of a chronograph can be expressed in terms of clock speed: the faster the clock, the more resolution is possible with a given screen spacing. Although this calculation is valid in theory, there are several real world effects which end up being more important than a calculation based on clock speed.

One reason why clock speed is less important is because in modern times, even the less expensive chronographs have super-fast clock speeds capable of resolving small bits of time. However the biggest reason why clock speed based resolution claims are invalid is because the ability of the sensors to accurately pick up the bullet ends up being far more limiting.

Since most modern chronographs use some kind of optical sensors, we're going to spend some time discussing how they work and what the common problems are with them. Later we'll contrast the other kinds of sensors (electromagnetic and acoustic).

In my experience, the actual sensors used in modern chronographs are all good. The problems aren't with the sensors themselves, but with the spacing and alignment of the mechanical supports; this is where chronographs tend to differ. You can have perfect sensors, but if they're not accurately spaced or are misaligned, then you won't get good measurements. Figure 15.1 shows some examples of common sensor placement problems which each cause different types of inaccuracies.

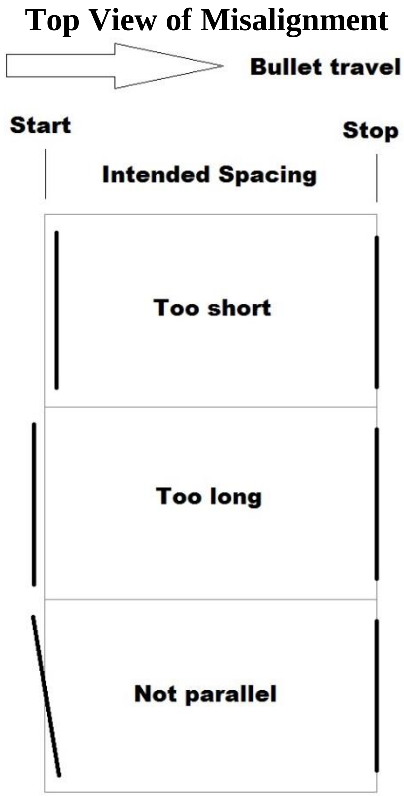


Figure 15.1. Different types of sensor placement error cause different kinds of accuracy and precision problems.

Figure 15.1 is a top view of the optical sensors, with the bullet traveling over them from left to right. In the top example, the sensor spacing is shorter than intended. This kind of error will result in the chronograph reporting velocities which are faster than reality. For example, suppose the chronograph is basing its velocity calculation on an intended screen spacing of 24 inches (2 feet), but the screens are actually 23.95 inches apart. That's an error of just 0.050", which is not out of the question for an affordable mass produced instrument. The percentage error in indicated velocity will be equal to the percentage error in screen spacing. In this example there is 0.2% error in screen spacing. For a bullet traveling at 3000 fps, this equals just over 6 fps of error in measured velocity. In the case where the sensors are 0.050" too close, the indicated velocity would be 3006 fps for a bullet that's actually traveling at 3000 fps. If the sensors are too far apart by 0.050", the instrumental velocity would be 2994 fps.

Another kind of problem that's possible is if the sensors are not parallel is shown at the bottom of Figure 15.1. In this case, instrumental velocity would be higher or lower than actual depending on where the bullet passes thru the screens.

Figure 15.2 shows a side view of a potential sensor misalignment scenario. For chronographs which make use of hinged/folding rails, it can be difficult to keep the sensor planes in alignment. In the scenario depicted in Figure 15.2, a bullet passing thru the bottom of the window would travel less than the intended distance and a bullet passing thru the top of the window would travel more than the intended distance between the timer starting and stopping. Typically sensors that are mounted on solid one piece rail maintain better alignment.

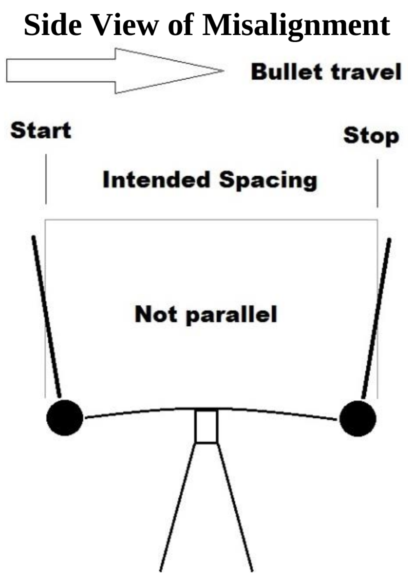


Figure 15.2. If the chronograph rail is hinged or bends in the middle, it can result in the sensor planes being misaligned.

The challenge with these errors in sensor alignment is that the smallest amount of misalignment can cause significant error in measured velocity. In the example above, just 0.050" (less than 1/16") results in 6 fps error over a sensor spacing of 2 feet. For a chronograph based on a 1 foot spacing, the error would be twice that much; 12 fps for the same 0.050" error in spacing.

Given the absolute importance of exact sensor spacing, you might be compelled to try and measure the distance between your chronograph sensors to see if they're exactly where they should be. Unfortunately, measuring the physical location of the sensors themselves won't necessarily tell you where the beam is projecting above the sensors where the bullet passes.

Another thing which can cause trouble with your effective sensor alignment and spacing is wind. Most optical based chronographs use some kind of light diffuser above the sensors which are supported with uprights that you shoot thru. These skyscreens can catch the wind and cause the chronograph to shake and torque. However the bending and shaking of the support rail can cause the sensors to become misaligned to different extents from shot to shot.

There are other mechanical issues which can cause problems for the sensor spacing, but I think you get the point. Moving on…

Another challenge for optical chronographs is ambient light conditions. Basically the optical sensors work by detecting the shadow of a passing bullet. The ability of the sensors to resolve the passing shadow depends a lot on the ambient light conditions. For most chronographs, the best case scenario for lighting conditions is overcast skies.

One method that's employed to make chronographs less sensitive to ambient light conditions is IR illuminators. These are basically powered diffusers which create their own light and the sensors look for shadows only in that particular spectrum. This enables the chronograph to detect bullets in low light conditions and even complete darkness since they're not operating in the spectrum of visible light.

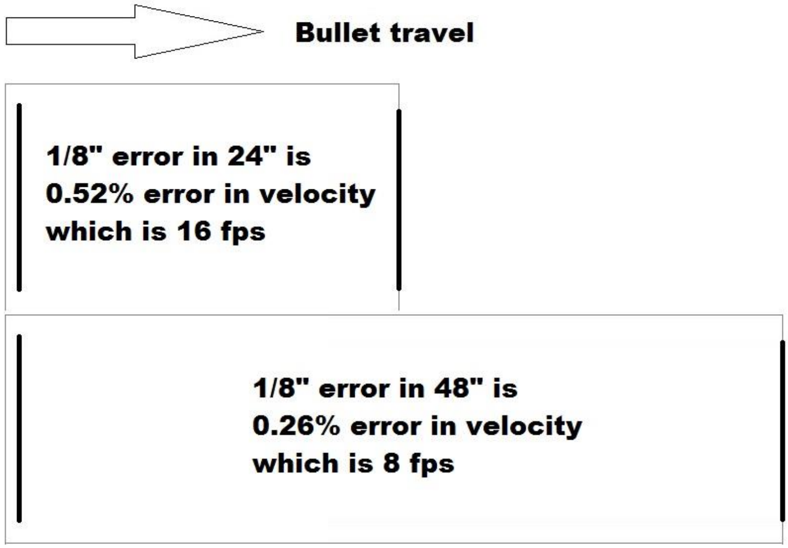
Along these lines, it's also possible to supply normal light in the form of incandescent light bulbs over the light diffusers to enhance the performance of the light sensors. Supplying IR or visible light is usually necessary for chronographs that operate indoors. When applying artificial light to chronographs, it's important to avoid fluorescent lighting. Florescent lights actually flicker at a high frequency which plays havoc on the sensors which are looking for shadows passing at high speed.

Regardless if the sensors are working with natural or artificial light, there are variables related to the bullet which can affect the sensors ability to detect it. Large caliber bullets with blunt tips will cast an abrupt shadow which the sensor can pick up easily. On the contrary, small caliber bullets with needle points (imagine a 22 caliber 90 grain VLD) can *slip thru* the sensor window to various degrees before the sensor trips. You might get a bullet passing 1/8" thru the first sensor before it trips, and the second sensor might trip when the bullet has passed ¼" thru. In this example, it would be like having a 1/8" error in screen spacing. However, unlike screen spacing error which is the same on every shot, sensor triggering error can be different on every shot. The fixed screen spacing error would result in measurements which are *inaccurate*, while the inconsistent sensor error would result in measurements which are not *precise.*

All of these errors with sensors and alignment don't paint a very optimistic picture for chronographs! The good news is there's a very basic way to mitigate these errors, and that is to *separate the sensors as far apart as you can*. Increasing the distance between the start and stop sensor will reduce the velocity measurement error due to sensor spacing error and misalignment. As an example, suppose you have 1/8 inch (0.125 inches) of sensor spacing error due to some mounting imperfections. If the intended separation is 1 foot (12 inches), the velocity error will be 0.125/12 = 1%, which is 30 fps on a 3000 fps shot. However, if the sensors are separated by 4 feet (48 inches), the same 1/8 inch error in sensor spacing would result in only 0.125/48 = 0.26% which is only 8 fps on a 3000 fps shot.

