Substituting the value of P_{1s} from equation (54) and reducing we have

$$l_t = -\frac{(b-a)S_1}{(b-1)2R_1} \qquad (56)$$

from which we may obtain at once the tangential compression when the absolute shrinkage is known.

Since, equation (13), $El_t = S_t$ the tangential stress on the bore in pounds per square inch is found by multiplying the relative compression by the modulus of elasticity; 30,000,000 for gun steel.

123. Graphic Shrinkage.—Equation (54) becomes for a given compound cylinder

$$S_1 = MP_{1s}$$

It is represented in Fig. 45 by the line S_1P_{1s}, the axis of S_1 coinciding with the axis of P_0. Different scales are used on these two axes. The coordinates of any point of the line S_1P_{1s} represent, for the given compound cylinder, absolute shrinkage and the pressure produced by it at the surface of contact. Therefore to find the shrinkage necessary to produce the required pressure at rest, P_{1s}, draw the horizontal line from P_{1s} and the vertical line from its intersection with S_1P_{1s}. The intercept on the axis of S_1 is the value of the absolute shrinkage that will produce the pressure P_{1s}. $S_1 = 0.0085$ in the case illustrated.

124. Radial Compression of the Tube.—The value of the pressure on the exterior of the inner cylinder at rest is given by equation (45),

$$P_{1s} = P_{1\theta} - \frac{(b-a)P_0}{a(b-1)}$$

It will be seen from this equation that the larger the value of P_0 used the less will be the value of P_{1s}; and from equation (54) we see that the less the value of P_{1s} the less will be the shrinkage. Therefore if when $P_{0\theta}$ is greater than $P_{0\rho}$ we use $P_{0\theta}$ in equation (45), the resulting shrinkage will be less than if $P_{0\rho}$ were used, and as may be shown by equation (14) the resulting radial stress at the inner surface of the inner cylinder, system in action, will be increased. Now in deducing the value for the shrinkage we have used the pressures calculated to strain the metal to its elastic limit. Therefore with reduced shrinkage the pressure P_{0_ρ} will produce a stress of radial compression at the inner surface of the tube greater than the elastic limit of the metal.

But it is found that the metal of the inner cylinder supported as it is by the outer cylinder has greater strength to resist radial compression than is indicated by the tests of the detached specimens of the metal used in determining the elastic limits; and as the reduced shrinkage resulting from the use of $P_{0\theta}$ in equation (45) reduces all the stresses on the system in a state of rest, and those on the outer cylinder in a state of action, it is the practice to use $P_{0\theta}$ instead of P_{0_ρ} in calculating the shrinkage.

Guns as constructed yield by tangential extension, and the radial over-compression if it exists does not determine rupture. Consequently the tangential elastic resistance of the gun, even though frequently greater than the radial elastic resistance, is taken as the elastic strength of the gun.

125. Prescribed Shrinkage.—Equation (54) expresses the relation between the shrinkage and the pressure that it produces. When for any reason the compound cylinder is not assembled in such a manner as to offer the maximum elastic resistance, as, for instance, when a certain shrinkage less than the maximum permissible shrinkage is prescribed, the pressure due to the prescribed shrinkage may be found by solving equation (54) for P_{1s}. The elastic resistance of the compound cylinder assembled with the prescribed shrinkage will then be found from equations (49) and (50) by substituting for P_{1_ρ}, which represents the pressure at rest, the value of P_{1s} from equation (54), which is the actual pressure applied.

The prescribed value of S_1 will give in equation (56) the resulting relative tangential compression of the bore.

Graphic Representation.—In Fig. 45 let the point 0.008 be the value of the prescribed shrinkage. By following the broken lines from this point we find on the axis P_1 the resulting pressure at the surface of contact, system at rest; and at b on the line $P_1P_{0\theta}$ the point whose coordinates are the limiting interior and exterior pressures, system in action.

126. Application of the Formulas.—Assuming the caliber of the bore and the thicknesses of the cylinders, to determine the shrinkage and the permissible pressures in the compound cylinder assembled to offer the maximum resistance.

The formulas usually required for a system composed of two cylinders are here assembled for convenience.

$$a=R_1^2/R_0^2, \quad b=R_2^2/R_0^2 \tag{12}$$

$$P_{1\theta}=\frac{3(b-a)}{4b+2a}\theta_1 \tag{37}$$

$$P_{0\theta}=\frac{3(a-1)\theta_0+6aP_{1\theta}}{4a+2} \tag{38}$$

$$P_{0\rho}=\frac{3(a-1)\rho_0+2aP_{1\theta}}{4a-2} \tag{39}$$

$$p_1=\frac{(b-a)}{a(b-1)}p_0 \tag{43}$$

$$P_{1s}=P_{1\theta}-\frac{(b-a)P_{0\theta}}{a(b-1)} \leqq \frac{a-1}{2a}\rho_0=P_{1\rho} \tag{47}$$

$$S_1=\frac{4R_1a(b-1)P_{1s}}{E(a-1)(b-a)} \tag{54}$$

$$l_t=-\frac{(b-a)S_1}{(b-1)2R_1} \tag{56}$$

$$P_{0\theta}=\frac{3(a-1)\theta_0+6aP_{1\rho}}{(4a+2)-6\dfrac{b-a}{b-1}} \tag{49}$$

$$P_{0\rho}=\frac{3(a-1)\rho_0+2aP_{1\rho}}{(4a-2)-2\dfrac{b-a}{b-1}} \tag{50}$$

$$El_t=S_t=\frac{2(P_0-aP_1)}{3(a-1)}+\frac{4a(P_0-P_1)}{3(a-1)}\frac{R_0^2}{r^2} \tag{13}$$

$$El_p=S_p=\frac{2(P_0-aP_1)}{3(a-1)}-\frac{4a(P_0-P_1)}{3(a-1)}\frac{R_0^2}{r^2} \tag{14}$$

In equation (43) above, $-P_0$ has been replaced by its value p_0 from equation (40) in order to make the equation general. $-P_0$ is a particular value of p_0.

In the first member of (47) $P_{0\theta}$ is written for P_0 to make the equation conform to the practice of using $P_{0\theta}$ in determining the shrinkage.

PROCESS.—Use the values of θ and ρ determined in the testing machine.

Find $P_{1\theta}$ from equation (37).

Find $P_{0\theta}$ and $P_{0\rho}$ from (38) and (39).

Make the test indicated in (47) and if either of the conditions are met use the value of the first member of (47) for P_{1s} in (54) and find S_1.

The values already found for $P_{1\theta}$ and $P_{0\theta}$ are then the limiting safe pressures.

If the first member of (47) is greater than the second,

Find $P_{0\theta}$ and $P_{0\rho}$ from (49) and (50).

Use $P_{1\rho}$ from (47) for P_{1s} in (54) to find S_1.

The stresses and strains produced by any pressures are found by means of equations (13) and (14); the tangential stresses and strains from equation (13), the radial from equation (14).

127. Problem 1.—The dimensions of the 4.7 inch siege rifle, at the section marked IV in Fig. 47, are:

$R_0 = 2.35$ inches, $R_1 = 3.86$, $R_2 = 6$. The prescribed elastic limit for both tube and jacket is 50,000 lbs. per sq. in. What will be the shrinkage when the cylinders are assembled to offer the maximum resistance, and what will be the maximum permissible interior pressure?

We have
$$a = R_1^2/R_0^2 = 2.698$$
$$b = R_2^2/R_0^2 = 6.5187$$
$$b - a = 3.8207$$

Equation (37) $$P_{1\theta} = \frac{3 \times 3.8207}{26.0748 + 5.396} 50000 = 18210$$

(38) $$P_{0\theta} = \frac{3 \times 1.698 \times 50000 + 6 \times 2.698 \times 18210}{12.792} = 42956$$

(39) $$P_{0_\rho}=\frac{5.094\times 50000+5.396\times 18210}{8.792}\doteq 40146$$

(47) $$P_{1_s}=18210-\frac{3.8207\times 42956}{2.698\times 5.5187}=7187<\frac{1.698}{5.396}\,50000$$

(54) $$S_1=\frac{4\times 3.86\times 2.698\times 5.5187\times 7187}{30{,}000{,}000\times 1.698\times 3.8207}=0.008489$$

The outer diameter of the tube must therefore be 0.0085 inches greater than the inner diameter of the jacket before assembling.

If P_{0_ρ} were used in place of P_{0_θ} in the determination of P_{1_s}, equation (47), we would obtain $P_{1_s}=7909$, and from (54) $S_1=0.00934$.

128. Graphic Solution.—In Fig. 45 is shown the graphic solution of Problem 1. For this problem the equations take form as follows.

(38) $$P_{0_\theta}=19910+1.325P_1$$

(39) $$P_{0_\rho}=28968+0.614P_1$$

(43) $$p_1=0.2566P_0$$

(47) $$S_1=0.0000118P_{1_s}$$

These equations are represented by the lines of the figure drawn to scale. Determine from equation (37) the limiting interior pressure on the jacket, P_{1_θ}. From this point on the axis of P_1 draw the horizontal line. It cuts $P_1P_{0_\theta}$ at the point c, for which $P_0=42956$. Passing from action to rest the pressure P_1 varies at the rate indicated by the inclination of the line p_1P_0. Therefore draw from c a line parallel to this line. It cuts the axis of P_1 at P_{1_s}, which is the pressure at rest. P_{1_s} is less than P_{1_ρ}, equation (47), also represented in the figure. Therefore P_{1_θ} in action is a safe pressure. Drawing the horizontal line from P_{1_s} and the vertical line from its point of intersection with $S_1P_{1_s}$ we find that the absolute shrinkage that will produce the pressure P_{1_s} is $S_1=0.0085$.

129. Problem 2.—What are the stresses on the inner and outer surfaces of the tube of the gun in the last problem, both at rest and in action, assuming the gun to be assembled with the shrinkage determined in that problem, and using the pressure $P_{0_\rho}=40146$, equation (39), as the interior pressure in action?

The pressure at rest, $P_{1_s}=7187$, determined in Problem 1, acts alone.

Tangential stresses, (13), $S_t(R_0)=-22839 \quad S_t(R_1)=-13257$

Radial stresses, (14), $S_p(R_0)=+7613 \quad S_p(R_1)=-1970$

In Problem 1 in determining by equation (47) the pressure at rest we used $P_{0\theta}=42956$ lbs. as the pressure in action. The pressure at the outer surface of the tube in action as given by equation (37), $P_{1\theta}=18210$, will therefore be produced only by the interior pressure $P_{0\theta}$. An interior pressure $P_{0_\rho}=40146$ lbs., less than $P_{0\theta}$, will produce a pressure on the exterior of the tube less than 18210 lbs. Equation (43) gives the value of the variation in the exterior pressure due to any variation p_0 in the interior pressure. Making $p_0=42956-40146=2810$ in equation (43) we find $p_1=721$. The pressure P_1 in action, due to the interior pressure P_{0_ρ}, is therefore $18210-721=17489$ lbs.

Making $P_0=40146$ and $P_1=17489$ we find

Tangential stresses, (13), $S_t(R_0)=+45236 \quad S_t(R_1)=+15027$

Radial stresses, (14), $S_p(R_0)=-50764 \quad S_p(R_1)=-20555$

Had the shrinkage in Problem 1 been determined by the use of $P_{0_\rho}=40146$ in equation (47), that pressure in action would have compressed the inner layer of the tube radially to its elastic limit, 50000 lbs. But with the reduced shrinkage due to the use of $P_{0\theta}$ in equation (47) the pressure of 40146 lbs. exerts a radial stress on the inner layer of the tube of 50764 lbs., which is in excess of the elastic limit.

130. GRAPHICALLY.—The pressure P_1 in action, used in determining the stresses from equations (13) and (14), may be obtained from Fig. 45. The shrinkage being 0.0085, P_{1_s} is the pressure at rest. From P_{1_s} follow the line of variation in pressure to the point a, whose abscissa is $P_{0_\rho}=40146$. The ordinate of this point is the pressure P_1 in action when $P_0=40146$. Therefore $P_1=17489$.

131. Problem 3.—The shrinkage actually prescribed at the section of the 4.7 inch rifle used in Problem 1 is 0.008 of an inch. What is the elastic resistance of the gun, tangential and radial, at the section, and what is the relative compression of the bore and the stress of tangential compression at the surface of the bore?

$$(54)\qquad P_{1_s}=\frac{0.008\times 30{,}000{,}000\times 1.698\times 3.8207}{4\times 3.86\times 2.698\times 5.5187}=6773$$

$$(49)\qquad P_{0_\theta}=\frac{3\times 1.698\times 50000+6\times 2.698\times 6773}{12.792-6\,\dfrac{3.8207}{5.5187}}=42178$$

$$(50)\qquad P_{0_\rho}=\frac{3\times 1.698\times 50000+2\times 2.698\times 6773}{8.792-2\,\dfrac{3.8207}{5.5187}}=39319$$

$$(56)\qquad l_t=-\frac{3.8207\times 0.008}{5.5187\times 7.72}=-0.000717$$

$$(13)\qquad S_t=El_t=21510$$

132. GRAPHICALLY.—From the point 0.008, Fig. 45, on the axis of S_1 follow the broken lines and obtain successively the values found above for P_{1_s}, P_{0_ρ}, and P_{0_θ}.

133. Curves of Elastic Resistance.—In the same way the elastic resistances are found at various sections of the gun, and the curves of elastic resistance shown in Fig. 47 are constructed. By comparing the ordinates of these curves with the corresponding ordinates of the curve of powder pressures it will be seen that the gun has a factor of safety of about $1\frac{1}{4}$ over the part of its length that is subjected to the maximum pressure.

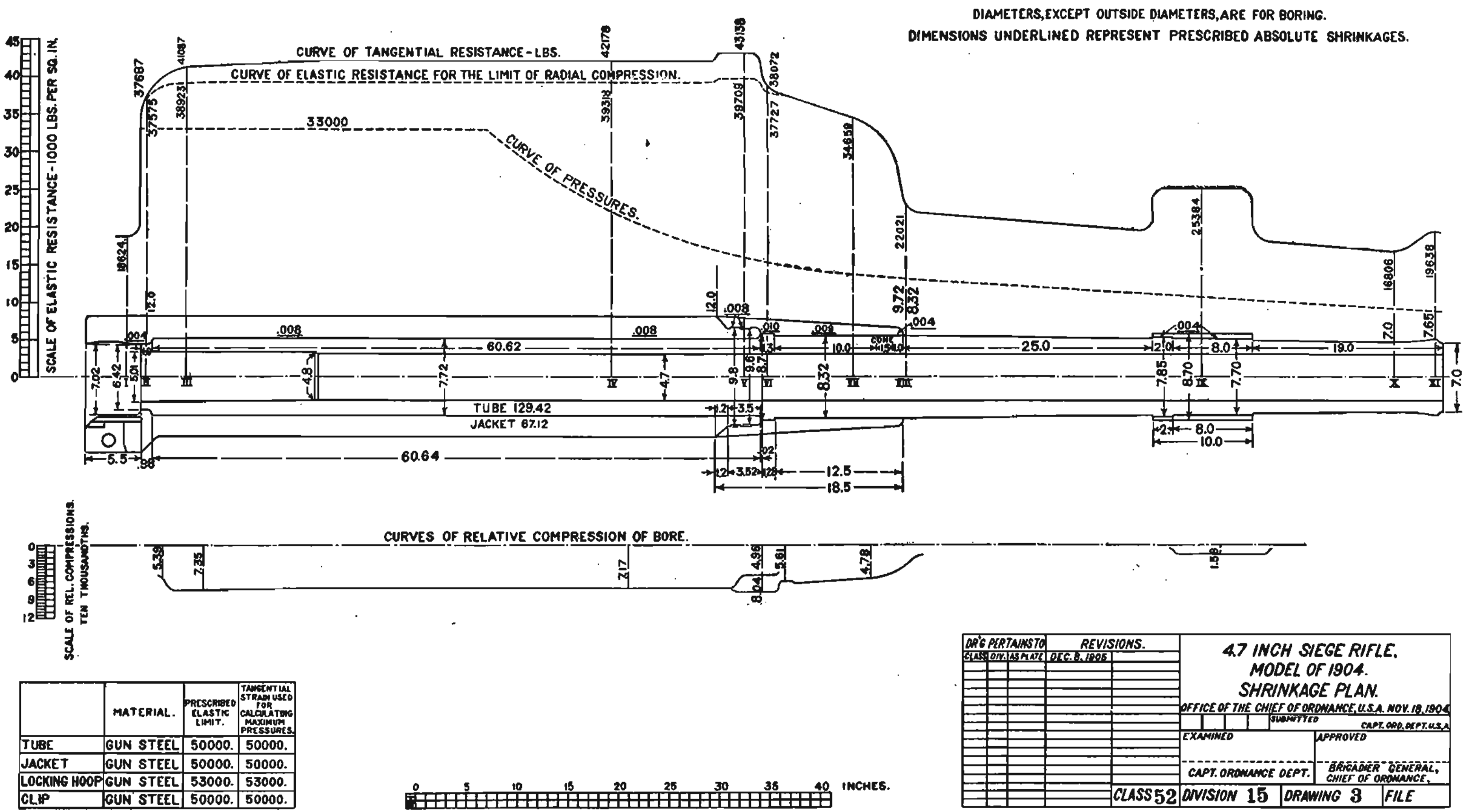
Problem 4.—What will be the tangential stresses in the system assembled as in Problem 3 under a powder pressure of 32,000 lbs. per sq. in.?

$$R_0=2.35\qquad R_1=3.86\qquad R_2=6\quad \text{(See Problem 1)}$$

The pressure at rest, $P_{1_s}=6773$, determined in Problem 3, produces stresses as follows, equations (13) and (36).

$$\text{Tube, (13), } S_t(R_0)=-21523\qquad S_t(R_1)=-12493$$

$$\text{Jacket, (36), } S_t(R_0)=+18596\qquad S_t(R_1)=+9566$$



	MATERIAL.	PRESCRIBED ELASTIC LIMIT.	TANGENTIAL STRAIN USED FOR CALCULATING MAXIMUM PRESSURES.
TUBE	GUN STEEL	50000.	50000.
JACKET	GUN STEEL	50000.	50000.
LOCKING HOOP	GUN STEEL	53000.	53000.
CLIP	GUN STEEL	50000.	50000.

FIG. 47.—Shrinkages and Elastic Resistance of the 4.7-inch Siege Rifle, Model 1904.

The stresses within the elastic limit produced by an interior or exterior pressure on a compound cylinder are exactly the same as would be produced by the same pressure on a simple cylinder of the same dimensions. If therefore we consider the gun as a simple cylinder and calculate the stresses due to an interior pressure of 32,000 lbs., these stresses will be the variations in the stresses in the compound cylinder as it passes from rest to action, and the algebraic sums of the stresses at rest and the variations will be the stresses in action.

Considering the gun as a simple cylinder acted on only by the interior pressure, 32,000 lbs., we obtain from equation (13) for the stresses at the surfaces for which $r=R_0=2.35$, $r=3.86$, and $r=R_1=6$:

$$\text{Inner surface of cylinder,}\quad S_t=+54265$$

$$\text{At } r=3.86,\quad S_t=+22546$$

$$\text{Outer surface of cylinder,}\quad S_t=+11597$$

Taking the algebraic sums of these stresses and those above determined for the system at rest, we find for the stresses in action:

$$\text{Tube,}\quad S_t(R_0)=+32742,\quad S_t(R_1)=+10053$$

$$\text{Jacket,}\quad S_t(R_0)=+41142,\quad S_t(R_1)=+21163$$

134. Graphically.—As in the graphic solution of Problem 2, the pressure P_1 corresponding to the interior pressure $P_0=32{,}000$ is found from Fig. 45 by following the line of variation of pressure for $P_{1s}=6773$ to the point d whose abscissa is $P_0=32{,}000$. The ordinate of this point is P_1, and this being substituted with P_0 in equations (13) and (14), the values of the stresses are derived.

135. **Curves of Stress in Section.**—The curves of tangential stress in a section of a gun composed of two cylinders assembled to offer the maximum resistance are shown in Fig. 48. The curves s show the stresses in the cylinders produced by the shrinkage, the system being at rest. The curves r show the stresses in the cylinders for the system in action. The curve p shows the stresses that would result from the pressure P_0 in a single cylinder.

In each cylinder the ordinates of the curve r are the algebraic sums of the ordinates of the curves p and s.

The gain and loss of strength in the compound cylinder as compared with the single cylinder are shown in Fig. 49. The curve t is the curve of tangential stress due to the maximum permissible interior pressure in the single cylinder. The gain in strength in each cylinder of the compound cylinder is shown by the cross-shaded area marked with the plus sign, and the loss in strength by the single-shaded area marked with the minus sign. The total tangential stress in the single cylinder is the area between the curve t and the horizontal axis. The inner cylinder of the compound cylinder gains over an equal portion of the single cylinder the shaded area below the axis, representing the compressive stress due to the shrinkage; and loses the area between the curves t and r, since the single cylinder would be under the stress t while the compound cylinder is subjected only to the lower stress r. The outer cylinder at rest being under the stress of extension represented by the area under the curve s, that area is lost to it in action, as compared with the single cylinder, while it gains the area lying between the curves r and t.

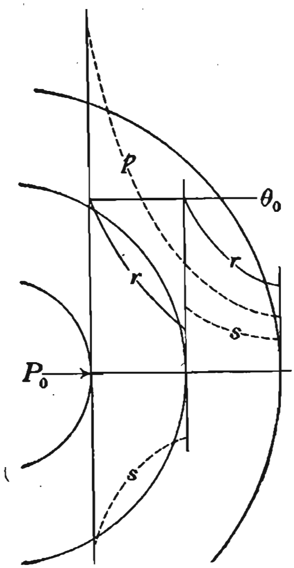


FIG. 48.

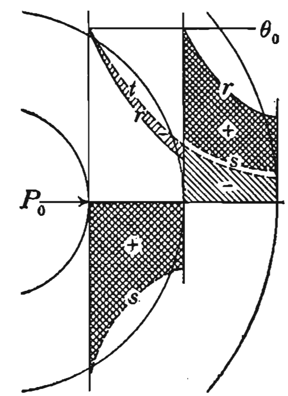


FIG. 49.

136. Problems.—5. A section of the 2.38 inch experimental field rifle, model of 1905, has the following dimensions: $R_0 = 1.19$

inches, $R_1 = 1.95$, $R_2 = 3$. What is the elastic resistance of this section assembled to offer the maximum resistance, and what is the absolute shrinkage? The elastic limit of the metal, nickel steel, is 65,000 lbs. per sq. in.

$P_{1_\theta} = 23243$ lbs. $P_{0_\theta} = 55184$ lbs.

$P_{0_\rho} = 51875$ lbs.

$P_{1_s} = 9158$ lbs. $S_1 = 0.00554$ in.

6. The prescribed shrinkage for the above section is 0.005 of an inch. What is the elastic resistance of the section with this shrinkage and what is the stress of tangential compression on the bore?

$P_{1_s} = 8271$ lbs. $P_{0_\theta} = 53527$ lbs.

$l_t = 0.000879$ in. $S_t = 26360$ lbs.

137. Systems Composed of Three and Four Cylinders.— The construction and elastic strength of the larger guns built up of three or four cylinders are determined by considerations similar to those explained in the foregoing discussion. Precaution is taken, by modifying the shrinkages if necessary, that the inner cylinders at rest shall not be injured by the shrinkage pressures of the outer cylinders. The elastic strength of the system, that is, the maximum permissible interior pressure, is the pressure that will bring any one of the elementary cylinders to its elastic limit of extension or compression. In a proper construction the tube is subjected to the greatest pressures both at rest and in action, and consequently if the elastic strength of the gun is exceeded by the powder pressure the tube will yield first.

In Fig. 50 are shown the curves of stress in a section through the powder chamber of the 8 inch gun, model of 1888.

The curves s_1 show the stresses due to the assembling of the jacket on the tube, the curves s_2 the stresses due to the shrinkage of the outer hoop. The curves s_r show the resultant stresses due to both shrinkages.

The numbers on all curves are the actual values of the stresses in tons per square inch due to an interior pressure $P_{0_\theta} = 23.2$ tons.

The curve p shows the stresses that would be produced by this pressure in a single cylinder of the same dimensions as the compound cylinder.

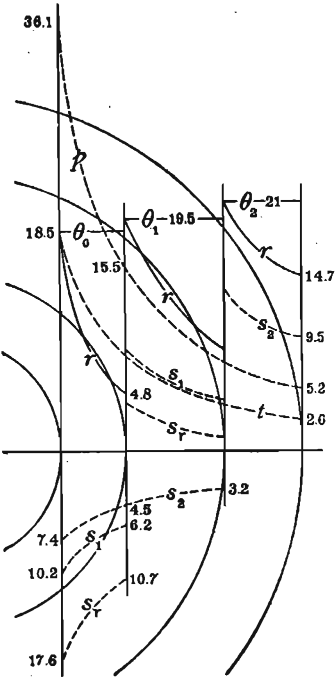


Fig. 50.

The curves r, the stresses in action, are the resultants of the curves s_r and p in each cylinder.

The curve t shows the stresses resulting in a single cylinder from the maximum interior pressure, 12.4 tons, permissible in a single cylinder of these dimensions.

The area between the curves p and t represents the gain in strength due to the compound construction.

Minimum Number of Cylinders for Maximum Resistance.—It will be noticed in Fig. 50 that although in action all the cylinders are stretched to their elastic limits the compression of the tube at rest is less than the elastic limit of compression ρ, assumed equal to θ. In this construction therefore there was not obtained the maximum resistance that the metal was capable of offering. The same conditions exist in the two cylinder gun, as may be seen in Problem 2. The stress of tangential compression at the surface of the bore at rest is found in that problem to be 22,839 lbs., while the elastic limit of the metal is 50,000 lbs.

It may be shown by the equations that in a two or three cylinder gun whose parts have essentially the same elastic limits the conditions that the parts shall be strained to the elastic limit in action and that the tube shall be compressed to its elastic limit at rest are incompatible. That both these conditions may be fulfilled the compound cylinder must be composed of at least four parts.

138. Graphic Construction. Three Cylinders.—The equations deduced for the compound cylinder of two parts are used for the cylinder of three parts, the subscripts and radius ratios in these equations being changed as required. Due to the application of the third cylinder the relation between the variations in pressure in the bore and at the first contact surface, equation (43), takes the form

$$p_1=\frac{(c-a)}{a(c-1)}P_0 \tag{57}$$

and between the first and second contact surfaces, see equation (34),

$$p_2=\frac{a(c-b)}{b(c-a)}p_1 \tag{58}$$

The shrinkage at the second surface of contact, equation (54), becomes

$$S_2=\frac{4R_2b(c-1)}{E(b-1)(c-b)}P_{2s} \tag{59}$$

In addition we need for the graphic representation the pressure at the first contact surface due to the shrinkage pressure at the second surface. This is given by the equation

$$p_{12}=\frac{b(a-1)}{a(b-1)}P_{2s} \tag{60}$$

in which p_{12} *represents that part of the pressure at the first contact surface that is due to* P_{2s} *only.*

Equation (60) also gives the value of the variation in the pressure at the first contact surface due to a variation in P_{2s}. The equation is deduced by equating the stresses at R_0 due to the pressures p_{12} and P_{2s}.

With the above equations we may now proceed to the graphic representation of the pressures and shrinkages shown in Fig. 51. We will call the three cylinders in order from the center outwards the tube, the jacket, and the hoop.

