Superior Shooting Systems Inc.

SSSinc.

FEBRUARY 2012

AN ANALYSIS OF THE EFFECT FIRING PIN SYSTEM PERFORMANCE HAS ON RIFLE ACCURACY, INCLUDING REDUCING LOCK-TIME AND IMPROVING IGNITION CHARACTERISTICS

FIRING PIN IMPACT STUDIES

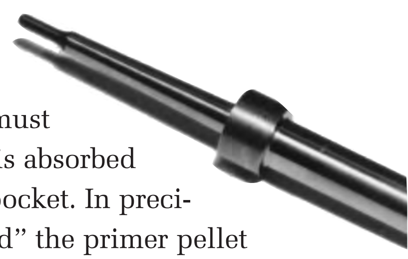
ARTICLE

AN ARTICLE BY JAMES A. BOATRIGHT

TERMS TO KNOW:
LOCK-TIME: Time elapsed between the trigger release and firing pin impact with the primer.

INTRODUCTION

The impact delivered *by the tip of the rifle's firing pin to crush the primer pellet against its anvil is critical to the repeatable accuracy of a target rifle.*



For best accuracy the tip of the firing pin should be coaxial with the primer pocket. Coaxial alignment promotes consistent primer ignition by crushing each primer pellet against its anvil in the same way in each firing. The primer must be fully seated into its pocket so that no variable amount of the striking energy is absorbed simply in completing the seating of the primer all the way to the bottom of its pocket. In precision cartridge preparation for benchrest competition, most competitors "pre-load" the primer pellet by fully seating each primer *by feel* and then carefully using their "calibrated thumb" to add a consistent amount of extra seating force to slightly compress the anvil. Neither "constant force" seating nor "constant depth" seating can be optimal for all primers. As a prerequisite for consistent primer ignition, the headspace of the cartridge fit within the chamber of the rifle must also be held consistently to a minimum clearance. The firing pin must deliver the correct amount of kinetic energy very repeatably to the primer pellet under all firing conditions in order to produce consistent rifle accuracy.

As Maj. Gen. J.S. Hatcher reported in *Hatcher's Notebook,* Stackpole, 1947; page 394; all samples of military 30-caliber (large rifle) primers must fire when a kinetic energy (**KE**) of **60 inch-ounces** is properly delivered to them during lot acceptance testing, and none should fire with **12 inch-ounces** of similar one-time impact. He specified that a ball weighing **4.0** ounces be dropped onto proper firing pins from heights of 15 inches and 3 inches, respectively, to generate these amounts of kinetic energy for these primer tests.

Arguably the best of the military bolt-actions of Hatcher's day, the Mauser Model 1898, utilized a mainspring with about a **17-pound average force** over about **0.5-inch of firing pin travel** to generate about **130 inch-ounces** of **KE** with about **1.4 ounce-seconds of impact momentum**. With a **3.0-ounce** striker assembly weight, this reliable military rifle action required about **5 milliseconds of lock time**.

*Current U.S. Army sensitivity requirements are **48 inch-ounces** for small-rifle primers and **64 inch-ounces** for large-rifle primers.*

These Mauser data values and the later military primer sensitivity data in the quotation are from

ARTICLE COPYRIGHT © 2012 DAVID TUBB AND SUPERIOR SHOOTING SYSTEMS INC.

Stuart Otteson's wonderful book, *The Bolt Action (Volume I)*, 1976, now published by Wolfe Publishing of Prescott, Arizona.

Modern hunting-style bolt actions utilize higher-speed strikers and are expected consistently to deliver about 100 inch-ounces to the primers used in current sporting ammunition with a lock time of about 3 milliseconds. Modern commercial large-rifle primers probably should all fire with a single strike of at least 75 inch-ounces of impact energy even under *severely cold* conditions, but some might also fire with as little as 12 inch-ounces of impact in more ideal conditions since sporting ammunition is not required to withstand the rigors of rough military handling. Application of more than 150 inch-ounces of **KE** to any rifle primer would probably be excessive and counterproductive to best accuracy. Pistol primers are much more sensitive and are designed to operate properly at significantly lower levels of striking energy. Interestingly, according to M. L. McPherson, laboratory technicians firing "standard receivers" fitted to pressure barrels have noted that modern primers do produce slightly more chemical energy (with corresponding measured increases in chamber pressure and muzzle velocity) when they are struck with slightly more than the "standard" amount of **KE**.