Table 15.3 shows how velocity error is affected by screen spacing error for different scenarios.

Velocity Error for a 3000 fps Shot



Sensor Spacing (feet)	Sensor spacing error 1/64" (0.016")	1/32" (0.031")	1/16" (0.063")	1/8" (0.125")
1	4.0 fps	7.8 fps	15.8 fps	31.3 fps
2	2.0 fps	3.9 fps	7.9 fps	15.6 fps
4	1.0 fps	1.9 fps	3.9 fps	7.8 fps
6	0.7 fps	1.3 fps	2.6 fps	5.2 fps
8	0.5 fps	1.0 fps	2.0 fps	3.9 fps
10	0.4 fps	0.8 fps	1.6 fps	3.1 fps
12	0.3 fps	0.6 fps	1.3 fps	2.6 fps

Figure 15.3. Measurement error is minimized for longer screen spacing.

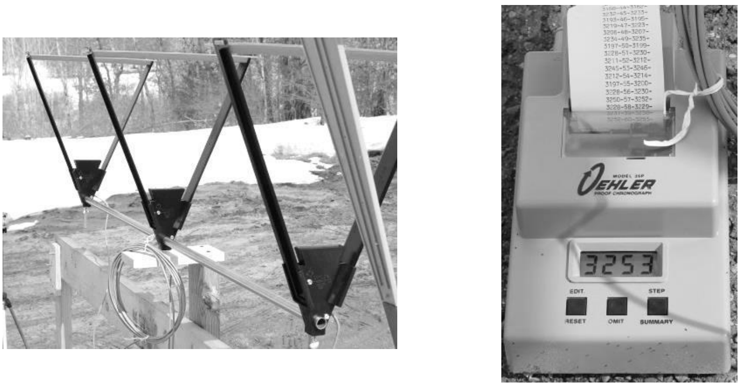
The benefits of long sensor spacing are obvious from Figure 15.3. Both the accuracy and precision of your chronographs measurements will be affected by screen spacing errors. In the case where the spacing error is the same for every shot, the resulting measurements will be inaccurate, but may still be precise. However, if the spacing error is different for each shot (windy conditions or bullets that are difficult to detect) then the measurements will lack precision.

Optical sensors are not the only kind of sensors used in chronographs. One modern chronograph known as the Super Chrono uses acoustic sensors. Rather than *looking* for the bullet to pass, the acoustic sensors *listen* for the bullet to pass. Although the type of sensor is different, the principles of sensor spacing and error apply the same.

Another type of chronograph sensor is electromagnetic. The Magnetospeed chronograph which attaches to the barrel uses an electromagnetic sensor to detect the bullets motion and determine velocity.

All of these types of chronographs have advantages and disadvantages. The following section presents an overview of each chronograph that was tested.

Oehler Model 35P



Screen Spacing	Variable from 1 to 15 feet
Clock speed	4 MHz
Mounting hardware	½” electrical conduit
Price	$575 USD

Figure 15.4. The Oehler 35P has been a staple in the ballistics industry for decades.

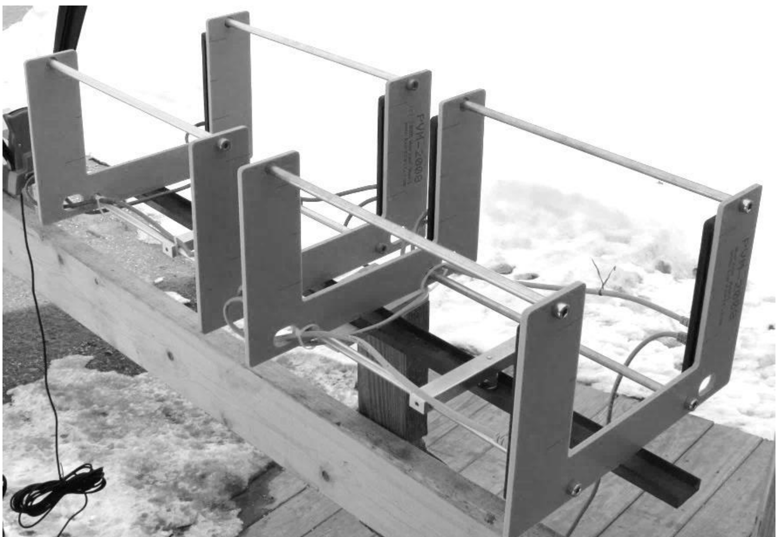
The Oehler 35P is a flexible chronograph in the sense that it can be configured on any rail from 1 to 15 feet in length. The rail is simply ½” electrical conduit which is commonly available. You just cut a conduit to the desired length, measure the spacing, mount the sensors and tell the computer what the screen spacing is. The unit comes with a 4’ rail which has indents for the sensors which are precisely located.

You can get more accuracy by using a rail longer than 4 feet, but you have to be careful; if you use a rail that’s too long (somewhere around 8 feet) you can start to get a significant amount of flex in the conduit which affects the alignment of the sensors. The Oehler unit comes with two tripods which support the rail from each end. This minimizes the flexing problem compared to a central mount.

However, the challenge with the two end supports is with uneven ground; it's difficult to set up on a slope, which is common in front of shooting benches on a range.

The primary chronograph that I use in my laboratory is an Oehler 35P mounted on a 12' rail. I have the rail mounted in a sturdy wooden cradle which supports the conduit for most of its length so it stays straight and doesn't flex. Since it's set up indoors, I have incandescent tube bulbs over each skyscreen which provide consistent illumination. This indoor 12 foot Oehler with artificial lighting is the most accurate chronograph I have and is what the others are measured by (more on this later).

PVM-21



Screen Spacing	14 inches (1.16 feet)
Clock speed	16 MHz
Mounting hardware	Machined rods support the rectangular screens at all 4 corners
Price	$795 USD

Figure 15.5. Two PVM-21 chronographs mounted in tandem.

The PVM-21 is made by a German technology company called Kurzzeit. Kurzzeit produces many different kinds of ballistic instrumentation including high speed cameras. The PVM-21 is the commercial grade product intended for use by recreational shooters outdoors (as opposed to their professional systems which are for laboratory applications).

I have two of the PVM-21 chronographs so I included them both in this test. The units were mounted in tandem on a common rail as shown in the Figure 15.5 so their measurements could be compared directly. The PVM-21 chronograph works entirely on IR lighting, which makes it less sensitive to ambient light conditions. Rather than a V shaped window to shoot thru, the PVM-21 has a goal post shaped window with alignment marks which help you set up the unit parallel to the line of sight. The structural design of the PVM-21 is very strong. With metal rods supporting each of the 4 corners, the distance between the sensor planes is not likely to vary across the window, nor is the unit likely to experience deflection in windy conditions.

Pact Professional XP Chronograph

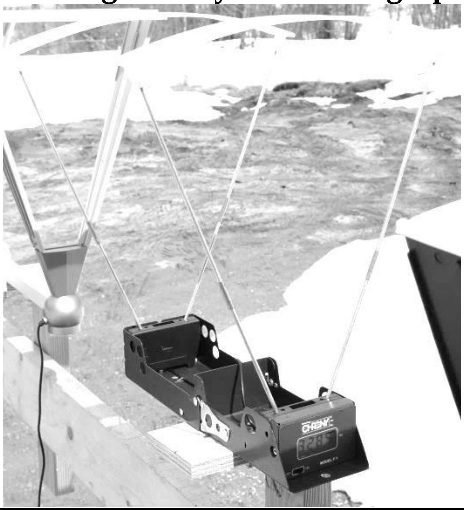
Screen Spacing	1.5 feet
Mounting hardware	1.5 foot rectangular rail
Price	$200 USD

Figure 15.6. The Pact Professional XP Chronograph is a conventional optical configuration with a base unit that's rich with features including a built in printer.

The Pact Professional XP chronograph is a traditional design with optical sensors placed on a rail and V shaped sky screen supports to shoot thru. There is an optional IR screen kit for the Pact, but the standard screens were used for this test.

The Pact Professional XP chronograph has a built in printer and can even print ballistics charts based on other inputs related to bullets and atmosphere. Although these are nice features, they don't affect the fundamental accuracy potential of a chronograph which is where the current test is focused.

Shooting Chrony F1 Chronograph



Screen Spacing	1 foot
Mounting hardware	Folding steel box
Price	$100 USD

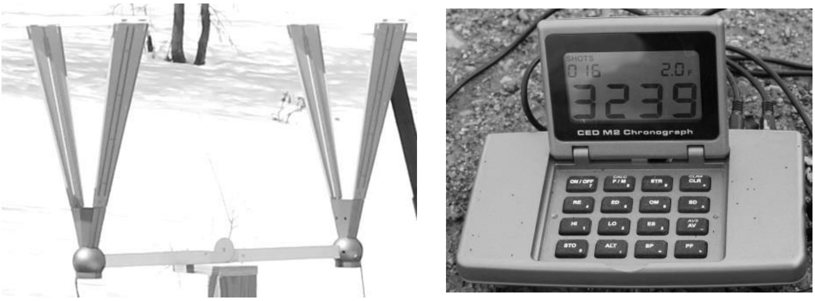
Figure 15.7. The Shooting Chrony is possibly the most common and recognizable units out there. If your local gunstore only has one chronograph on the shelf, it's probably a Chrony!