The first quadrant of the figure, similar to Fig. 45, refers to the tube and the shrinkage at the first contact surface. The second quadrant shows the pressures on the surface of the jacket. The shrinkage at the second contact surface is put in the third quadrant for convenience. The numbers of the equations

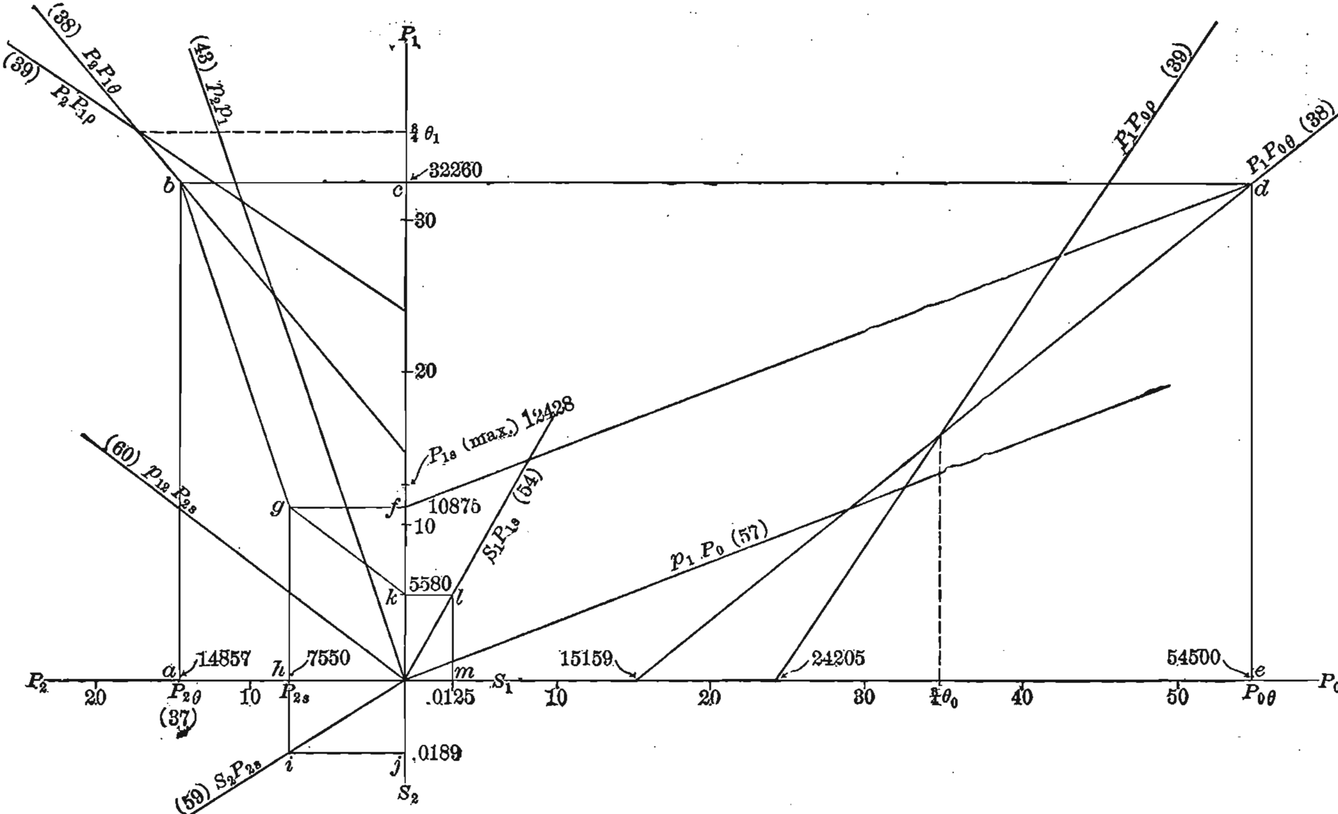


FIG. 51.—Pressures and Shrinkages in 6-inch Rifle, Model 1905, 3 Cylinders.

from which the lines are derived are shown on the lines. It will be understood that the subscripts and radius ratios in any equation must be such as make the equation refer to the particular cylinder to which it is applied.

$P_{2\theta}$ is first determined from equation (37). It will stretch the inner surface of the hoop to its elastic limit in action. It is therefore the greatest pressure that may be permitted on the exterior of the jacket. Draw *ab*, to $P_2P_{1\theta}$, and *bc*. *c* is the pressure P_1 that, acting on the interior of the jacket, will produce the limiting pressure $P_{2\theta}$ on the exterior. Draw *cd*, to $P_1P_{0\theta}$, and *de*. *e* is the value of P_0 in action that will produce the value *c* of P_1 and therefore the limiting pressure $P_{2\theta}$ on the interior of the hoop.

When the system passes from action to rest the pressure on the outer surface of the tube falls along the line *df* drawn parallel to p_1P_0. *f* is the total pressure on the exterior of the tube at rest. It is composed of the pressure P_{1s} due to the first shrinkage and the pressure p_{12} due to the second shrinkage.

The pressure on the outer surface of the jacket falls along the line *bg* parallel to p_2p_1, which line shows the relation existing between the variations in pressure at the two surfaces of the jacket. As the change in interior pressure on the jacket stops at *f* the change in the exterior pressure stops at *g*, and projecting *g* to *h* on the axis of P_2 we find the pressure P_{2s} on the exterior of the jacket at rest. This is the shrinkage pressure, and drawing *hi* and *ij* we find the shrinkage *j* that will produce the pressure P_{2s}.

The total pressure *f* on the exterior of the tube is composed of the pressure due to the first shrinkage and the pressure due to the second shrinkage. The variation in interior pressure on the jacket due to variation in the exterior pressure is given by equation (60), which is represented in the figure by the line $p_{12}P_{2s}$. If therefore we draw *gk* parallel to this line the point *k* will be the interior pressure on the jacket when the exterior pressure is 0, that is before the second shrinkage. The pressure *k* is therefore the pressure due to the first shrinkage only, and the shrinkage that will produce it is obtained by drawing the lines *kl* and *lm*.

For the system to be safe the total pressure *f* on the exterior of the tube must be less than the maximum permissible pressure as given by the last half of equation (47). We will now designate the maximum permissible pressure on the exterior of the tube by $P_{1s(\max)}$, since $P_{1\rho}$ designates now an interior pressure on the jacket.

The values of the pressures and shrinkages marked on the figure apply to the chamber section of the 6-inch rifle, model 1905, the section being assembled to offer the maximum resistance. For the section,

$R_0=4$ inches	$\theta_0=46000$ lbs. per sq. in.
$R_1=5.9$	$\theta_1=48000$
$R_2=8.35$	$\theta_2=47700$ assumed, 53000 actual
$R_3=12$	$\theta\ =\rho$

The equations become with this data,

(37)	$P_{2\theta}=14857$	(38)	$P_{0\theta}=15159+1.2197P_1$
(38)	$P_{1\theta}=14425+1.2003P_2$	(39)	$P_{0\rho}=24205+0.64920P_1$
(39)	$P_{1\rho}=24023+0.6664P_2$	(57)	$p_1=0.39209P_0$
(43)	$p_2=0.33963p_1$	(54)	$P_{1s}=446400S_1$
(60)	$p_{12}=0.70129P_{2s}$	(47)	$P_{1s(\max)}=12428$
(59)	$P_{2s}=401610S_2$		

139. Wire Wound Guns.—As shown in Fig. 50 the various cylinders of a built up gun are strained to the elastic limit at the interior surfaces only. It is apparent that if the same thickness of wall is composed of a greater number of cylinders, each cylinder being brought to its elastic limit at the interior surface, more of the total strength of the metal will be utilized. It follows that with a greater number of cylinders the gun may be given the same elastic strength with less thickness of wall.

The most convenient method of increasing the number of cylinders is by winding wire under tension around the tube of the gun. The tension of the successive layers of wire may be so regulated that each layer will be strained to its elastic limit when the system is in action. Usually, however, the wire is wound with uniform tension. In the form of wire the metal in the gun is much more likely to be free of defects, and can be given a much higher elastic limit than when in the form of forged hoops. An elastic limit of over 100,000 pounds is obtained in steel gun wire.

But the elastic strength of the gun is determined by the elastic strength of the tube that forms the bore of the gun; and if the tube is worked only within its elastic limit the wire wound gun cannot be stronger than the built up gun. In the Brown wire wound gun shown in Fig. 5 on page 238, the wire is wound with a tension of 112,000 lbs. per sq. in., compressing the inner surface of the tube beyond its elastic limit without apparent injury. This gun is composed of a lining tube about which are wrapped overlapping sheets of steel 1/7 of an inch thick and of the shape shown in Fig. 6 on page 238. The steel sheets form, about the lining tube, an outer tube which is afterwards wrapped with wire from breech to muzzle. The wire wrapped overlapping sheets give longitudinal stiffness to the gun. Over the wire is shrunk a steel jacket with just sufficient tension to prevent its rotation upon the tube. The jacket is not depended upon to add to the tangential strength of the gun. It takes, however, a part of the longitudinal stress.

The Ordnance Department 6 inch wire wound gun is shown in Fig. 4, page 238. The wire, 1/10 of an inch square, is wound with a uniform tension of 47,400 lbs. per sq. in., much less than in the Brown gun. The wire winding extends over the breech and half way along the chase of the gun.

After 31 rounds had been fired from each of these guns with velocities of about 3280 feet and pressures of about 45,000 pounds, it was reported that the most notable result observed in the test of the guns was the considerable wear of the rifled bore near the seat of the projectile and near the muzzle of the gun. The wear of the bore was much greater than in built up guns of the same caliber fired with velocities of 2600 and 3000 feet.

This indicates that the life of the wire wound gun will be very short if fired with the higher velocities and pressures. In other words we are unable at present to take economical advantage of the greater strength of these weapons. The wire wound gun has, however, a greater reserve of strength when fired under ordinary pressures than has the gun of the same dimensions built up wholly of steel forgings.

No wire wound guns have yet been put in service in the United States. They have been extensively used for some years by the British Government.

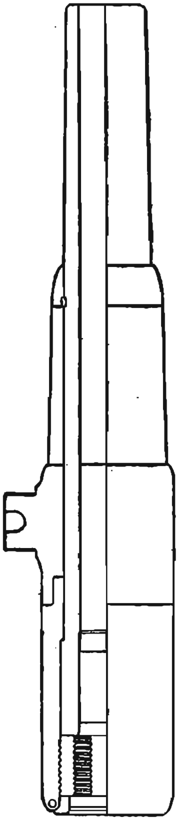
CONSTRUCTION OF GUNS.

140. **General Characteristics.**—The smaller guns in our service, such as the mountain gun, the field and siege howitzers and mortars, are made from single forgings. All other guns are built up. The smaller built up guns of caliber up to 5 inches consist of a central tube (see opposite page), a jacket surrounding the breech end of the tube, and a locking ring which locks the tube and jacket together. Guns of caliber greater than 5 inches have one or more layers of hoops surrounding the tube and jacket. The bore of the tube forms the powder chamber, the seat of the projectile, and the rifled bore. The jacket embraces the tube from the breech end forward nearly half the length of the tube and extends to the rear of the tube a sufficient distance to allow the seat of the breech block to be formed in the bore of the jacket. Through the bearing of the breech block in the jacket the longitudinal stress due to the pressure of the powder gases is transmitted to the jacket and the metal of the tube is thus relieved from this stress.

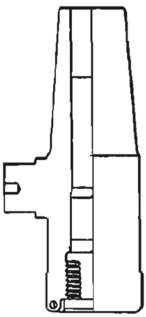
All guns of 6 inch caliber and above are hooped to the muzzle. The 6 and 8 inch guns have a single layer of hoops over the jacket. Guns of caliber larger than 8 inches have two layers of hoops over the jacket.

The construction of the several classes of guns and mortars of the latest models may be seen in the illustrations, pages 237 and 238.

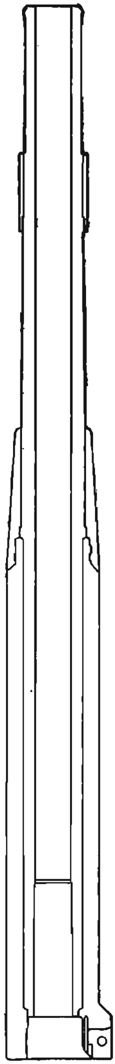
The forward end of the jacket of the field and siege rifles is threaded with a broad screw thread. The rear end of locking hoop is provided with a similar female thread, and the locking hoop is both screwed and shrunk on the jacket. The hoop is also shrunk to the tube, and by means of a bearing against a shoulder on the tube just forward of the jacket it holds the tube and jacket firmly together.



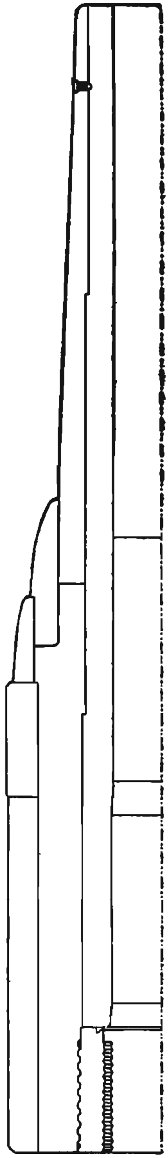
7-inch Howitzer, 1890.



Field and Siege Mortars.



Field and Siege Rifles.



12-inch Mortar.

A noteworthy difference will be observed in the construction of the two 12 inch rifles, Figs. 1 and 2, page 238. While the gun

12-INCH RIFLE. MODEL OF 1888, 34 CALS., 52 TONS.

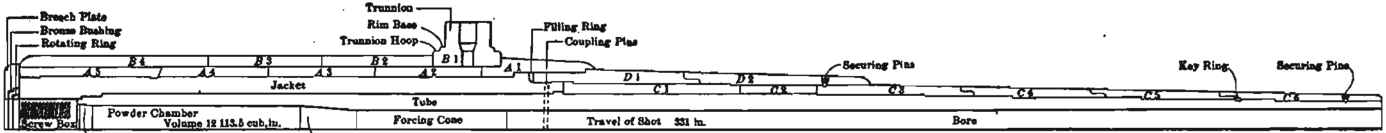


FIG. 1

12-INCH RIFLE. MODEL OF 1900, 40 CALS., 59.10 TONS.

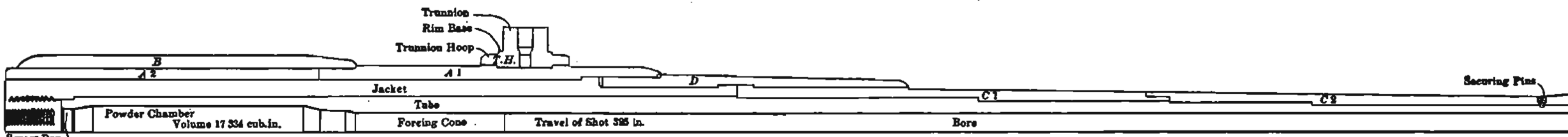


FIG. 2

6-INCH R.F. GUN, MODEL OF 1903, 50 CAL., 19 990 LB.

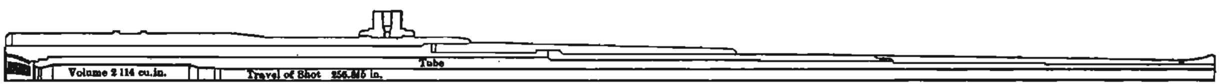


FIG. 3

INVOLUTE SHEET

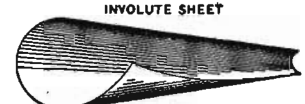


FIG. 6

6-INCH CROZIER, WIRE-WRAPPED GUN, 50 CAL., 20 600 LB.

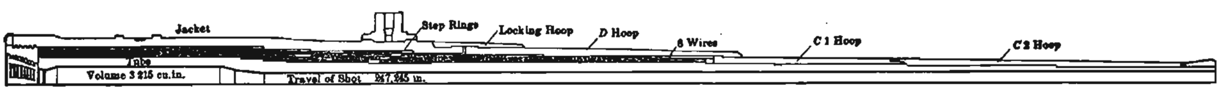


FIG. 4

SECTION ON A-A

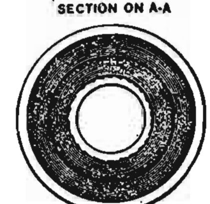


FIG. 7

6-INCH BROWN, WIRE-TUBE GUN, 50 CAL., 19 300 LB.

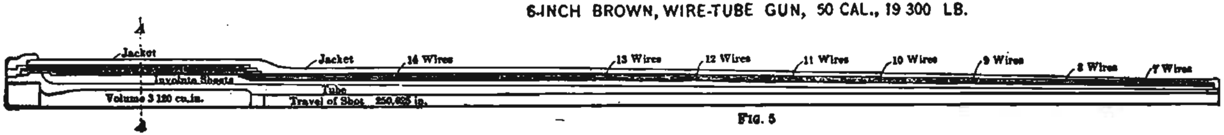


FIG. 5

of the older model, 34 calibers long, is composed of a tube and jacket and 17 hoops, the gun of later model, 40 calibers long, is composed of tube and jacket and but 7 hoops. The reduction in the number of the hoops by increasing their lengths has been made possible by the great advances that have been made in recent years in the production of large masses of steel of the requisite high quality. The improvement has been largely due to the demand of the Ordnance Department, and to the stringent and increased requirements in successive specifications for gun forgings.

By the increase in the size of the hoops there has been gained, in addition to ease and economy of manufacture, largely increased longitudinal strength and stiffness in the gun, which permits the construction of a longer gun without the tendency to droop at the muzzle.

The *D* hoop shown in Fig. 2, page 238, locks together the jacket and the C_1 hoop; and these, bearing against shoulders on the tube, in rear and in front, hold the tube firmly in place. The space behind the *D* hoop, left to accommodate the increase of length of the hoop when heated for shrinking, is filled with a steel filling ring as noted in the 1888 model. The joint between the C_1 and C_2 hoops is coned, as shown exaggerated in Fig. 52. Four securing pins passing through the C_2 hoop near the muzzle assist in preventing forward movement of the hoops under the vibration set up in the gun by the shock of discharge.

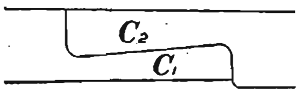


Fig. 52.

As the metal at the muzzle receives support from one side only the gun is thickened there to make the section of equal strength with those near it. The thickening of the metal produces what is called the swell of the muzzle.

141. Operations in Manufacture.—The steel forgings from which the parts of the guns are made are manufactured by private concerns and are delivered rough bored and turned to within about 3/10 of an inch of finished dimensions.

As the parts of the gun are of a general cylindrical form the principal operations in preparing them for assembling are the operations of boring and turning.

In making long bores of comparatively small diameter, as in the tubes of guns, special tools are necessary in order to insure straightness of the bore.

The tube is carefully mounted in the lathe and so centered that any bending or warping that may exist in the long forging will be wholly removed in the operations of boring and turning. The bore is started true with a small lathe tool and continued for a length of about three calibers. The tool shown in Fig. 53 is then

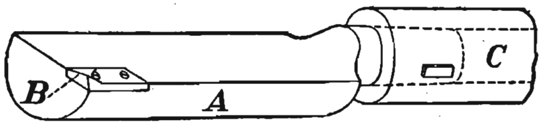


FIG. 53.

used to continue the bore. This tool, called a reamer, has a semi-cylindrical cast iron body, or bit, *A*, carrying the steel cutting tool *B*. It is supported in the boring bar *C*, which is pushed forward by the feed screw of the lathe. The semi-cylindrical bit exactly fits in the bore already started. As the tube rotates, the pressure against the cutting edge *B* forces the bit against the bottom of the bore. This together with the length of the bit prevents deviation of the cutting edge as the tool advances down the bore, and makes the bore a true cylinder.

In order to make the surface of the bore smooth and uniform the light finishing cuts are made with a packed bit or wood reamer, shown in Fig. 54.

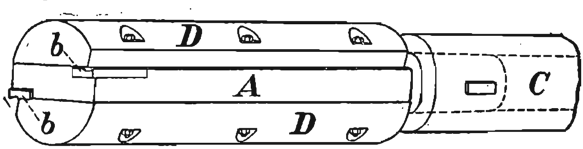


FIG. 54.

The cast iron bit *A* carries two cutters, *b*, at opposite extremities of a diameter. Two pieces *D* of hard wood packing are bolted to the bit and serve to guide the cutters accurately. The tool fits tightly in the bore. The light cut taken and the pressure of the oiled wood packing leaves the surfaces of the bore very smooth and uniform and highly polished.

142. Gun Lathe.—The general features of the lathe, by means of which the larger forgings are bored and turned, are shown in

Fig. 55. The principal parts are: the bed, B, made very strong and much larger than for the ordinary lathe; the head stock and cone pulley C; the face plate F, to which the work T is clamped; the slide rest S, carrying a cutting tool; the back rests R, forming intermediate supports for the tube T; the boring bed O, supported on the bed proper, B, and carrying the boring bar P with its tool Q; the feed screw V, which lies inside the boring bar P; and the gears W, by which the feed screw is driven.

Motion is communicated to all the parts by the belt X, acting on the cone pulley. This causes the face plate and tube to rotate and also communicates motion to the long shaft, not shown in the figure, upon the end of which is the lower gear wheel W''. The motion is transmitted through W' to W, and thence to

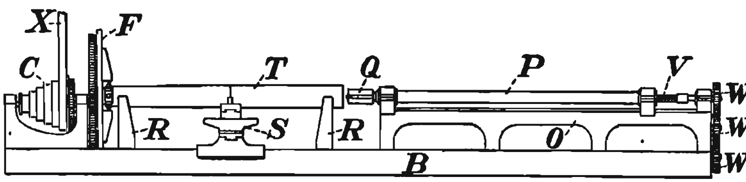


Fig. 55.

the feed screw V. By changing the gears any ratio between the velocity of rotation of the tube and that of translation of the tool Q can be obtained. It is necessary that there be only one source of motion, since if the feed screw or slide rest were driven independently of the cone pulley which drives the work, a change in the speed of one would not cause a corresponding change in the speed of the others, and damage to the tools, the work, or the machine might result.

The slide rest S is driven by a second feed screw not shown.

The back rests R can be adjusted to any diameter of forging.

The lathe is supplied with an oil pump, by means of which a stream of oil is forced into the bore while the work is in progress. The chips or cuttings come out at the opposite end of the tube from that at which the tool enters.

Boring and Turning Mill.—The smaller hoops are usually machined on a vertical boring and turning mill, shown in Fig. 56. The work is bolted to the slotted table t. The cutting tools are carried in the tool holders o at the lower ends of the boring bars *a*. In the illustration one of the boring bars is shown in a vertical position and the other inclined. The table rotates, carrying the work with it. By means of the feed mechanism the cutting tools are fed either vertically or horizontally or at an angle as desired.

On account of the greater difficulty of boring than of turning to prescribed dimensions, the bored shrinkage surface is always finished first. Allowance may then be made in turning the male surface for any slight error in the diameter of the bored surface. The desired shrinkage is thus obtained.

143. **Assembling.**—The interior diameter of the jacket, when bored to finished dimensions, is less than the exterior diameter of the tube by the amount of the shrinkage prescribed. In order to assemble the jacket on the tube it is therefore necessary to expand the jacket sufficiently to permit its being slipped over the tube into its place. The expansion is accomplished by heat. The jacket is placed in a vertical furnace heated by oil or other fuel to a temperature varying from 600 to 750 degrees Fahrenheit, depending upon the thickness of the forging and the amount of expansion required. Great care is exercised that the heating shall be uniform throughout the length of the forging. The requisite expansion, which in general is about 0.004 of an inch per inch of diameter, is determined by a gauge set to the exact diameter to which the bore should expand. The gauge, held at the end of a long rod, is tried in the bore of the forging in the furnace. When it enters the bore properly the requisite expansion has been attained. Care is taken to avoid overheating which might injuriously affect the qualities of the metal.

When the desired expansion has been attained the jacket is hoisted vertically from the furnace. It will be seen by reference to the figures on page 238 that the shoulders on the tubes of the 12-inch guns are so arranged that the jacket must be slipped over the breech end of the tube, while the arrangement of the shoulders on the wire wrapped tubes of the 6-inch guns require that the tube be inserted into the breech end of the jacket.

The method of assembling is called *breech insertion* or *muzzle insertion* according as the breech or muzzle end of the jacket first encircles the tube. For breech insertion, as in wire wrapped

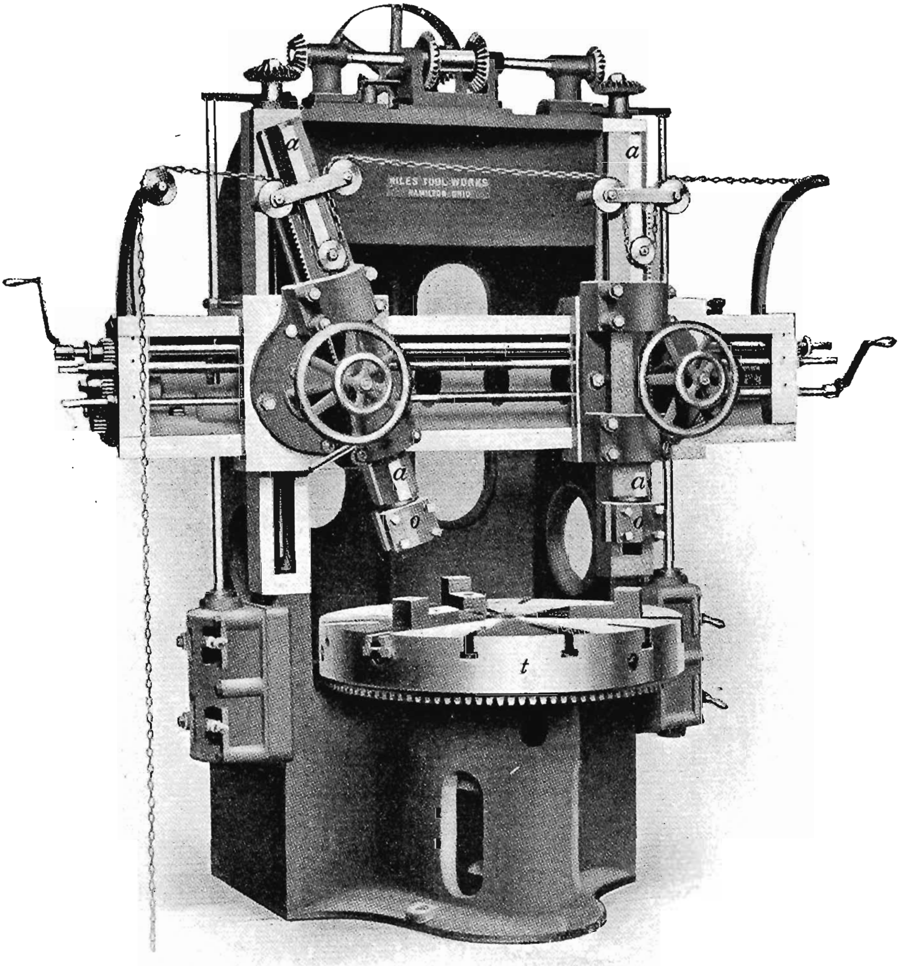


Fig. 56.—Vertical Boring and Turning Mill, 37-inch.

Page 242b
Back of Figure 56
Faces Page 243

guns, the jacket after being lifted from the furnace is placed upright on a strong iron shelf supported at the mouth of a deep pit, Fig. 57. The tube is then carefully lowered into its seat in the jacket. For muzzle insertion, as in the 12-inch guns, the tube is supported upright in the pit, the breech end up, and the jacket is lowered over the tube.

Cooling of the heated jacket is accomplished by means of sprays of water directed against the forging from an encircling pipe as shown at *D* in Fig. 58. The cooling is begun at the section of the jacket which it is desired should take hold of the tube first,

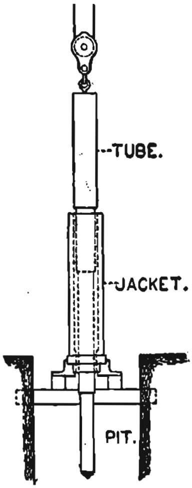


FIG. 57.

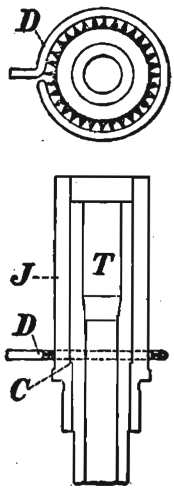


FIG. 58.

as at the shoulder *C*, Fig. 58. As the cooling of the remainder of the jacket progresses the metal is drawn toward the section first cooled, and thus a tight joint at the shoulder is insured. After the jacket has gripped at the shoulder the cooling pipe is moved very gradually upward toward the breech, care being exercised that the jacket shall grip at successive sections in order that longitudinal stresses due to unequal contraction may not be developed in the metal.

The shrinking on of hoops is conducted in practically the same manner as the shrinking of the jacket. When the hoops are small and can be handled quickly they are often assembled to the gun in a horizontal position. Cooling of the hoop is begun at the end toward the jacket, or toward the hoop already in place, in order that contraction shall take place in that direction and make a tight joint between the parts.

When the assembling of all the parts is completed the tube is finish smooth-bored and the exterior of the gun turned to prescribed dimensions.

144. Rifling the Bore.—The rifling of the bore is effected in the rifling machine, which is essentially similar to the boring and turning lathe previously described. The gun does not rotate in the rifling machine, but the cutting tool is given the combined movement of translation and rotation necessary to cut the spiral grooves in the bore. The rifling bar takes the place of the boring bar, *P* Fig. 55. The rifling bar, *m* Fig. 59, carrying at its forward

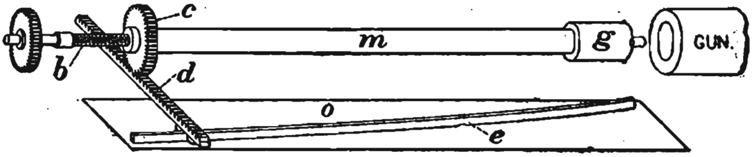


Fig. 59.

end the rifling tool *g* provided with cutters for the grooves, is moved forward and backward by means of the feed screw *b*. The desired motion of rotation is given to the rifling bar by means of the pinion *c* and the rack *d*, which engages on a guide bar *e* bolted to a table made fast to the side of the rifling bar bed. The bar *e* is flexible and is given the shape of the developed curve of the rifling. As the rack travels forward with the rifling bar it is forced to the left by the guide bar, imparting the proper amount of rotation to the rifling bar and cutting tools.

