Stress Caused by Differential Thermal Expansion

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Introduction

As a rifle warms in firing, parts which had been stress-free when assembled at room temperature can become significantly stressed due to ***differential thermal expansion***. Here we will examine a "worst case" example of this problem that is unfortunately becoming more commonplace—the extremely rigid mounting of a large aluminum-bodied tactical scope onto a carbon-steel receiver. While a minor version of this problem has always been with us, the new popularity of reasonably priced, ultra-rigid "tactical scope mounts" has exacerbated the problem of differential thermal expansion of the aluminum scope body with respect to the steel receiver. The hunting-type and ultra-light target-type scope mounts that we formerly used would allow these thermal stresses to dissipate through slippage and flexing. We also outline a specific retro-fit modification for certain existing rear scope rings that we believe could eliminate this problem without creating others. This un-tested modification may not be feasible, but it is presented to give suitable ideas to any designers who care to try it.

The Physics of the Problem

As a rifle is fired, the temperature of the barrel increases due to the excess heat energy released in burning the powder and due to friction between the bullet and the barrel. The barrel then gradually warms the action and the remainder of the rifle. Depending upon the type of metal from which it was made, each component of the rifle tries to ***expand*** in length, in area, and in volume at its own rate as it warms up. [Later, of course, each part also ***contracts*** at its same rate as it cools back down.] The rate of expansion per degree of temperature increase is specified as the ***coefficient of thermal expansion*** **(C)** for each different material. For example, the coefficient of linear (lengthwise) expansion for a stainless steel barrel is **5.5** millionths of an inch (micro-inches) per inch of barrel length per Fahrenheit degree of temperature increase. *Even the empty bore of the barrel expands in all dimensions as the barrel warms up, just as if it were made of barrel steel and it were maintained at the barrel's core temperature!* The corresponding length expansion rate for a high-strength aluminum alloy scope tube is **13.0** micro-inches per inch per Fahrenheit degree. And the value of the thermal expansion coefficient (**C**) for a chrome-moly steel receiver is **6.3** parts per million per degree. Notice that these thermal expansion coefficients are formulated as ***linear strain rates*** for each material as it undergoes a specific amount of change in temperature. The thermal expansions per unit ***area*** and per unit ***volume*** are **twice** and **three times** these linear expansion rates, respectively.

One type of ***differential thermal expansion*** occurs when two parts, made of different materials having *different thermal expansion coefficients* and rigidly attached to each other at two or more well-separated locations, undergo a gradual change in temperature together. A second type of differential expansion happens when two rigidly attached parts (or even two different regions of the same rigid part), having non-zero coefficients of thermal expansion, are temporarily at *different temperatures* from each other. This second type of differential thermal expansion is what causes so much trouble whenever a part is subjected to a *large temperature gradient* as frequently happens due to cooling the part too rapidly. On the other hand, any assemblage of materials having *either matching or near zero* thermal expansion coefficients can undergo gradual temperature changes together *without* suffering differential thermal expansion.

An Example of the Problem

Now, let us look at a simple example of ***thermal stress*** caused by the first type of differential thermal expansion and attributable to a reasonable temperature excursion that might happen in gradual fashion to any typical target rifle. Say we have attached an expensive aluminum-bodied tactical scope in stout four-screw steel rings, lapped into even contact and mounted on two-piece 20 MOA angled steel bases, attached with two 8-40 socket-head capscrews each to the front and rear rings of my target rifle's chrome-moly steel receiver. We mounted the scope in an air-conditioned shop in the morning at an ambient temperature of 70 degrees Fahrenheit. Then, while firing the newly-scoped rifle on an outdoor range that afternoon, we notice that the rifle has stabilized at 120 degrees Fahrenheit as it sits in the summer sun after a few shots.

If these stout scope rings and bases *do not slip*, how much compression force might be applied to the body of the scope between the rings due to this gradual 50-Fahrenheit-degree temperature rise for both the scope body and the receiver? We can estimate the *maximum possible* axial compression force (**F**) on the scope body in this example from:

$$\mathbf{F = E\ A\ (C1 - C2)(T - T0)}$$

$$\mathbf{= 502\ pounds} \qquad \mathbf{[Wow!]}$$

where

E = Young's Modulus for the aluminum alloy scope tube
= **10,600,000 PSI**
A = Cross-Sectional Area of scope tube material (30mm OD; 28mm ID),
[**A** = **0.1412 square inches**]
C1 = Thermal Expansion Coefficient for the aluminum alloy scope tube
= **13.0 per million per Fahrenheit degree**
C2 = Thermal Expansion Coefficient for the chrome-moly steel receiver

= **6.3 per million per Fahrenheit degree**

T = Current Temperature of the rifle parts

= **120 degrees Fahrenheit**

T0 = Initial Temperature when the parts were joined

= **70 degrees Fahrenheit**.