The Shooting Chrony is a very common and affordable chronograph which is small, simple and easy to set up. The compact folding design allows you to easily store this unit in your range bag and there are no wires to string out and get tangled up. Although the unit packs down to a small size, the shooting area is on par with the larger units when it's set up. The folding base is quite sturdy and doesn't seem like it would flex much in the wind. However, the short screen spacing is not likely to be conducive to accurate velocity measurements.

The CED M2 chronograph is another traditional style unit with optical sensors. The sensors mount to the ends of an aluminum rail which unfolds to a length of 2 feet. Although this sensor spacing is decent in comparison to some other units on shorter rails, the folding aluminum rail is rather flimsy. With the large skyscreens mounted to the ends of the rail, this unit bends and flexes quite a bit during set up and in windy conditions which means the optical planes can move around when the bullet is passing thru.

Where the CED M2 really shines is in clock speed. The super-fast processor ticks along at 48 MHz, which means that (in theory) it should be able to resolve within 0.1 fps on a 3000 fps shot. In addition to the advanced internals, this unit also has a convenient display which has large digits that are visible from a distance in all conditions.

CED M2 Chronograph



Screen Spacing	2 feet
Clock speed	48 MHz
Mounting hardware	2 foot hinged aluminum rail
Price	$200 USD

Figure 15.8. The CED M2 Chronograph.

The CED M2 chronograph also has an optional IR screen kit for use in dark conditions or indoors.

Super Chrono

Screen Spacing	8 inches (0.75 feet)
Mounting hardware	One solid unit mounts to tripod
Price	$380 USD

Figure 15.9. The Super Chrono uses acoustic sensors to detect the passage of the bullet.

The Superchrono is a small, self-contained unit made by Steinert Sensing Systems in Norway. The SuperChrono uses acoustic sensors (microphones) instead of optical sensors to detect the passage of the bullet. The advantages to the acoustic sensors are that they work over a greater distance, meaning you don't need to thread the needle as you do with optical based units. This means no sky screens, and you can place the chronograph further out of harm's way which simplifies set up. Another advantage to acoustic sensors is that they're unaffected by ambient light conditions.

The problem with the SuperChrono is that the acoustic sensors are only 8 inches apart. Recalling our discussion of the importance of sensor spacing to accuracy, this is bad news for the potential accuracy of the SuperChrono. But don't give up on it yet, wait to see how it does in the testing.

Magneto Speed

Sensor Spacing	5 inches (0.417 feet)
Clock speed	12 MHz
Mounting hardware	Bayonet style to rifle barrel
Price	$350 USD

Figure 15.10.

The MagnetoSpeed chronograph is a relatively new option which steps away from the conventional optical sensors. The MagnetoSpeed mounts right to the barrel and uses electromagnetic sensors to detect the passage of the bullet. Since these types of sensors only work well over a very short distance, the MagnetoSpeed has to be placed very close to the path of the bullet. You simply wouldn't be able to achieve this precise spacing using conventional (tri-pod) mounting, which is the reason for the muzzle mount.

The sensors in the MagnetoSpeed are only separated by 5 inches which seems like it would be too short. However, the sensors are fundamentally different than optics and don't have the same sensitivities to alignment. Based on the 12 MHz processor speed and 5 inch sensor spacing, the theoretical resolution on a 3000 fps shot is 1.8 fps (+/-0.9 fps).

Another benefit of a non-optical sensor is that it's not affected by ambient light conditions.

Mounting the MagnetoSpeed to your barrel may be alarming to some shooters who use a chronograph for load development due to the possibility of its affecting barrel harmonics. This aspect of the MagnetoSpeed was not specifically tested during this study, but I can say that I haven't noticed a significant shift in zero for the rifles I've used it on.

Now that all the chronographs have been given a short overview of their physical characteristics, let's see how they actually performed in a live fire comparison.

Live Fire Testing

The basic idea is to line up all the chronographs and shoot thru them to see how they each measure the speed of a common shot. Although this is simple in concept, there are a few points to be careful on.

First of all, you have to account for the bullet slowing down as it travels the distance between the various chronographs. The first chronograph in the line should read a little faster than the last one in line. In the case where you have chronographs strung out for 50 feet, the bullet can slow down quite a bit between the first and last measurement. This is accounted for by calculating how much velocity the bullet loses per foot, and adjusting the measured value to reflect this loss. For clarity, we'll refer to the *instrumental velocity* as the velocity the chronograph actually reads. Mostly we'll be talking about the *adjusted velocity* which is corrected for the velocity decay of the bullet between units.

There were two rifles used for this testing; one was a .308 Winchester and the other a .223 Remington. The reason for the two calibers is to see how chronograph accuracy is affected by the caliber and speed of the bullet. In theory, the optical based sensor units should be able to detect the larger (.30 caliber) bullets more accurately than the smaller .22 caliber bullets. Both ammo types used were inexpensive bulk ammo loaded with full metal jacket bullets. Remember, the objective isn't to test the ammo, the objective is to test the chronographs. In other words, for this test we're not looking at how consistent the ammo is shot-to-shot, but rather how consistent the chronograph measurements are with each other.

The other challenge in comparing chronograph performance is the choice of a standard for comparison. In other words, how do you know what the *true* velocity of a shot is so you can identify the error? One way to do this is to average all the measurements and compare each individual chronograph to the average. You might use this approach if you expected the accuracy of all the units to be roughly the same. However in this case, there is one chronograph which clearly stands to be the most accurate, and that's the Oehler 35P mounted on the 12 foot rail. There are several reasons why this unit is expected to be most accurate. First, the long separation in the sensors physically limits the amount of error that will occur with a given error in screen spacing or alignment. Second, this chronograph operates completely indoors, with a consistent artificial light source. Finally, the Oehler 35P actually prints two velocity measurements which are taken independently over the first and

Figure 15.11. The array of chronographs as tested. In order from left to right: MagnetoSpeed (not visible), indoor Oehler on 12 foot rail, 4 foot Oehler built into light box, two PVM-21's, Pact, Shooting Chrony, CED-M2, Oehler on a 4 foot rail in natural light, SuperChrony (not shown)

middle screens (proof channel), as well as the first and last screens (primary channel). In other words, the unit provides two independent measurements of velocity over two distances. Any difference in these numbers would indicate bad measurements. On the 12 foot Oehler, *these measurements are taken over 6 feet and 12 feet, and never deviate more than +/-1 fps between the two channels.*

This is a good indication of accuracy; basically two measurements of every shot.

Based on the above, the 12 foot Oehler was chosen as a standard for evaluating the accuracy and precision of the other chronographs. We will know if this was a bad choice based on the results. For example, if every chronograph happens to have the same +25 fps *error* for a given shot, then we might suspect that in fact the control had a -25 fps error on that shot and all the other units were correct. You'll see this doesn't happen in the actual results.

There were actually 3 different Oehler 35P chronographs tested. One was on the 12 foot rail with artificial lighting which is always used inside. Another Oehler unit is mounted on a 4 foot rail and built into a box which also has artificial lighting. I use this unit for mobile testing and for placing downrange to shoot thru when measuring ballistic coefficients. The third Oehler is on a 4 foot rail and mounted as it came out of the box new. This unit was included to provide a fair sample of what a typical user might expect from the Oehler unit outdoors in ambient light conditions.

The thinking behind including all these units was multi-fold. First, to see the effects of screen spacing (12 foot vs. 4 foot) for two units which use artificial lighting, and second, to see the effect of artificial lighting vs. natural light for two units having the same screen spacing (4 feet).

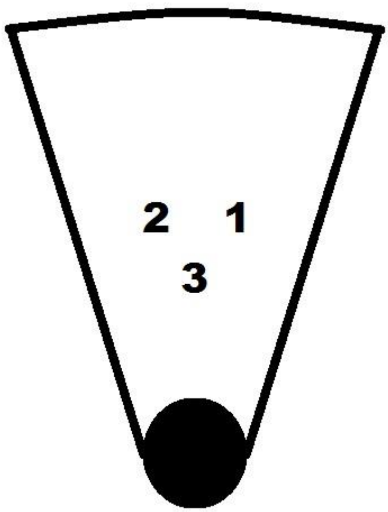


Figure 15.12. Groups were fired thru 3 different parts of the screens to see if the chronograph would read them differently

Procedure

The testing was conducted in the following way. First, a group of 10 shots was fired with the .30 caliber rifle and the reading from each chronograph was recorded. Then the rifle was repositioned 1 inch to the left, and another group of 10 shots was fired. Then, the rifle was placed between the first and second positions and lowered 1 inch and another group of 10 shots was fired.

