Scope Calibration

A Description of the Problem

The typical response to the question, "Have you calibrated your scope?" is a blank stare; most shooters do not know about scope calibration. This article will explain who should be concerned about scope calibration, why they should be concerned, and how to perform the calibration. At the conclusion of this article you should be able to perform a calibration, understand what you are doing, why you are doing it, and see the beneficial results.

First, let's identify the type of scope this article does not apply to: it does not apply to scopes that have friction adjustable turrets. These turrets are designed to set a specific zero and then to be left alone. They are not precision instruments and are not designed to be adjusted for varying ranges on the fly. They generally are found on hunting rifles where shots will not exceed 250 yards; they are generally set up with a "point blank" zero which will involve an actual zero at around 220 yards which will suffice for all shot taken at ranges between zero yards to about 250 yards and can be counted on to put all rounds within a six to 8-inch circle within those range brackets. Those scopes do not need and will not benefit from calibration.

This article, then, is written for shooters who use a precision type scope to shoot beyond normal hunting distances and whose scopes are the "clickable" type, typically having 1/4 MOA or 0.1 Mil per click. Owners of these scopes are expected to dial elevations for longer shots and to return to a zero position reliably and accurately. Now that we have defined our audience for this article, let us proceed to explain the concept.

Let's say you, the shooter, religiously keep a log book and record the temperature, pressure, wind values, and resulting points of impact over a variety of ranges. For 1000 yards on a standard sea-level day let's say that your log book says that in days past you have recorded that it takes 40.75 MOA of elevation to hit point of aim. Now, as a sophisticated shooter you know that MOA means "Minute of Angle" and that when you dial to 40.75 on the scope you are elevating the muzzle of your rifle to an angle equal to 40.75 minutes of angle (about 2/3s of on degree) above the barrel's zero position to launch the projectile such that it arcs into the target right at the point that the vertical plane of the target intersects your line of sight to the target. Question: how do you know it takes 40.75 MOA to hit the target at 1000 yards? The only way you know this fact is that the scope tells you so. The rifle scope is, in essence, a highly refined protractor helping you raise the barrel of your rifle a specific angle. The interesting thing here is that when you record that angle, you do not know for certain that the rifle was raised to 40.75 minutes; you only know that the scope has reported to you that it moved the reticle down 40.75 minutes causing you to raise the barrel that same angular amount. So the real question is this: How do you know the scope is telling you the truth? The only way you know that is because you dialed the elevation turret 40.75 minutes by turning the knob 163 clicks and at 1/4 MOA per click, which equals 40.75 minutes. The truth is, however, that you rely upon the accuracy of the turret; you assume that each and every click is, in fact, equal to 0.250 MOA. If it is, then you have indeed dialed 40.75 minutes. But what if each click is only 0.248 MOA per click? Or, 0.252 MOA per click? If the former is true, then each time you dial up the turret, each click is giving you slightly less than a whole quarter minute of elevation. If the latter, then each click is moving the reticle slightly more than the expected 1/4 minute. So if each click is only 0.248 MOA/click, after 163 clicks you have only dialed 40.42 MOA; alternatively, if the click value as 0.252, you actually dialed 41.08 MOA. In either case, this tiny click value error of less that 1% results in a 1/4 MOA error in what was actually dialed.

You may respond, “So what? For that rifle and scope, I dial 40.75 MOA and hit point of aim. I don’t care what I actually dialed. I know the scope setting for 1000 yards and I know it under a range of temperatures and pressures. I don’t care what the actual elevation is.” And that is a fair observation. But what if you replace your scope? Unless the new scope has exactly the same erroneous click value, which is highly unlikely, your log book data will no longer be accurate or reliable. Or, what if you start using a ballistic computer? The computer will hopefully give you a mathematically correct elevation but when you dial it on a scope with an errant click value, you will not be dialing the computed solution, you will be dialing something else. You will be low or high and you won’t know what the problem is. You will assume that the program is at fault when it actually is your scope.

You may retort that errant click values are rare in high quality scopes. Unfortunately this is not correct. Errant click values can and do occur in scopes of every manufacture. And these errors are not consistent in a given line or model of scope for a given manufacture. Two shooters having the same scope, i.e., the same model and same manufacture, can have different click values. This is not a criticism of the scope manufacturers; this is simply a reflection of the fact that scopes are high precision mechanical devices that magnify the smallest of internal differences in tolerances as variations in click value at range. It would be a miracle to see precision rifle scopes coming off an assembly line each having the same identical click value day in and day out. They don’t and until scopes use a HUD display controlled electronically, probably never will.