Shown is a complete ***SpeedLock Systems*** striker assembly for a Remington 700 designed by David Tubb and produced by Superior Shooting Systems Inc.

It utilizes alloy construction and a Chrome Silicon (CS) spring to dramatically reduce lock-time, and improve ignition.

[All speedLock pins feature a steel tip for durability]

MECHANICAL ANALYSIS

This mechanical analysis is generally applicable to rotating-hammer-fired guns, as well as to the linear striker-fired systems discussed here as an example. Just substitute moment of inertia about the axis of the hammer pin for the mass of the striker assembly, torques for linear forces, and angular for linear positions and rates. At this basic level of analysis, there is also no inherent difference between hammer-fired

ARTICLE COPYRIGHT © 2012 DAVID TUBB AND SUPERIOR SHOOTING SYSTEMS INC.

designs in which the hammer nose carries the firing pin or those designs in which the hammer strikes a separate firing pin to ignite the primer.

Neglecting friction losses (which should be practically negligible for linear strikers), the available potential energy (**PE**) stored in the cocked striker spring is just the cocking force **f(s)** integrated, or mathematically summed, over the total cocking displacement **s**. By Hooke's Law for elastic spring deformations, the restoring force **f(s)** of the compressed mainspring is a linear function of the spring compression distance **s** given by:

$$f(s) = k*s$$

where **k** is the spring constant in pounds of spring force per inch of spring compression, and the displacement **s** in inches equals **0.0** at the current relaxed length of the spring. To avoid a proliferation of “minus” signs, we are here defining the spring compression force **f(s)** and its movable-end displacement s to be measured as positive in opposite directions.

The potential energy **PE** stored in the striker spring as the cocking piece is retracted from **point a** (the fired position) to **point b** (the cocked condition), through the cocking distance **S = b–a**, is the definite integral of this cocking force function **f(s)** over the compression distance variable s from position a (the “installed” position) to position b (the “cocked” position):

$$PE = {}_a\int^b f(s)\,ds$$

$$PE = k*{}_a\int^b s\,ds$$

$$PE = k*(b2 - a2)/2$$

$$PE = [k*(b + a)/2]*(b - a)$$

$$PE = F * S$$

where **F** = Average Cocking Force = [f(b) + f(a)]/2 = k*(b + a)/2

or **PE** = (Average Cocking Force)*(Cocking Distance).

When the mainspring is compressed to its cocked position (at **s = b**), it must still be short of being compressed all the way “solid” to its “coil bound” condition. However, this “solid” position is an important design consideration because in most modern rifle bolts this is how and where the rearward travel of the firing pin is halted when a ruptured primer allows high-pressure gas to flow back through the firing pin hole. After sear break (and still neglecting friction), the *total kinetic energy* **KE** imparted to the striker during its fall is:

$$KE = (1/2)*m*V2$$

where **m** is the effective mass of the striker and **V** is the terminal velocity of the striker.

However, the spring-driven striker, starting from rest would accelerate its effective mass **m** to the same terminal velocity **V** whether:

1. The driving force *varies linearly* from **f(b)** to **f(a)**, as is ideally the physical situation here with our mainspring obeying *Hooke’s Law,* **or**

ARTICLE COPYRIGHT © 2012 DAVID TUBB AND SUPERIOR SHOOTING SYSTEMS INC.