The purpose for moving the rifle around is to detect any difference in measured velocity due to where the bullet passes thru the screens (see Figure 15.12). If a chronograph has optical sensors projecting in planes which are not parallel, it will show up as a difference in the average error between the 3 groups. For example, if the average velocity error is the same between groups 1 and 2, but different for group 3, that indicates sensors which are misaligned vertically meaning the bottom of the window has a different spacing than the top.

Finally, the 22 caliber rifle (223 Remington) was set up and a single string of 10 shots was fired. The purpose of shooting the smaller caliber rifle was to see if the measurement error was affected by the smaller faster bullet.

Presentation of Results - Important!

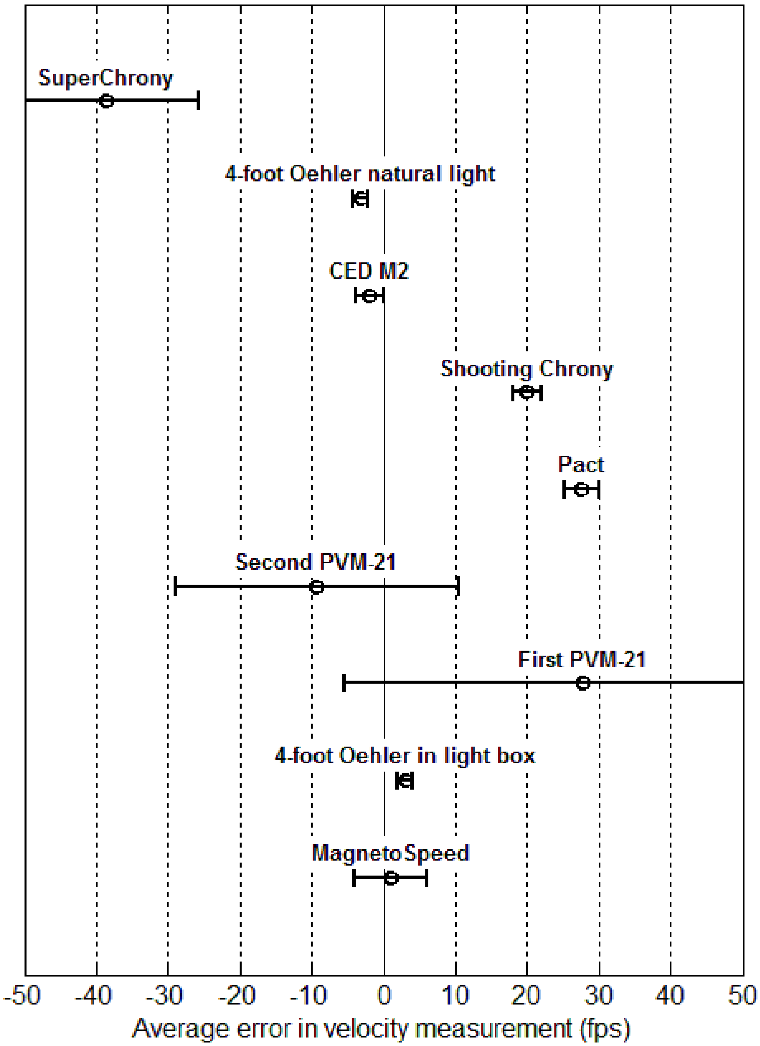
The results will be presented for each 10 shot group. The important metrics we're looking at are related to the error in measured velocity. In the following plots, the average error is indicated by a black circle for each chronograph, and the error bars represent +/- 1 standard deviation. For us as shooters, what this means is:

- The closer the black circle is to the *zero error* line, the better the chronograph is at finding the true average velocity for a string of shots. This is most important when entering muzzle velocity into a ballistics program.
- The narrower the error bands are, the better the chronograph is at determining the consistency of muzzle velocity. This is most important when doing load development where you don't necessarily need to know the actual velocity, but you care about the extreme spread or standard deviation of velocity.

Of course the best chronograph is one which is both accurate and precise, which is indicated by a black circle close to zero error which also has narrow error bars.

For practical use, the standard deviation in the error would add (RSS) to the standard deviation in actual velocity spread as follows. Suppose you fire a string of shots that has an actual standard deviation of 10 fps, but your chronograph has a standard deviation of 5 fps in its ability to measure velocity. This would result in an instrumental SD of: $\sqrt{10^2 + 5^2} = 11.2\,fps$. In other words, your string of shots which actually had an SD of 10 fps would show up as having an SD of 11.2 fps due to the error in the chronograph. This example isn't so alarming, but what if your chronograph actually has an SD of 15 fps and the SD of your shots is only actually 5 fps? In this case, you would see an SD of $\sqrt{5^2 + 15^2} = 15.8\,fps$ even though your ammo only has an SD of 5 fps.

Error Analysis for the First String of 30 Caliber Shots



Chronograph	Average error	Standard Deviation
MagnetoSpeed	1.0 fps	5 fps
4’ Oehler in light box	3.0 fps	1 fps
First PVM-21	27.7 fps	33.2 fps
Second PVM-21	-9.3 fps	19.7 fps
Pact	27.6 fps	2.4 fps
Shooting Chrony	20 fps	2.0 fps
CED M2	-1.9 fps	2.0 fps
4’ Oehler natural light	-3.2 fps	1.0 fps
SuperChrono	-38.6 fps	13.0 fps

Figure 15.13. Accuracy and precision results for all chronographs.

The point here is to elaborate on the meaning of the error bars and to understand how the standard deviation of your instrumental error impacts the effectiveness of your chronograph. If you're a careful handloader who's trying to make the most consistent ammo but no matter what you do you can't get your SD below 7 or 8 fps, it might be because your chronograph has close to 7 or 8 fps SD on its own. In other words, you could be making *perfectly consistent* ammo with zero SD, but the measured SD will only be as good as the combined SD of the ammo and chronograph. In fact I know many handloaders who have suffered thru this lesson the hard way.

Figure 15.13 shows the results for the first string of 10 shots fired thru the high right position of the screens.

The MagnetoSpeed has a very low average error of 1.0 fps, but a standard deviation of 5 fps. Something I've noticed about the SD with the MagnetoSpeed is that the closer you mount the sensor to the centerline of the bore, the more precise the measurements will be (meaning lower SD). The MagnetoSpeed comes with a spacer that you're supposed to use to determine the mounting height of the sensor. The testing I'm reporting on here was done with the sensor mounted in the recommended position, however I've seen better (lower) SD's for the MagnetoSpeed when mounting it higher, meaning closer to the path of the bullet. The accuracy doesn't seem to be affected, but SD can be reduced by mounting the sensors closer to the bore than recommended. Be careful if you decide to mount the sensor closer to the muzzle! If you get too close and the strapping comes loose even a little, you can easily make shrapnel out of the $350 instrument.

Figure 15.14. Groups

The 4 foot Oehler in the light box has an average error of 3 fps, and an SD of only 1 fps. This indicates that the *accuracy* is more affected than *precision* by the 12' vs. 4' separation of the light screens than the precision is for Oehlers set up with artificial light. Nevertheless, a 3 fps error in average velocity is negligible in all but the most demanding applications.

The two PVM-21 units functioned very poorly in terms of both accuracy and precision. In fact, this is the reason why I have two of these units. After purchasing the first one and using it for a while, I started noticing strange results. In an attempt to sort out the issue, I purchased another unit and made the tandem mount shown in Figure

15.5. Much to my disappointment, the two units disagreed on the velocity of shots by a great deal. They were included in this test to compare performance with other commercially available models. As you can see, the average error spans from +27.7 fps to -9.3 fps, and the SD is 33.2 fps and 19.7 fps which is borderline useless for anything a shooter would want to do. This is a surprising result considering that this is the most expensive chronograph tested.

Next is the Pact Professional XP Chronograph. This is a good example of a chronograph that's got good precision, but poor accuracy. The SD of this unit is only 2.4 fps, however the average corrected velocity is 27.6 fps too high. This chronograph would be good for load development where you're looking at velocity consistency, but not so good for determining the average muzzle velocity for a ballistics program.

It's a similar story with the Shooting Chrony: 20 fps error in the measured average, but only 2.0 fps SD.

The CED M2 chronograph produced both; high accuracy and high precision, averaging only 1.9 fps low, and having an SD of 2.0 fps. We'll see how this result holds for the rest of the test, but this is a good indication of the CED M2's performance.

The Oehler 35P mounted on a 4 foot rail in natural light had an average error of -3.2 fps and an SD of 1 fps. Recall that the 4 foot Oehler in the light box had an average error of +3.0 fps and an SD of 1 fps. It seems that this unit is just as capable in natural light conditions as it is in a controlled light box. Note; light conditions on the day of this test were between sunny to mildly overcast. Sunny conditions tend to be harder on chronographs with overcast being ideal.

The SuperChrono was the last unit in the line-up and it turned out to be pretty bad in terms of accuracy and precision. The MagnetoSpeed produced good results over a very short (5 inch) sensor spacing, unfortunately the acoustic microphones were not able to do so well over their short (8 inch) spacing. The average error in measured (corrected) velocity was -38.6 fps, and the SD was 13.0 fps. When it first came out, some shooters (including myself) were optimistic about the possibility of using it to capture velocity downrange in order to measure BC's of bullets. Unfortunately with the poor accuracy and precision performance of the SuperChrono, the results of any BC testing would not be very meaningful.