So you should accept the fact that it is probable that your scope has a click value slightly different from that printed on the turret. But there is a work-around. If we can determine the actual click value, we can convert any calculated elevation into a corresponding turret solution for that scope. Assuming the values above, if we needed to dial 40.75 MOA with a turret that has click values of 0.248 we would dial 164 clicks which would equal 41 MOA on the scope’s turret. That would correctly implement a 40.75 MOA elevation. You may now be thinking, "But why go through the bother? It's only a 1/4 MOA difference and at 1000 yards we are off by 2.5 inches. Big deal." And you would be right; it probably isn't worth the trouble. But what if you are shooting 1500 yards? Or a mile? That little less than 1% error begins to translate into a significant POI error at long range targets. Even tiny click errors become significant impact errors given enough range. And what if the click error was not a number less than 1%? What if the error was 2% or 3%? At three percent, these errors start to show up at ranges of only 300 yards and at 1000 yards are quite noticeable. In fact, at 3% the scope is probably defective by definition and needs to be returned to the manufacturer for repair or replacement. But how would you ever know that there was a problem unless you checked?

Before we get into how to determine the scope's click value, let me discuss a couple of other reasons to go through the exercise. Let's say you have a Mil scope with Mil turrets, 9 Mil per turn. You perform a scope calibration for the first 5 Mils and determine that the click values are right on, 0.1 Mil per click. Are you done? No, you are not. You need to check the entire turn, the full 9 Mils. In fact, if you are able, you should probably check two full turns, 18 Mils. Why? Sometimes the scope is defective and it will show a *changing* click value as you move through the rotation. And sometimes, although not often, the change in click value does not show up until after the first turn is completed. While an errant click value can be managed, it is manageable only if the click value is **consistent** throughout the entire range of the reticle movement. If the click value *changes* at some point, the scope truly is defective and must be returned to the manufacturer for repair. It is not possible to deal with varying click values as you cannot compute any reliable come-ups with such a scope. It is completely worthless as a precision instrument. But, again, how would you know how the scope tracks insofar as its click value is concerned unless you check?

Also, there is value in determining a scope's click value in order to monitor the overall health of the scope over time and use. Let's assume that you perform a calibration on one of your scopes and the calibration shows the scope has a click value exactly as it should, 0.25 MOA per click. You use the scope a lot for competition for the ensuing year and in preparation for the next year's competition schedule you quickly run it through a calibration just to check its health and find that the click value has changed to 0.249. It is not a big deal - or is it? Is there wear going on that accounts for the change in click value? Is your scope in the process of deteriorating such that during an important match it becomes erratic or fails? Or does the change in click value suggest that perhaps a screw is loose on the scope rail? Maybe one of the rings has loosened slightly and requires a re-torque. The problem could be simple or serious but you would never have discovered the potential problem except for the calibration process.

I hope I've convinced you that scope calibration is an absolute requirement for the any shooter who is trying to hit targets beyond 500 meters and is a good thing to do even for those who shoot short ranges if for no other reason than just to check on the overall health of the scope. It is a way to establish a baseline of operation for the scope and that is good for future reference.

How to Calibrate Your Scope
The process is not very difficult but does require precision in the various measurements.

First: create a chart of some kind, something that is around a foot wide and 72 inches high. There is nothing magical about these dimensions; you merely want something that you can use to track the reticle movement from the top of the chart down a significant distance. Make hash marks at regular intervals from top to bottom; these marks must thick enough to be visible through the scope at our measurement range, typically 100 yards/meters.

Alternatively, create the same foot wide, 72 inch high target but place 1 inch tape down the middle from top to bottom and place an aiming point at the very bottom. Or, do both: make a chart with hash marks and place the tape strip down the center and an aiming dot at the bottom.

Second: place the chart at around 100 yards. I say "around" not to imply that the distance can be approximate, but rather to signify that few ranges have surveyed distances from bench to target face and as long as the range is "around 100 yards or 100 meters" it will do. Place the chart at the target end of the range and take a little time to ensure that it is vertical particularly if you have the tape strip running down the middle. Make sure that tape strip is exactly vertical.

Third: back at the shooting bench, set up your rifle. Measure the distance between the face of the chart and the turret section of your scope. This distance must be very precise, the more precise the better but in no event more than plus/minus one foot. If the best you can do is plus/minus a yard, you really cannot perform the calibration because an accurate distance from the reticle to the target face is critical to a precise calculation. The difference between using 100 yards and 101 yards is enough to change the resulting click value computation. Some people use a steel tape; some use a laser range finder that can has an accuracy of plus/minus 1 foot; some actually survey the distance, set up markers, and create a permanent calibration space. Whatever method you use, it must give you the distance that is correct within 99.6% of actual. For purposes of our example here, we are going to assume that the range distance is 101.5 yards.

Fourth: now we are going to measure the distance the reticle travels over the face of the chart. If you are a good shooter with a rifle that can clover leaf shots, then you can start by setting the scope at a 100 yard/meter zero and take a shot at the bottom aiming dot - just to make sure the rifle is zeroed correctly. Assuming you have center punched the aiming dot, dial the turret up 3 Mils (10 MOA) and fire a couple of shots while insuring your rifle is level with an anti-cant device. Dial up a second 3 Mil (10 MOA) and repeat. Do this until you have dialed through at least one rotation of the elevation and if you have room on the chart continue until you are close to the top. (When you are finished you should see all of the rounds march straight up the tape. If you don't, then you have a scope leveling problem and are introducing a windage factor where none exists due to a canted scope. Re-level the scope and perform this exercise again.) For our example, we are assuming that we have moved up 192 clicks (48 MOA) for our MOA scope and 139 clicks (13.9 Mil) for our Mil scope.