Cutting tools are carried at both ends of a diameter of the rifling tool. At the end of a cut the cutting tools are automatically withdrawn toward the center of the bar and the bar retracted for a new cut.

When a number of guns of the same design are to be manufactured, a spiral groove is cut in the rifling bar itself. A stud fixed in the forward support of the rifling bar works in the groove and gives to the bar the proper movement of rotation. The guide bar with rack and pinion is not then used.

MEASUREMENTS.

145. Necessity of Accurate Measurements.—In order that the gun may be assembled with the required shrinkages the surfaces of the various cylinders composing the gun must be accurately turned and bored to the prescribed dimensions. The dimensions of all parts of the gun must be in accord with the design. The tolerances, or allowed variations from prescribed dimensions, are in general two thousandths of an inch for the diameters of shrinkage surfaces, and one hundredth of an inch in lengths.

Accurate measurements of the various dimensions of every part of a gun are therefore essential.

The exact length of any dimension of a forging is usually obtained by means of one of two instruments, called measuring points and calipers. The points of the instrument used are adjusted until the distance between them is the exact length of the dimension to be determined. The length between the points of the instrument is then measured in a vernier caliper.

Vernier Caliper.—The vernier caliper is shown in Fig. 60. The steel blade *a* graduated in inches and decimal divisions is pro-

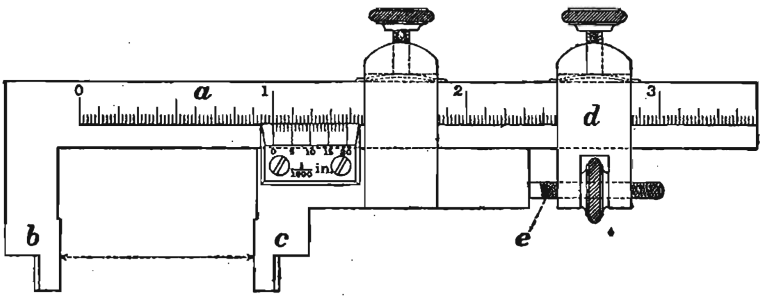


FIG. 60.

vided with a fixed jaw *b* and movable jaw *c*. By means of the clamp *d* and small motion screw *e* the movable jaw may be brought accurately to any distance from the fixed jaw. The distance between the jaws is read from the scale and vernier. The least reading of the vernier is one thousandth of an inch. The ends of the jaws *b* and *c* are usually one eighth of an inch wide so that the measurement between their outer edges is a quarter of an inch greater than the reading of the scale.

Measuring Points.—The measuring point consists ordinarily of a rod of wood into the ends of which are set metal points, Fig. 61. One of these points at least is capable of a small movement out and in. The rod is of wood in order that the heat of the hand may not affect its length. One of the metal points may

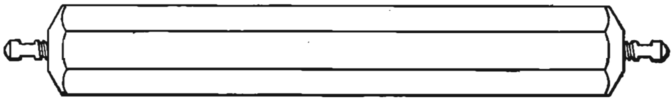


FIG. 61.

be provided with a micrometer head from which the movement of the point out and in from a fixed length may be read at once.

Measuring points are used in determining interior diameters and the distance between surfaces that face each other. In measuring an interior diameter at any point in a bore, as at *a*, Fig. 62, one end of the measuring point is placed at *a*. As the diameter is the longest line in the cross section, the end *b* must be moved out until the rod cannot be revolved about the end *a* in the plane of the cross section.

To determine, when touch is made at *b*, that the rod is truly in the cross sectional plane the rod must be revolved in a direction at right angles to this plane, for as seen in Fig. 63 the diameter is

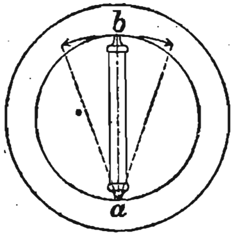


FIG. 62.

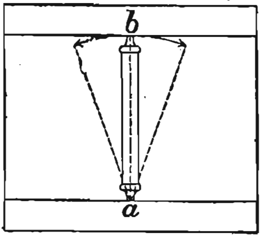


FIG. 63.

the shortest line in the longitudinal plane, and the rod when set to the proper length must be capable of revolution in that plane, touching only at the point *b*. In other words the measuring point has the length of the diameter when the measuring point is incapable of revolution in the cross sectional plane and at the same time capable of revolution in the longitudinal plane.

Similarly when applying the rod to the vernier caliper to read the length of the rod, the movable jaw of the caliper must be brought to such a distance from the fixed jaw that the rod when revolved about one end in two planes at right angles to each other will touch at one point only in each plane of movement. The length of the interior diameter may then be correctly read from the scale of the caliper.

In making measurements the sense of touch is depended upon to determine when contact exists. When the distance that separates a measuring point from a surface is so minute that light cannot be seen between the point and the surface, the lack of contact can be unerringly detected by the touch.

146. The Star Gauge.—In the case of long tubes all parts of which are not readily accessible some means must be adopted of making the measurements at a distance from the operator. The instrument used for this purpose is called a star gauge.

Its general features are shown in Fig. 64. The long hollow

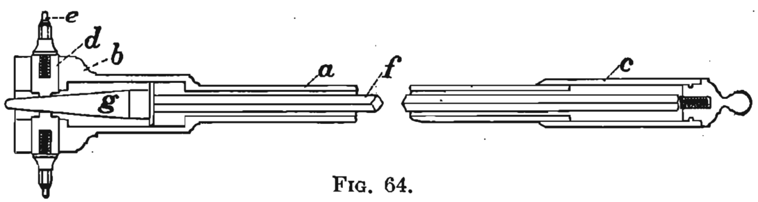


FIG. 64.

rod or staff *a* carries at its forward end the head *b*. Embracing the rear end of the staff is the handle *c* to which is attached the square steel rod *f*. The handle has a sliding motion or screw motion on the end of the staff, and any movement of the handle is communicated through the rod *f* to the cone *g* in which the square rod terminates at its forward end.

The head *b* has three or more sockets, *d*, which are pressed inward upon the cone *g* by spiral springs not shown in the figure. Into these sockets are screwed the star gauge points *e*. Three points are generally used, 120° apart. The points are of different lengths for the different calibers to be measured.

Any movement of the cone forward or backward causes a corresponding movement of the measuring points out or in. The cone has a known taper, and the change in its diameter under the measuring points due to any movement of the handle is marked on a scale at the handle end of the staff. The handle carries a vernier by means of which the scale may be read to a thousandth of an inch. The reading of the scale is the change in length of the diameter that is measured by the points when the handle is at the zero mark.

The staff *a* and rod *f* are made in sections, usually 50 inches long, so that the gauge may be given a length convenient for the measurement of any length of bore.

The star gauge is set for any measurement by means of a standard ring of the proper diameter. The standard rings are of steel, hardened and very carefully ground to the given diameter. If it is desired to measure a 10-inch bore for instance, measuring points of the proper length are inserted in the sockets *d* of the star gauge. The 10-inch ring is held surrounding the points, and the handle *c* of the star gauge is pushed in until the points touch the inner surface of the ring. The handle is then adjusted until the reading of the scale is zero. The instrument is now ready for use.

The gun or forging whose bore is to be measured is supported so that its axis is horizontal. The star gauge is also carefully supported in the axis of the bore prolonged, and in the bore when necessary. The distance of the measuring points from the face of the bore is read from a scale of inches marked on the staff. At each selected position of the gauge the handle is pushed forward until the measuring points touch the surface of the bore. The difference between the diameter of the bore at this point and the standard diameter for which the gauge is set is then read from the scale at the handle in thousandths of an inch.

147. Calipers.—For the measurement of outside diameters calipers are used. The ordinary calipers for measurement of short exterior lengths are shown in Fig. 65. For the measurement of the large exterior diameters of gun forgings, calipers as shown in Fig. 66 are employed. One of the points *a* or *b* is movable and may be provided with a micrometer head. As in the case of interior measurements the caliper must be revolved in two planes about the end that is held at the point from which the diameter is to be measured, and the distance between the points of the caliper must be adjusted until touch is made at one point only in each plane.

The distance between the points of the caliper, as determined by the length between the outer edges of the jaws of the vernier caliper, is then the true length of the exterior diameter.

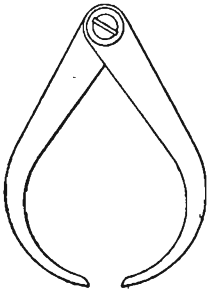


FIG. 65.

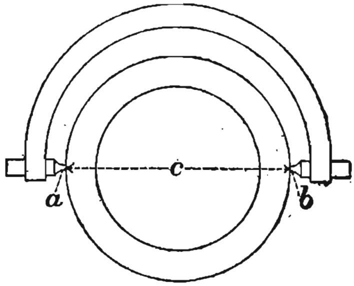


FIG. 66.

The frames of the large exterior calipers required for gun measurements must be made heavy in order that the calipers shall have sufficient stiffness and not be subject to change of form. In

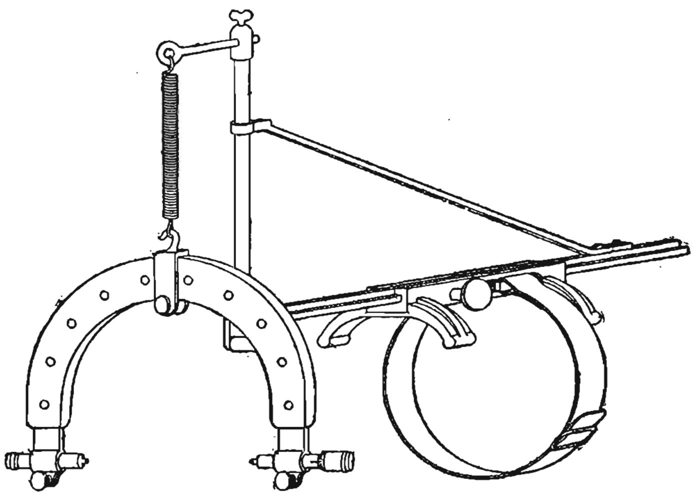


FIG. 67.

use these calipers are therefore supported from above by a spring connection with a frame that is secured to the piece being measured, Fig. 67.

Standard Comparator.—In order to insure accuracy in all measurements, all measuring scales are compared with a common standard. For this purpose the standard comparator is provided.

A heavy metal bar very accurately graduated in inches and decimal divisions rests in a very stiffly constructed cast iron bed. Sliding heads on the bed, one of which carries a reading microscope, may be set accurately at any determined distance apart.

RIFLING.

148. Purpose.—The purpose of the rifling in a gun is to give to the projectile the motion of rotation around its longer axis necessary to keep the projectile point on in flight. The rifling consists of a number of spiral grooves cut in the surface of the bore. The soft metal of a band on the projectile is forced into the grooves by the pressure of the powder gases, whereby a rotary motion is communicated to the projectile.

Twist.—The twist of the rifling at any point in the bore is the inclination of the tangent to the groove, at that point, to the axis

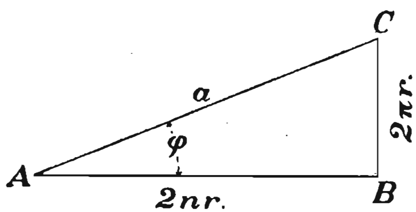


FIG. 68.

of the bore. Twist is usually expressed in terms of the caliber, as one turn in so many calibers. If the inclination of the groove is constant the rifling is of uniform twist. If the inclination of the groove increases from breech to muzzle the rifling has an increasing twist.

Let a, Fig. 68, be the development of one turn of a groove with uniform twist, n the twist in calibers, or the number of calibers in which the groove makes a complete turn, and r the radius of the bore. Then $AB=2nr$, $BC=2\pi r$, and we have

$$\tan\phi=2\pi r/2nr=\pi/n \qquad (61)$$

for the value of the tangent of the angle of the rifling. For the groove with increasing twist ϕ is variable, but at any point its tangent is π/n.

Let v denote the velocity of the projectile at any point of the bore, in feet per second,

ϕ the angle made by the tangent to one of the grooves with an element of the bore,

ω the angular velocity of the projectile,

r the radius of the bore, *in feet.*

The velocity of the projectile along the groove is the resultant of two components, v and $v \tan \phi$, at right angles to each other.

The actual velocity of rotation of a point on the surface of the projectile is $\omega r = \omega d/2$, and this is equal to the component $v \tan \phi$. Therefore

$$\omega d/2 = v \tan \phi \quad \text{and} \quad \omega = 2v \tan \phi / d \tag{62}$$

Increasing Twist.—When the twist is uniform the inclination of the grooves to the axis of the bore is the same throughout the length of the bore, and therefore it is greater at the breech than the inclination of the grooves of an increasing twist that is equal to the uniform twist at the muzzle. The pressure required to cause the projectile to take the grooves is therefore greater in the case of the uniform twist, and the greater resistance offered to the starting of the projectile serves to increase the maximum pressure in the gun. The total energy absorbed by the projectile in taking the rifling is greater with an increasing twist than with the uniform twist on account of the increased frictional resistance due to the continual change in the inclination of the grooves. The total energy absorbed is, however, small compared with that required to give the projectile its velocity of translation.

149. Equation of the Developed Curve of the Rifling.—If the twist increases from zero at the breech uniformly to the muzzle, the equation of the developed curve of the rifling will be of the form

$$y = ax + bx^2$$

which being differentiated twice gives

$$d^2y/dx^2 = 2b$$

That is, the rate of change in the tangent to the groove is constant.

A twist of this form would offer less resistance than the uniform twist to the initial rotation of the projectile. But to still further diminish this resistance, a twist that is at first less rapid than the uniformly increasing twist and later more rapid has been generally adopted for rifled guns. The equation of the semicubic parabola

$$x^{\frac{3}{2}} = 2py \tag{63}$$

is generally adopted for the developed curve of the rifling. The twist is assumed at breech and muzzle and the curve between these points is obtained from the above equation.

The tangent to the curve at any point makes with the axis of x an angle whose tangent is dy/dx. The value of the tangent of the angle at any point is π/n, see equation (61), n representing the twist in calibers, the number of calibers in which the groove makes a complete turn.

Therefore, differentiating equation (63),

$$dy/dx = \tan \phi = 3x^{\frac{1}{2}}/4p = \pi/n \tag{64}$$

Problem 1.—Determine the equation of the developed rifling curve, and the part of the curve to be used, for the 3 inch rifle, model 1905. The twist is 0 at the breech end, 1 turn in 25 calibers at a point 12.52 inches from the muzzle, and from this point uniform to the muzzle. The length of the rifled bore is 72.72 inches.

The twist at the breech is 0, or one turn in an infinite number of calibers. Therefore n in equation (64) is infinite, $\tan \phi$ is 0 and $x = 0$; and from equation (63) y is also 0. The origin of the curve is therefore at the breech.

At 12.52 inches from the muzzle, $x = 72.72 - 12.52 = 60.2$, and the twist $n = 25$.

Substituting these values in equation (64) and solving for p,

$$p = 3(60.2)^{\frac{1}{2}}25/4\pi = 46.31$$

Substituting in (63) we have for the equation of the developed groove of the rifling from the breech to a point 12.52 inches from the muzzle

$$x^{\frac{3}{2}} = 92.62y$$

and the part of the curve to be used lies between the origin and the ordinate for which the abscissa is $x = 60.2$. From this point to the muzzle the curve is a straight line making with the axis of x an angle whose tangent is $\pi/25$.

The curve is shown numbered 1 in Fig. 69.

150. Problem 2.—Determine the equation of the developed rifling curve, and the part of the curve to be used, for the 4.7 inch Armstrong gun, 50 calibers long. The twist is 1 turn in 600 calibers at the breech, and 1 turn in 30 calibers at the muzzle. The length of the rifled bore is 203.12 inches.

At the breech $n=600$ and $\tan\phi=\pi/600$

At the muzzle $\tan\phi=\pi/30$

The curve represented by equation (64) passes through the origin of coordinates.

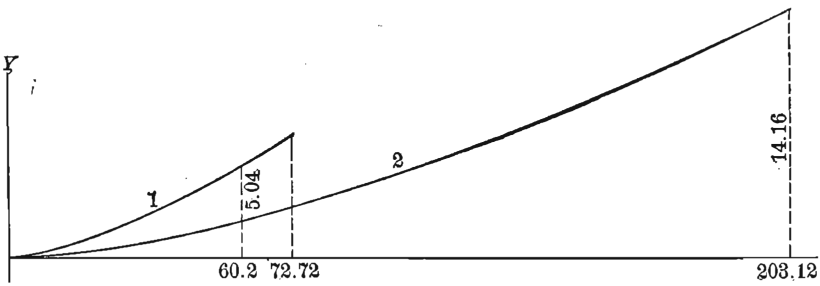


FIG. 69.

Let x_1 be the abscissa of the point of the curve at which the tangent is $\pi/600$. Then $x_2=x_1+203.12$ will be the abscissa of the point at which the tangent is $\pi/30$.

From equation (64)

$$\pi/600=3x_1^{\frac{1}{2}}/4p \qquad \pi/30=3(x_1+203.12)^{\frac{1}{2}}/4p$$

We have two equations involving x_1 and p. Solving we find

$$p=102.2 \qquad x_1=0.51 \qquad x_2=203.63$$

The equation of the developed curve of the rifling is, equation (63),

$$x^{\frac{3}{2}}=204.4y$$

And the abscissas of the extremities of the part of the curve to be used are the values determined for x_1 and x_2.

The curve is shown numbered 2 in Fig. 69.

Service Rifling.—An increasing twist is adopted for the guns in our service. In all guns of recent model the twist is one turn in 50 calibers at the breech, and increases to one turn in 25 calibers at a point about $2\frac{1}{2}$ calibers from the muzzle. The purpose of the uniform twist for a short length at the muzzle is to give steadiness to the projectile as it issues from the bore.

A right handed twist is used in all guns in our service.

The number of grooves depends on the caliber of the gun. In the siege and seacoast guns the number is six times the caliber of the gun in inches. Thus the 5 inch gun has 30 grooves and the 10 inch gun 60. The 3 inch field rifle has 24 grooves.

The shape of the grooves is shown in Fig. 70. The widths of

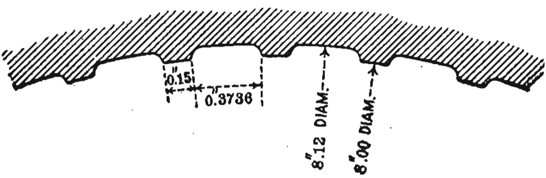


Fig. 70.

land and groove noted in the figure are the same for all guns of 5 inch caliber and greater. The depth of the groove varies from 0.03 of an inch in the 3 inch gun to 0.06 in the seacoast rifles, and 0.07 in the seacoast mortars.

A form of groove called the hook section groove, used in Navy rifles, is shown in Fig. 71. The view is from the breech end.

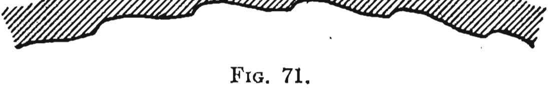


Fig. 71.

The driving edge of the groove makes a sharp angle with the surface of the bore, and the other edge has a gradual slope to that surface.

The depth of the groove in the larger naval guns is 0.05 of an inch.

In the service 30 caliber rifle the depth of the grooves is 0.004 of an inch. It is desirable in small arms to limit the depth of the grooves to the minimum, in order to lessen the thickness of barrel and to permit ready cleaning of the bore. There are four grooves each 0.1767 inches wide. The lands are one third as wide. The twist is uniform, one turn in 10 inches.

BREECH MECHANISM.

151. General Characteristics.—The breech mechanism comprises the breech block, the obturating device, the firing mechanism, and the mechanism for the insertion and withdrawal of the block.

The breech block closes the bore after the insertion of the charge and transmits the pressure of the powder gases as a longitudinal stress to the walls of the gun.

There are two general methods of closing the breech. In the first method the block is inserted from the rear. The block is provided with screw threads on its outer surface which engage in corresponding threads in the breech of the gun. In order to facilitate insertion and withdrawal of the block the threads on block and breech are interrupted.

The surface of the block is divided into an even number of sectors and the threads of the alternate sectors are cut away. Similarly the threads in the breech are cut away from those sectors opposite the threaded sectors on the block. The block may then be rapidly inserted nearly to its seat in the gun, and when turned through a comparatively small arc, say 1/8 or 1/12 of a circle, depending upon the number of sectors into which the block is divided, the threads on the block and in breech are fully engaged and the block locked.

In the second method a wedge-shaped block is seated in a slot cut in the breech of the gun at right angles to the bore, and slides in the slot to close or open the breech.

Variations of these two methods will be noted in the descriptions of the breech mechanism of some of the guns in service.

The breech block is usually supported in the jacket of the gun or in a base ring screwed into the jacket. The seat in the jacket being of greater diameter than could be provided in the tube, the bearing surface of the screw threads on the block is increased, and the length of the block may be diminished.

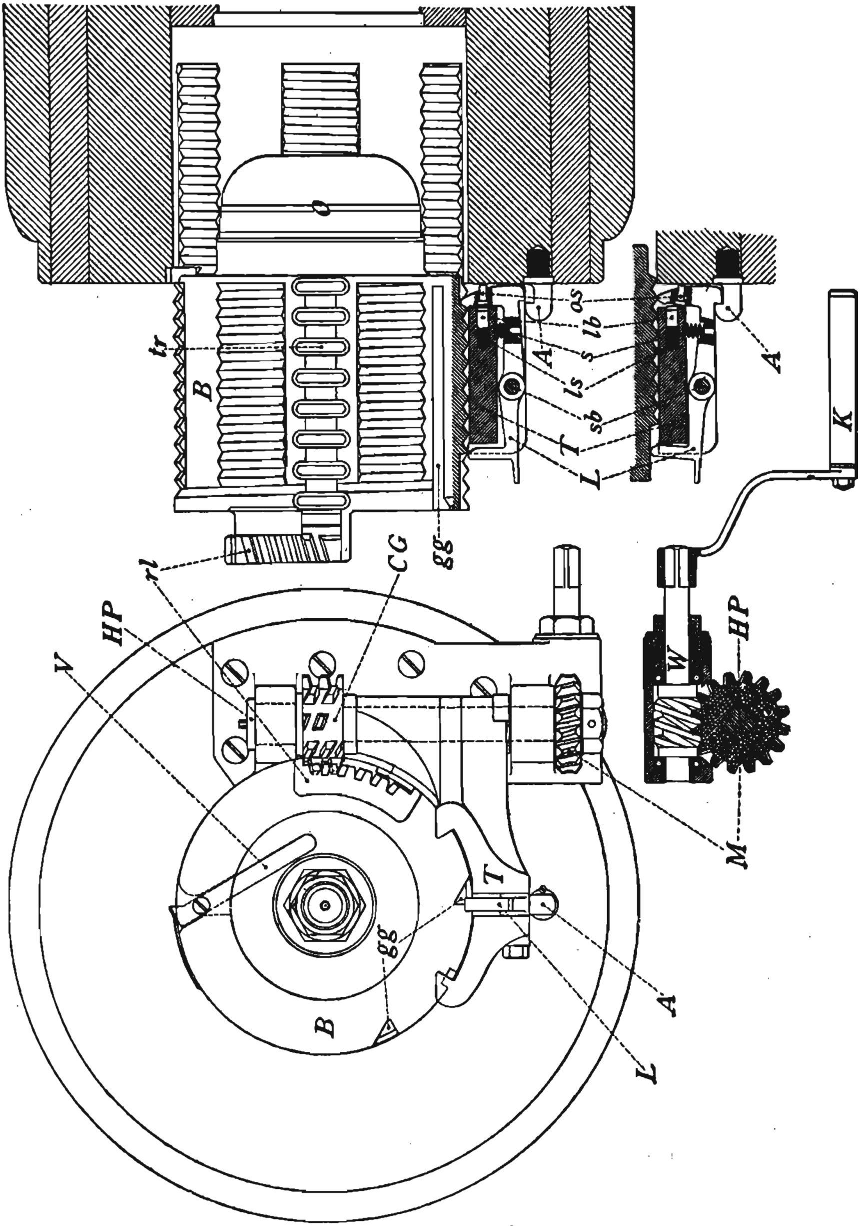


FIG. 72.—Breech Mechanism for Heavy Guns.

The Slotted Screw Breech Mechanism.—The slotted screw breech mechanism is better adapted than any other for use in heavy guns. It is also used in most of the field and siege guns of our service. The form used in the field and siege guns is described with the 3-inch field gun in Chapter VIII.

An example of the slotted screw breech mechanism as used in the heavier guns is shown in Figs. 72 to 74, which represent the breech mechanism of the 12-inch rifle. The breech block *B* has six threaded and six slotted sectors. When the breech is closed the threads on block engage with the threads in the breech. The breech is opened by turning the crank *K* mounted on the shaft *W*. The movement of the crank is transmitted through the worm gear to the hinge pin *HP*, and through the compound gear *CG* to the rotating lug *rl* formed on the rear of the block. The block is thus rotated one twelfth of a turn, and its threaded sectors then lie in the slotted sectors of the breech. Further movement of the crank causes the teeth of the compound gear *CG* to engage in the teeth of the translating rack *tr* cut in a slotted sector of the block. The block is thereby caused to slide to the rear on to the tray *T*, the guide rails of the tray engaging in the grooves *g g* in the block. When the block is sufficiently withdrawn the bottom of the block depresses the rear end of the tray latch *L* and lifts the forward end of the latch out of the catch *A*, where it has been held by the pressure of the spring *s*. The tray is now unlocked from the breech. The upper front toe of the latch *L* engages in a groove in the breech block, locking the block and tray together. The further action of the compound gear on the last teeth of the translating rack *tr* then causes the tray to swing to the right about the hinge pin, carrying the block clear of the breech. As the tray swings clear of the breech the locking bolt *lb* forces forward the operating stud *os* and enters a seat in the latch. The latch is thus locked in its raised position and secures the breech block against being pushed forward off the tray when open.

In closing the breech the operations are reversed in order. When the tray comes in contact with the face of the breech the operating stud *os* forces the locking bolt *lb* from its seat in the latch. The latch is depressed by the spring *s* and thus unlocks the block from the tray.

The two plugs shown in the obturator head of the breech mechanism, Fig. 74, are in the seats provided for the insertion of pressure gauges when it is desired to measure the pressure in the gun.

In recent mechanisms of this type there is added a locking device which locks the block in position when closed and insures against the opening of the block by the pressure of the powder gases. The locking bolt is withdrawn by hand before opening the block.

152. Bofors Breech Mechanism.—The mechanism shown in Figs. 75 to 78, known as the Bofors breech mechanism, is most suitable for guns of medium caliber. It is applied to the 6-inch gun in our service. The block, *b* Fig. 75, is ogival in shape and

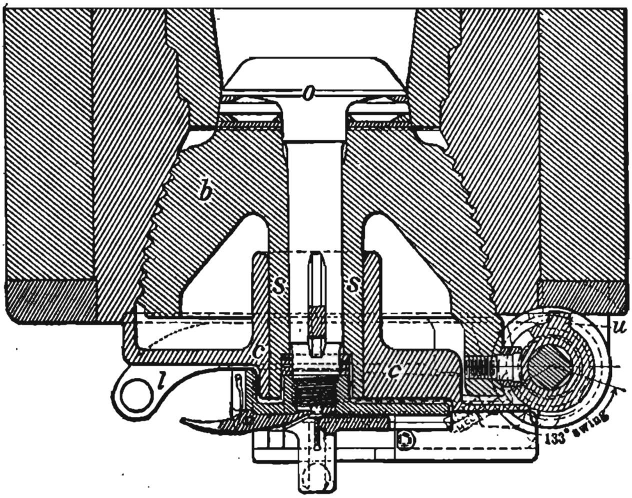


FIG. 75.

has six threaded and six slotted sectors. With the ogival shape a very small retraction to the rear is necessary before the block may be swung open. In the 6-inch gun this retraction is 1.2 inches, just sufficient to withdraw the obturator *o* from its seat in the bore. The block is supported when the breech is opened by the block carrier *c* provided with a central tube which embraces a spindle *s* formed in the block.