2. The driving force is modeled as *constant* at its *average* force **F** over the distance **S = b – a**.

Note that in general this equivalence only occurs with driving forces that vary linearly with displacement, as with *Hooke's Law.*

That is, the integrals of the areas (or the recovered mechanical energy values) under the two force-versus-distance curves have the *same values* (as illustrated just above for storing the energy). For mathematical tractability, we shall formulate the equivalent terminal **KE** of the striker in terms of the optional *constant average cocking force* **F**. This *constant force* **F** is the average of the cocked **f(b)** and un-cocked **f(a)** spring forces, as if it were unvaryingly applied to the striker as a constant driving force during the fall of the firing pin. The *distance-average* for this linearly varying cocking *force* **F** is then the *arithmetic* mean of the two end-point values for this *Hookean compression force* **f(s)**:

F = [f(b) + f(a)]/2 = k*(b + a)/2

Recalling Newton's *Second Law of Motion* in the form:

F = m*A

then **A = F/m =** *Average* acceleration of the striker assembly here.

From physics, we know that the *terminal velocity* **V** produced by a *constant acceleration* **A** (as we can now assume here) acting through a *distance* **S** is given by the relationship:

V2 = 2*A*S = 2*(F/m)*S

so that, substituting into our expression for kinetic energy:

KE = (1/2)*m*V2 = (1/2)*m*[2*(F/m)*S] = F*S

or **KE** = (Average Cocking Force)*(Cocking Distance).

So, still neglecting friction, we see that:

KE = PE = F*S

*That is, the **kinetic energy** of the striker assembly upon impact with the primer is determined **only** by the **potential energy** stored in the mainspring during the cocking of the action, and either amount of energy is equal to the product of the **average cocking force F** times the **cocking distance S** for a mainspring operating in accordance with Hooke's Law.*

The *effective mass* **m** of the striker ***does not matter very much*** as far as the conversion of stored **PE** into delivered **KE** is concerned. The *mass* **m** divides out, so it cannot be too nearly zero, or the *average acceleration* **A** and the *terminal velocity* **V** would have to become very large, with larger associated friction losses. In an ideally *Hookean*, lossless (completely friction-free) system, the striker impact **KE** depends only upon the spring constant **k** of the striker spring, its current relaxed length (where **s = 0.0**), its installed length (where **s = a**), and the striker fall distance **(S = b – a)**.

By the way, the analytical approach used here for integrating the *spring force* **f(s)** over the *cocking distance* **S** to find the stored potential energy is at least as good as the approach used by Otteson in the *Appendix* to his book. He used the second time-derivative of the striker position to set up the differential

ARTICLE COPYRIGHT © 2012 DAVID TUBB AND SUPERIOR SHOOTING SYSTEMS INC.

equation of motion for a simple harmonic oscillator (i.e., as for a mass on a spring). While the approach is certainly valid and the solution is well-known, his approach is unnecessarily complicated because the fall of the striker is only a tiny fraction of one half cycle of the free sinusoidal harmonic oscillation.

Consistent primer ignition depends upon reliably striking the primer centrally with a consistent **KE** greater than a threshold value of about **75 inch-ounces** in all firing conditions. Allowing for reasonable worst-case friction losses, something like **24 pounds of compressed spring force** falling through about **0.3 inches** of striker movement should provide plenty of **KE** (up to **115 inch-ounces**) to fire these large rifle primers.

It is *preferable* in a target rifle, without affecting the **KE** transfer from the striker to the primer, to *minimize the* ***momentum transfer*** from the moving striker to the entire cartridge assembly by utilizing a *low-mass* aftermarket striker assembly having about *half* the effective mass of the factory **Remington 700** long-action striker. Otteson reports that careful testing has shown that the "snappier" striker fall of a low-mass striker system results in so much more reliable primer ignition that systems producing lower **KE** could have been used just as successfully. This information suggests that the rating of striker systems and primer sensitivities *based solely upon the kinetic energy delivered by the firing pin* is not entirely adequate. Perhaps the *momentum* of the striker at impact, its *terminal velocity*, or the *impulse* (in both its force and duration aspects) delivered to the primer should also be specified.

With its *impact momentum* **p** reduced by **24-percent**, the low-mass aftermarket striker will not be as likely to set back the case shoulders (thereby increasing the cartridge headspace for rimless-style rifle cartridges that headspace on the annealed brass of their shoulders) or to reseat a jam-seated bullet deeper into the thinned case neck in firing a benchrest competition rifle. The low-mass striker assembly also promotes target accuracy by reducing the excitation of barrel vibrations via reducing the size of the *terminal momentum dump* **p** of the impacting striker. The *lock-time* **T** is also reduced by *30 percent* with this low-mass striker, and that is always an improvement — especially for shooting from any unsupported position.