Now that we've seen the comparative results for all the chronographs, let's move on to the next phase of the test. What happens when you shoot thru different parts of the chronograph screens? On a well designed and manufactured chronograph, the sensor planes should be parallel. If they're not, the bullet might actually travel different distances between the sensors depending on where you shoot thru it. This is most apparent if you measure different average velocities on subsequent trips to the range using the same rifle and ammo. Sometimes there are reasons why the average velocity would actually be different, but sometimes you're just shooting thru a different part of the chronograph. If the sensor planes aren't parallel, this would make it look like your average velocity is different when in fact it's not.

I'm copying Figure 15.12 here so you can see where the groups were shot thru the chronograph screens. The Figure on the following page shows the same accuracy and precision information for all 3 groups which were fired at different places in the window. By shooting 3 groups of shots thru the 3 positions, if the screens are not parallel, it will show up as different average error for the same chronograph. The rifle was re-positioned sideways by lining up the heal of the stock with marks on the bench 1 inch apart and aiming at the same aimpoint 300 yards away. The height of the bore-line was adjusted for the third group by lowering the bi-pod by 1 inch, and the heal of the stock was placed ½ way between the first two points. Note that the vertical and horizontal movements were only 1 inch so the actual range of average error could be greater by shooting thru wider extents of the window. However, given the long line of chronographs lined up with different shaped windows, I couldn't get too close to the edges of any one unit without hitting another one. Also, it's probably not too common for shooters to shoot thru the extreme edges of the windows; most shooters are probably putting their bullets within inches of the center which is the area I tested in.

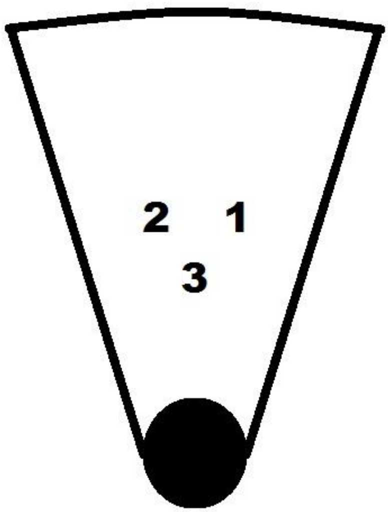
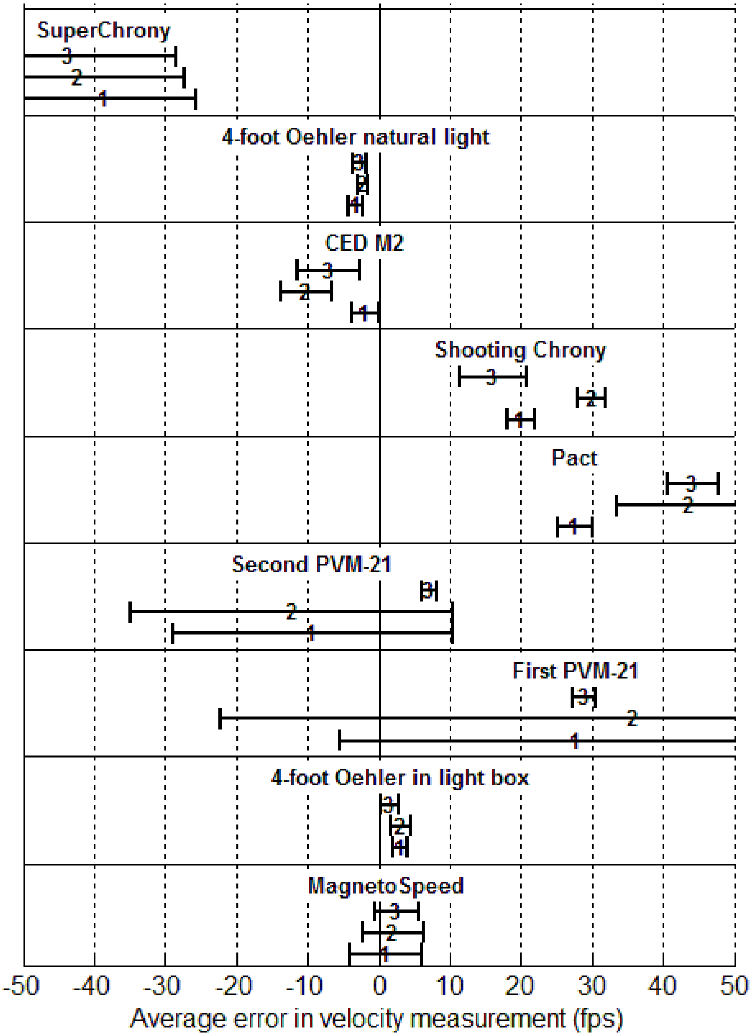


Figure 15.12. Groups were fired thru 3 different parts of the screens to see if the chronograph would read them differently

Figure 15.15 shows the results of all 3 groups of 10 shots fired thru different parts of the screens.

For the MagnetoSpeed, moving the rifle should have no effect since the sensors are mounted to the barrel. However you can see that the average error grows from 1.0 fps, to 2.0 fps, to 2.5 fps as the test progresses. This is not an alarming amount of error, but the consistent trend begs the question *why?* One possibility is that the

Error Analysis for 3 Strings of 30 Caliber Shots



Chronograph	Average error			Standard Deviation		
	1	2	3	1	2	3
MagnetoSpeed	1.0	2.0	2.5	5	4.3	3.1
4’ Oehler in light box	3.0	3.1	1.6	1	1.3	1.2
First PVM-21	27.7	35.9	28.9	33.2	58.1	1.6
Second PVM-21	-9.3	-12.2	7.1	19.7	22.6	1.1
Pact	27.6	43.7	44.2	2.4	10.1	3.5
Shooting Chrony	20.0	30.0	16.1	2.0	2.0	4.7
CED M2	-1.9	-10.2	-7.1	2.0	3.6	4.4
4’ Oehler natural light	-3.2	-2.2	-2.6	1.0	0.7	0.9
SuperChrono	-38.6	-42.2	-43.6	13.0	15.0	15.2

Figure 15.15. Results for all 3 rifle positions.

mounting strap worked loose and the unit was allowed to rotate slightly out of alignment as the test progressed. Having the sensor come increasingly out of alignment would decrease the effective sensor spacing, thereby indicating slightly faster speeds which is what we see in the results, so that's a plausible explanation. The SD of the Magnetospeed error diminishes from 5.0 fps to 3.1 fps over the test and I don't have any explanation as to why.

The 4 foot Oehler in the light box saw a small shift in average error from 3.0 fps and 3.1 fps at the first and second positions down to 1.6 fps in the third position. This suggests that the plane of the screens might be closer to the correct length near the bottom (where the third group was fired) than at the top where the first two groups were fired. To put this into perspective, a difference in average error of 1.5 fps over 4 feet indicates a difference in effective sensor spacing of about 0.025" between the top groups and the bottom group. It's this kind of minor alignment errors which are always present to some degree in every optical chronograph, the only question is how severe is the misalignment. The sure fire way to minimize error due to this misalignment is to *space the screens as far apart as you can*. Of course this is only possible with chronographs that provide for mounting to various length rails such as the Oehler.

We see an interesting occurrence with the PVM-21 units. For the third group, the SD on both units shrank dramatically. This is possibly due to the shot group dropping into a sweet spot within the optical sensor plane. You can see in the raw data at the end of this chapter that the enormous SD's seen in groups 1 and 2 with the PVM-21's is largely due to the extreme error in a single shot of the string, which has a huge effect on the SD. It wasn't always the same shot which was read incorrectly by each unit. This seems like something that has a rational explanation but I don't know what it is. I do know that this kind of error can play havoc on analysis in the real world when you only have one unit and you're trying to decide if it's lying to you or not.

The PVM-21's have an adjustable gain which you have to set based on caliber. The gain was adjusted to the proper level for .30 caliber during these tests. The units were also running on AC power (not batteries) and the shots were going thru near the center of the windows (not close to the edges). Whatever the problem was with repeatability in groups 1 and 2 wasn't there in group 3 for either unit. Putting the precision of the PVM-21's aside for a moment, even when the SD was decent on group 3, the averages were still pretty far off; 28.9 fps and 7.1 fps. Based on this performance, it's difficult to have confidence in this unit.

An interesting thing happened with the light which I think affected the performance of the Pact unit. The rail which supported all the chronographs extended from inside the lab to outside. The Pact was near the thresh-hold where the sun was casting a shadow. During the first string, the sun was at an angle which had both the skyscreens of the Pact unit in the shade. As the test went on, the sun came around and began to shine on one of the screens while the other screen remained in the shade. *Uneven lighting of chronograph screens is a known issue in causing inaccurate readings for optical chronographs*. The transition of light conditions for the Pact in the second group correlates to the highest SD (10.1 fps) in measured error for the Pact. By the time the sun had completely settled over the one light diffuser in the third group, the SD of the Pact unit dropped down to 3.5 fps, which is similar to the 2.4 fps it had prior to the sun coming over one of the sensors.