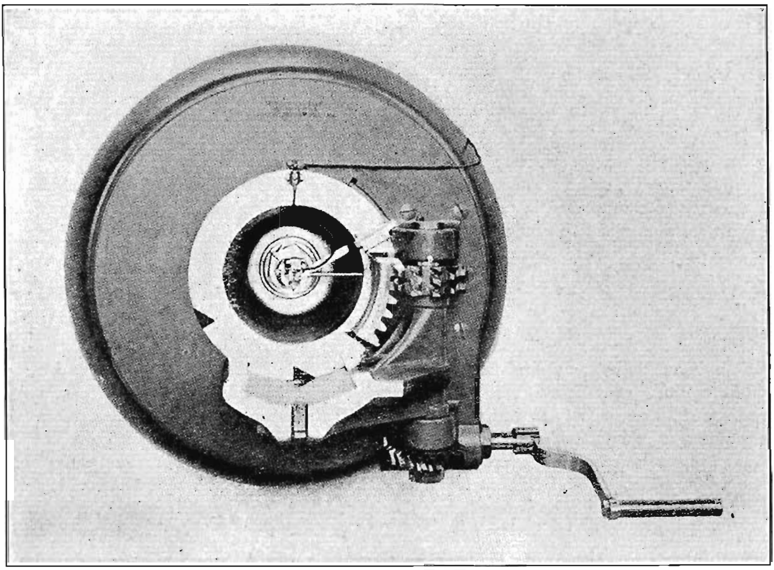


Fig. 73.—Closed.

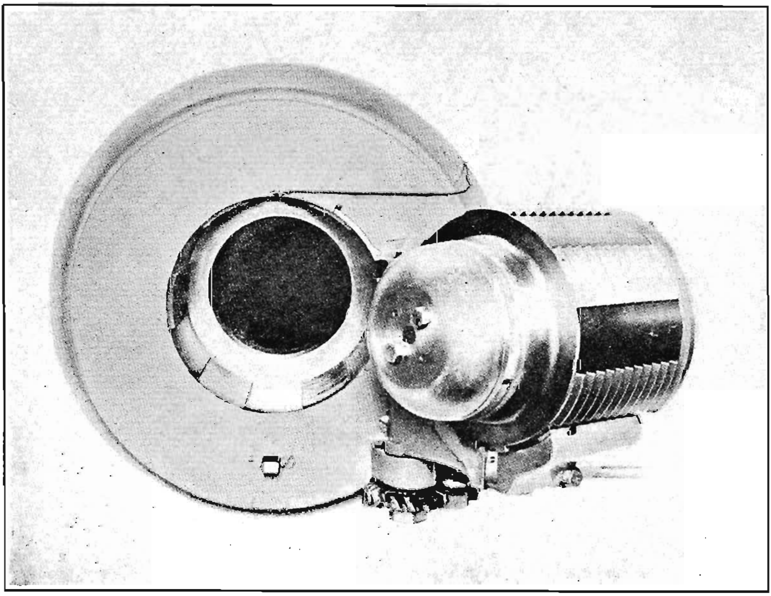


Fig. 74.—Open.

Breech Mechanism for Heavy Guns.

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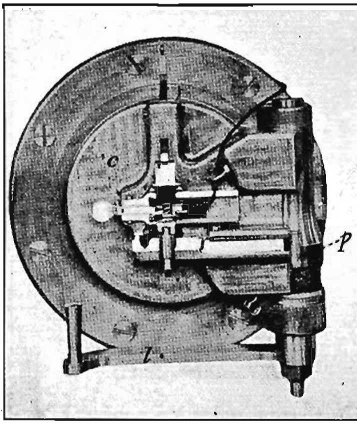

Fig. 76.—Closed.

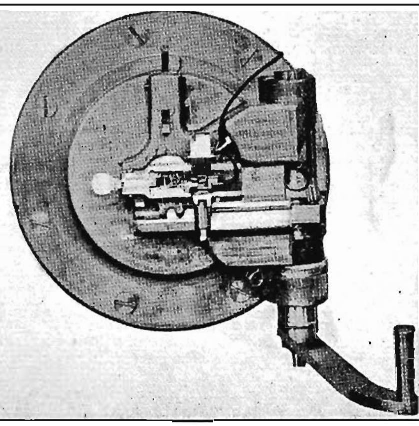

Fig. 77.—Block Unlocked, Ready to Swing Open.

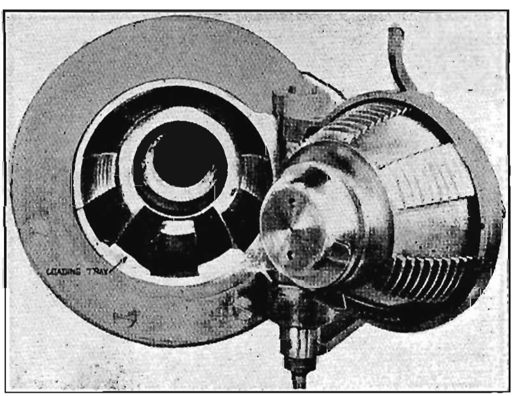

Fig. 78.—Open.

Bofors Rapid Fire Breech Mechanism.

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This mechanism is not applicable to the larger guns because the greater weight of the breech blocks in these guns requires better support than can be conveniently given by this method.

The mechanism is actuated by means of the lever *l*, Fig. 76, which is attached to the lower end of the hinge pin. A spool *p* mounted on the hinge pin has teeth cut near its lower end which engage in the rack *r*. The rack slides in a horizontal groove cut in the block carrier *c*, and the teeth at its left mesh with corresponding teeth on the hub of the breech block which projects through the rear face of the carrier.

When rotation of the block is completed a lug, *u* Fig. 75, on the spool engages in a slot at the rear end of the block and translates the block slightly to the rear. Before this translation is complete the block carrier is unlocked from the gun, and swings to

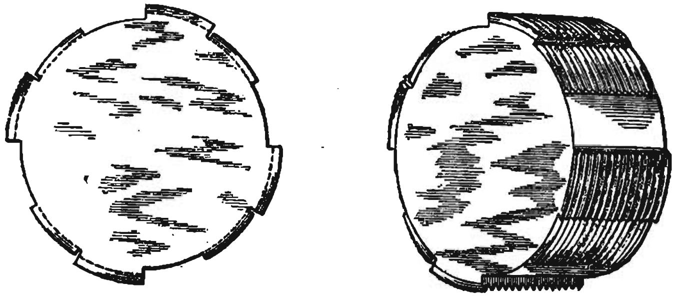

Fig. 79.

the rear with the block, fully uncovering the bore. The loading tray, shown in Fig. 78, the purpose of which is to protect the threads of the breech from injury as the shot is put into the bore, remains permanently in the breech. When the block is entered and rotated the tray is pushed aside by the threads on the block until it covers the slotted sector. On opening the block it is brought back into the position shown.

In the breech mechanism shown in Fig. 74 the loading tray is a separate piece placed in the breech by hand when loading, and removed before closing the block.

153. **The Welin Breech Block.**—The Welin breech block, largely used in naval ordnance, has the threaded sectors arranged in steps at different distances from the center of rotation, as shown

in Figs. 79 and 80. By this means the threaded area may cover two thirds, three fourths, or even a larger portion of the surface of the block. A large increase in threaded area is thus secured over that obtained on a cylindrical block with alternate threaded sectors, and the block may therefore be made smaller. The amount of rotation required in locking and unlocking is also diminished, one twelfth of a turn sufficing for the block shown in Fig. 79, and one sixteenth for the block of Fig. 80.

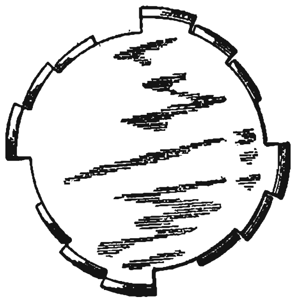

FIG. 80.

Obturation.—There must be provided at the breech of the gun some device that will prevent the powder gases from passing to the rear into the threads and other parts of the breech mechanism. If any passage is open to the gases they are forced through it with great velocity by the high pressure existing in the bore. Their velocity together with their high temperature gives to them great erosive power, and the threads and other parts of the breech mechanism subject to their action are eroded, channeled, and worn away to such an extent that the breech mechanism is soon ruined and the gun is rendered useless.

In guns that use fixed ammunition the obturation is performed by the cartridge case, which expands under the pressure in the bore to a tight fit against the walls of the gun. The breech mechanism of these guns contains, therefore, no obturator parts.

With the slotted screw breech block two systems of obturation are used. They are known by the names of their inventors, DeBange and Freyre.

154. The DeBange Obturator.—This system is in the most general use. It is seen at *o*, Figs. 72 and 75, in the breech mechanisms already described. The details are shown in Fig. 81. The obturator consists of the steel mushroom head *h* with the spindle *s*, the pad *p*, the split steel rings *r*, and the steel filling-in disk *d*. The pad *p* is made of asbestos, tallow, and paraffine or other substance, that together form a plastic mixture that melts only at a high heat. The ingredients are mixed and then pressed into shape under a hydraulic press and protected by a cover made of canvas or of asbestos wire cloth. The split rings, *r* Fig. 81 and

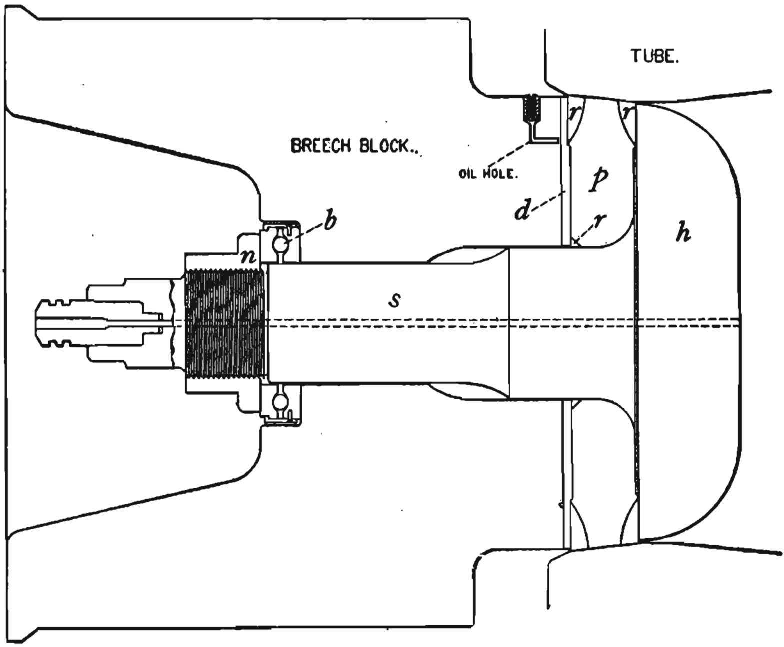

Fig. 81.

Fig. 82, are hardened, and their outer surfaces, which are coned toward the front, are very carefully ground, so that their diameters when the rings are free are 0.01 of an inch larger than the diameters of the conical seat in the bore. The edges of the rings therefore always bear against the walls of the bore.

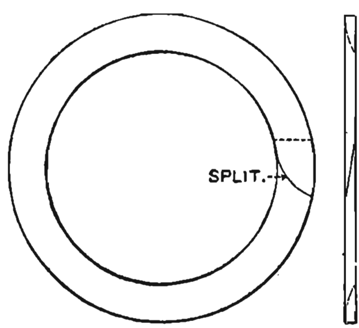

Fig. 82.

The pressure of the gases against the mushroom head compresses the elastic pad and further presses the split rings against the walls of the bore, thus effectually preventing the passage of gas to the rear.

The smaller split ring surrounding the spindle serves to prevent escape of the pad composition between the filling-in disk and the spindle.

The spindle *s* passes through a central hole in the breech block. The obturator parts are held in place by the split nut *n* clamped on the spindle. The nut bears against a shoulder in the block through the ball bearing *b*. It will be seen that the breech block may rotate independently of the obturator parts, so that in opening the breech the rotation of the block is not affected by any sticking of the obturator to its seat in the gun. On retraction of the block the obturator is readily withdrawn from its conical seat.

A vent is drilled the full length of the obturator spindle to afford a passage for the flames from the primer to the powder charge in the gun. The two grooves at the rear end of the spindle serve for the attachment of the firing mechanism.

The Freyre Obturator.—The Freyre obturator shown in Fig. 83 is used in the 3.6 inch field mortar. The head *g* is cone shaped.

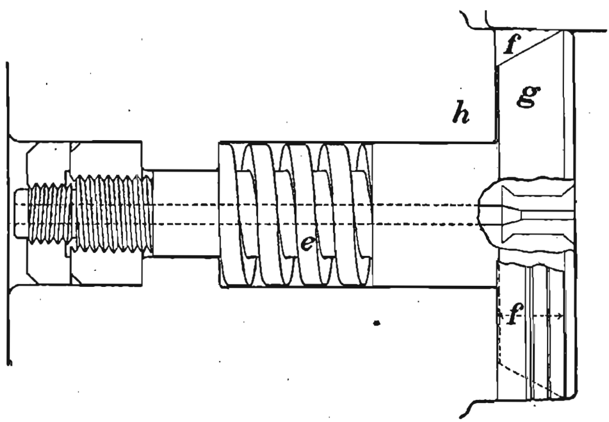

FIG. 83.

In rear of it resting against the head of the breech block *h* is the cone shaped steel ring *f*. The head *g* is constantly pressed forward by the spring *e*. Under the action of the powder pressure the head is forced to the rear and expands the ring *f* against the walls of the bore.

With this obturator the breech mechanism is comparatively short and light in weight, which is an important advantage in a field mortar. The obturator ring with its thin front edge is, however, readily subject to accidental injury, which would render the obturation imperfect.

155. Firing Mechanism.—A seat for the firing mechanism is formed on the rear end of the obturator spindle by two grooves, *g* Fig. 84, cut in the spindle. A hinged collar *k* embraces the end of the spindle. The housing *h* screws over the collar and is locked

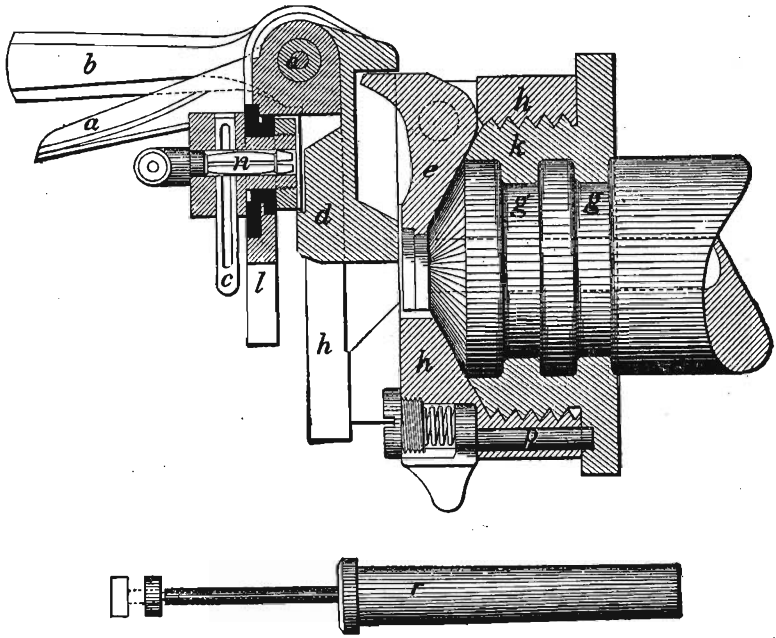

Fig. 84.

to it by the spring pin *p*. The ejector *e* pivoted in the housing has at its lower end a forked seat for the head of the primer. Projecting ribs on the front face of the housing form guides for the slide, *d* Fig. 84 and Fig. 85. The slide is moved up or down by means of the handle *b*, the catch lever *a* being first pressed to release a holding catch. Pivoted at *o* in the slide is the slotted firing leaf *l*, which carries the insulated brass contact clip *c* and is provided with an eye into which the hook of the lanyard engages.

The slide being at its uppermost position, the primer *r* is inserted in the vent in the obturator spindle, the head of the primer resting in its seat in the ejector. The slide is then pushed down. The firing leaf *l*, by means of the slot, embraces the insulated primer wire just in front of the button at its outer end. The two halves of the contact clip *c* spring apart and embrace the uninsulated button.

If the breech is closed, a pull on the lanyard rotates the firing leaf *l* about its axis *o*, drawing out the primer wire and firing the primer by friction; or the closing of the electric circuit, which enters the mechanism through the electric terminal *n*, will fire the primer electrically. The electric current passes through insulated parts to the platinum firing bridge inside the primer and thence through the body of the primer to the metal of the gun and to the ground.

Firing by either of these methods cannot be accomplished unless the slide *d* is all the way down and the breech is fully closed.

A safety lug on the right side of the housing engages in a groove in the firing leaf and prevents the latter being drawn to the rear before the slide is all the way down. The contact clip engages the primer button only in the last part of the downward movement of the slide.

The inner end of the safety bar, *s* Fig. 85, also engages the firing leaf. The outer end of the safety bar embraces a stud projecting from the safety bar slide, *i* Fig. 87, and the safety bar slide carries at its outer end a stud that engages in a groove cut in the gun. The groove is so shaped as to withdraw the safety bar only at the last part of the movement of the block in closing. At this moment also the parts of the electric circuit breaker, fixed one to the block and the other to the gun, Fig. 87, come into contact.

It will be seen therefore that the primer cannot be fired until the breech block is locked.

We have seen that the breech block rotates independently of the obturator spindle. In order then that the firing mechanism may always be in an upright position when the breech is closed, a guide bar, *m* Fig. 87, fixed at one end to the housing and at the other end to the block, causes the mechanism to rotate on the spindle with the block.

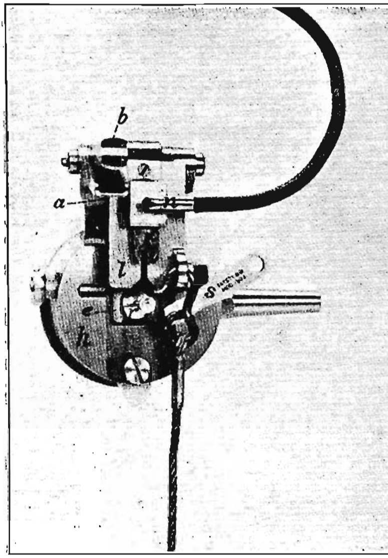

FIG. 85.—Slide Raised and Primer Inserted.

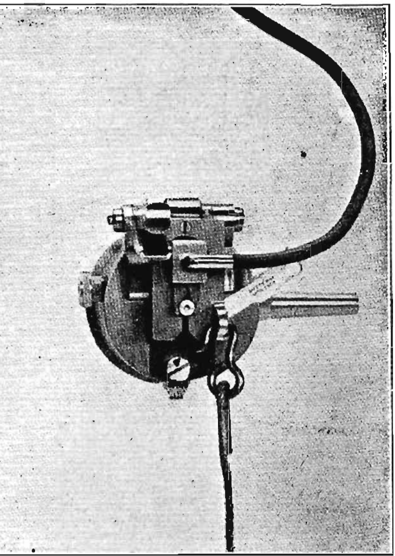

FIG. 86.—Slide Lowered Ready for Firing.

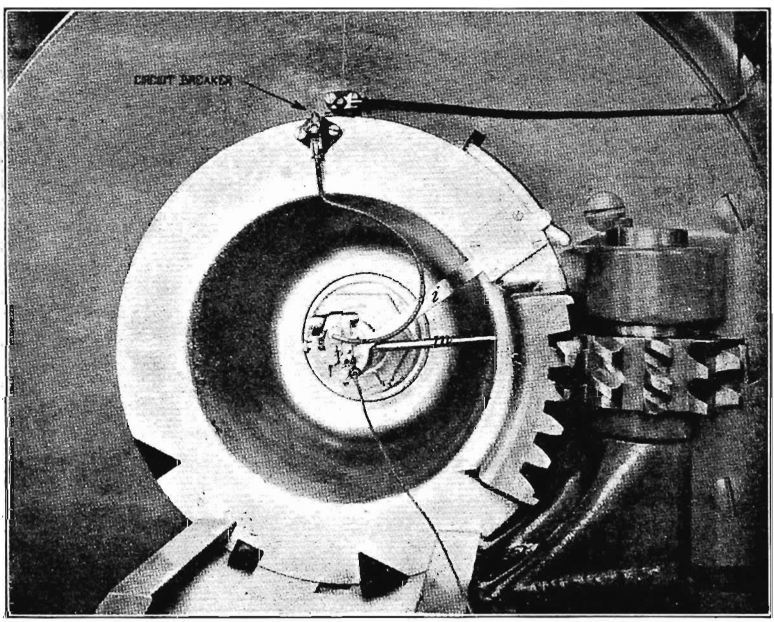

FIG. 87.—Breech Partially Unlocked. Safety Bar Forced in by Cam Slot, and Electric Circuit Broken.

FIRING MECHANISM FOR HEAVY GUNS.

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The fired primer is ejected by lifting the slide. The lug on the slide, *d* Fig. 84, strikes the upper part of the ejector lever, giving to the lower end a sharp movement to the rear, which throws the primer clear of the piece.

156. Sliding Wedge Breech Mechanism.—The method of closing the breech by means of a sliding wedge-shaped block is used principally by Krupp, and to some extent by other makers. The jacket of the gun, *a* Fig. 88, extends to the rear of the tube, and the bore of the gun is continued through the extension. A slot cut transversely through the jacket just in rear of the tube forms a seat for the sliding breech block *k*. The front surface of the slot is a plane surface perpendicular to the axis of the bore, the rear surface is cylindrical and inclined to the axis of the bore. Two guides *b b′* similarly inclined guide the breech block in its movements. The breech block is of the same shape as the slot and slides in and out to close and open the breech. The greater part of the movement of the block is accomplished rapidly by means of the translating screw *c*, which is held in two bearings at the ends of the block and works in a half nut *d* on the gun. The screw is turned by means of the handle *e*, which is removed from the position in which it is shown and applied to the end of the screw *c*. The final movement in closing and the initial movement in opening are effected more slowly and more powerfully by the locking screw *g*. A nut *f* carried on the locking screw locks the block when closed.

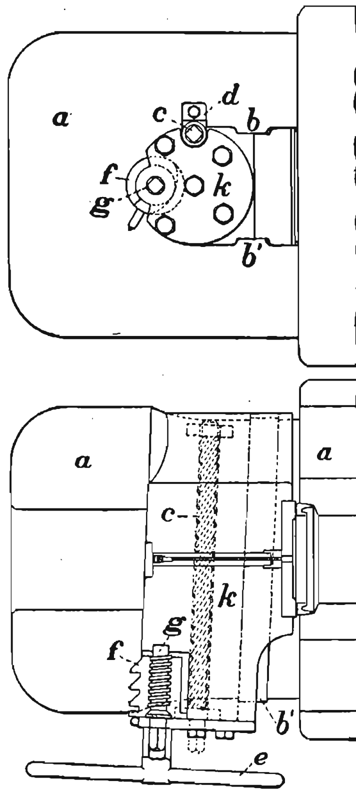

Fig. 88.

Obturation.—Obturation is effected with the sliding breech block by means of a steel obturator plate, *b* Fig. 89, carried in the block, and a steel cup-shaped ring, *a*, called the Broadwell ring, seated in the end of the bore. The pressure of the gases forces the ring back tightly against the plate and at the same time presses the thin lip *c* against the walls of the bore. The grooves shown in the rear surface of the ring serve as air packing and also to collect any dirt that may be on the surface of the plate. The hollow *e* in the plate also serves to collect fouling and to remove it from the bearing surface. The plate is forced tightly against the ring by the last movement of the locking screw in closing.

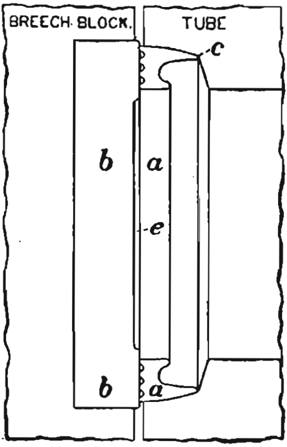

FIG. 89.

This mechanism is better adapted to small than to large guns. The light breech block of a small gun may be pushed to its seat by hand. Only a limited screw motion is then necessary to firmly seat and lock the block. Better obturation is also obtained when a cartridge case is used with this mechanism than when dependence is placed on the Broadwell ring.

In guns using fixed ammunition, if the breech block closes from the rear less care is required in inserting the round than if the breech is closed from one side. In the latter case if the round is not sufficiently inserted, the block in closing strikes the cartridge case and a temporary jamming of the mechanism occurs.

157. Older Forms of Breech Mechanism.—There are mounted in our fortifications many guns equipped with the breech mechanism shown in Fig. 90.

The block is revolved by means of one crank fixed to the gun, and withdrawn and swung aside by a second crank attached to the tray. The shaft of the revolving crank carries at its end the pinion *p*, Fig. 91, which works in the rack of the rotating ring *b*. The rotating ring revolves in bearings provided in the face plate, and communicates its motion of rotation to the block through the lug *a*, which engages in one of the slotted sectors. When the rotation of the block is completed the translating stud at the bottom of the block has entered one of the threads of the double threaded translating roller. The other thread of the roller works in a corresponding thread cut in the tray. Rotation of the translating

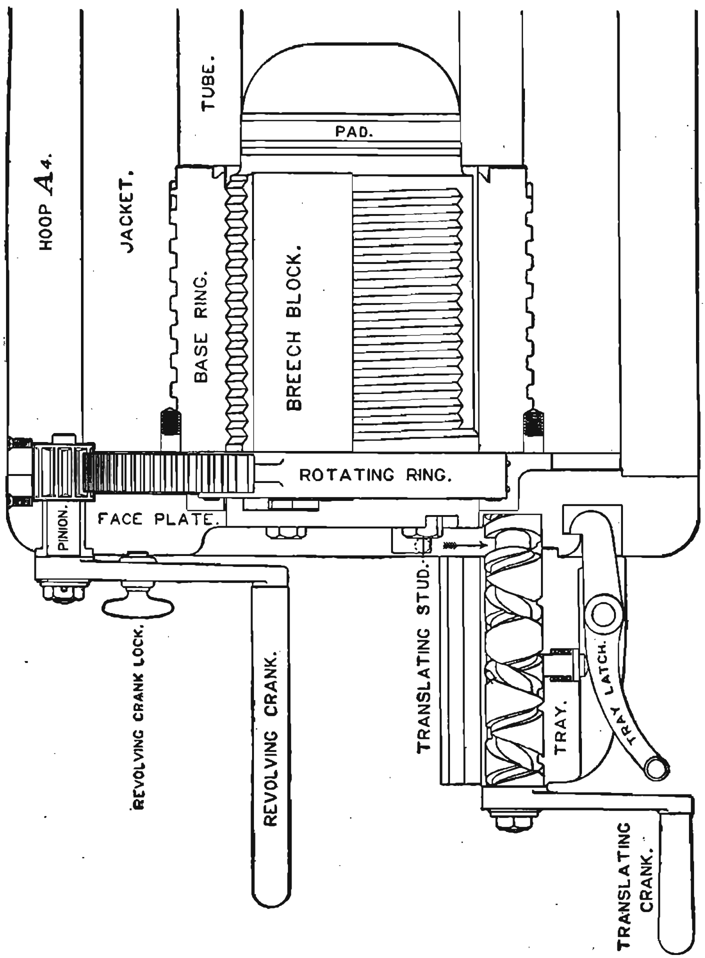

Fig. 90.

crank causes the block to move to the rear with a movement equal to the sum of the movements due to each of the two threads. When the front of the roller passes to the rear of the stud shown acting on the tray latch, the block is brought to a stop on the tray, and the shock of its arrest is sufficient to release the tray latch from its hold on the lip of the recess in the gun. The tray then swings aside, carrying the block clear of the breech.

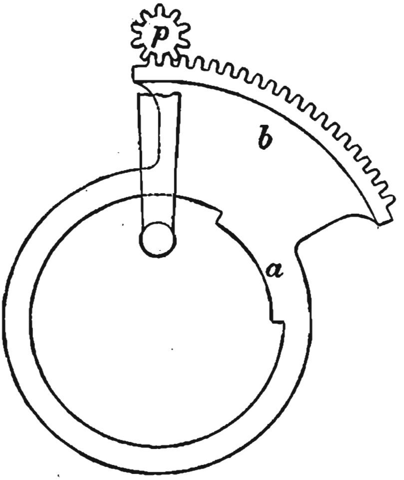

FIG. 91.

The tray is similar in general shape to the tray of the more modern mechanism shown in Fig. 72.