NUMERICAL EXAMPLE

Page 8 shows a comparison of the physical parameters which might be evaluated in choosing between using a factory **Remington 700** long-action striker system versus using David Tubb's ***SpeedLock*** (from Superior Shooting Systems Inc.) replacement low-mass striker assembly in an "accurized" target rifle.

The included light-weight aftermarket spring is only slightly more forceful at its "cocked" position than is a newly installed factory spring, but it holds its "springiness" much longer in service (over at least 500,000 cycles). The factory spring is significantly weakened by simply installing it and cocking the action for the first time. The relaxed length of a factory spring removed from the action of a new rifle will measure significantly shorter than the length of a never-installed replacement factory spring. The metallurgically superior chrome-silicon steel material of the Tubb spring is of the factory-designed strength when installed and compressed to its "cocked" length — it is not simply a heavier gauge or longer free-length "extra-power" spring. Notice in the table on page 8 that the chrome-silicon Tubb spring is over *20 percent lighter* in weight than the factory Remington spring that it replaces. The spring constant **k** is about *20 percent lower* for the Tubb mainspring than with a similar "music wire" spring made of ordinary carbon "spring" steel, which allows for a spring of much longer "relaxed length" to be used in any given application. This longer relaxed-length spring is cycled over a much smaller fraction of its compression

ARTICLE COPYRIGHT © 2012 DAVID TUBB AND SUPERIOR SHOOTING SYSTEMS INC.

distance during the cocking of the action. In other words, *the spring force is more nearly constant over its cocking cycle in actual use.* Much less "stacking" of the spring force is felt during cocking, thus making for a smoother-feeling bolt operation with less apparent bolt-lift (easier-seeming re-cocking effort). Perhaps a mainspring should be "application rated" based on the average cocking force that is required in that application (which directly defines the amount of potential energy stored in the spring over the required cocking distance as discussed here) rather than based on its "installed," "cocked," or "solid" compression forces as spring makers seem to prefer.

The *striker fall distance* **S** used here is the same 0.275 inches (the total dry-fire distance) in both comparison cases:

S = b – a = 0.275 inches

Initial contact of the firing pin tip with the rear face of the primer cup typically will occur at between 20 and 60 thousandths of an inch less travel than this maximum "dry-fire" distance. This early contact distance increases with greater "maximum firing pin protrusion" through the bolt-face, and decreases both with effective headspace (clearance) and with primer seating depth (below "flush with the case head") of the individual cartridge. Then, somewhere between **15** and **30** thousandths of additional "primer crush" travel of the firing pin seems to be required for consistent ignition of properly seated large rifle primers before the forward motion of the firing pin finally comes to a halt.

The *effective weight* **w** (in grains) of the entire striker assembly is well approximated by combining the *striker weight with one half of the spring weight.* The striker weight itself includes the firing pin, the cocking piece, and the small pin that holds them together. The parts were weighed using a reasonably accurate digital powder scale within its calibrated weighing range. The *effective mass* **m** in slugs of the striker assembly is calculated as its *effective weight* **w** in grains divided by 7000 grains per pound and 32.174 feet per second per second, as the *average effective acceleration of gravity* **g** on the surface of the earth:

m = w/(7000*g)

The two *average spring forces* **F** (in pounds) of the two different striker systems were measured rather crudely by depressing over a bathroom scale each of the two fully complete firing pin assemblies to the point where each bolt shroud reached its estimated mid-cocking position. These *average spring-force values* **F** are thought to be fairly typical for this rifle application, however.

The amount of *potential energy* **PE** (in inch-ounces) stored in the mainspring during cocking and the equal amount of *kinetic energy* **KE** delivered to the primer in firing are calculated from:

PE = KE = F*S

The *average acceleration* **A** of the striker (in feet per second squared) is found from:

A = F/m

An equivalent way of formulating the *average acceleration* **A** (in **g's**, or multiples of 32.174 feet per second squared) is to ratio the *average driving force* **F** (in pounds) with the *effective weight* **w** of the striker (also expressed in pounds):

A = F*7000/w (in g's).