The Pact saw its average error grow from 27.6 fps in the first group to 43.7 fps and 44.2 fps in the second and third groups. If it weren't for the uneven lighting on the screens, we might be able to infer something about the misalignment of the screens. However in this case the poor lighting conditions raises questions about the cause of the shift in average error.

Figure 15.16. Uneven lighting of light diffusers is trouble for optical chronographs.

Although the situation with the light was unfortunate in the sense that it prevented a fair assessment of the Pact unit, it did provide a valuable opportunity to see the damaging effects of transient light conditions on the performance of optical chronographs. Remember this the next time you think about setting your chronograph up under moving clouds, trees or anything that casts shadows and maybe moves with the wind!

The shooting Chrony was safe from the light conditions, but there was still some measurable difference in error depending on where the shots passed thru its window. The average error seems to be similar for groups 1 and 3 (20.0 fps and 16.1 fps), but grows to 30 fps for group 2. Based on the location of the groups, this suggests that maybe the screens have some combination of vertical and horizontal misalignment going on. The SD of error for the Chrony was actually quite good at 2.0 fps for groups 1 and 2, and climbing to 4.7 fps for group 3. Although I wouldn't count on the *average velocity* reported by a Shooting Chrony based on these results, I might consider it useful for measuring the *consistency* of ammunition, provided I'm not looking to resolve SD's below 5 fps.

The average error for the CED M2 chronograph shows a clear trend in relation to the horizontal location of shots across its sensor window. Starting at the furthest right position (group 1) the average error was only -1.9 fps which is very good. However, the next group to the left (group 3) had an average error of -7.1 fps, a difference of 5.2 fps. The group that was furthest to the left was group 2, and the average error for that group was -10.2 fps. The obvious trend of error getting worse as you move across the shooting window is a clear indication of non-parallel screens. I suspect the flimsy hinged aluminum rail is to blame for this. It's also possible that the rail is fine, but the sensors are poorly aligned internally. Either way, *the average velocity measurement of the CED M2 unit is noticeably different based on where you shoot thru the screens*. Bad as this might sound, the worse case scenario in this test was only -10.1 fps average error. That's good enough to put you within a click at 1000 yards on most trajectory predictions which is not bad at all. The obvious sensitivity to where you shoot thru the window surfaced during the testing, but keep that in perspective when considering your intended use. I wouldn't use a CED M2 to make serious BC measurements, but its fine for shooters to measure their average velocity for practical purposes.

The SD for the CED M2 grew from 2.0 fps, to 3.6 fps to 4.4 fps in order of firing. This doesn't correlate to the shot placement thru the window, and the unit wasn't affected by light conditions either. The CED M2 was given a fresh battery at the beginning of the test (as were all the battery powered chronographs in this test). The only explanation I can think of for why the SD would have grown is wind. When the testing started in the morning, the conditions were calm; not a breath of wind. Several hours into the testing as the day went on the wind began to pick up a little. It never got too high, I would estimate it at 2 to 4 mph. However even these small gusts were visibly moving the skyscreens on some of the chronographs. This movement puts torsion on the structure which bends the sensor planes. As you know by this point, it doesn't take much flexing at all to cause a noticeable error in velocity measurement. Given the nature of wind, it makes sense that this kind of dynamic influence on the frames of the chronographs would lead to their measurements being less *precise* (higher SD's) even if the average velocity (*accuracy*) is not affected much. That's exactly what we see for the CED M2; the SD rises as the wind picks up. The Shooting Chrony also had its highest SD for the last group. As noted the Pact was affected by the light which at least influenced, if not overwhelmed its SD.

The last optical chronograph on the test rail was the Oehler 35P in it's *out of the box* configuration, meaning a 4 foot rail and natural light. The performance of this chronograph was exceptional both in terms of accuracy and precision. The error for all 3 shot locations ranged from -2.2 fps to -3.6 fps, a span of only 1.4 fps. Based on the systematic growth in error from left to right (groups 2, 3, and 1), we might conclude that there is some slight lateral misalignment in the sensors. Even if this is so, the error remains small enough for almost any purpose over the full range.

Precision is also remarkably good with SD's of: 1.0 fps, 0.7 fps and 0.9 fps. In fact, this was the highest precision chronograph tested. It was only second in accuracy by a fraction of a fps compared to the 4 foot Oehler in the artificial light box. This came as a surprise to me, as I expected the light box unit to perform better than the version operating in natural light, but that was not the case.

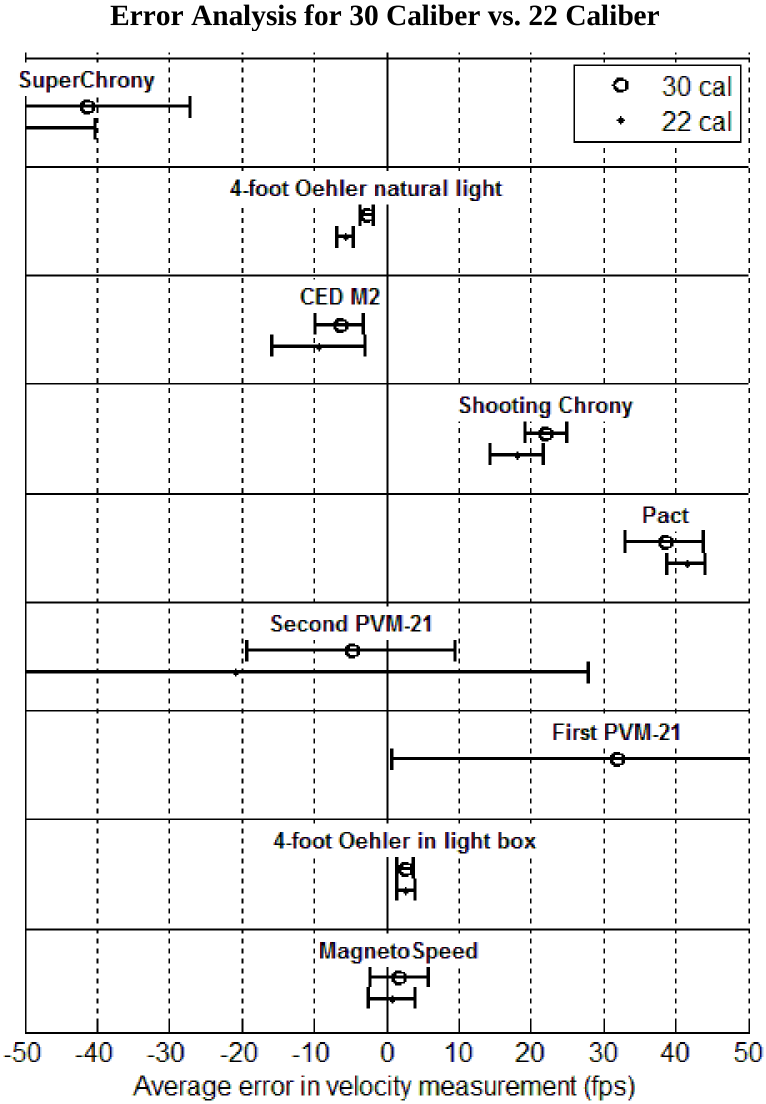
Another strength of the Oehler unit is that its precision (SD) wasn't affected by the wind like the CED M2 was. I attribute this to the stout hardware and the stiffness of the ½" steel conduit. Even though the skyscreens may be shifting in the wind a little, the movement doesn't translate to sensor deflection, at least not according to the test results.

Finally we have the SuperChrono. Like any other chronograph, the SuperChrono has to be mounted very carefully to insure alignment with the bullet path. Considering the short length of the unit, this can be a difficult task. To allow for precise alignment, and to prevent shadowing the acoustic sensors with nearby obstructions, the SuperChrono was placed on an independent tripod downrange from the mounting jig used to support all the other chronographs.

Despite the efforts to put the SuperChrono in optimal working conditions, both the accuracy and precision performance were poor. The average error (inaccuracy) for the 3 groups was -38.6 fps, -42.2 fps, and -43.6 fps. The SD for the 3 groups was 13.0 fps, 15.0 fps, and 15.2 fps. Although the acoustic sensors provide a number of advantages in the set up and use of this device, unfortunately the lack of accuracy and precision render it useless for use in long range shooting. The short 5 inch sensor spacing seems to work well for the MagnetoSpeed which uses electromagnetic sensors. However the acoustic sensors spaced by 8 inches on the SuperChrono are unable to provide practical velocity measurements.

Now that we've looked at 3 groups fired thru different parts of the windows with the .30 caliber bullets, let's see how the different chronographs do with smaller faster bullets; 62 grain FMJ's from a .223 Remington.