12-inch Mortar Breech Mechanism.—The 12-inch mortars are provided with the mechanism shown in Fig. 92. It differs from the mechanism just described only in the method of rotating the breech block. A steel plate *k* is fixed to the rear face of the breech block and extending upwards provides journals for the pinions *a*, *b*, and *c* of the rotating gear. The pinion *c* meshes in the rack *e* fixed to the gun, and when the crank *d* is turned the

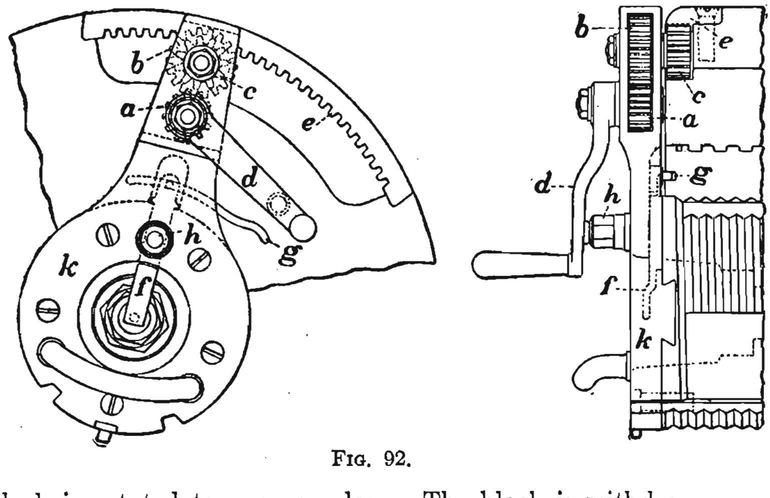

FIG. 92.

block is rotated to open or close. The block is withdrawn on a tray as described above. The translating stud that engages in the translating roller is seen at the bottom of the block.

The vent shield *f*, cut shorter than shown in the figure, is provided with a stud at its lower end that engages with the safety bar of the firing mechanism already described. The stud at its upper end works in the groove *g* cut in the gun, withdrawing the safety bar as the breech is fully closed.

Automatic and Semi-automatic Breech Mechanisms.—In guns provided with automatic breech mechanism the energy of recoil or the pressure of the powder gases is utilized to open the breech, withdraw the fired shell, insert a new cartridge and close the breech. After the firing of the first round the only operation necessary for firing the succeeding rounds is pulling the trigger. The automatic mechanism is at present applied only to guns of small caliber that use the small arm cartridge or fire a projectile weighing not more than a pound.

The semi-automatic mechanism is applied to guns of medium caliber, up to 6 inches, and efforts are being made to adapt it to the larger guns. The breech is opened by mechanism that is operated during the recoil or counter recoil of the piece, and if fixed ammunition is used the fired shell is ejected. At the same time power is stored in a spring to be later used in closing the breech.

In some mechanisms the insertion of the succeeding round by hand operates the breech closing mechanism. In others the pulling of a lever after the insertion of the round actuates this mechanism.

158. THE 2.38-INCH FIELD GUN BREECH MECHANISM.—The semi-automatic breech mechanism of the 2.38-inch light field gun is shown in Figs. 93 to 95.

The wedge shaped breech block *b* is seated in a vertical slot cut through the extension of the jacket. Projecting guide ribs, *t* Fig. 94, in the slot engage in grooves cut in the sides of the block. The block is lowered or raised to open or close the breech by means of the crank *c*. A stud at the end of the crank engages in the cam groove *g* on the right side of block, the groove being so shaped that the crank gives vertical movement to the block. On the outer end of the crank shaft is the operating lever, *l* Fig. 95, attached to which is the operating bar *r*, and the coiled operating spring.

The forward end of the operating bar embraces the pin protruding from the sliding piece *s*, which slides in an undercut groove

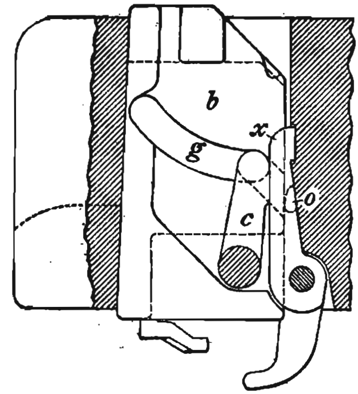

Fig. 93.

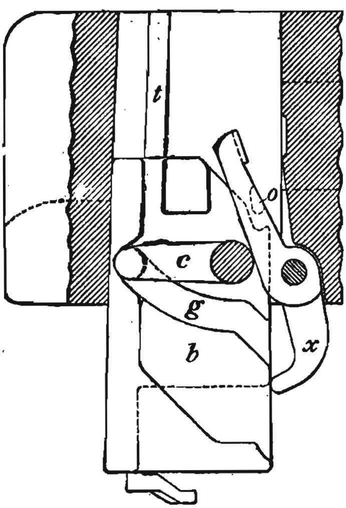

Fig. 94.

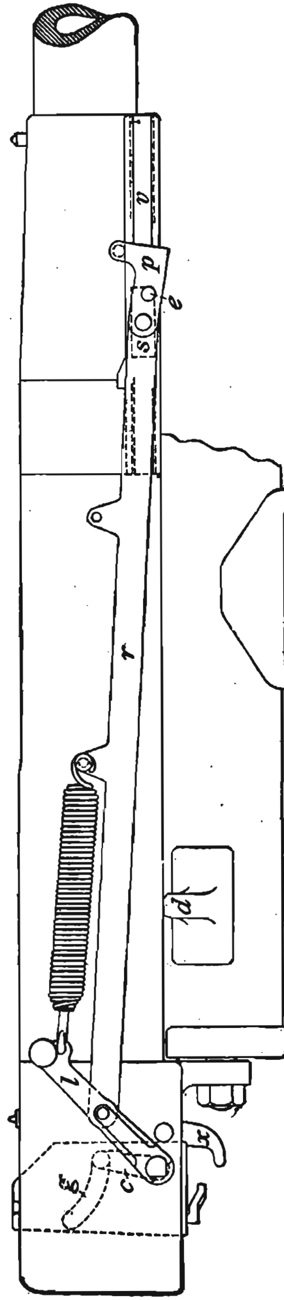

Fig. [illegible]

2.38-inch Field Gun, Semi-automatic Breech Mechanism.

v in the locking ring of the piece. The pawl *p*, pivoted on the same pin, has at its upper end a stud which rests on a shoulder above the groove. The end of a spring pin, *e*, in the pawl works in a slot cut in the sliding piece *s* and limits the motion of the pawl.

The mechanism above described is fixed to the piece and moves with the piece in recoil.

A stud, *d*, is fixed on the recoil cylinder of the carriage. When the piece recoils, carrying the mechanism with it, the pawl *p* is lifted by the stud and falls back into the position shown as soon as it has passed the stud. As the piece returns in counter recoil the pawl is engaged by the stud and held. The piece continues its forward movement. The slide *s* moves, relatively, to the rear in its slot, causing the bar *r* to rotate the operating lever *l* against the tension of the coiled spring.

The rotation of the lever lowers the breech block and opens the breech. The block in the last part of its movement operates the forked extractor *x* which ejects the empty cartridge case.

The stud on the upper end of the pawl *p* has now moved up the incline at the rear end of the shoulder on which it slides, lifting the pawl, disengaging it from the stud *d* on the carriage, and allowing the piece to finish its movement into battery. The pawl *p* being disengaged from the stud the breech block moves upward under the action of the operating spring until the curved locking studs *o* on each arm of the extractor, Fig. 94, engage in the corresponding recesses cut in the sides of the block. The curved shape of the locking studs and recesses, together with the directions in which the engaging parts are constrained to move, prevent further movement of the parts and the block is therefore locked open against the tension of the operating spring.

The rear part of the jacket extension is trough shaped to permit the ready insertion of the cartridge into the breech. As the cartridge is pushed into the breech with force its flanged head engages the extractor arms and forces the locking studs *o* out of the recesses. The action of the operating spring through the lever *l* and the crank *c* then lifts the block and closes the breech.

The firing mechanism is similar to that of the 3-inch field gun which is fully described in Chapter VIII.

159. The 3-inch Seacoast Gun Breech Mechanism.—The operating parts of the U. S. Ordnance Co.'s semi-automatic breech mechanism, applied to the 3-inch seacoast gun, are shown in Figs. 96 and 97. Attached to the gun is the actuating rod *a*, its front

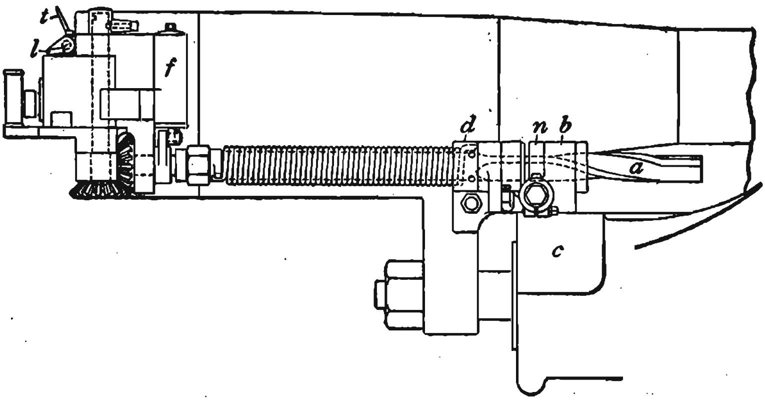

Fig. 96.

end provided with three twisted ribs which are practically screw threads with a very long pitch. The nut *n* similarly threaded is held in the bearing *b* which is fixed on the recoil cylinder *c* of the carriage.

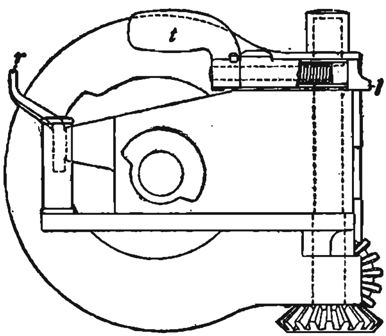

Fig. 97.

When the gun recoils the nut *n* is turned through 128 degrees by the actuating rod, but in counter recoil the nut is held by a pawl and the actuating rod turns clockwise, looking from the rear, in passing through the nut. The turning of the actuating rod operates the miter gears at its rear end and through them opens the breech and ejects the fired shell.

The operating spring, one end of which is held in the adjusting nut *d* which is carried in a bearing on the gun, is wound up by the movement of the actuating rod during counter recoil, and the energy stored in the spring is later utilized to close the breech. A small hydraulic buffer, *f*, modifies the action of the spring and relieves the mechanism of violent shock. The block is held open by the lug *l*, which under the action of a spring falls inside the carrier when the breech is open.

After the insertion of the cartridge, hand pressure on the tripping lever *t* lifts the lug *l* from inside the carrier. The operating spring, then free to act, closes the breech block.

The firing mechanism is similar to that described in Chapter VIII in the 3-inch field gun. The trigger is seen at *r*, Fig. 97.

Automatic breech mechanisms are described in Chapter XVI, in the descriptions of the guns in which they are used.

CHAPTER VII.

RECOIL AND RECOIL BRAKES.

160. Stresses on the Gun Carriage.—The stresses to which a gun carriage is subjected are due to the action of the powder gases on the piece. Gun carriages are constructed either to hold the piece without recoil or to limit the recoil to a certain convenient length. In the first case the maximum stress on the carriage is readily deduced from the maximum pressure in the gun. In the second case it becomes necessary to determine all the circumstances of recoil in order that the force acting at each instant may be known, and the parts of the carriage designed to withstand this force and to absorb the recoil in the desired length.

Velocity of Free Recoil.—Suppose the gun to be so mounted that it may recoil horizontally and without resistance. On explosion of the charge the parts of the system acted upon by the powder gases are the gun, the projectile, and the powder charge itself, the latter including at any instant both the unburned and the gaseous portions. While the projectile is in the bore, if we neglect the resistance of the air, none of the energy of the powder gases is expended outside the system. The center of gravity of the system is therefore fixed and the sum of the quantities of motion in the different parts is zero. The movement of the powder gases will be principally in the direction of the projectile. We may therefore write

$$Mv_f = mv + \mu\, v_c \tag{1}$$

in which M, m, and μ are the masses of the gun, projectile, and charge of powder, respectively; and v_f, v, and v_c the velocities of the same parts. The mass of the charge is the same whether the charge is unburned or partially or wholly burned.

The velocity of the projectile at any point in the bore of the gun may be determined from the formulas of interior ballistics, equations (112) to (115), page 100. The velocity of the center of mass of the products of combustion is unknown. The velocity of the products varies from zero near the breech to v at the base of the projectile, and we may, without material error, consider the velocity of the center of mass of the products as equal to half the velocity of the projectile.

Writing $v/2$ for v_c in equation (1), replacing masses by weights, and solving for v_f we obtain

$$v_f = \frac{w + \frac{1}{2}\varpi}{W} v \tag{2}$$

W, w, and ϖ being the weights of the gun, projectile, and charge.

At the muzzle of the gun v becomes the initial velocity V, and for the velocity of free recoil at that instant

$$v_f' = \frac{w + \frac{1}{2}\varpi}{W} V \tag{3}$$

This value v_f' is not the maximum velocity of free recoil, though it is the maximum value reached while the velocities of the gun and of the projectile are connected. At the departure of the projectile the bore of the gun is still filled with gases under tension, which continue to exert pressure on the breech and increase the velocity of recoil. The value v_f' obtained by the above equation is about 7/10 of the maximum velocity of free recoil.

It has been determined by experiment with the Sebert velocimeter that the maximum velocity of free recoil may be obtained from equation (3) by substituting for the quantity $\frac{1}{2}\varpi V$ the quantity 4700ϖ. The equation then becomes

$$V_f = \frac{wV + 4700\varpi}{W} \tag{4}$$

V_f being the maximum velocity of free recoil.

The coefficient 4700 applies to smokeless powders. The coefficient for black powders was 3000.

161. Determination of the Circumstances of Free Recoil.—In the above equations the velocity of free recoil is expressed as a function of the velocity of the projectile, and we have in the ballistic formulas the velocity of the projectile expressed as a function of the travel of the projectile. We might therefore now determine the velocity of free recoil as a function of the travel of the projectile. But in the determination of all the circumstances of recoil it is necessary to know the relations between the velocity, time, and length of recoil; and in order to arrive at these relations by means of equation (2), we must obtain an expression for the velocity of the projectile as a function of the time.

With the velocity of the projectile expressed as a function of the time, equation (2) will then express the velocity of free recoil as a function of the time, and with the velocity of recoil so expressed we may obtain the length of recoil from the equation

$$x=\int v_f dt \tag{5}$$

x representing the length of free recoil.

We thus obtain the complete relations between the velocity, time, and length of free recoil.

162. Velocity of the Projectile as a Function of the Time.—The velocity of the projectile as a function of the time is obtained in the following manner. Representing the travel of the projectile by u, we have

$$v=du/dt, \quad \text{from which} \quad t=\int \frac{1}{v}du \tag{6}$$

That is, t is the area under the curve whose ordinates are values of $1/v$ and whose abscissas are values of u.

Therefore if we construct such a curve the area under the curve from the origin to any ordinate will be the time corresponding to the velocity whose reciprocal is represented by the ordinate.

Construct the curve v, Fig. 98, from the ballistic formulas, the abscissas representing travel, the ordinates velocity of the projectile.

Take the value of v as expressed by any ordinate and lay off its reciprocal on the same ordinate, to any convenient scale. The curve $1/v$ in the figure is obtained in this way. Its ordinates are values of $1/v$, its abscissas are values of u. The areas under the curve are therefore values of t, equation (6).

For very small values of v the ordinates $1/v$ will be very large and will not fall within the limits of an ordinary drawing. We cannot determine, then, from the drawing, the area under the first part of the curve. But we can obtain a sufficiently close approximation to this area in the following manner. We may assume,

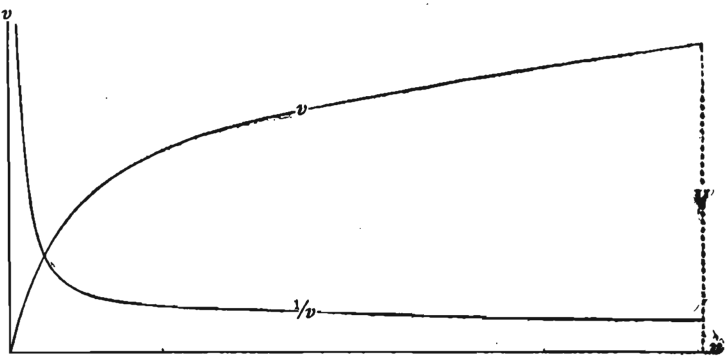

FIG. 98.

without material error in the determination of this small area, that the velocity of the projectile as a function of the time is expressed by the equation of a parabola

$$v=\sqrt{2pt} \tag{7}$$

Multiplying by dt and integrating, we have, since $\int v\,dt=u$,

$$u=\int\sqrt{2pt}\,dt=\tfrac{2}{3}\,(2p)^{\frac{1}{2}}t^{\frac{3}{2}} \tag{8}$$

At the instant at which the shot leaves the bore, v in equation (7) becomes the initial velocity V, and denoting the corresponding time by t' we obtain from that equation

$$V=\sqrt{2pt'} \quad \text{or} \quad \sqrt{2p}=V/\sqrt{t'}$$

Substituting this value of $(2p)^{\frac{1}{2}}$ in equation (8), t in that equation becoming t' and u the total travel of the projectile U, we obtain

$$t'=\frac{3}{2}\frac{U}{V}$$

t' is then the total area under the curve $1/v$, Fig. 98, and subtracting from t' the area that can be measured we obtain the area under that part of the curve near the origin that is not plotted.

Having now from the v curve the values of $v=f(u)$ and from the areas under the $1/v$ curve the values of $t=f(u)$ we may, by combination, determine the desired values of $v=f(t)$.

Using as abscissas the areas under the curve $1/v$, which are the values of t, and as ordinates the corresponding ordinates of the curve v, which are the velocities, we obtain the curve of the velocity of the projectile as a function of the time, Fig. 99.

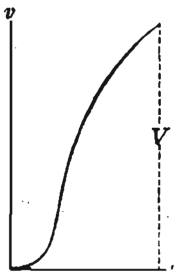

FIG. 99.

Since the velocity of free recoil as given by equation (2) is equal to the velocity of the projectile multiplied by a constant, the curve in Fig. 99 becomes at once the curve of velocity of free recoil, if we consider the scale of the ordinates as multiplied by the coefficient of v in equation (2).

163. Maximum Velocity of Free Recoil.—The curve shown in Fig. 99 gives the velocity of free recoil only while the projectile is in the bore, and as previously explained the velocity of recoil has not reached its maximum when the projectile leaves the piece. The value of the maximum velocity of recoil is given by equation (4). With this value as an ordinate, Fig. 100, draw a line parallel to the axis of t and continue the curve of velocity already drawn until it is tangent to this line. It is reasonable to infer that the rate of change in the curvature of the curve of recoil will continue uniform from the point corresponding to the muzzle of the gun to the point of maximum velocity, and the curve so continued will with sufficient exactness express the circumstances of motion. A slight error made in the selection of the point of tangency will be without practical effect on the determinations to be later made from this curve. The abscissa of the point of tangency is the time corresponding to the maximum velocity of free recoil.

As, by assumption, there is no resistance to recoil, the maximum velocity attained will never be reduced, and the curve will extend indefinitely parallel to the axis of t.

The tangent to the curve at any point is a value of dv_f/dt, and therefore represents the acceleration at the instant of time represented by the abscissa of the point. The tangent has a maximum value at the point of inflexion of the curve, the point where the curve ceases to be convex toward the axis of t, and becomes concave. This point is therefore the point of maximum acceleration.

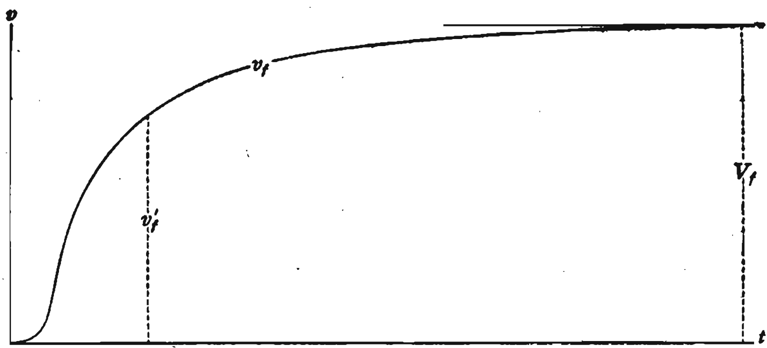

FIG. 100.

The maximum acceleration being due to the maximum powder pressure in the gun the abscissa of the point of inflexion is the time of the maximum pressure.

Since, equation (5), $x=\int v_f dt$, the area under the curve v_f, Fig. 100, from the origin to any ordinate is the length of free recoil corresponding to the velocity represented by the ordinate.

Retarded Recoil.—In the discussion thus far we have neglected all resistances and have considered the movement of the gun in recoil as unopposed. When the gun is mounted on a carriage the recoil brakes, of whatever character, begin to act as soon as recoil begins, and consequently the velocity of recoil is less at each instant than the velocity shown by the curves just determined.

The manner of obtaining the velocity of retarded recoil will be explained later.

Recoil Brakes.—To absorb the energy of recoil and to bring the gun to rest in a convenient length, all gun carriages which permit movement of the gun in recoil are provided with recoil brakes.

These are of two general classes, friction brakes and fluid brakes. Friction brakes were formerly used on seacoast carriages, but are now confined exclusively to wheeled carriages. Fluid brakes are either hydraulic or pneumatic. Pneumatic brakes, depending for their resistance on the compression of air, have been used in England to some extent on seacoast carriages. On account of the difficulty of preventing loss of pressure in the brakes through leakage of the air these brakes are not satisfactory.

164. **Hydraulic Brakes.**—A hydraulic recoil brake consists of a cylinder filled with liquid, and a piston. Relative movement is given to the cylinder and piston by the recoil, and provision is made for the passage of the liquid from one side of the head of the piston to the other by apertures cut in the piston or in the walls of the cylinder. The power of the brake lies in the pressure produced in the cylinder by the resistance offered by the liquid to motion through the apertures.

If the area of the apertures is constant it is evident that the resistance to flow will be greater as the velocity of the piston or the velocity of recoil is greater. Therefore the pressure in the cylinder, which measures the resistance offered, will vary with the different values of the velocity of recoil. If, however, the apertures are constructed in such a manner that the area of aperture increases when the velocity of the piston increases and diminishes when that velocity diminishes, the variation in the area of aperture may be so regulated that the pressure in the cylinder will be constant or will vary in such a manner as to keep the total resistance to recoil constant.

Both of these methods have been used in the construction of recoil brakes for gun carriages. The brakes with constant orifices and variable pressures were used on the old carriages for 15-inch smooth bore guns.

For a fixed length of recoil a constant resistance will have a lower *maximum* value than a variable resistance, and consequently will produce a less strain on the gun carriage. For this reason and for other advantages that will appear in the discussion which follows, the brake with variable orifices, and constant or variable pressure as circumstances may require, is at present used to the exclusion of all others on gun carriages.

Hydraulic Brake with Variable Orifice.—The mode of action of the hydraulic brake with variable orifices will be understood

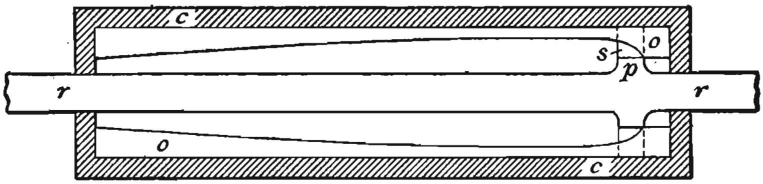

FIG. 101.

from Fig. 101, which represents a longitudinal section through a recoil cylinder of the form used in our seacoast carriages.

Fig. 102 represents a cross section through the cylinder. To the walls of the cylinder c are fastened two bars o called throttling bars, of varying cross section as shown. The piston p is stationary, the piston rod r being fixed to a stationary part of the carriage. The cylinder c is attached to the gun and moves to the rear in recoil.

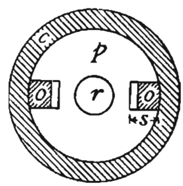

FIG. 102.

The direction of the movement of the cylinder is to the right in the figure. The figure shows the relative positions of cylinder and piston at the beginning of recoil.

Through the piston head are cut two slots or apertures, s, through which the liquid is forced from one side of the piston to the other as the *cylinder* moves in recoil. Each slot has the dimensions of the maximum section of the throttling bar, with just enough clearance to permit operation. The area of orifice open for the flow of liquid at any position of the piston is therefore equal to the area of the slots minus the area of cross section of the throttling bars at that point; and the profile of the throttling bars is so determined that the resistance to the flow of the liquid, or the pressure in the cylinder, is made constant or variable as desired.

165. Total Resistance to Recoil.—The total resistance to recoil is composed of the resistance opposed by the brake, the resistance due to friction, the resistance—either plus or minus—due to the inclination of the top of the chassis, and the resistance due to the counter recoil springs if there are such included in the recoil system. The function of the counter recoil springs is to return the gun to battery after recoil.

The resistance of the counter recoil springs varies with the degree of compression. Therefore to maintain a constant total resistance when springs are included in the system the resistance of the brake must also vary, the other resistances being constant.

Let W be the weight of the moving parts,
M the mass of the moving parts,
f the coefficient of friction,
α the angle of inclination of the chassis rails,
S the resistance of the springs at any time t,
P the total resistance of the hydraulic brake, or the total pressure in the cylinder, at the time t,
R the total resistance to motion,
v_r the velocity of *retarded recoil* at the time t,
V_r the maximum velocity of retarded recoil.

The resistance due to friction will be $fW\cos\alpha$; that due to the inclination of the chassis rails will be $W\sin\alpha$. The total resistance at the time t is therefore

$$R = W(\sin\alpha + f\cos\alpha) + S + P \tag{9}$$

Dividing the total resistance by the mass, we have, for the retardation,

$$-dv/dt = R/M \tag{10}$$

When the total resistance to recoil is constant, the retardation R/M is constant, and we may substitute it for g in the equation that expresses the law of constant forces,

$$v^2 = 2gh$$

Assuming the origin of movement as at the maximum velocity of recoil, V_r, and designating by l' the length of recoil from this point to the end, the above equation becomes

$$V_r^2 = 2l'R/M$$

or

$$l' = V_r^2 M/2R \tag{11}$$

l' is the length in which the constant resistance R will overcome a velocity of recoil V_r.

For the velocity at any point whose distance from the origin is x, we have the relation

$$l' - x = v_r^2 M/2R \tag{12}$$

since $l' - x$ is the length in which the constant resistance must overcome the velocity v_r.

Values of the Total and Partial Resistances and Velocities of Recoil.—In the construction of a gun carriage the length of recoil is usually fixed by the design of the carriage. We will therefore assume a length l as the total length of recoil. We must now determine the total constant resistance that will restrict the recoil to this length and then determine the portion of this resistance that is to be contributed by the brake. In so doing we will arrive at the values of the velocities of recoil at all points in the path.

166. Total Constant Resistance.—The curve v_f in Fig. 103, which as far as the point m is the curve v_f in Fig. 100 drawn to a

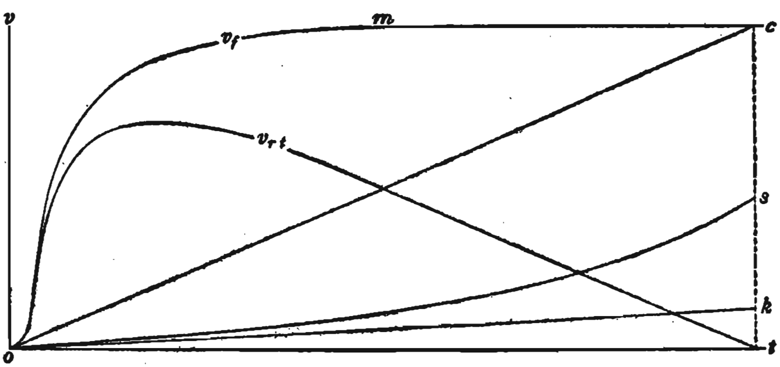

Fig. 103.

different scale, represents the velocity of free recoil as a function of the time. We have seen that the tangent to the curve at any point represents the acceleration at that point.

We may represent the negative velocities due to a constant resistance by the ordinates of some straight line *oc*, whose abscissas are the corresponding times. The tangent of the constant angle toc is therefore equal to $-dv/dt$, the retardation due to the force.

The line oc is for convenience drawn above the axis of t. As its ordinates represent the negative velocities due to the resistance the line properly belongs below the axis.

Now if we subtract from the velocities of free recoil, represented by the ordinates of the curve v_f, the velocities due to the retarding force, the ordinates of oc, the ordinates of the resulting curve v_{rt} will be the velocities of retarded recoil. The curve v_{rt} is therefore the curve of the velocity of retarded recoil as a function of the time. The abscissas of the curve being values of t, the area under the curve will be the total length of retarded recoil, see equation (5).

We have assumed a total length of recoil, l, and if the area measured under the curve of retarded recoil, as obtained above, does not give this length, we must change the angle toc, draw a new line oc, and construct a new curve. After a few trials the proper direction of oc will be determined and the area under the curve of retarded recoil, v_{rt} Fig. 103, will be the length l.

