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ARTICLE FOR "PRODUCT ENGINEERING"

DESIGN OF MODEL 721

In the 1920's, following the first world war, the high power bolt action rifle became popular as a Sporting Rifle. No doubt this was influenced by the close association of our service personnel with the 1903 Springfield and the 1917 Enfield, and as a result of this popularity, Remington introduced a Sporting Bolt Action High Power Rifle based on the 1917 Enfield and designated as the Model 30. In 1940 this rifle was redesigned and improved and called the Model 720. However, the relatively high cost and resultant high selling price limited the volume. Thus the need for a new design.

The objective of good gun design can be condensed to this general statement applicable to many products, "Design for reliability and ease of manufacture with resultant low cost and selling price, while retaining approved features and if possible, introducing new features to improve consumer acceptance." An attempt will be made to show how this statement was applied in the design of the Model 721-722 Remington High Power Bolt Action Rifle, including some of the engineering problems involved.

EASE OF MANUFACTURE AND LOW COST

The bolt action rifle is basically one of the most simple to produce. However, tradition as well as Paul Mauser's M/'98 Action have influenced previous designs to the extent that manufacturing cost was given very little consideration. As an example, the receiver and bolt of the 1917 Enfield took over 250 operations to complete. The total on the M/721 Receiver and Bolt is less than 25% of that number.

Formed or drawn parts were used very little in gun manufacture until the last war, when speed and conservation of material became very important. There are 20 parts of this type in the M/721, none of which detract from the function or appearance, but contribute appreciably to moderate selling price.

Of the total of 58 parts in the rifle, 20 are formed, 25 are completed on high production automatic machines such as screw machines and spring winders, and 9 have secondary operations after being partially completed on automatic machines. Only four parts, the Receiver, Barrel, Stock and Front Sight have a major portion of their operations on production machines such as milling machines and lathes.

In order to keep the investment in inventory and parts in process as low as possible, it was necessary to make all parts interchangeable except those few which are applicable to individual calibers. For example, all parts in the M/721 are interchangeable between calibers except the Barrel and the Bolt Head. There are three calibers supplied in the M/721 at present. The rifle for the 270 Winchester caliber is exactly the same as for the 30-06 except for the internal dimensions of the Barrel. The rifle for the 300 H&H Magnum caliber is identical with the 30-06 except for the Barrel chamber and Bolt Head. Whereas 48 parts are needed for any one caliber, only 61 separate parts are necessary for the three calibers.

DESIGN FEATURES

Several desirable features were incorporated in the new model which are not new, but had not been previously featured in their entirety in any single design. These features are:

1. A Bolt Handle design which allows low mounting of a telescope sight without interference. Placing the telescope line of sight close to the line of the open sight is desirable to alleviate the necessity for changing the Stock when "iron" and telescopic sights are used alternately. Telescope sights are ordinarily from 3/4" to 1-1/4" in diameter. With the metal sight line 1/8" above the Receiver, there is necessarily from 1/4" to 1/2" difference between the telescope and metal sight line.

2. For those shooters who object to the difference between telescope and metallic line of sight, a Stock is available which provides a 1/2" higher comb and heel.

3. A trigger mechanism providing a pull approximately .05" in length without preliminary take up or overtravel or backlash. This allows the shooter to discharge the arm with proper control without disturbing the alignment of sights and target. This was previously available only on match rifles, however, this feature is available on the Model 721 by designing for a minimum number of required operations. In fact after forming there are only 3 drilling operations and 3 grinding operations on all of the trigger parts.

4. Short Firing Pin travel (.290") giving a lock time of about .003 seconds (only 40% of the 1903 Springfield lock time) yet providing definitely superior ignition characteristics. This superiority can be accounted for by the positive seating of the cartridge in the chamber with the spring urged ejector. This makes it unnecessary for the Firing Pin to overcome the inertia of the whole cartridge and its total energy is used for indentation of the primer. The result is that normal variation in cartridge length has no effect on the ignition, each primer is delivered the full energy of the firing pin blow.

5. The Safety can be operated equally well by either right or left handed shooters, and its position is such that low mounted telescopes do not

interfere with its operation. With normal care its operation to the "off" position is noiseless.

New features are incorporated which are available in no other sporting bolt action rifle at the present time. These are:

1. Strength characteristics which have defied all efforts to make the action fail under over load conditions. The reason for this, of course, is that the design is based on sound engineering principles.