The above formulation treats the scope rings as "rigid clamps," and ignores the stretching and bending of the stronger steel receiver and any slippage or distortion of the scope rings and bases. This potential force of **502 pounds** would not only compress the weaker scope tube between the rings (which would ***bend the scope body*** and change where it looks), but this force would also ***bend my receiver*** (which would change where the barrel points) by acting through the **2-inch** lever arms of the scope rings and mounts. Admittedly, both the scope bending and barrel pointing errors are in the same general direction (downward, and slightly to the left for the barrel in a right-handed action), but I would not want to count on them always having equal effects.

The next time the rifle is fired, the typical **500 to 700 pounds** of peak recoil force on the scope mounts divided equally between the two scope bases, would briefly *cancel out* most of this **502-pound** thermal expansion force on the rear ring, while, ***almost doubling the momentary shearing and tensile stresses on the front base-mounting screws*** at this elevated temperature. And the scoped target rifle certainly could be subjected to *even larger temperature excursions*.

Possible solutions to the Problem

Now, if *one ring or base* is allowed to *slide freely*, this same **50-degree** temperature increase produces a *differential length expansion* (**dL**) between the scope rings, separated by an initial free length **L** (**5.31 inches**) that can be calculated as:

$$dL = L\,(C1 - C2)(T - T0)$$

$$= 0.0018 \text{ inches.}$$

One way to avoid this problem of stress caused by differential thermal expansion would be to devise a ***rear scope ring or base*** attachment system that is designed to ***slip freely*** in a fore-and-aft direction, by at least **0.005-inch** each way, while still precisely controlling the lateral and vertical locations of the scope tube with respect to the receiver. [See below.] There are several "good design" reasons why we prefer the scope to slip freely in the rear ring instead of in the front ring. One good reason behind this design choice would be to utilize the recoil moment from the scope, acting directly on the front ring of the receiver, to counter some of the recoil moment from the stock being transferred to the front ring via the recoil lug. This design should reduce the magnitude of the vertical plane transverse barrel vibrations that affect bullet impact points so much. Note that if we had used a *one-piece scope base* instead of these two-piece bases, we would simply have to concern ourselves with two other pair-wise combinations of differential thermal expansions (scope-versus-base and base-versus-receiver). This fundamental problem of differential thermal stress build-up can be controlled ***only*** by careful mechanical design and by choosing materials (ideally having *small* thermal coefficients) to be paired together that are *at least close to matching* in thermal characteristics because the various rifle components will be constantly changing temperature in use.

A Specific Retro-Fit Design Solution

The example rifle in the above calculations is meant to represent a typical "tactical-style target rifle" of the sort used in the increasingly popular "sniper matches." We discuss this type of rifle here because it probably has just about a ***worst-case problem*** with ***differential thermal expansion***. We are likely using a large and expensive riflescope having a **30 millimeter** (or larger) body-diameter and made of a high-strength aluminum alloy having a coefficient of thermal expansion of **13 parts per million per degree Fahrenheit** as mentioned earlier. The scope mounting rings and bases (either one-piece or two-piece) are likely to be quite stout and made of a heat-treated alloy steel having a typical thermal expansion coefficient of **6.3 parts per million**, and are probably attached using oversize **8-40 capscrews** to a rifle receiver made of chrome-moly steel having a similar expansion coefficient. [If the bases were mounted with the supplied **6-48 screws**, go back and replace them with the stronger **8-40 capscrews**.] If a *one-piece base* was selected, it should be *bedded to the receiver* so that the screws can be tightened securely without imposing any bending stress on the receiver. Whether, or not, the bases are angled down at the front by 20MOA (more or less) does not matter much at this point in the installation. For **0-degree-slope** two-piece bases, we recommend shimming the rear to the height of the front base and using a clamping jig to align the rear base with the front while the locking compound sets up. Two-piece, machined **20MOA bases** do not usually need shimming, but should still be clamped into angular alignment. Now permanently install the scope base(s) using a thread-locking compound and trial-install the rings. Once rings of the correct height for this application have been found, install them at the optimum locations on the bases and mark these locations. Also mark the rings, including their caps, so that they can always be re-installed exactly the same way. If everything is straight and true, the scope's internal windage adjustments will be nearly centered after bore-sighting.