Then the retardation represented by the line oc is given, see equation (10), by the equation

$$-\tan toc = -dv/dt = R/M \tag{13}$$

from which, after measuring the angle toc, we may determine R, the total constant resistance that will limit the recoil to the length l.

The length of retarded recoil corresponding to any velocity of retarded recoil represented by an ordinate of the curve v_{rt} is the area under the curve from the origin to the given ordinate.

We may now construct the curve of retarded recoil as a function of the distance recoiled. To construct a point of the curve measure the area under the curve v_{rt} in Fig. 103 from the origin to any ordinate; use the value of this area as an abscissa, and use the selected ordinate of the curve v_{rt} as an ordinate. The curve v_{rx} in Fig. 104, constructed in this manner from the curve v_{rt} in Fig. 103, represents the velocity of retarded recoil as a function of the distance recoiled.

Minor Constant Resistance.—The total resistance R is composed, equation (9), of the constant part $W(\sin \alpha + f \cos \alpha) = k$

and the two variable parts S and P. The value of $W(\sin\alpha + f\cos\alpha)$ may be readily determined. The retardation due to this resistance is equal to k/M, and is represented in Fig. 103 by a line ok drawn so that the tangent of the angle tok is equal to k/M.

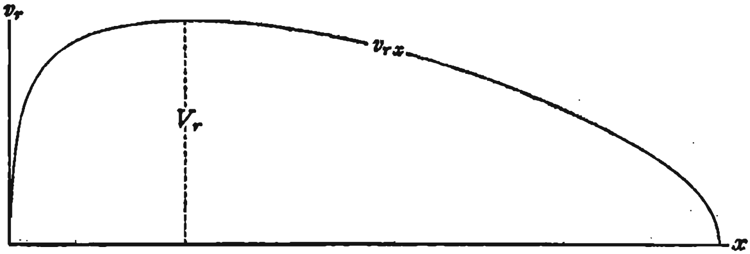

FIG. 104.

167. Resistance of the Spring.—The resistance S of a coiled spring varies directly with the compression of the spring.

Representing by G the force required to compress the spring, when free, over the first unit of length, the resistance of the spring at any length of compression x is

$$S = Gx$$

If the spring has an initial compression so that it exerts a resistance G', the resistance after further compression over a length x becomes

$$S = G' + Gx \qquad (14)$$

For the counter recoil springs of a gun carriage, G' represents the residual pressure in the spring when the gun is in battery, and x represents any length of recoil.

The resistance of the spring at any point may therefore be determined from equation (14).

To find the velocities taken out of the system by the spring, we proceed as follows.

Representing by v' the velocity in the mass M due to the spring alone, the retardation due to the spring is

$$-dv'/dt = (G' + Gx)/M$$

In order to integrate we must express dt in terms of dx. $dx = v'dt$. Therefore

$$dt = dx/v',$$

and
$$-dv'/dt = -v'dv'/dx = (G' + Gx)/M$$

and integrating,

$$-v'^2/2 = (G'x + Gx^2/2)/M$$

the constant of integration being O, since when x is O, v' is O.

The values of v' are obtained from this equation in terms of x. We may find from the curves v_{rx} and v_{rt} the value of t corresponding to any value of x. The values of v' obtained above may then be laid off in Fig. 103 as the true ordinates of the curve *os*. These ordinates are laid off in the figure from the line *ok* so that in the figure the ordinates of *os* are the sums of the true ordinates of *ok* and *os*. The ordinates of *os* are therefore the velocities taken out of the system by resistances other than the hydraulic brake.

As the ordinates of the line *oc* are the velocities taken out by the total constant resistance, the ordinates between the lines *os* and *oc* represent the velocities to be taken out of the system by the brake alone.

Resistance of the Hydraulic Brake,—Pressure in the Cylinder.—The pressure in the brake cylinder at any point of the recoil may now be determined from equation (9)

$$P = R - W(\sin\alpha + f\cos\alpha) - S \qquad (15)$$

if we substitute for R its constant value from equation (13), for S its value at the given point from equation (14), and for the remaining term its constant value.

168. Relation Between the Pressure, Area of Orifice, and Velocity of Recoil.—In this discussion we will designate by the term *aperture* the cut through the piston, and by the term *orifice* that portion of the aperture open to the flow of the liquid; and we will consider for simplicity that there is but one aperture and one orifice.

Let A be the *effective* area of the piston in square feet, that is, the area of the piston minus the area of the piston rod and aperture. The square foot is taken as the unit of area, because in the velocities involved in the discussion the foot is the unit of length.

Let a be the area of the orifice at any time t,
V_r the maximum velocity of retarded recoil,
v_r the velocity of retarded recoil at any time t,
v_l the velocity of the liquid through the orifice at the time t,
γ the weight of a cubic foot of the liquid,
P the total pressure on the piston at the time t.

The cylinder being full of liquid the volume that passes through the orifice is the volume displaced by the piston. We therefore have at any instant

$$v_r A = v_l a$$

or, for the velocity of flow,

$$v_l = v_r A/a \tag{16}$$

From Torricelli's law for the flow of liquids through orifices we know that the pressure required to produce this velocity of flow is the pressure due to a column of liquid whose height h is given by the equation

$$v^2 = 2gh \tag{17}$$

Substituting for v the value of v_l from equation (16) and solving for h we obtain

$$h = v_r^2 A^2/2ga^2 \tag{18}$$

The weight of a cubic foot of the liquid being γ, the weight of the column whose area of cross section is unity will be γh, and the weight of the column whose area of section is equal to that of the piston will be $A\gamma h$. $A\gamma h$ is therefore the pressure on the piston, and substituting in this expression the value of h from equation (18) we have, for the total pressure on the piston, for any velocity v_r

$$P = \gamma A^3 v_r^2/2ga^2 \tag{19}$$

This equation is general and expresses the relation that exists between P, A, and a for any given velocity of recoil.

Solving for a^2 we obtain

$$a^2 = \gamma A^3 v_r^2/2gP \tag{20}$$

169. Area of Orifice.—With the relations established in equations (14), (15), and (20), which are here repeated, and the curve v_{rx} in Fig. 104, we are now prepared to determine the variable area of orifice in the piston.

(14) $$S = G' + Gx$$

(15) $$P = R - W(\sin\alpha + f\cos\alpha) - S$$

(20) $$a^2 = \gamma A^3 v_r^2 / 2gP$$

The dimensions of the recoil cylinder will be fixed within narrow limits by the design of the carriage, and by the requirement that the pressure per unit of area must not be so great as to render difficult the effective packing of the stuffing boxes through which the piston rod passes. We will therefore assume that the diameters of the cylinder and piston rod are given, and as the relation between the total area of piston and the effective area may be readily established we will assume that the effective area A of the piston is known.

Brake with Variable Pressure.—The value of P at any point in the cylinder, for which the length of recoil is x, is obtained from equation (15), the proper value of S for the point having been first determined from (14). The value of v_r is taken from the curve v_{rx} in Fig. 104 at the ordinate whose abscissa is x. The values of P and v_r thus determined are substituted in equation (20). The resulting value of a is the area of orifice at the given point.

170. Constant Pressure.—If P in equations (19) and (20) is constant we will have in a given cylinder, for any other values of v_r and a, as V_r and a_o, respectively the maximum velocity of recoil and the maximum area of orifice

$$a_o^2 = \gamma A^3 V_r^2 / 2gP \qquad (21)$$

and by combining equations (20) and (21) we obtain for any given cylinder

$$a/a_o = v_r / V_r \qquad (22)$$

from which we see that to maintain a constant pressure in the cylinder the area of the orifice must vary directly with the velocity of recoil.

Assuming the maximum velocity of recoil as the origin of movement and substituting in equation (22) the value of v_r/V_r obtained by combining equations (11) and (12), in which l' represents the total length of recoil *after the maximum velocity has been reached,* we obtain

$$a=a_o\sqrt{1-\frac{x}{l'}} \qquad (23)$$

that is, with constant pressure in the cylinder the area of orifice varies as the ordinates of a parabola.

Equation (23) and all equations in which l' appears refer only to that part of the recoil from the maximum velocity to the end of recoil.

Brake with Constant Pressure.—When there are no springs or other variable resistance in the recoil system, S becomes 0 in the value of P, equation (15), and a constant resistance will be required in the brake.

To determine the area of orifice we have, for this case,

$$P=R-W(\sin\alpha+f\cos\alpha)$$

$$(21) \qquad a_o^2=\gamma A^3V_r^2/2gP$$

$$(22) \qquad a/a_o=v_r/V_r$$

Find the value of P from the first equation in the manner already explained on page 286.

The maximum ordinate of the curve v_{rx}, Fig. 104, is the value of V_r in equation (21). A is known. The maximum area of orifice a_o may be now determined from equation (21) and the area of orifice at all other points more simply by means of equation (22), using the values of v_r taken from the curve v_{rx}. The areas from the maximum velocity to the end may also be obtained from equation (23).

Horizontal Chassis.—If the chassis rails are horizontal and the top carriage is mounted on rollers, so that we may neglect the friction, the term $W(\sin\alpha+f\cos\alpha)$ in the value of P, equation (15), also becomes zero, and P reduces to R. Substituting for R in equation (11) the value of P from (21) and solving for a_o we obtain

$$a_o^2=\gamma l'A^3/W \qquad (24)$$

The maximum area of orifice is in this case independent of the velocity of recoil, and is dependent only on the length of recoil. Therefore for a given maximum area of orifice the length of recoil will be the same no matter what the initial velocity of the projectile, the charge of powder, or the angle of fire may be.

Under these conditions the brake requires no adjustment for varying conditions of fire, and in this respect it possesses further advantage over the brake with constant orifices and variable pressure.

The explanation of the independence, under the given conditions, of the length of recoil and the velocity will appear if we substitute P for R in equation (11). We obtain

$$l' = MV_r^2/2P \tag{25}$$

In equation (21) we see that for a given maximum area of orifice the pressure P must vary directly as V_r^2 varies. Therefore in (25), P varying with V_r^2, l' will remain constant.

171. Profile of the Throttling Bar.—Suppose there are n similar apertures cut in the piston. The area of each orifice at any point in the cylinder will then be a/n, a being determined for the particular point from equation (20). Let b, Fig. 105, be the width and d the depth of each aperture. The throttling bar has the same depth, and a variable width y.

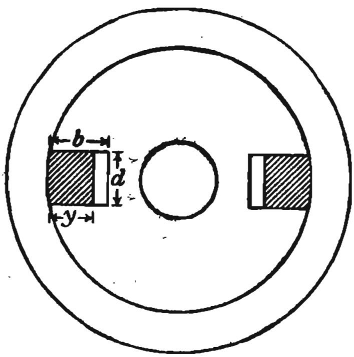

Fig. 105.

Then for the area of each orifice at the given point in the cylinder we have

$$a/n = d(b-y)$$

For the brake with constant pressure the profile of the throttling bar from the point of maximum velocity to the end will be a parabola. Its equation, obtained by substituting the value of a from the above equation in equation (23) and reducing, is

$$y = b - \frac{a_0}{nd}\sqrt{1-\frac{x}{l'}}$$

Neglected Resistances.—In the foregoing discussion we have neglected the resistance due to the friction of the liquid and the contraction of the liquid vein. It has been found by experiment that the error due to the neglect of these resistances may be corrected by assigning to v_l, the velocity of the flow through the orifices, equation (16), a value greater than the actual value as expressed in equation (17). The value to be substituted is determined by experiment for each class of carriage and takes the form $v_s = av_l + b$, a and b being constants. The result of the substitution is an increase in the area of orifice for any given pressure in the cylinder, see equation (20).

172. Recoil System of Seacoast Carriages.—The arrangement of the parts of the recoil system on our seacoast disappearing carriages, and on barbette carriages for guns 8 inches or more in caliber, is shown in Fig. 106.

The two cylinders *c* are integral parts of the top carriage, the top carriage, including the cylinders, forming a single steel casting in the sides of which above the cylinders are trunnion seats, for the gun trunnions in a barbette carriage, and for the gun lever trunnions in a disappearing carriage.

The piston rods of the recoil cylinders are fixed to the chassis in front and supported in the rear. They enter the cylinders through stuffing boxes. On discharge of the piece the top carriage and recoil cylinders move to the rear with the gun, forcing the liquid in the cylinders through the orifices in the stationary pistons.

The direction of the movement of the cylinders is to the *right* in Fig. 106.

To equalize the pressure in the two cylinders their interiors are connected at the front by the pipe *a* and at the rear by the two pipes *d* and *f*. Each half of the pipes *d* and *f* has unobstructed communication with the other half of the same pipe through a valve box *v*. A cross pipe *b* connects the pipe *a* with the valve box. A path is afforded through the pipes *a*, *b*, and *d* and *f* for the flow of liquid from one side of the piston to the other, which path, as well as the orifices in the pistons, must be considered in determining the area of orifice.

The area of orifice, and consequently the length of recoil, is calculated for standard conditions of loading. Any variation in

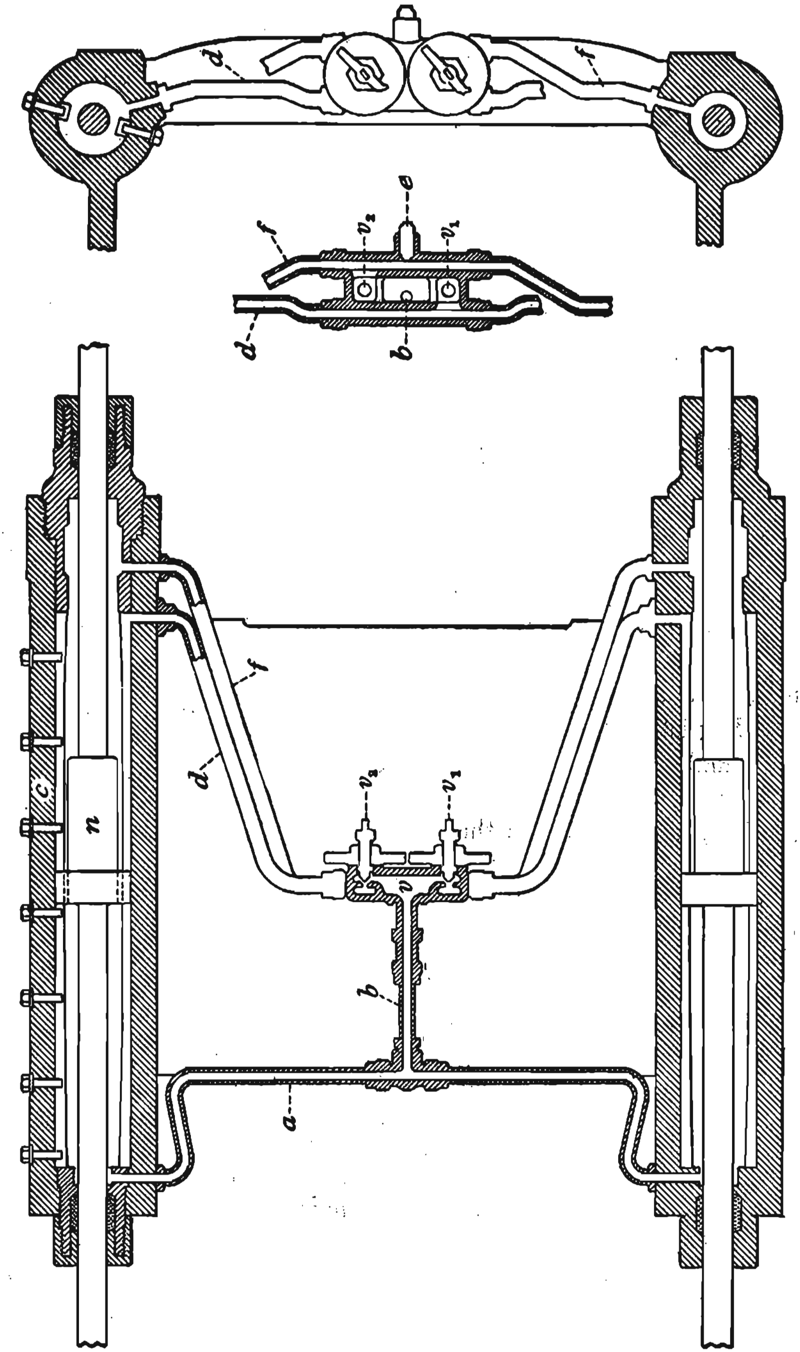

FIG. 106.—Recoil System, Seacoast Carriages.

these conditions will vary the length of recoil, and thus, in disappearing carriages, vary the height of the breech of the gun above the loading platform. Standard conditions of loading do not always exist, and it is therefore desirable to have means for varying the resistance in the cylinders in order that the prescribed length of recoil may be obtained under any conditions, as for instance when reduced charges are being used.

For the purpose of varying the area of orifice, and therefore the resistance in the cylinders, adjustable valves called throttling valves are provided at v_1 and v_2. The flow from the pipe *b* into the pipe *d* communicating with the body of the cylinder is regulated by the valve v_1, and the area open to the flow is affected to increase or diminish the pressure in the cylinder as desired. The pipe *d* and its valve v_1 are for the control of the recoil.

To control the counter recoil and to bring the gun and top carriage to rest without shock as they come into battery under the action of gravity, the counter recoil buffer is provided. The rear cylinder head is provided with a cylindrical recess into which the enlargement *n* of the piston rod, just in rear of the piston, enters as the carriage approaches its position of rest in battery. The lug *n* is slightly conical, so that the escape of the liquid from the recess is gradually obstructed. The pipe *f* with its valve v_2 assists in the regulation of this part of the counter recoil.

The valves v_1 and v_2 are moved to increase or diminish the area of orifice by means of the handles seen in the rear view, at the right of Fig. 106.

The cylinders are filled, through holes provided in the top, with a mineral oil called hydroline. The freezing point of the oil is below 0° F. Its specific gravity is about 0.85. The oil may be drawn off through a hole *e* in the valve box, ordinarily stopped with a screw plug.

The throttling bars are fastened to the cylinders by screw bolts through the cylinder walls, as shown in Fig. 106.

Modification of Recoil System.—In the recoil system just described it will be noticed that, at the beginning of recoil, as the enlargements *n* of the piston rods emerge from the recesses in the rear cylinder heads there is around the enlargements but little clearance by which the oil displaced by their bulk in the cylinders proper may enter the vacated recesses. Consequently if the cylinders are full of oil the liquid will be forced with great velocity through the clearances, and the pressure in the cylinders will be correspondingly high.

To prevent this high pressure, oil is withdrawn from the cylinders in sufficient quantity to leave an air space in the cylinders nearly equal to the space occupied by the enlargements of the piston rods, and on emerging from the recesses the enlargements occupy the air space without giving to the liquid an excessive velocity of flow.

The removal of oil from the cylinders is objectionable in that if the cylinders are not completely filled with oil the uncovered parts of the piston and of the cylinder walls are attacked by rust.

It will be noticed, too, that any movement of *either* of the throttling valves that control the recoil and counter recoil affects the area of orifice. Therefore the regulation of the counter recoil affects also the recoil.

For these reasons it has been found desirable to separate the two systems so as to have independent control of both recoil and counter recoil; and in a 6-inch disappearing carriage now being tested an additional recoil cylinder is fixed in the counterweight of the carriage. The control of the recoil is effected wholly by this large cylinder, and the counter recoil is controlled by smaller cylinders whose pistons are acted on by the top carriage in the last part of its movement into battery.

Other advantages of this arrangement will appear in the description of the carriage in the next chapter.

173. Wheeled Carriages, Recoil.—To arrive at the effect of the recoil on a wheeled carriage we must consider the effects of all the forces that act upon the carriage. These forces include the weight of the system composed of the carriage and gun, and the various forces developed by the transmission of the powder pressure to the points of support of the carriage.

In Fig. 107 is represented the trail of a wheeled carriage with the wheel and spade. For the purpose of discussion we will assume that the carriage is a rigid body, that the wheels are locked, and that the pressure developed in the gun, or the pressure developed in the recoil system when the gun recoils on the carriage, is transmitted to the carriage at the point o.

The points of application and the directions of the forces acting on the carriage and of the reactions at the points of support are represented in the figure.

ϕ is any angle of elevation,
P the transmitted pressure.

Let M be the mass of the system composed of the gun and carriage,
W its weight,
$F = F' + F''$, the total friction on the ground.

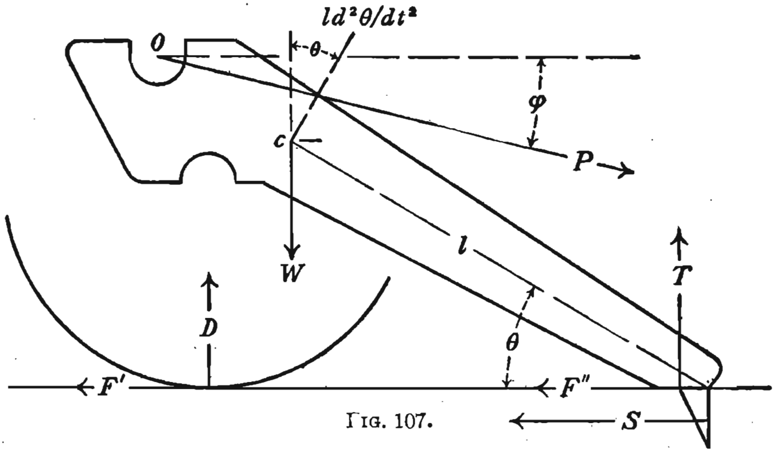

Fig. 107.

The center of gravity of the system is represented at c.

The forces acting on the carriage are symmetrically disposed with respect to the axial plane, and therefore their resultant acts in that plane.

A system of forces acting in a plane is completely known when its components in the direction of two rectangular axes in the plane and the moments about any axis perpendicular to the plane are determined.

We will assume the rectangular axes as horizontal and vertical, the vertical axis through the center of gravity and the horizontal axis on the surface of the ground.

The effect of the forces acting on the carriage will be, under the most general consideration, a movement of the carriage to the rear, and at the same time, since the resistance to motion is greatest at the point of support of the trail, there will occur a movement of rotation of the carriage about the point of support.

Applying to the carriage, in the manner shown in Fig. 107, all the forces that act upon it, we may consider the carriage as a free body and may then determine the values that the forces must have in order to produce in the free body the actual movement of the carriage in recoil.

The movement of a free rigid body acted on by forces may be considered as composed of a movement of translation of the center of gravity and a movement of rotation of the body about the center of gravity. The movements of translation and of rotation may be considered separately.

We have for the equations of motion of the center of gravity

$$\frac{P\cos\phi - F - S}{M} = \frac{d^2x}{dt^2} \tag{26}$$

$$\frac{D + T - W - P\sin\phi}{M} = \frac{d^2y}{dt^2} \tag{27}$$

The sum of the moments of the applied forces with reference to an axis through the center of gravity is the same whether the center of gravity is in motion or at rest, and is equal to the product of the acceleration of rotation into the moment of inertia of the body about the axis. Therefore, representing with small letters the lever arms of the forces with respect to an axis through the center of gravity, we have the equation

$$\frac{Pp + Ff + Dd + Ss - Tt}{Mk_1^2} = \frac{d^2\theta}{dt^2} \tag{28}$$

k_1 representing the principal radius of gyration of the body.

174. CONDITION OF MOVEMENT.—Now to introduce into the three general equations of motion, (26), (27), and (28), the condition that the movement of the free body shall be the same as the movement of the carriage in recoil, we may write

$$y = l\sin\theta$$

since this condition holds in the actual movement of the carriage; that is, as long as the point of the trail is on the ground the center of gravity is at the distance $l \sin \theta$ from the ground.

Differentiating y twice we obtain

$$dy = l \cos \theta d\theta$$

$$d^2y = l \cos \theta d^2\theta - l \sin \theta d\theta^2$$

and dividing by dt^2

$$\frac{d^2y}{dt^2} = l \cos \theta \frac{d^2\theta}{dt^2} - l \sin \theta \frac{d\theta^2}{dt^2}$$

$d\theta/dt$ is the angular velocity of the carriage about the point of the trail. $ld\theta/dt$ is therefore the linear velocity of the center of gravity about the same point. Representing this linear velocity by v we obtain from the above equation after multiplying the last term by l/l

$$\frac{d^2y}{dt^2} = l \frac{d^2\theta}{dt^2} \cos \theta - \frac{v^2}{l} \sin \theta \tag{29}$$

This equation expresses that the vertical acceleration of the center of gravity rotating about the point of the trail is equal to the vertical component of the linear acceleration $ld^2\theta/dt^2$ about that point, see Fig. 107, minus the vertical component of the acceleration along the radius l.

Any change in the angle that the trail makes with the ground is accompanied by an equal change in the angle of revolution of the body about the center of gravity, see the two angles θ in Fig. 107. Therefore the quantities $d^2\theta/dt^2$ in equations (29) and (28) are the same.

Substituting the value of d^2y/dt^2 from equation (29) in equation (27) we introduce into the general equations the actual condition of motion. We then have, for the gun carriage, the three equations

$$\frac{P \cos \phi - F - S}{M} = \frac{d^2x}{dt^2} \tag{30}$$

$$\frac{D + T - W - P \sin \phi}{M} = l \cos \theta \frac{d^2\theta}{dt^2} - \frac{v^2}{l} \sin \theta \tag{31}$$

$$\frac{Pp + Ff + Dd + Ss - Tt}{Mk_1{}^2} = \frac{d^2\theta}{dt^2} \tag{32}$$

We may determine any three of the quantities in these equations if we establish, or assume, values for the other quantities; and in this way we may determine the effects that follow from variations in the values of any of the quantities that enter the equations.

The above equations are applicable only while $y=l\sin\theta$; that is, as long as the point of the trail remains on the ground.

As the linear velocity of the center of gravity is usually small the value of the term $v^2\sin\theta/l$ in equation (31) is very small and is generally neglected in computations. In the computations of the stresses before movement begins v is 0.

175. Application of the Equations.—The general equations (26), (27), and (28) are applicable in the solution of all problems that involve the determination of the stresses, and of the movement, produced by the application of a force or a system of forces to any body or structure.

The equations have been deduced under the most general considerations, and while the number of quantities that appear in them is greatly in excess of the number of equations, it will be found, in practical application under given conditions, that equations of relation between the various quantities may be readily established in sufficient number to reduce the number of unknown quantities in the equations to three, whose values may then be determined.

Thus to apply the general equations, under given conditions, to any given construction, such as the gun carriage represented in Fig. 107.

The intensity and direction of the applied force or forces are usually known or assumed. We will therefore assume that in equations (26), (27), and (28) P and ϕ are known.

For the gun carriage, the condition $y=l\sin\theta$ eliminates the quantity d^2y/dt^2 and brings the equations into the forms (30), (31), and (32). *A similar condition of restraint will ordinarily be found in all constructions that are free to move in given directions only.*

In the modified equations, P, ϕ, W, and M are known. All dimensional quantities such as l, p, t, etc., are determined from the known dimensions of the construction. k_1 may be determined. θ is known.

D and T being parallel forces their intensities have a relation to each other dependent on the distances of their points of application from the directions of the vertical components of the applied forces, which relation may be determined from the known dimensions of the construction.

Representing by f' the coefficient of friction we have $F=F'+F''=f'D+f'T$. This equation and the established relation between D and T provide two equations by means of which two of the quantities, D and F for instance, may be expressed in terms of the third, T.

Neglecting the term $v^2 \sin\theta/l$, there are now left unknown in the original equations the quantities T, S, d^2x/dt^2, $d^2\theta/dt^2$.

If a value of any one of these quantities is established by the given conditions the values of the others may be determined from the equations. For instance, the problem may specify that the pressure on the spade shall not exceed a certain limit. Then S would be known. Or it may be specified that there shall be no horizontal movement. This would make $d^2x/dt^2=0$. Or that there shall be no rotation; $d^2\theta/dt^2=0$.

Integrating the expression for the value of d^2x/dt^2 we obtain $dx/dt=v$, the velocity in the direction of x as a function of the time, and integrating again we obtain x, the distance passed over, also as a function of the time. Similarly, if the term d^2y/dt^2 remains among the unknown quantities.

Integrating $d^2\theta/dt^2$ we obtain the velocity of rotation, and integrating a second time we obtain the angular displacement, both as functions of the time.

The problem is now completely solved.

If there is no movement of the body the problem is much simplified, as under that condition the terms involving the differentials and the velocity v become 0.

The equations are also applicable in determining the relations that must exist, in order that any given condition may be fulfilled, between the dimensions and weight of a construction and the forces applied to it. This will be shown in the following problem.

176. Problem.—Determine, for the 3-inch field carriage, the relations that must exist between the constant resistance in the recoil system and the weight and dimensions of the carriage in order that there may not be any movement of the carriage when the firing is at zero elevation.