ARTICLE COPYRIGHT © 2012 DAVID TUBB AND SUPERIOR SHOOTING SYSTEMS INC.

The *terminal (or impact) velocity* **V** (in feet per second) is found, with **S** having been converted into feet and with **A** given in feet per second, from the expression:

V2 = 2*A*S

The *lock-time* **T** (in seconds) is found from:

T2 = 2*S/A

The *impact momentum* **p** of the striker (in ounce-seconds) is found (with 16 ounces to the pound) from:

p = m*V

Finally, modeling the striker deceleration as being approximately uniform during the primer impact process, the *time-average impulse force* **Q** (in pounds) acting on the primer for the *time duration* **ΔT** required for the *terminal momentum dump* **p** is calculated as:

Q = p/ΔT

where the time-duration of the primer impact process for the factory Remington striker **ΔT(Rem)** is estimated as:

$\Delta T(Rem) = 2*D_{pr}/[V(Rem)]$

ΔT(Rem) = (0.075 inch)/[(15.0 f/s)*12 in/ft]

ΔT(Rem) = 417 microseconds,

and $\Delta T(Tubb) = 2*D_{pr}/[V(Tubb)]$

ΔT(Tubb) = 0.075 inch/[(21.2 f/s)*12 in/ft]

ΔT(Tubb) = 295 microseconds

where D_{pr} = *Depth of primer penetration* (in feet).

The firing pin assembly first comes to a momentary stop (with **v = 0**) at this *depth* **Dpr** that is observed (post-firing) usually to match approximately the hemispherical tip radius of the firing pin (or half of 0.075 inch, in this case, about 0.0375 inch). The *average velocity* **(V/2)** is used in estimating the *time interval* **(ΔT)** required to halt the forward motion of the firing pin.

SUMMARY

We have presented the basic physics that allows us to calculate the various parameters for choosing optimal hammer and striker firing system components. We have described the important advantages of using a low-mass striker assembly in a target rifle:

1. **Superior primer ignition.**
2. **Reduced lock-time.**
3. **Reduced barrel muzzle vibrations at bullet exit.**
4. **Reduced momentum transfer from the firing pin to the cartridge case.**

ARTICLE COPYRIGHT © 2012 DAVID TUBB AND SUPERIOR SHOOTING SYSTEMS INC.

FIRING PIN IMPACT STUDIES

We also discussed the advantages of changing to a factory-design-weight replacement chrome-silicon mainspring. Finally, we have shown that the kinetic energy delivered to the primer is a function only of the potential energy stored in the mainspring during cocking and is unaffected by reducing the mass of the hammer or striker assembly.

Firing Pin Comparisons	Remington 700 Long-Action	Tubb L/A SpeedLock
Striker Weight (grains)	914.8 grains	468.7 grains
Spring Weight (grains)	203.1 grains	161.6 grains
Effective Weight (w) (grains)	1,016.4 grains	549.5 grains
Average Spring Force (F) (pounds)	22 pounds	24 pounds
Potential Energy (PE) (in.-oz.)	97 inch-ounces	106 inch-ounces
Average Acceleration (A) (g's)	151.5 g's	305.7 g's
Impact Velocity (V) (ft./sec.)	15.0 ft/sec.	21.2 ft/sec.
Lock Time (T) (milliseconds)	3.07 milliseconds	2.16 milliseconds
Impact Momentum (p) (oz.-sec.)	1.083 oz.-seconds	0.828 oz.-seconds
Av. Impulse Force (Q) (pounds)	162 pounds for 417 μsec.	175 lbs. for 295 μsec.

CONTACT INFORMATION
James A. Boatright, Retired Engineer
Technical Website: http://www.**theWellGuidedBullet**.com
E-mail: jim@theWellGuidedBullet.com

ARTICLE COPYRIGHT © 2012 DAVID TUBB AND SUPERIOR SHOOTING SYSTEMS INC.