Here is where we begin to deviate from conventional "best practice" scope installation. If you are installing typical horizontally-split, heavy-duty 4-screw steel rings (with at least **0.095-inch** minimum section thickness everywhere around the walls of the rear scope ring), fasten the two bottom ring-halves into place correctly and start "lapping them in" with a suitable abrasive and lapping bar. After you can verify that the rings and bases are basically mounted straight, remove the abrasive from the rear ring and the matching portion of the lapping tool, and replace it with ordinary grease. Thereafter, just concentrate on *lapping the front ring* into alignment with the rear one. When the lapping of the bottom part of the front ring is completed and all abrasive and grease have been removed, dismount the *rear ring* and lightly install its cap. Measure the ***vertical inside diameter*** and subtract this distance from the ***scope tube diameter***. This difference is the ***shim thickness*** that you need to install in the gap on ***each side*** of the horizontally split rear ring. You do not need to be too exact here if you err a little on the "too thick" side for the shims. Install these shims and torque down the four ring screws.

Now, you need to make or adapt a simple face-clamping fixture for use in the 4-jaw chuck of your lathe so that you can bore out the inside diameter of the rear ring to **0.040-inch** oversize ***in diameter*** (to **1.040-inch** for **1-inch** scopes and **1.221-inch** for **30mm** rings). Most of the suitable rear rings can be face-clamped for this non-critical boring operation in the same fixture used for boring-out the recoil lug. Greg Tannell (GTR Tooling, a ***PS*** advertiser) sells the one we use and it works well. Place the mounting foot of the bottom part of the ring up against the shank of a clamping bolt, the better to resist the forces of boring, and center-up the bottom half of the hole in the ring with the axis of the lathe. While the ring is still set-up in your fixture after boring, change to an *inside grooving tool* and cut a **0.095-inch wide,** square-bottom groove **0.065-inch deep** right in the *middle* of the ring. Obtain some (Aerospace Standard) **AS568A-121** *neoprene* **O-rings** for 30mm scopes, and perhaps some **-119 O-rings** for 1.0-inch scopes; or some **3/32-inch** neoprene O-ring cord material. Now, disassemble the ring and press one of the **0.103-inch** *sectional diameter* O-rings into the groove in the bottom part of the rear ring. Slice off the O-ring even with the tops of the ring splits, and repeat that procedure putting the cut off piece of O-ring into the top portion of the scope ring. We are finally ready to assemble the rear ring permanently onto the scope. Just remember to install your spacing shims in each side of the rear ring and to torque down its ring screws tightly using a thread-locking compound. The above dimensions should cause the O-ring material to be compressed into a *rectangular cross-sectional shape* with a radial thickness of about **0.085-inch**:

$$(\mathrm{Pi}/4)(0.103\text{-inch})^2 / 0.095\text{-inch} = 0.088\text{-inch}$$

If you vary from the **0.020-inch** recommended radial clearance in boring out the ring, then adjust the **0.065-inch** groove depth accordingly. The scope tube should now slide stiffly through the rear ring, but still be positively located into alignment with the front ring as long as the "hard-mount" up front does not cause too much side force in the "soft-mount" rear ring.

Burris Signature Z-Rings, with their plastic spherical inserts, are probably the easiest commonly used rings to modify for providing the needed rear ring slippage. After proper mounting, one needs only to add **0.020-inch *shims*** to each side of the rear ring—even if ***offset*** spherical insert pairs have been employed as a "poor man's way" of obtaining a **20MOA** scope mounting. ***Talley's*** integrated-ring-and-base scope mounts are also suitable for this modification, having been manufactured from (barely) thick-enough, high-strength aluminum alloy and requiring a shim thickness of only **0.020-inch,** as well. Most other Picatinny-base or Weaver-base strongly-made, aluminum alloy rings are suitable for this modification, but some are not—due to thin ring-wall sections or some design weirdness. The proprietary direct-mount ring systems (Ruger, CZ, etc.) are mostly ***unsuitable*** for this modification, being made of thinly sculpted steel. And the old windage-adjustable "turn-in" scope bases already provide all of the rear-ring slippage we might ever need to handle thermal stresses. Manufacturers of scope mounting systems could easily beef-up their front rings and bases, while incorporating a designed-in O-ring for scope slippage fore-and-aft within the rear ring.

Summary

Differential thermal expansion is a real physical phenomenon. We can continue ignoring it, but it will not go away as long as our rifles continue to warm up in firing. The O-ring modification discussed here is un-tested, and is presented simply to get designers and manufacturers thinking of similar solutions. Builders of these types of "tactical rifles" need to decide for themselves whether, or not, to tackle the problem of differential thermal expansion between the scope and the receiver or to continue passing on the problem to their customers.