Only 1 group of 10 shots was fired from the .223 Remington thru the center of the screens. To compare the two calibers, I'll show the average error and SD for all 30 caliber groups compared to the average and SD for the one 22 caliber group. This will be a



Chronograph	Average		Standard Deviation	
	30 cal	22 cal	30 cal	22 cal
MagnetoSpeed	1.8	0.8	4.1	3.2
4’ Oehler in light box	2.6	2.7	1.2	1.3
First PVM-21	30.8	78.9	31.0	16.1
Second PVM-21	-4.8	-20.9	14.5	48.9
Pact	38.5	41.5	5.3	2.6
Shooting Chrony	22.0	18.1	2.9	3.6
CED M2	-6.4	-9.3	3.3	6.4
4’ Oehler natural light	-2.7	-5.7	0.9	1.1
SuperChrono	-41.5	-54.9	14.4	14.7

Figure 15.17. 30 caliber vs. 22 caliber results.

good indication of the difference in accuracy and precision for 30 caliber vs. 22 caliber.

Figure 15.17 shows the results of the comparison. Starting with the MagnetoSpeed, you can see that the average and SD are both slightly better for the 22 compared to the 30 caliber. My guess for explaining this is that when the MagnetoSpeed was re-mounted to the barrel of the 223 Remington, it was better aligned with the bore line and that's why it produced slightly better results. If you remember, there was a systematic *slipping* in the numbers as the 30 caliber test went on, possibly due to the MagnetoSpeed coming slightly out of alignment. Also the recoil effects of the 223 were much less than the 308, which may have allowed the device to stay in place better, hence the better performance for 22 caliber. To keep things in perspective, *the MagnetoSpeed demonstrated exceptional accuracy for both calibers, and above average precision (meaning low SD) for both calibers as well*.

Moving on to the 4 foot Oehler in the light box, there was barely any difference in the accuracy or precision for this unit going from 30 caliber to 22 caliber. Accuracy was 2.6 fps vs. 2.7 fps, and the SD (precision) was 1.2 fps vs. 1.3 fps. For all practical purposes, this set-up is not affected by caliber at all.

When rifles were changed to 22 caliber, the gain was adjusted on the PVM-21's to the proper level for 22 caliber. However these units displayed even worse performance for the smaller caliber. The first unit was inaccurate by 78.9 fps (off the scale in the plot). Strangely the SD was better than the average for 30 caliber, but still poor at 16.1 fps. The second PVM-21 was inaccurate by -20.9 fps, and had a standard deviation of 48.9 fps. This was the worse SD measured for any unit under any condition.

The Pact unit had about the same inaccuracy, on the order of 40 fps for both 30 caliber and 22 caliber. However the SD was lower for 22 caliber than 30 caliber (2.6 fps vs. 5.3 fps). The light transition that occurred during the 30 caliber test was the likely cause behind the higher SD's.

The average error for the Shooting Chrony was similar for both calibers; 18.1 fps for the 22 caliber vs. 22.0 fps for the 30 caliber groups. However, the precision (SD) was slightly worse for the 22 caliber at 3.6 fps vs. the 2.9 fps SD we saw for the 30 caliber. Regardless of this slight increase in SD, it's still quite good and very useful for detecting velocity spreads in a group of shots.

The CED M2 had a little more error for the 22 caliber bullets compared to the 30 caliber bullets: -9.3 fps for 22 caliber vs. -6.4 fps for 30 caliber. Knowing the sensitivity of the CED M2 to shot placement thru the screen, it's possible that this was the cause of the inaccuracy as opposed to the smaller caliber bullet. The CED M2 measured a higher SD for the 22 caliber bullets, but again, this might not have been due to the smaller caliber bullets, but possibly related to the wind. If you look at the progression of SD's for the CED M2, the first 3 groups fired with 30 caliber had SD's of: 2.0 fps, 3.6 fps, and 4.4 fps. The last group fired was the 22 caliber group and had an SD of 6.4. I strongly suspect that this increasing progression of SD's measured for the CED M2 unit was influenced by the wind, as it is the *flimsiest* unit that was tested, and would be most affected by windy conditions flexing its rail and sensors. There could also be an element of *small bullet* effect going on which increased the SD beyond what was measured for 30 caliber in addition to wind effects. In order to truly separate the two effects (wind and small caliber) the test would have to be repeated in calm conditions. We do know just from the 3 groups of 30 caliber shots that the SD increased proportionally with wind speed so we know that wind can cause precision issues for this unit. If I could suggest an improvement to the design, it would be to use a stiffer rail, possibly a solid steel rail vs. a folding aluminum rail. The stiffer rail should make the precision of the unit less susceptible to wind effects.

The 4 foot Oehler 35P mounted in natural light appears to have its accuracy affected by the smaller bullet. The average error for all 30 caliber groups was -2.7 fps, and it was -5.7 fps for 22 caliber. Although this error is still acceptable for most applications, it does seem like the small bullet affected this *natural light* set-up more than the artificial light set-up was affected. The SD of the natural light set-up was 1.1 fps for 22 caliber vs. 0.9 fps for 30 caliber. Although we see a higher SD for the smaller bullet, the instrument is still producing very precise measurements.

The average error in the SuperChrono grew from -41.5 fps for 30 caliber to -54.9 fps for 22 caliber. The cause of the increase in average error is not known; possibly it has something to do with the difference in volume between the two calibers. Interestingly, the SD was nearly the same for 30 caliber vs. 22 caliber; 14.4 fps vs. 14.7 fps.

Caveats to the Test Results

One thing that's important to remember about this type of testing is that you're only seeing a limited sampling of a particular chronograph. In other words, the performance we measured for the Shooting Chrony (for example) only applies to that specific Shooting Chrony. A different Shooting Chrony won't necessarily have the same performance; it could be better or worse. In order to truly test the inherent performance of a certain chronograph, many units of the same model would have to be tested in order to truly characterize the performance of a given chronograph. The testing I conducted, although it might seem extensive, was actually just a cursory look at chronograph performance.

Another caveat has to do with the selection of a control standard. In this case, I chose to use the Oehler 35P mounted on a 12 foot rail and supplied with a constant artificial light source. This unit was chosen due to the inherent accuracy of longer screen spacing. Just because these attributes suggest it's the most accurate unit doesn't guarantee that it's *perfectly* accurate. In any test where you're looking at the performance of measurement instruments, the questions of calibration and control standards are important to consider. At some point you have to declare some measurement as accurate, and define error in relation to it. If the chosen control standard is not accurate, it's usually evident as biased or skewed results. For example, if the control standard produced measurements that were inaccurate by 15 fps (for example), then we would expect to see an average error of 15 fps in all the other chronographs. Although some of the units did have error in relation to the standard, the average error was not skewed in one direction or the other. This is a good indication that the control standard was likely accurate.

Furthermore, if the control standard were imprecise, meaning it had a high SD in its measurements, then it would not be likely that any of the test units would have low error in comparison. In fact, several of the units produced SD's below 3 fps, with the lowest being 0.9 fps. This simply wouldn't be possible (or it would be highly unlikely) if the control standard had a significant random error in its measurements. The point of this caveat is that this test was not an absolute and direct measurement of the accuracy and precision of various units, but it's likely that the results are very close to reality.

Trends in the Results and Chapter Summary

After doing a test like this and seeing all the results, I always want to know what the major points are to take away. Were there any underlying principles discovered or verified? What key facts can we use to guide our understanding and decisions? Sometimes these things boil down to statements like: *you get what you pay for*. However, in the case of chronographs, I think we discovered a different underlying principal.

Let's consider the accuracy and precision of the various units tested as a function of sensor spacing. For this analysis, only the optical units will be considered because the acoustic and electromagnetic based units are fundamentally different and wouldn't be expected to follow the same trend.

Based on the results in Figure 15.17 (30 cal ave vs. 22 cal ave), we can make the following statements about units with a sensor spacing of at least 24 inches:

- Average error never exceeded +/- 10.2 fps under any circumstance.
- Average SD was 2.4 fps

Based on the same results, we can say the following about chronographs that have screen spacing of less than 24 inches:

- Average error was *never* within +/- 10 fps, but ranged from -12.9 fps to +54.9 fps.
- Average SD was 15.6 fps. However, if you don't include the PVM-21 units, the average SD for the Shooting Chrony and Pact was 3.6 fps.

From these facts, we can make the following statements about optical chronographs:

If a chronograph has a sensor spacing of at least 24 inches, then it's likely to produce acceptable (+/-10 fps) accuracy. If the screen spacing is smaller than 24 inches, it's **not** ***likely to produce acceptable accuracy.***

And:

Chronographs with small sensor spacings (less than 24 inches) <u>**can**</u> ***produce acceptable precision (SD's under 5 fps).***

Remember that the first statement above about accuracy is related to predicting accurate trajectories based on your true average muzzle velocity. The second statement about precision (SD) is more related to load development or verifying the consistency of ammunition.

So if you're purpose for owning a chronograph is to use it for load development and you don't really care about knowing your true average velocity, then one of the smaller units like a Pact or Shooting Chrony could serve you well, but don't count on it to give you an accurate average muzzle velocity. If you truly want to measure an accurate *average* muzzle velocity, then you need a chronograph with sensor spacing of at least 24 inches.

Unlike the specific results associated with individual units, the above statements can be applied more generally to chronographs based on screen spacing.