2. A new and novel Extractor entirely contained in the Bolt Head gives better extraction characteristics than the old hook type.

3. A Barrel and Bolt design which completely encloses the cartridge case in steel makes the strength of the action independent of the strength of the cartridge case.

4. A weight very close to 7 lbs. complete, approximately one pound lighter than previous high power bolt action rifles, yet stronger and safer from the standpoint of cartridge or gun failure.

ENGINEERING PROBLEMS

1. Barrel Strength

The exterior dimensions of a shoulder arm are limited by the appearance, the weight, and the required handling qualities. To meet the strength requirements in high power rifles without an adverse effect on appearance, weight and handling characteristics, it is often necessary to heat treat several of the parts. The barrel is one of these parts. As the most economical way to heat treat steel is in furnace size lots, the cartridge with the highest strength requirements is used for calculating the necessary physical properties of the barrel steel for all cartridges in any one model. In the M/721 this cartridge is the 300 H&H Magnum (300 stands for bore, H&H for Holland and Holland, and Magnum, a large glass of liquor, in other words, a big "shot").

The highest pressure in a shoulder rifle occurs while the bullet is moving its first few inches of travel. Therefore, the chamber portion of the barrel must be the strongest. Ordinarily some derivations of Lame's thick wall tubing formula is used for calculating stress in gun barrels.

For tangential stress -

$$S = P\frac{\left(R_1^2 + \frac{R_1^2 R_2^2}{R^2}\right)}{R_2^2 - R_1^2}$$

Where

- S = Stress
- P = Unit pressure in tube
- R_1 = Internal radius
- R_2 = External radius
- R = Radius at which stress is taken

Substituting in this formula the average tangential stress 1 inch in front of the receiver using 84,000 p.s.i., internal pressure is 65,000 p.s.i. From this calculation and others a minimum yield strength of 80,000 p.s.i. was established. In addition, an alloy is used which will give at least 50% reduction of area and 20% elongation to prevent fragmentation in case the shooter gets an obstruction in his barrel. An obstruction will wreck even the strongest of barrels.

2. Action Strength

Due to the strict control of the loads used in a high pressure rifle, the factor of safety used in the design of barrels and actions is generally not over 1.3. However, in the M/721 design it was possible to get a larger factor of safety. The greatest load applied to the bolt face occurs with the 300 Magnum proof. This load is in the neighborhood of 84,000 p.s.i. x .21 sq. in.= 17,500 pounds maximum force. The smallest area in tension is .48 sq. in., in shear is .43 sq. in., and in compression is .14 sq. in. The highest probable stress then is 17,500/.14 = 125,000 p.s.i. The Receiver and Bolt are austempered to a yield strength of 190,000 average. An alloy was selected which has excellent impact properties, averaging Izod 35 at the selected hardness.

3. Ignition Characteristics

Using the primer sensitivity specifications set up by the Small Arms and Ammunition Manufacturers Institute, the minimum energy of firing pin blow for proper ignition in a firearm has been established. The conventional method for measuring the sensitivity of primers uses the drop test machine. A steel ball of known weight is dropped on a light Firing Pin which strikes the primer. Samples of 25 to 100 primers are tested at each of several heights of fall and the fraction of primers that fire at each height is recorded. The controlling factor, under any given set of conditions, which determines whether or not a primer fires is the energy with which it is struck by the Firing Pin. The drop test data recorded in terms of height of fall is readily expressed in convenient energy units of inch-ounces from the product of the height of fall in inches and the weight of the falling ball in ounces. All that remains is to determine the variables introduced by a gun mechanism under field conditions. These are usually friction, head space (the space from the face of the Bolt to the surface in the chamber which supports the cartridge longitudinally), eccentricity of blow, and temperature. These factors have been evaluated and reasonable limits set relative to their effect on the ignition.

A blow approximately 85 inch-ounces is required to compensate for ignition variables in the gun. Knowning this and the length of travel of the Firing Pin, the figures can be substituted in the equation:

$$E = F \frac{M_f}{M_f + 1/3 M_s *} D$$

Where

E = Energy delivered in inch-ounces.
F = Average force of Main Spring (in ounces) between cocked and fired load.
M_f = Weight of Firing Pin Assembly.
M_s = Weight of spring
D = Distance Firing Pin travels from cocked to fired position (in inches).