In the three equations (30) to (32), ϕ, the angle of elevation, becomes 0; and since there is to be no movement of the carriage the terms involving the accelerations and the linear velocity become 0. Without movement there will be no friction and F will also be 0.

The three equations then reduce to

$$P-S=0$$
$$D+T-W=0$$
$$Pp+Dd+Ss-Tt=0$$

which express the relations that must exist between the resistance P to recoil, the weight, and the dimensions of the carriage under the condition of stability imposed.

As the center of gravity of the system moves to the rear when the gun recoils on the carriage, the most unfavorable position of the center of gravity must be used in the equations. This will be the rearmost position.

Design of a Field Carriage to Fulfil the above Conditions.—Using the equations established in the preceding problem, W, the weight of the system composed of the gun and gun carriage must be such that when the weight of the limber filled with ammunition is added, the weight behind each horse of the team shall not exceed 650 pounds. The length of the trail l will be limited by considerations of draft and of the turning angle of the limbered carriage. The height of the carriage, $f+p_{(\phi=0)}$, must be such that the gun may be readily served and not too easily overturned. The area of the spade must be such that the pressure against it will not exceed 80 pounds per square inch, as it is found that in average ground the spade will not satisfactorily prevent movement of the carriage when the pressure against the spade exceeds this limit. Therefore the area of the spade $=S/80$.

By carefully weighing these and other considerations, and assuming successive values for the various quantities in the established equations, satisfactory dimensions for the carriage as a whole are finally determined.

Similar equations are established for each of the individual parts of the carriage in exactly the same manner as explained for the carriage as a whole. The stresses to which each part is subjected and the necessary strength and best form of the part to perform its functions are thus determined.

The pressure P determined from the above equations is the greatest pressure that may be transmitted to the carriage under the condition of stability imposed. The 3-inch gun recoils on its carriage and the recoil is controlled by a hydraulic brake and counter recoil springs. If we neglect the friction of the moving parts, P becomes at once the maximum constant resistance that may be permitted in the recoil controlling system. It is a value of R in equations (9) and (15). We will then determine, as explained under hydraulic brakes, the length of the recoil when opposed by this resistance, and the length so determined will be the minimum length of recoil that may be permitted on the carriage.

177. 3-inch Field Carriage Recoil System.—A longitudinal section through the gun recoil system of the 3-inch field carriage is shown in Fig. 108, drawn to a distorted scale in order to show the parts more clearly.

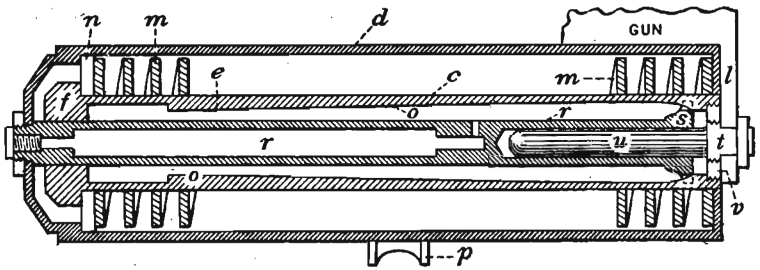

Fig. 108.

A cylindrical cradle d, of cross-section as shown in Fig. 109, is pintled by the pintle p in a part of the carriage called the rocker, not shown. The grooves a of the pintle are engaged by clips provided on the rocker. The rocker embraces the axle of the carriage and has a movement in elevation which is transmitted to the gun by the cradle.

The gun is provided with clips *k* which engage the upper flanges of the cradle; and when fired, the gun slides to the rear on the upper surface of the cradle. The lug *l*, Fig. 108, is an integral part of the gun. The counter recoil buffer *u* is attached to the lug by a bolt *t*, and the recoil cylinder *c* is attached to the same bolt by means of the screw *v*. Integral with the walls of the cylinder are three throttling bars *o*. The piston head *s* is provided with three corresponding apertures, Fig. 109.

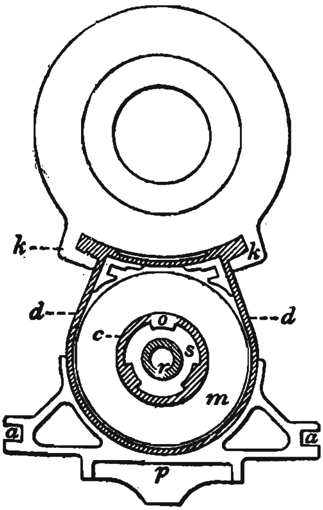

Fig. 109.

The hollow piston rod *r* is held to the front end of the cradle by a nut screwed on the forward end of the rod. The rod terminates at its rear end in the piston head *s*. The outer shoulder formed on the front head *f* of the recoil cylinder receives the thrust of the counter recoil springs *m* transmitted through the annular spring support *n*, which also serves to center the cylinder in recoil. The flat coiled springs *m* extend continuously from the front end to the rear end of the recoil cylinder.

The gun in recoiling draws with it, by means of the lug *l*, the recoil cylinder *c*, filled with oil, and the counter recoil buffer *u*. The piston, attached to the cradle, does not move. When the forward end *e* of the curve of the throttling bar reaches the piston head *s*, the apertures in the piston are completely closed against the flow of the liquid, and recoil ceases. The counter recoil buffer *u* has now been drawn all the way out of the piston rod.

Under the action of the springs *m*, which have been compressed by the recoil, the gun returns to battery. The first part of the counter recoil, during which the counter recoil buffer is out of the hollow piston rod, is unobstructed. When the buffer enters the piston rod the escape of oil from inside the rod is permitted only through the narrow clearance between the rod and the buffer. The resistance thus offered gradually diminishes the velocity of counter recoil and brings the gun to rest without shock as it comes into battery. The buffer is cylindrical for the greater part of its length, with a clearance in the piston rod of 0.025 of an inch on the diameter. The diameter of the buffer gradually enlarges over a length of three inches at the rear until the clearance is but 1/1000 of an inch on the diameter.

The pressure on the piston due to the recoil is transmitted through the cradle to the pintle p and thence to the carriage.

The length of recoil is 45 inches.

Recoil System of Other Carriages.—The recoil-controlling parts of the carriages for siege guns, and of the barbette carriages for seacoast guns six inches or less in caliber, embody the same principles as the system described above.

CHAPTER VIII.

ARTILLERY OF THE UNITED STATES LAND SERVICE.

178. Classification.—Service artillery may be broadly divided into two classes: mobile artillery and artillery of position.

Mobile artillery consists of the guns designed to accompany or to follow armies into the field, and comprises mountain, field, and siege artillery.

Artillery of position consists of the guns permanently mounted in fortifications. As the fortifications of the United States are all located on the seacoasts, the guns that form their armament are usually designated *seacoast guns.*

Mobile Artillery.—The mobile artillery of the United States as at present designed will consist of the following guns:

Gun.	Caliber.	Projectile.
Mountain gun	2.95 inch	18 lbs.
Light field gun	2.38 inch	$7\frac{1}{2}$ lbs.
Field gun	3.0 inch	15 lbs.
Field howitzer	3.8 inch	30 lbs.
Heavy field gun	3.8 inch	30 lbs.
Heavy field howitzer	4.7 inch	60 lbs.
Siege gun	4.7 inch	60 lbs.
Siege howitzer	6.0 inch	120 lbs.

The selection of these calibers is based on the following principles. The field gun, the principal artillery weapon of an army in the field, must have sufficient mobility to enable it to accompany the rapidly moving columns of the army. Long experience indicates that to attain the desired degree of mobility the weight behind each horse of the team should not exceed 650 pounds. A six horse team is used with the field gun. The total weight of the gun, carriage, limber, and equipment, with a suitable quantity of ammunition, is therefore limited to 3900 pounds. Limited by this requirement the power of the gun should be as great as it can be made. The shrapnel being the most important projectile of the field gun the caliber of the gun should be such as to give the shrapnel the greatest efficiency. Consideration of these requirements has led to the adoption of the 3-inch caliber for the field gun of our service.

A gun of greater power will, on those occasions when it can be brought into action, be more effective than the 3-inch gun. The heavy 3.8-inch field gun, firing a 30-pound projectile and possessing sufficient mobility to enable it to accompany the slower moving columns of the army, is therefore provided. The weight behind the six horse team is limited to 4800 pounds. With this weight the gun is capable of rapid movement for short distances.

The caliber of the siege gun is limited by the requirement that the weight of the gun shall not exceed the draft power of an eight horse team. The draft power of this team, for the siege gun, is taken as 8000 pounds.

Allowing for bad roads and rough usage and for the occasional necessity of covering considerable distances at high speed, the draft power of a horse for artillery purposes is taken as considerably less than the draft power of the horse used in ordinary commerce.

The guns above named are intended for the attack of targets that can be reached by direct fire, that is, by fire at angles of elevation not exceeding 20 degrees. For the attack of targets that are protected against direct fire and for use in positions so sheltered that direct fire cannot be utilized, curved fire, that is, fire at elevations exceeding 20 degrees, is necessary. There is therefore provided, corresponding to each caliber of gun, a howitzer of an equal degree of mobility. The howitzer is a short gun designed and mounted to fire at comparatively large angles of elevation.

In order to reduce to the minimum the number of calibers of the mobile artillery and thus simplify as far as possible the supply of ammunition in the field, the calibers of the guns and howitzers have been so selected that, while both guns and howitzers fulfil the requirements as to weight and power for each degree of mobility, the caliber of each howitzer is the same as that of the gun of the next lower degree of mobility. That is, the howitzer corresponding in mobility to one of the guns is of the same caliber as the next heavier gun and uses the same projectile.

As there may be occasions when profitable use can be made of a gun throwing a lighter projectile than that of the 3-inch field gun, the light field gun, 2.38-inch caliber, is provided. The weight of the projectile is $7\frac{1}{2}$ pounds, this weight being considered the lowest limit for an efficient shrapnel. The 2.38-inch gun will probably be used for the movable defense of seacoast fortifications.

179. Advantages of Recent Carriages.—The chief difference between the latest and earlier designs of carriages for mobile artillery lies in the provision made in the later carriages for recoil of the gun on the carriage. By this means a part of the force produced by the discharge is absorbed in controlling the recoil of the gun on the carriage, leaving only a part available to produce motion of the carriage; and by the addition to the end of the trail of a spade which is sunk in the ground the carriage is enabled to withstand the transmitted force without motion to the rear. When the spade is once fixed firmly in the earth further firing of the gun does not produce recoil of the carriage. Rapidity of fire is thereby greatly increased, and the soldier is relieved from the fatiguing labor of running the carriage back into battery after each round.

Rapidity of fire is also increased by the use of fixed ammunition, and by the provision for a slight movement in azimuth of the gun on the carriage. The movement in azimuth permits a change in the pointing of the gun of three or four degrees to either side without disturbing the carriage after the spade is set in the ground.

In addition, the gun sights on all modern constructions are fixed to some non-recoiling part of the carriage so that they are not affected by the recoil. The operation of sighting may therefore go on continuously, independently of the loading and firing.

Our service field and siege carriages, with the exception of the 6-inch siege howitzer carriage, are so designed that the wheels will not be lifted from the ground under firings at zero elevation.

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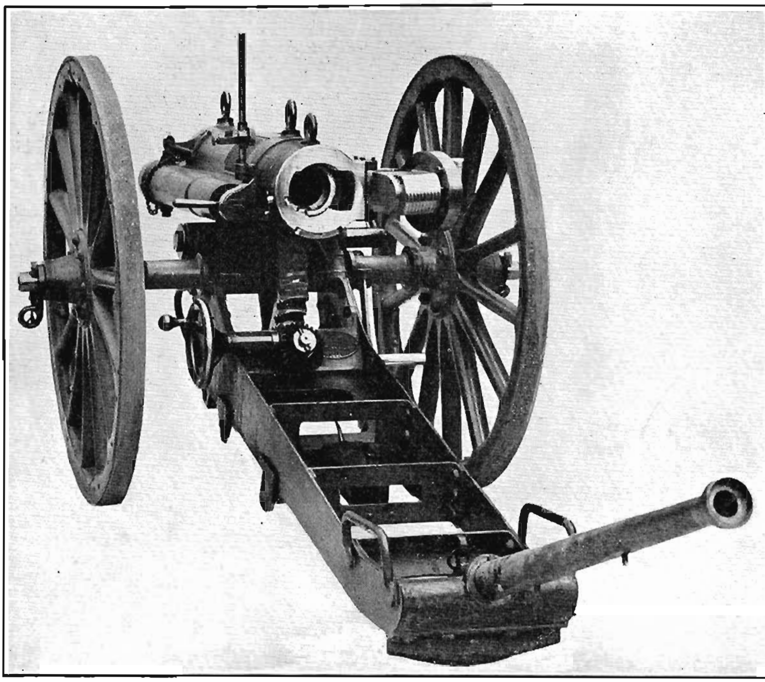

FIG. 110.— 2.95-inch Mountain Gun.

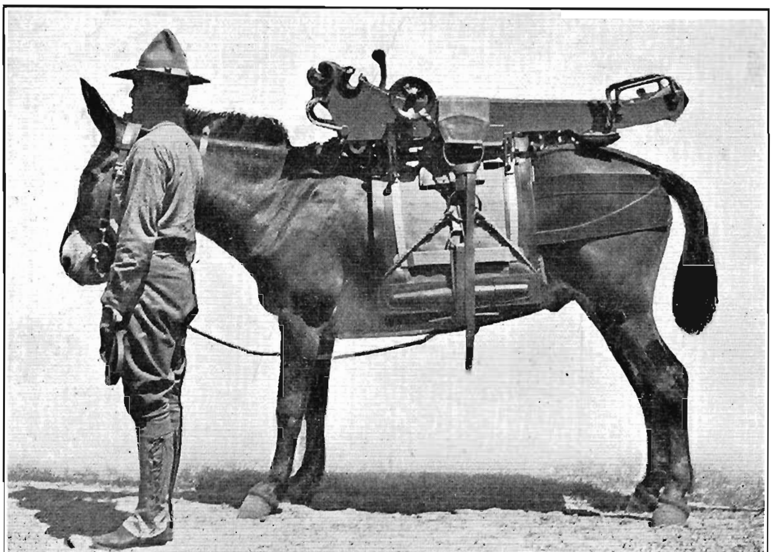

FIG. 111.—Transport of Trail.

The Mountain Gun.—For mountain service the system composed of gun and carriage must be capable of rapid dismantling into parts, no one of which will form too heavy a load for a pack mule. The weight of the load, including the saddle and equipment of the mule, should not exceed 350 pounds. The system must be capable of rapid reassembling for action.

The mountain gun used in our service, originally made by Vickers Sons and Maxim of England, has a caliber of 75 millimeters, or 2.95 inches, and fires projectiles weighing 12½ and 18 pounds. The caliber of this piece will probably soon be changed to 3 inches so that it may use the same projectile as the 3-inch field gun.

The gun is made from a single forging, and weighs complete with breech mechanism 236 pounds. Fixed ammunition is used in it. The breech mechanism, Fig. 110, is of the interrupted screw type. The block has two threaded sectors separated by flat surfaces. It is provided with percussion firing mechanism so arranged that the gun cannot be fired until the breech block is fully closed and locked. The trigger to which the firing lanyard is attached is seen to the left in the figure outside the breech. In case of a misfire the mechanism may be recocked without opening the breech.

180. The Carriage.—A low wheeled carriage is provided for the mountain gun. The wheels are 36 inches in diameter and have a track of 32 inches. The principal parts of the carriage are the cradle, the trail and elevating gear, the wheels and axle.

THE CRADLE.—The cradle is a bronze casting, with a central cylindrical bore and a smaller cylinder on each side. The central cylinder embraces the gun to within a few inches of the muzzle and forms a support in which the gun slides in recoil. The side cylinders are hydraulic buffers the piston rods of which are secured to lugs on the gun by interrupted screws so that the gun may be readily separated from the cradle. Grooves of varying width and depth cut in the interior walls of the buffer cylinders allow passage of oil from one side of the piston to the other in recoil. Constant pressure is maintained in the cylinder throughout the length of recoil, 14 inches. Spiral springs surrounding the piston rods return the gun to battery.

The cradle is secured to the trail by a bolt, seen above the axle in Fig. 110, which passes through two lugs formed on the under side of the cradle, the outer ends of the bolt fitting into two bearings or sockets provided at the forward upper end of the trail. The cradle moves in elevation about this bolt.

Light lifting bars are provided for use in dismantling and assembling the gun and carriage. They are passed through the two eye bolts on the top of the cradle, and through one on the gun.

Front and rear sights are attached to the cradle. The rear tangent sight is detachable.

THE TRAIL.—The trail consists of two outside plates or flasks of steel joined together by a shoe and three transoms. The shoe is provided with a spade on the under side to assist in checking recoil, and with a socket on the upper side, in which a handspike may be fitted, or the shafts attached when traveling on wheels. At the front end of the trail are the bearings for the cradle bolt and further to the rear are bearings for the axle. The bearings are open at the top, Fig. 112, the openings having a width less than the diameter of the bearing. The cradle bolt and axle tree are cylindrical, with flats cut on them so that they can only enter their bearings at a certain angle. When in position in the bearings they are turned through 90 degrees and thus secured. The crank secured to the axle at the right, Fig. 110, is for the purpose of turning the axle, in dismantling the carriage, to bring the flats of the axle in line with the openings of the bearings. When assembled the axle is locked in position by a spring latch bolt in the crank handle which engages in a slot provided in the trail.

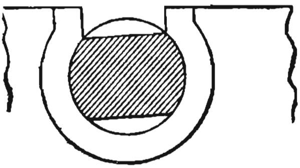

FIG. 112.

THE ELEVATING GEAR.—The elevating gear is permanently attached to the trail. Motion of the hand wheel, Fig. 110, is communicated to the gun through bevel gears, *b* Fig. 113, a worm, *w*, and a toothed quadrant, *q*, attached at its rear end to the cradle. An arm formed on the forward end of the quadrant embraces the cradle bolt and revolves around it. A cross bar, *c*, on each side near the upper end of the arm keeps the quadrant in a central position, and two spiral springs fastened to the front transom and acting on the arm maintain practically a uniform weight on the elevating gear while the gun is being elevated or depressed.

The gun may move in elevation from minus 10 degrees to plus 27 degrees.

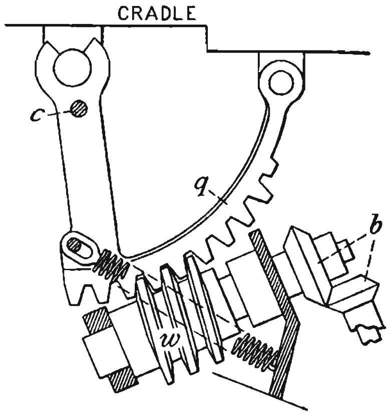

FIG. 113.

181. Ammunition. — Fixed ammunition is used. The charge is about 8 ounces of smokeless powder. The 110-grain percussion primer is used in the cartridge case and a front igniter of about $\frac{1}{8}$ ounce of black rifle powder. Three kinds of projectiles are provided: canister, shrapnel, and high explosive shell. The canister and shrapnel weigh $12\frac{1}{2}$ lbs., the high explosive shell 18 lbs. The canister contains 244 cast iron balls each $\frac{5}{8}$ of an inch in diameter. The shrapnel contains 234 balls. The bursting charge for the shell is 2.07 lbs. of high explosive.

The muzzle velocity of the $12\frac{1}{2}$-lb. projectile is 850 feet. The maximum pressure in the bore is 18,000 lbs.

The gun has an effective range of about 4000 yards.

Transportation.—For purposes of transportation the gun and carriage, with tools, implements, and equipments, are divided into four loads, the principal items of which are the gun, the cradle, the trail, the wheels and axle. These loads, without the pack equipment, weigh approximately 250 lbs. each. The pack saddle and equipment weigh 90 lbs., so that the total weight carried by the mule is about 340 lbs.

The trail, which forms the most inconvenient load, is shown in Fig. 111, loaded on the pack animal.

The ammunition is carried in nine loads of 10 or 12 rounds each, according as the projectiles weigh 18 or $12\frac{1}{2}$ lbs. A box holding 5 or 6 rounds is slung on hooks on each side of the pack saddle by loops formed in wire straps about the box. The boxes open at the end so that the ammunition may be removed from them without disturbing the pack.

Field Artillery.—The field artillery as at present designed will consist of the 2.38-inch gun, the 3-inch gun, the 3.8-inch gun, and the 3.8-inch and 4.7-inch howitzers. It is also the intention to modify the carriage of the mountain gun so that the piece may be fired at high angles of elevation and be used as a light field howitzer. The caliber of the gun will then be changed to 3 inches so that the projectiles of the 3-inch field gun may be used in it. There is also at present in service a 3.6-inch field mortar.

Fixed ammunition is used in all field pieces except the mortar.

The following table contains data relating to the guns and carriages of the field artillery.

	Guns.			Howitzers.		Mortar.
Caliber, inches	2.38	3	3.8	3.8	4.7	3.6
Date of Model	1905	1905	1905	1906	1906	1890
Charge, lbs.	0.72	1.62	3	1.2	1.3	0.38
Projectile, lbs.	7.5	15	30	30	60	20
Bursting charge, lbs.	0.8	0.82	2.1	2.1	3.1	0.6
Cartridge complete, lbs.	9.5	18.75	38	35	65	..
Shrapnel balls, number	118	252	526	526	1063	..
Muzzle velocity, f. s.	1700	1700	1700	900	900	690
Maximum pressure, lbs.	33000	33000	33000	15000	15000	17000
Weight, limbered, lbs.	2400	3900	4800	3900	4800	..
AT MAXIMUM ELEVATION.						
Elevation, degrees	15	15	15	45	45	45
Time of flight, seconds	19.4	21.9	21	36.3	37.4	21.2
Remaining velocity, f. s.	664	737	769	707	752	515
Range, yards	5800	6100	6900	6300	6850	3360

Other data concerning the guns of the field artillery will be found in the table on page 135.

The velocities and pressures are fixed at the low figures given in the table in order that the guns and carriages may be kept within the limits as to weight.

With velocities of 400 feet the service shrapnel balls are effective against men, and with velocities of 880 feet, against animals. As the velocity of the balls is increased by from 250 to 300 feet at the bursting of the shrapnel, it will be seen from the table that shrapnel fire from the field pieces is effective at all ranges.

The designs of the field guns of different caliber, with their mounts, differ practically only in the size of the parts. A description of one will therefore answer for all.

182. The 3-inch Field Gun.—The 3-inch field gun is the principal weapon of the field artillery. The gun, of nickel steel, is built up in the manner described on page 236. A hoop called the clip is shrunk on near the muzzle. On the under side of this hoop, and of the locking hoop and jacket, are formed clips, *k* Fig. 117, which embrace the guide rails of the cradle of the carriage. The gun slides in recoil on the upper surface of the cradle. A downwardly extending lug, *l* Figs. 116 and 117, at the rear of the jacket serves for the attachment of the recoil cylinder, which moves with the gun in recoil.

The Breech Mechanism.—The breech mechanism, model 1904, is shown in Fig. 114, in the locked position. The mechanism is of the slotted screw type.

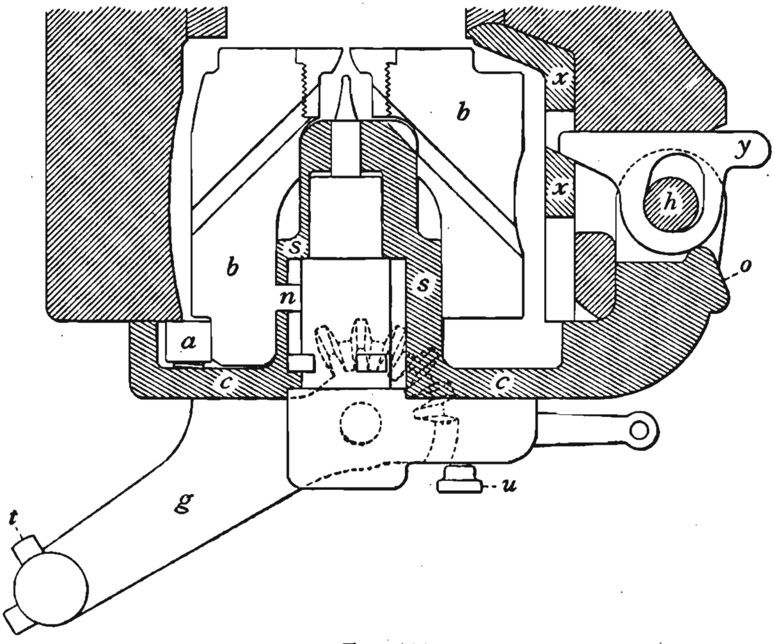

Fig. 114.

The breech block *b* is cylindrical with four threaded and four slotted sectors. It is mounted on a hollow spindle *s* formed on the carrier *c*, to which it is held by the lug *n*, which engages in a slot cut in the enlarged base of the spindle. On a semi-circular boss formed on the rear face of the block is cut a toothed rack, outlined at *z*, Fig. 117. The teeth of a bevel pinion formed on the inner end of the operating lever *g* mesh in the teeth of the rack. The lever is pivoted on a pin which passes through two lugs formed on the rear face of the carrier. On grasping the handle of the lever the pressure against a latch *t* in the handle unlocks the lever from the face of the breech. Swinging the lever to the rear rotates the block until it is stopped by a lug inside the carrier and locked in position by the spring stud *a*. Further movement of the lever causes both block and carrier to rotate together about the hinge pin *h*. When the movement is nearly complete the surface *o* of the carrier bears against the arm of the extractor lever *y*, which causes the extractor *x* to move sharply to the rear and eject the empty cartridge case.

183. The Firing Mechanism.—The firing mechanism, Fig. 115, is contained in the firing lock case *f*, which is inserted into the

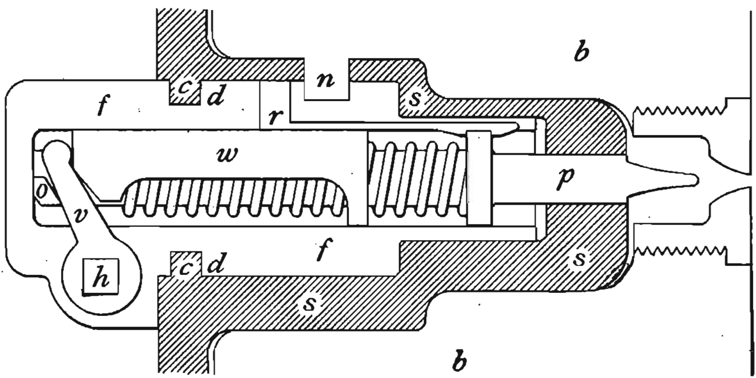

Fig. 115.

hollow spindle from the rear, the interrupted lugs *d* on the lock case engaging behind corresponding interrupted lugs *c* on the carrier. Assembled in the lock case are the firing pin *p*, the spiral firing spring, the firing pin sleeve *w*, and the trigger fork *v*, the latter fitting over the squared end of the trigger shaft *h*, which is journaled in an arm of the lock case *f*, Fig. 117, extending downward and to the right outside the carrier.

At the lower end of the trigger shaft *h*, Fig. 117, are two levers at right angles to each other, one marked trigger provided with an eye for the hook of the lanyard, the other acted upon by an upwardly extending lug on the end of the firing lever shaft.

A narrow section of the forward end of the lock case, Fig. 115, is cut out for the flat sear spring *r*. A notch in the sear engages the shoulder formed on the firing pin. The sleeve *w* at its rear end bears upon the last coil of the firing pin spring. When the trigger shaft *h* is turned by a pull on the lanyard, or by means of the firing lever, the trigger fork *v* forces the sleeve *w* to the front, compressing the firing spring. The forward end of the sleeve pushes the sear spring aside from its engagement on shoulder of firing pin, and the compressed spring then drives the firing pin forcibly forward until arrested by the shoulder striking the inner surface of the spindle. When the pull on the lanyard has ceased, the firing spring, still compressed, exerts a pressure against the rear end of the sleeve *w*, thence on the fork *v*, and on the head *o* of the firing pin; and the construction of these parts is such that the spring can regain its extended length only when the parts are in the position shown in the figure. The firing pin is therefore immediately withdrawn, on the cessation of the lanyard pull, until caught again by the sear.

The system of cocking and firing the piece by one movement is called the continuous pull system. The firing spring is compressed only at the moment of firing, whereas in the mechanism that is cocked in opening the breech the firing spring is compressed whenever the breech is opened and may remain compressed for a long time.