The performance of the non-optical sensor based units (acoustic and electromagnetic) varied greatly. Whereas the SuperChrony displayed poor performance with acoustic sensors spaced at 8 inches, the MagnetoSpeed did very well with its electromagnetic sensors spaced at only 5 inches.

Recommendations

Based on the test results and trends, I would say the Oehler 35P is hard to beat in terms of its accuracy, precision, and price. It's not the easiest to set up, but for serious ballistic measurements, it's hard to beat for accuracy and precision which improves with the length of mounting rail you choose.

The MagnetoSpeed takes the prize for the *modern advancement* in chronograph technology. The instrument isn't necessarily *more accurate* than the older Oehler units, but the use of electromagnetic sensors provides comparable accuracy and precision in a very different package which is easier to use. The accuracy and precision performance of the MagnetoSpeed combined with its ease of set-up and use are good examples of modern technology being put to good use in ballistics instrumentation. The MagnetoSpeed is gaining popularity in many applications including military snipers who need a small instrument they can deploy with and check velocities of different lots of issued ammo without setting up large instruments. The potential effect on barrel harmonics was a big concern of mine initially, but it just hasn't been a real issue for the kinds of rifles and testing I've done with it.

The CED M2 can be considered the best value if price is a concern. At only $200US, this unit provides accuracy and precision which is adequate for all practical purposes. I wouldn't use it for serious ballistics analysis, but for developing loads and getting on target, it's a good value for the money. Investing in a solid rail could be an easy upgrade to improve the performance of the CED M2.

The Shooting Chrony and Pact had similar performance; acceptable precision (ability to measure SD), but poor accuracy. I attribute the difference in cost ($200 USD for the Pact vs. $100 USD for the Shooting Chrony) mainly to the differences in features which are unrelated to accuracy and precision.

Unfortunately I cannot recommend the PVM-21 chronograph based on the erratic performance of the two units that I tested. The extreme errors in both accuracy and precision might suggest improper use, but every effort was made to provide optimal working conditions (direct AC power, properly adjusted gain, careful alignment, solid support, etc.) and the results were still poor.

The SuperChrono is another newer unit which I cannot recommend for any kind of velocity measurements. I think if a larger version of the acoustic sensor chronograph was produced, for example at least 4 feet long, it might be better able to make accurate velocity measurements. However, in its current form, the SuperChrono is not recommended.

Raw Test Data

The following tables show the raw, instrumental velocity measurements which were recorded for each chronograph. The results presented in this chapter all came from processing this data as follows:

1) The raw (instrumental) velocities were corrected for the bullets velocity decay as it traveled between the various chronographs using the center of the 12 foot Oehler as the zero distance point.
2) Each of the *corrected* velocities were compared to the velocity measured by the 12 foot Oehler and the errors tabulated.
3) The average and standard deviation of these tabulated errors is what was reported in this chapter as accuracy and precision.

Table 15.1 shows the relative distance from the center of each chronograph to the baseline (center of 12 foot Oehler).

Chronograph	**Distance from baseline**
MagnetoSpeed	-14 feet
4’ Oehler in light box	8.75 feet
First PVM-21	12 feet
Second PVM-21	13.5 feet
Pact	16 feet
Shooting Chrony	18.25 feet
CED M2	21 feet
4’ Oehler natural light	24.75 feet
SuperChrono	32 feet

Table 15.1. Distance from each chronograph to the baseline

The velocity decay of the 30 caliber bullets used for this test was 0.87 fps/foot, and for the 22 caliber bullets the decay rate was 1.08 fps/foot. For example, suppose the instrumental velocity for the Pact was 2750 fps for one of the 30 caliber shots. Since the Pact was 16 feet downrange from the baseline measurement, and the 30 caliber bullet loses 0.87 fps/foot, the *corrected* velocity would be 2750 + 16 (foot)*0.87 (fps/foot) = 2764 fps. This is the value that would be compared to the baseline measurement to determine error.

The following tables present the raw measured data. Combined with the velocity decay rates for both calibers and distances for each chronograph from the baseline, you should be able to re-create the entire error analysis.

In order to fit all the raw data in the tables, the names of the chronographs are represented with letters A thru I as follows:

A = MagnetoSpeed
B = 12 foot Oehler
C = 4 foot Oehler in light box
D = First PVM-21
E = Second PVM-21
F = Pact Professional XP
G = Shooting Chrony
H = CED M2
I = 4 foot Oehler in natural light
J = SuperChrony

30 caliber group #1 raw measurements

	A	B	C	D	E	F	G	H	I	J
1	2862	2850	2847	2878	2836	2865	2852	2834	2826	2788
2	2804	2797	2791	2823	2782	2815	2800	2778	2772	2736
3	2855	2844	2838	2871	2830	2857	2850	2825	2820	2801
4	2865	2849	2844	2879	2832	2861	2850	2829	2823	2769
5	2891	2871	2866	2794	2854	2881	2878	2850	2846	2785
6	2866	2857	2853	2887	2780	2871	2862	2837	2833	2791
7	2862	2843	2838	2870	2828	2854	2848	2823	2818	2769
8	2849	2836	2832	2866	2822	2850	2841	2815	2813	2759
9	2885	2867	2863	2894	2855	2881	2869	2846	2843	2808
10	2826	2820	2816	2845	2805	2836	2826	2796	2794	2765
Ave	2856.5	2843.4	2838.8	2860.7	2822.4	2857.1	2847.6	2823.3	2818.8	2777.1
SD	25.8	21.9	22.3	31.2	26.2	20.3	22.1	22.2	22.2	21.6

Table 15.2.

30 caliber group #2 raw measurements

	A	B	C	D	E	F	G	H	I	J
1	2821	2810	2804	2843	2792	2814	2825	2789	2787	2746
2	2855	2840	2836	2983	2819	2874	2854	2814	2816	2782
3	2868	2855	2852	2882	2767	2889	2871	2826	2831	2801
4	2903	2882	2879	2908	2868	2912	2893	2853	2859	2811
5	2858	2849	2846	2876	2834	2893	2860	2817	2826	2782
6	2893	2874	2870	2895	2859	2907	2889	2844	2851	2782
7	2876	2863	2858	2760	2847	2893	2880	2833	2840	2769
8	2875	2866	2860	2893	2850	2898	2880	2832	2842	2811
9	2850	2838	2833	2862	2822	2868	2854	2812	2814	2778
10	2885	2866	2860	2896	2846	2893	2879	2839	2841	2782
Ave	2868.4	2854.3	2849.8	2879.8	2830.4	2884.1	2868.5	2825.9	2830.7	2784.4
SD	23.7	21.0	21.4	55.9	31.3	28.0	20.5	18.5	21.0	19.6

Table 15.3.

30 caliber group #3 raw measurements

	A	B	C	D	E	F	G	H	I	J
1	2896	2875	2868	2891	2869	2908	2886	2855	2851	2795
2	2862	2852	2845	2871	2847	2888	2854	2827	2828	2769
3	2900	2888	2881	2906	2882	2922	2888	2863	2862	2831
4	2880	2867	2863	2883	2863	2897	2869	2835	2844	2821
5	2858	2844	2840	2863	2840	2877	2845	2811	2821	2791
6	2886	2871	2865	2891	2867	2900	2873	2851	2847	2805
7	2866	2852	2847	2873	2846	2880	2848	2829	2828	2765
8	2910	2892	2885	2911	2889	2920	2891	2867	2868	2801
9	2883	2867	2860	2885	2863	2893	2861	2844	2842	2791
10	2888	2875	2869	2894	2871	2901	2871	2848	2852	2801
Ave	2882.9	2868.3	2862.3	2886.8	2863.7	2898.6	2868.6	2843	2844.3	2797.0
SD	16.9	15.5	14.9	15.1	15.7	15.1	16.5	17.5	15.2	20.3

Table 15.4.

22 caliber raw measurements

	A	B	C	D	E	F	G	H	I	J
1	3207	3195	3189	3248	3178	3222	3191	3169	3162	3113
2	3278	3264	3256	3326	3090	3291	3261	3236	3233	3188
3	3240	3227	3221	3295	3207	3250	3227	3203	3195	3136
4	3274	3256	3250	3303	3242	3280	3253	3231	3223	3179
5	3253	3238	3232	3322	3220	3263	3235	3210	3207	3159
6	3287	3268	3262	3336	3246	3289	3272	3229	3235	3166
7	3253	3233	3224	----	3201	3253	3237	3195	3199	3159
8	3274	3262	3256	3360	3243	3288	3256	3222	3230	3143
9	3261	3244	3238	3301	3223	3271	3238	3210	3212	3149
10	3300	3280	3271	3336	3262	3302	3280	3242	3246	3179
Ave	3262.7	3246.7	3239.9	3314.1	3211.2	3270.9	3245.0	3214.7	3214.2	3157.1
SD	26.4	24.8	24.4	32.2	49.3	24.2	25.5	22.1	24.7	22.7

Table 15.5.

To read more about the live fire ballistic testing being done in the Applied Ballistics Lab, look up: *Modern Advancements in Long Range Shooting*. You can learn more about this book here: https://store.appliedballisticsllc.com/ProductDetails.asp?ProductCode=0004