*Reference "Vibration Problems in Engineering" - Timoshenko.

Substituting -

$$85 = F \frac{61.5}{61.5 + 4.2} .290$$

$$F = 313 \text{ oz.} = 19.6 \text{ lbs. Average Force}$$

With the average load requirements and the space in which the spring must operate, a relatively precise design can be accomplished. In the M/721 the Main Spring must work in a .420" dia. hole and over a .283" dia. Firing Pin. The cocked length of the spring is 3.348 and the fired length is 3.638. The maximum solid height of the spring can be no more than 2.30" as the spring must be compressed to this height during assembly.

A certain amount of experience in spring design, although not absolutely necessary, reduces the time and effort involved. A good rule in designing gun springs is to use all the space available for spring energy keeping the tolerances and the stress within reasonable limits. The extra effort involved is in the trial and error choice of wire diameter and spring diameter. The wire diameter is therefore set a .055" and the O.D. at .400". This choice leaves space on both inside and outside for winding tolerance. Having set the wire diameter the maximum number of coils can be determined from the maximum solid height. 2.30 ÷ .055 = 41+, the extra wire diameter produced in winding complete coils reduces this to 40+. Leaving a coil for clearance brings the total coils to 39. Then to prevent excessive buckling and consequent friction, the end coils are squared and ground, leaving 37 active coils. The necessary lengths are then determined from the constant $\frac{P}{F}$, pounds load per inch deflection.

The usual formula for deflection is:

$$F = \frac{8PD^3N}{Gd^4} \quad \text{or} \quad \frac{P}{F} = \frac{Gd^4}{8D^3N}$$

Where

- F = Deflection in inches.
- N = Number of active coils.
- G = Torsional Modulus of rigidity which for steel wire averages 11,500,000.
- D = Mean spring diameter (O.D. - d)
- d = Wire diameter.
- P = Spring load in lbs.

Substituting

$$\frac{P}{F} = \frac{11.5 \times 10^6 \ (9.1 \times 10^{-6})}{8 \ (.0411)37}$$

$$\frac{P}{F} = 8.6$$

Since a minimum, approximately 19.6#, is desired at a length of 3.493:

$$\frac{19.6}{L-3.493} = 8.6 \qquad \text{Where L = Free length.}$$

$$L = 5.773 \text{ inches}$$

Are we sure?

If reasonable cost of manufacture is expected, the spring manufacturer should have at least 10% tolerance on the load. With a minimum free length of say 5.80" and a working load of 20#, the average free length was set at 5.94" giving a tolerance of ± .14 x 8.6 = 1.2#.

From the stress formula

$$S = \frac{8 \ PD}{\Pi \ d^3} = \frac{2.55 \ PD}{d_3} \ K \quad \text{the average working stress is}$$

$$(K = \text{concentration correction} = 1 + \frac{.5d}{D})$$

$$\frac{2.55 \ (5.94-3.493) \ 8.6 \ (.345)}{.000166}(1.08) = 120{,}000 \text{ p.s.i.}$$

With a solid height of .055 x 39 = 2.145 the solid stress is

$$\frac{2.55 \ (5.94-2.145) \ 8.6 \ (.345)}{.000166}(1.08) = 187{,}000 \text{ p.s.i.}$$

This is on the high side, but acceptable with good quality music wire.

From the proceeding information it is possible to calculate the lock time. From the fundamental equations $E = 1/2 \ MV^2$, $E = PS$ and $t = \frac{S}{V}$, lock time

$t = \sqrt{\frac{2MS}{P}}$, where M = mass of Firing Pin plus 1/3 the mass of the Main Spring, S = distance the Firing Pin travels in feet, and P = average force exerted by the spring. Substituting $t = \sqrt{\frac{2(.145).290}{21(32.2)12}}$ = .0032 seconds. By measurement this was found to be very close to actual. Lock time is important because it indicates the possible movement of the arm, in the hands of a shooter, between trigger release and ignition of the charge, i.e., greater lock time introduces greater possibility for human error in placing the shot at the target.

This is strictly a design article how about machine operations, detail pictures, production flow, etc. Does not "Broad Engineering" specialize in the latter presentations. Article very good though.

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from Mike's standpoint.

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