Safety Devices.—Safety against discharge before the breech is fully closed is secured as follows. The axis of the spindle *s* on the carrier, Fig. 114, lies $\frac{3}{10}$ of an inch below and $\frac{8}{10}$ of an inch to the right of the axis of the gun. The breech block which revolves on this spindle is therefore eccentric with the bore. The firing mechanism is eccentric with the block, the axis of the firing mechanism being fixed in the axis of the bore. When the block is locked the hole in its front end through which the firing pin protrudes in firing is also in the axis of the bore, but as the block is rotated in opening, the hole rotates out of the axis of the bore and the flat surface at its rear end comes in front of the firing pin and prevents movement of the firing pin until the breech is locked.

The headed spring pin *u*, Fig. 117, enters a hole in the carrier and retains the firing mechanism in its position in the carrier. By withdrawing this pin and rotating the firing lock case *f* upward through 45 degrees the interrupted lugs *d*, Fig. 115, on the firing lock case disengage from behind the interrupted lugs *c* on the carrier, and the firing mechanism may be withdrawn from the gun. The breech block is then readily removed. The breech mechanism may thus, without the use of tools, be readily dismantled for repair, or the gun may be quickly disabled in the event of imminent capture.

Four holes are drilled rearwardly through the breech block, *b* Fig. 114, to permit the escape of gas without injury to the screw threads of the mechanism in case the primer in the cartridge is punctured by the blow of the firing pin.

THE 3-INCH GUN, MODEL 1905.—The 3-inch gun, model 1905, is 50 lbs. lighter than the 1902 and 1904 models, the outside diameters being slightly diminished. The twist of the rifling, which in the earlier models increases from 1 turn in 50 calibers at the breech to 1 in 25 at the muzzle, increases from zero at the breech to 1 in 25 at $9\frac{3}{4}$ inches from the muzzle, from which point it is uniform to the muzzle. The purpose of the change in twist is to diminish the resistance encountered by the projectile in the first part of its movement and thereby diminish the maximum pressure. The short length of uniform twist at the muzzle steadies the projectile as it issues from the bore.

184. The Carriage.—The principal parts of the carriage are the cradle, the rocker, the trail, the wheels and axle.

THE CRADLE.—The cradle, *c* Figs. 116 and 117, is a long steel cylinder, which contains the recoil controlling parts. These parts are fully described in the chapter on recoil, and illustrated in Figs. 108 and 109 of that chapter. The gun slides in recoil on the upper surface of the cradle, the clips of the gun, *k* Fig. 117, engaging the flanged edges. A pintle plate fastened to the bottom of the cradle is provided with the pintle *p*, Fig. 117, and the grooved arc *a*, which serve to connect the cradle to the rocker.

THE ROCKER.—The rocker *r* embraces the axle between the flasks of the trail by the bearings at its ends. The cradle pintle fits in a seat provided in the rocker above the axle, and the clips

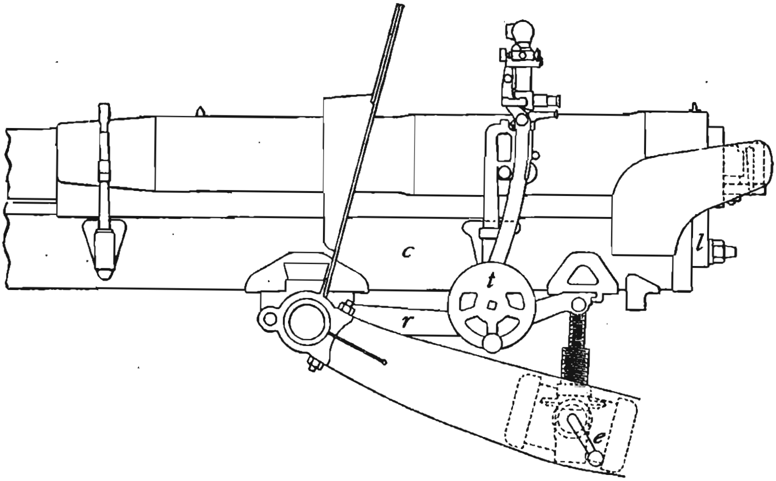

FIG. 116.

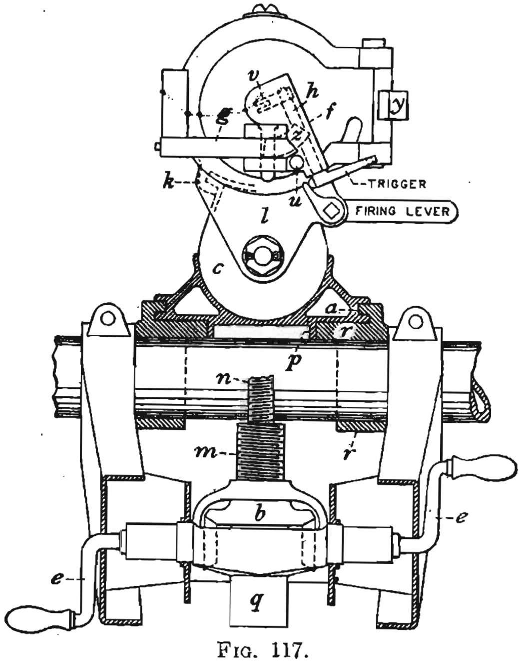

FIG. 117.

on the rocker engage in the grooved arc *a* of the cradle. This construction permits movement of the cradle and gun in azimuth on the rocker, while the rocker itself revolves about the axle and thus gives movement in elevation to the cradle and the gun. The movement in azimuth, 4 degrees either way, is produced by a screw on the shaft of the hand wheel *t*, Fig. 116. The shaft is fixed in bearings in the rocker arms and the screw works in a nut pivoted in a bracket fastened under the cradle.

The double elevating screw, actuated by either of the crank shafts *e* fixed in bearings in the trail, rotates the rocker and cradle about the axle. The bevel pinion on the end of each shaft *e* rotates the bevel pinion *b* in its bearings. The pinion *b* is splined to the outer screw *m* and causes the outer screw to turn in the fixed nut *q* which is supported below the pinion *b* by a transom. The outer screw *m* has a left handed thread on the exterior and a right handed thread in the interior. When turned it travels up or down in the nut *q*, and at the same time causes the inner screw *n* to move into or out of the outer screw, the inner screw being prevented from turning by its connection with the rocker arms, *r* Fig. 116. The movement of the inner screw for each turn of the pinion *b* is thus equal to the sum of the pitches of the outer and inner screws.

THE TRAIL.—The trail, Fig. 119, composed of two flanged steel flasks connected by transoms and top and bottom plates, terminates at its lower end in a fixed spade provided with a float or wings which prevent excessive burying of the spade in the ground. The lower edge of the spade is of hardened steel riveted on so that it may be readily replaced when worn out. The lunette, a stout eye bolt fixed in the end of the trail, engages over the pintle of the limber when the carriages are connected for traveling. Seats for two cannoneers who serve the piece in action are attached to the trail one on either side near the breech of the piece; and two other seats on the axle, facing toward the muzzle, are occupied in traveling by two cannoneers, one of whom manipulates the lever of the wheel brakes.

THE WHEELS AND AXLE.—The axle of forged steel is hollow. The axle arms are given a set so as to bring the lowest spoke of each wheel vertical.

The wheels are a modified form of the Archibald pattern, 56 inches in diameter with 3-inch tires. The hub, Fig. 118, consists of a steel hub box *h* and hub ring *r* assembled by bolts through the flanges, between which the spokes of the wheel are tightly clamped. The hub box is lined with a bronze liner forced in. A steel cap *c* is screwed on the outer end of the hub box. Riveted to the cap is a self closing oil valve, by means of which the wheels are oiled without removal from the axle. The hollow axle forms a reservoir for the oil.

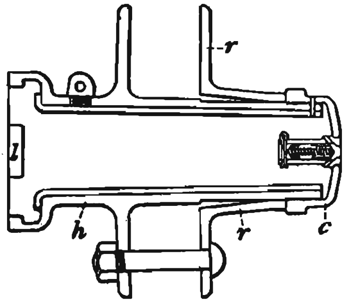

FIG. 118.

The wheels are secured to the axle by the wheel fastening, a bronze split ring, hinged for assembling around the axle. The ring revolves freely in a groove in the axle. Interrupted lugs on its exterior engage behind corresponding interrupted lugs, *l* Fig. 118, in the inner end of hub box, and hold the wheel on the axle. A hasp connects the hub and the wheel fastening so that they cannot revolve independently and disengage the lugs.

185. THE SHIELD.—The cannoneers serving the piece are protected by a shield of hardened steel $\frac{2}{10}$ of an inch thick. It is in three parts. One part, the apron, depends from the axle and is swung up forward under the cannoneers' seats when traveling. The main shield, rigidly attached to the frame of the carriage, extends upwards from the axle to $2\frac{1}{4}$ inches below the tops of the wheels. The top shield is hinged to the main shield. When raised its upper edge is 62 inches from the ground, a height sufficient to afford protection from long range and high angle fire to cannoneers on the trail seats. In traveling the top shield is folded over so that should the carriage turn over on the march the shield is partially protected from injury. Each shield before being attached to the carriage is tested at a range of 100 yards with a bullet from the service rifle. The plate must not be perforated, cracked, broken, or materially deformed in the test.

SIGHTS.—The piece is provided with three different means of sighting. Two fixed sights on the upper element of the gun, Fig. 116, determine a line of sight parallel to the axis, for use in giving general direction to the piece. For more accurate sighting a tangent rear sight and a front sight with crossed wires are provided. They are seated in brackets attached to the cradle. A telescopic panoramic sight is seated on the stem of the tangent sight. This sight is used for direct aiming and for indirect aiming, which consists in pointing the gun by means of a line of sight considerably divergent from the line of fire. By means of the panoramic sight any object in view from the gun may be used as an aiming point.

A range quadrant, seated on the cradle of the carriage, provides the means of determining the elevation in indirect fire.

The sights are fully described in the chapter on sights, Chapter XIII, and the range quadrant in Chapter XIV.

The Limber.—The limber, Fig. 120, is practically wholly of metal, the neck yoke and pole, and spokes and felloes of the wheels, being the only wooden parts. The body of the limber is a steel frame, composed of three rails riveted to lugs formed on the axle and braced by steel tie rods. The middle rail is in the form of a split cylinder, one half passing below the axle and the other above. The halves unite in front forming a socket for the pole, which is held firmly in place by a clamp. Similarly in the rear the middle rail forms a seat for the pintle hook. The pintle hook is swiveled in its seat, so that if at any time the gun carriage turns over the pintle will turn without overturning the limber as well.

The ammunition chest, of sheet steel, is fastened to the outer rails. The front of the chest and the door which forms the rear are strengthened by vertical corrugations. The door opens downward and is then supported by chains. The metallic ammunition is supported in the chest by three diaphragms each perforated with 39 holes. The middle and rear diaphragms are connected by flanged brass tubes cut away on top to reduce the weight. The tubes support the front ends of the cartridge cases and enable blank ammunition and empty cases to be carried.

Seats made of sheet steel are provided for three cannoneers on the limber chest, and a steel foot-plate rests on the rails in front of the chest.

The wheels of the limber and the wheels of all other carriages

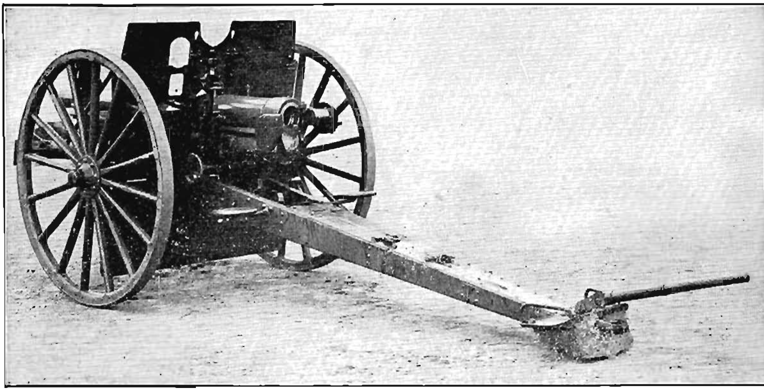

Fig. 119.—3-inch Field Gun, Model 1902.

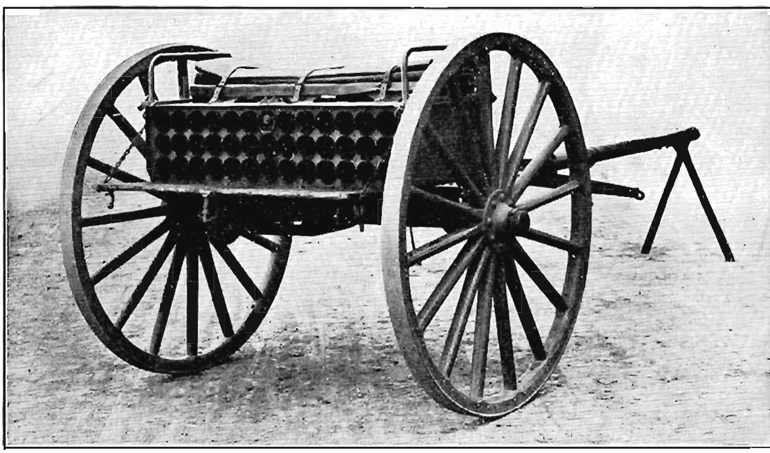

Fig. 120.—3-inch Field Limber.

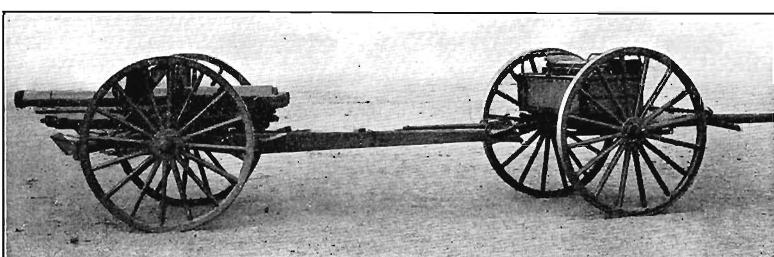

Fig. 121.—3-inch Field Gun, Limbered.

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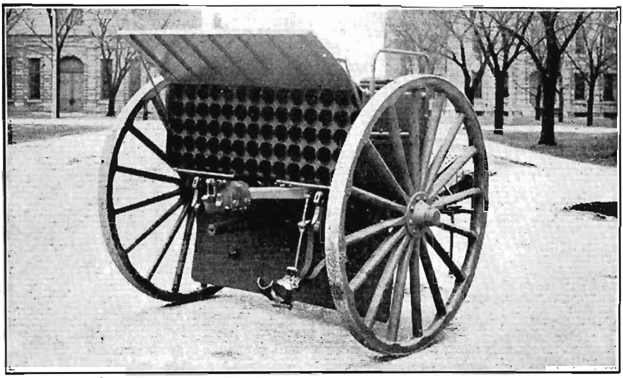

Fig. 122.—3-inch Field Caisson.

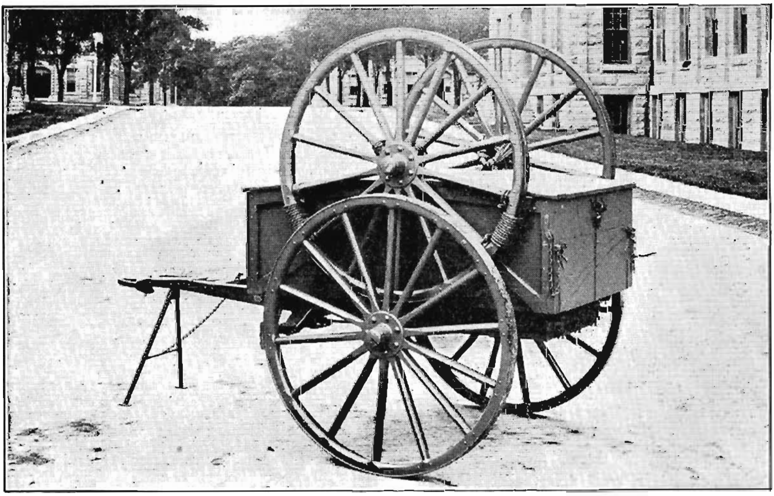

Fig. 123.—3-inch Field Battery Wagon.

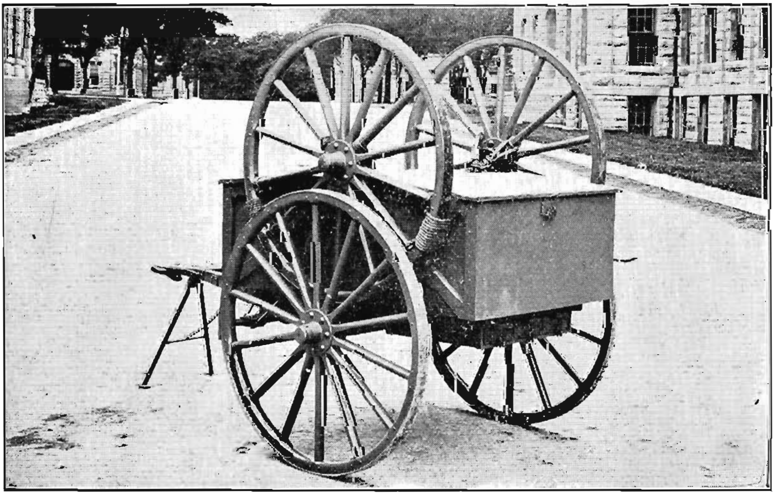

Fig. 124.—3-inch Field Store Wagon.

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that form part of a field battery are interchangeable with the wheels of the gun carriage.

186. The Caisson and other Wagons.—The construction of the caisson, Fig. 122, does not differ materially from that of the limber. The ammunition chest is larger and carries 70 rounds of ammunition. The front of the chest is of armor plate $\frac{2}{10}$ of an inch thick; and the door at the rear, which opens upward to an angle of about 30 degrees above the horizontal, is of armor plate $\frac{15}{100}$ of an inch thick. A $\frac{2}{10}$-inch plate also depends from the axle as in the gun carriage. The cannoneers serving the caisson are thus afforded protection for a height of 63 inches from the ground.

Attached to the caisson by a hinged bracket at the rear is an automatic fuse setter, by means of which the cannoneer at the caisson may quickly set the fuse of the projectile to the time of burning corresponding to any range ordered by the battery commander. The fuse setter is described in the chapter on primers and fuses, and is illustrated in Fig. 229.

Three caissons with their limbers accompany each gun into the field.

The wagons of a battery include also the forge limber, which, as its name indicates, carries a blacksmith's forge and set of tools; and the battery wagon, Fig. 123, which carries carpenter's and saddler's tools and supplies; materials for cleaning and preservation; spare parts of gun, of carriage, and of harness; tools and implements; miscellaneous supplies and two spare wheels.

A wagon called the store wagon, Fig. 124, is for use in carrying such stores, spare parts, and materials as cannot be carried in the battery wagon.

Experiments are now being conducted toward the development of an automobile battery wagon.

Field Howitzers and Mortars.—The 3.8-inch and 4.7-inch field howitzers have not yet been constructed. The principles of construction of the guns and carriages will be understood from the description of the 6-inch howitzer and carriage which follows later.

There is at present in service a 3.6-inch field mortar shown in Fig. 125. The piece is a short gun intended for vertical fire against troops protected by intrenchments or other shelter. The Freyre obturator described on page 262 is used in the breech mechanism to save weight. The gun weighs 245 lbs. and its mount 300 lbs. more, so that the gun with its mount may be readily moved in the field. The mount is a single steel casting. The gun is held at any desired elevation by means of a clamp which acts on a steel arc attached to the under side of the gun.

When in use the carriage rests on a wooden platform, and recoil is checked by a heavy rope attached to stakes driven into the ground in front.

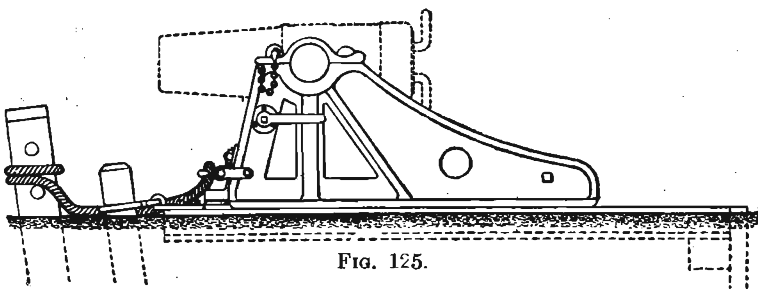

FIG. 125.

187. Siege Artillery.—The new siege artillery comprises the 4.7-inch gun and the 6-inch howitzer. The older siege pieces now in service are the 5-inch gun, the 7-inch howitzer, and the 7-inch mortar.

The following table contains data relating to the guns and carriages of the siege artillery.

	Guns.		Howitzers.		Mortar.
Caliber, inches	4.7	5	6	7	7
Date of model	1904	1898	1905	1898	1892
Charge, lbs.	5.94	5.37	4	4.6	4.0
Projectile, lbs.	60	45	120	105	125
Bursting charge, lbs.	3.1	1.75	3.86	7.4	11.9
Cartridge complete, lbs.	73¾	..	..	..	..
Shrapnel balls, number	1063	..	2150	..	..
Muzzle velocity, f. s.	1700	1830	900	1100	800
Maximum pressure, lbs.	33000	35000	15000	28000	20000
Weight, limbered, lbs.	8000	8800	7900	..	..
AT MAXIMUM ELEVATION.					
Elevation, degrees	15	31	45	35	45
Time of flight, seconds	21.8	38.2	37.5	34.3	32.9
Remaining velocity, f. s.	971	638	764	749	641
Range, yards	7600	10000	7000	7700	5200

Other data concerning the guns of the siege artillery will be found in the table on page 135.

The 4.7-inch Siege Gun.—The gun is similar in construction and in breech mechanism to the 3-inch field gun. Fixed ammunition is used in it.

THE CARRIAGE.—The carriage is, in general, similar in construction to the 3-inch field carriage. The greater weight of the gun and the increased force of recoil render necessary certain changes in the parts. In the 3-inch carriage the recoil cylinder and counter recoil springs are assembled together in a single cylinder in the cradle. The cradle of the 4.7-inch carriage, Figs. 127, 128, and 129, consists of three steel cylinders bound together by broad steel bands, the middle band provided with trunnions. The middle cylinder contains the mechanism for the hydraulic control of recoil. Each of the outer cylinders contain three concentric columns of coiled springs for returning the gun to battery. The front end of each of the outer two spring columns is connected to the rear end of the next inner column by a steel tube, flanged outwardly at the front end and inwardly at the rear end. A headed rod passes through the center of the inner coil and is fixed to a yoke that is fastened to the lug at the breech of the gun, see Fig. 128. The head of the rod acts on the inner coil only, and the pressure is transmitted through the flanged tubes or stirrups to the outer coils. In this way the springs work in tandem and have a long stroke with short assembled length.

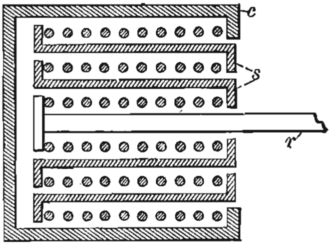

FIG. 126.

The arrangement of the springs will be understood by reference to Fig. 126, in which *r* represents the headed rod, *s* the tubular stirrups, and *c* the walls of the cradle cylinder.

The length of recoil is 66 inches.

The gun is supported, and slides in recoil, on rails *r* fixed on top of the spring cylinders. The distance apart of the rails broadens the bearing of the gun and gives it steadiness both in action and in transportation. An extension piece, bolted to the front end of the cradle and readily detachable, continues the rails to the front clip of the gun. When traveling this extension piece is detached and carried in fastenings under the trail.

THE PINTLE YOKE.—The cradle is trunnioned in a part called the pintle yoke, *y* Fig. 127, which is itself pintled in a seat, *p*, called the pintle bearing, mounted between the forward ends of the trail flasks, its rear end embracing the hollow axle *x*. A traversing bracket, *b*, is attached to the bottom of the pintle yoke and extending to the rear under the axle forms a support for the

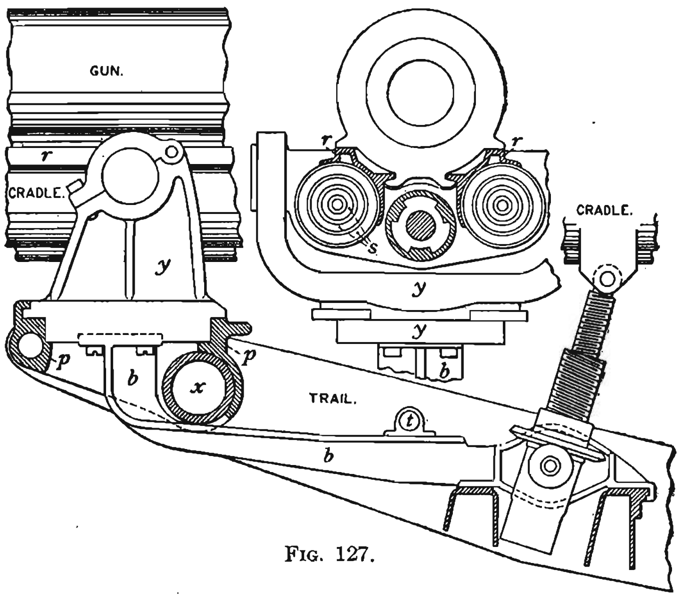

FIG. 127.

traversing shaft *t* and for the elevating mechanism. The rear end of the traversing bracket slides on supporting transoms between the flasks of the trail, motion being given to the bracket by means of a screw on the traversing shaft which works in a nut suitably attached to the trail. The gun may be moved in azimuth on the carriage 4 degrees either way. The elevating mechanism is carried on the traversing bracket and moves with the gun in azimuth. It is therefore not subjected to any cross strains. The gun may be moved in elevation from minus 5 to plus 15 degrees.

188. THE WHEELS AND THE TRAIL.—The wheels are 60 inches in diameter with 5-inch tires. Exhaustive tests recently con-

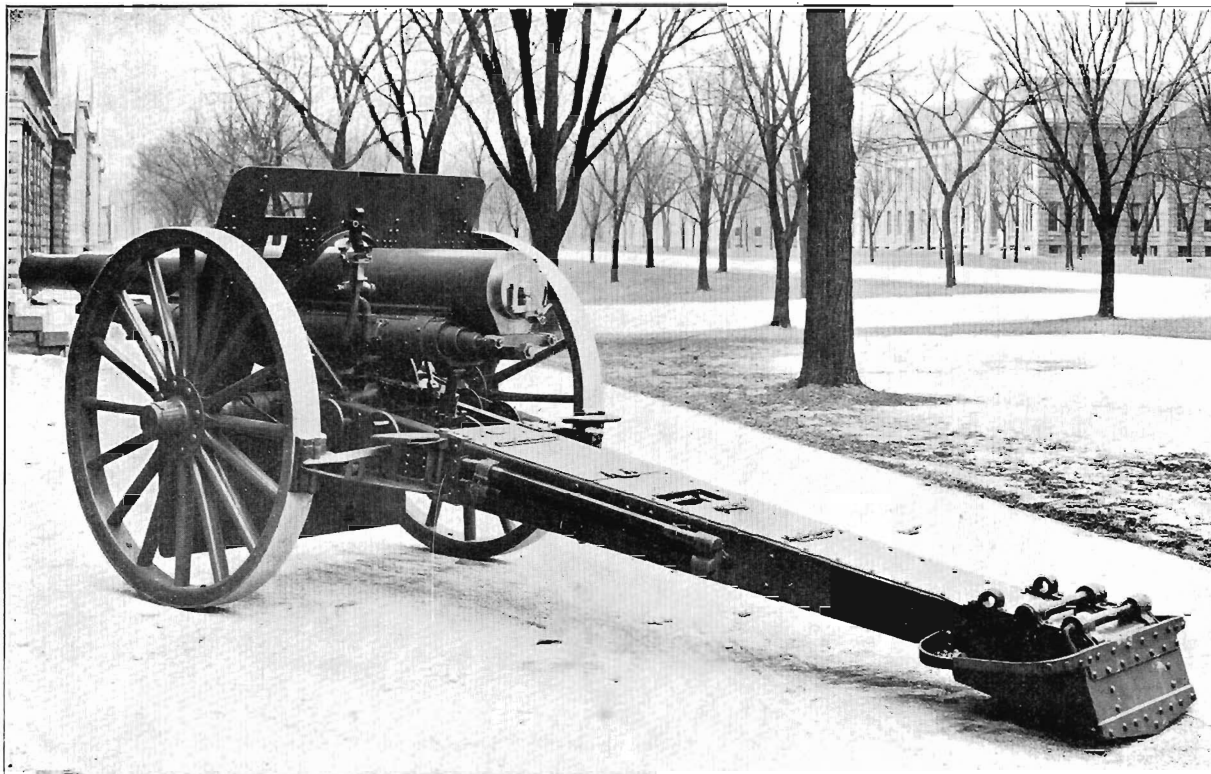

Fig. 128.—4.7-inch Siege Gun, Firing Position.

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