If you do not plan to shoot this process, you will use the chart itself to measure the amount of reticle travel. First place the rifle in some sort of firmly held vice or sand bagged position where dialing the scope will not disturb the rifle itself. You will dial to the scope's zero or close thereto and place the horizontal reticle element right on the top hash mark on the chart. Make note of the turret setting. Then begin to dial the turret up 3 Mils (10 MOA) at a time. You will see the reticle move downward in the scope as you do this. At each interval, note where on the chart the reticle is. Be precise with this; we are going to measure each of the distances with a tape measure to the nearest 1/8th of an inch after we have gathered the data, so be a careful and as precise as you can be in noting where the reticle is on the chart for each interval the reticle is moved.

Fifth: at this point, the data gathering is done. Bring the chart back to the shooting bench and for those that measured the reticle movement on the chart, take a tape measure and measure the distances from the top of the chart to each interval. Make pencil hash marks for each place the reticle landed as you moved through each interval and note not only the total increasing distance each point was from the beginning point, but make note of the distance between each interval. If the turret is uniform in its click value, then the distances between each interval will be the same over the whole distance measured. Record the total distance covered from the top of the chart to the last hash mark on the chart.

For those who shot the chart, do the same measurements and record the distance from the bottom aiming point to each group and measure the distances between each group.

Six: now we calculate the click value based upon the actual reticle movement across the face of the chart. There are three things we need to know: 1) the precise range from turret to chart face (range), in our case 101.5 yards; 2) the distance from the top (or bottom) of the chart to the last hash mark (or bullet group) at the bottom (or top) (this we will call the "chart distance"); and, the number of turret clicks it took to cover that distance (clicks).

First we compute the included angle that we have moved the reticle over the chart. You'll need a calculator to do this (and set it to "Degrees" as opposed to "Radians".) We take the Arctangent of the opposite divided by the adjacent sides of the triangle formed by the range from turret to chart as the adjacent side and the chart distance as the opposite side. The Arctangent will give us the included angle traversed by the reticle from the start of the measurement to the last measurement, i.e., the chart distance.

Included angle = Arctan (chart distance / range)

Important: the chart distance and range must be in the same units so if you are measuring the chart distance in inches, then the range must also be in inches; if in centimeters, then the range is in centimeters. For example, if the chart distance was 51 inches and the range between the turret and chart was 101.5 yards, that would be 101.5 yds * 36 in/yd and would equal 3654 inches. So the angle traversed during the data gathering from the first data point to the last is:

angle in degrees = Arctan (51 / 3654)
= Arctan (0.0139573071)
= 0.799642865 degrees

In other words, at 101.5 yards, that 51 inches represents 0.7996 degrees that the reticle has moved from top to bottom. But an angle in whole degrees doesn't do us much good. We need that angle in terms of MOA or Mils (depending upon how our scope measures angles.) So now we convert that angle into an MOA or Mil value:

MOA = angle in degrees * 60 minutes/degree
= 0.799642865 * 60
= 47.9785719 MOA

or

Mil = angle in degrees * 17.45329252 Mil/degree
= 0.799642865 * 17.45329252
= 13.9564008 Mils

What this means is that the vertical distance of 51 inches at the 101.5 yards is 47.9785719 MOA or 13.9564008 Mils. Knowing what the chart distance is in MOA or Mils allows us to figure out the click value of our scope since we know how many clicks it took to cover that distance on the chart. So now we simply divide by the number of turret clicks it took to traverse that number of Mils or MOA:

MOA/click = 47.9785719 MOA / 192 clicks
= 0.249888395
≈ 0.25 MOA/click

Mil/click = 13.95640083 Mils / 139 clicks
= 0.100405761 Mils/click
≈ 0.100 Mils/click

We round off to the nearest thousandth because there is little point in calculating the result beyond that given the fact that our measurement from turret to chart face was only plus or minus 1 foot. But try the calculations for yourself to see if a plus or minus 1 yard precision would be sufficient. I think you will find that the results will change if the range is 99 yards or 100 yards or 101 yards. But plus or minus a foot seems practical in terms of precision. If you can get a more precise measurement than that, by all means do so.

At this point we have calculated the click value for a substantial range of reticle movement over the chart. And if the distances between each segment of the movement are essentially equal, then we are finished because that shows a consistent click value. However, if there are significant variations between the segments, it may mean that the click value changes as the turret is rotated. You should spend a few extra minutes to calculate the click value for a few of these segments to see if the click values change significantly and if they do, then you should be on the phone with the manufacturer to discuss having the scope repaired. However, if you see a result that looks out of place or singularly bad, do not hesitate to repeat the measurements. We are dealing here with the need for very accurate measurements so if something looks out of place it very well may be the result of an inaccurate measurement.