WAVE ACTION IN GUNS.

By FREDERICK H. MCGAHIE.

THE regularity of action of smokeless powders has been made the question of the day in American ordnance circles by the destruction of a rifle during proof at Sandy Hook. The matter is now receiving a thorough examination by an investigating board, and all knowledge derived from past experience and theoretical investigation will be brought to bear upon this most important phase of propellants, for it is manifestly clear that the value of higher ballistics is negated entirely if the powder or system employed is accompanied by a decrease in the safety given as compared with the one to be superseded. The facts of the explosion are these: A new 10 inch rifle was being proved by Dupont smokeless powder made in accordance with the Schuppahaus-Maxim patents. Other rifles of the same caliber and type had been successfully tested in the same manner, and the powder had acted normally. The powder consisted of short grains with seven longitudinal perforations, the formula being the standard army one of 75 per cent. nitrocellulose and 25 per cent. nitroglycerin. In the gun in question a charge of 141 pounds had been fired, giving a pressure of 32,000 pounds. This charge was increased a few pounds to obtain the service pressure of 35,000 pounds, the increase being calculated by the Sarrau formula, which has been used most satisfactorily the world over for many years. Disaster followed the command to fire. The breech block was blown off with velocity sufficient to make it penetrate the protecting butt directly in the rear of the gun and to kill the recorder of tests. The breech tube was knocked off. As to the condition of the powder chamber and the rest of the gun, nothing can be known definitely until the report of the investigating board appears. A recovered gage indicated a pressure of 70,000 pounds. These conditions show plainly that detonation did not occur, this explosive action being characterized by enormous pressures developed so suddenly that lines of least resistance are utterly ignored in the destructive effects accompanying it. Had the charge of smokeless powder detonated, the whole chamber would have been subjected to an impulsive blow, around 100 tons per square inch, that would have torn it off completely from the tube of the gun and projected it in various sized pieces over the proving grounds. I doubt if a bona-fide case of detonation of a gunpowder charge has ever been clearly established. It serves as an explanation of unknown or unestablished causes. Had the powder cracked up through excessive internal pressure, the sudden increase of burning surface provided by the fragments would have given rise to a dangerous jump in the pressure, which, reacting on the velocity of combustion of the powder, would have carried it still higher before the movement of the projectile had sufficiently increased the expansion volume. Too long a multiperforated or tubular grain will break up into a few, not many, pieces. But the short grains used were far within the limit, and many tons of such powder have been fired since 1894 without giving the slightest hint of such action. The firings were made in a wide range of guns, with wide variations of loading and ballistic conditions. The accident has been made the subject of several articles in recent numbers of the SCIENTIFIC AMERICAN and SCIENTIFIC AMERICAN SUPPLEMENT.

In the light of the above matter the theories advanced by Hiram S. Maxim appear absurd, if indeed the replies of Hudson Maxim do not reveal the nature of those letters as a vicious attack upon an excellent powder, based upon personal animosities.

The phenomenon that took place in the wrecked gun was undoubtedly that conforming in general to the theory advanced by Hudson Maxim in his letter in the SCIENTIFIC AMERICAN of May 13, 1899. Conditions of loading and ignition, of which no data are at hand at present, originated a wave action in place of the normal distribution of pressure. This surging of the gases moved forward along the axis of the bore with great velocity. Meeting the base of the moving projectile, it was reflected back and impinged upon the mushroom head, which would result in compressing the gaseous column, running up the pressure around the burning charge, and accelerating abnormally the rate of emission of gases. This action itself would tend to abnormal pressures, but especially upon the rapid movement of a considerable weight of powder gases being arrested by the breech, the dynamic movement was translated into an impulsive blow in an axial direction that exceeded the endurance of the breech system. In some features it bore a resemblance to a water hammer.

When the late Capt. Sidney E. Stuart was detailed by the Chief of Ordnance of the United States Army to take full charge of the development and manufacture of service powders, brown prismatic was in use and abnormal pressures were observed every now and then in proving the various lots. A few illustrations are given from the firing records:

Gun.	Charge.	Velocity.	Pressure.	Remarks.
	Pounds	Foot Seconds	Pounds	
12 inch...	400	1932	36000	Normal
	406	2006	60000	
12 inch...	343	1724	33000	Normal
	350	1804	65000	
10 inch...	200	1813	37600	Normal
	200	1843	59000	

In the above firings the increase of velocities with increase of charge and variation of velocities with equal charges were those normal to single tests of brown powder. The changes in pressure were enormous. In the first group the pressure with 406 pounds should have been in the neighborhood of 37,000 pounds in place of the recorded 60,000 pounds, it being remembered that the gages are screwed into the mushroom head, and their axes are parallel to the axis of the bore. Neither an examination of the lot of powder from which the charges were taken nor an inspection of the factory records of the lot gave any facts to which the pressure variations could

be pinned. M. Vieille, one of the group of French explosive engineers who have published in the *Mémorial des Poudres et Salpêtres* some of the most valuable studies of explosives at our command, had investigated the action of powder gases in long closed tubes in connection with abnormalities found in French practice. He proved the existence of this wave action, and Capt. Stuart applied the theory to American practice with great success.

It will be well to examine this work of M. Vieille. The apparatus consisted of "a steel tube about 40 inches long and 2.4 inches in exterior diameter, the clear interior dimensions being about 35 inches and $\frac{3}{8}$ inch respectively. The ends of this tube were threaded and received exactly similar crusher gages, the pistons of which carried pins external to the tube and projecting perpendicularly to it, designed to record the motions of the pistons. Ignition was obtained by an electric fuse carried by a screw plug entering from the side near one end. Obturation was secured by seating the plugs in copper rings. The tube was fastened in a horizontal fashion on a metallic table in the firmest manner possible. A strong axle placed near and parallel to the tube carried at each end a metal cylinder with a blackened surface, so placed as to receive the trace of the pen carried by the piston of the corresponding crusher gage. This axle was rotated by an electric motor by means of a pulley attached midway of its length, in order to avoid differences in the torsion of the axle between the pulley and the two cylinders. The scale of time was obtained by a tuning fork making 500 vibrations per second, which were sustained by an electro-magnet. Various refinements in the character and manner of this portion of the apparatus secured a rigorously exact scale of time, and the whole apparatus operated in a manner insuring a high degree of accuracy in its indications."

Three kinds of powder were used in the experiments, (A) musket, (B) siege gun, (C) large rifle. The conditions of loading were varied in three ways, the charge being distributed uniformly throughout the length of the tube, collected at one end, or collected similarly in equal parts at each end.

While the pressure was developing during an experiment, the piston of the crusher gage would move forward in reducing the height of the copper plug, and the pin carried by it would trace a curve upon the revolving cylinder, the tuning fork meanwhile estab-

lishing a time scale. As the weight of the piston was designedly light in accordance with the theory of crusher gages, the deformation of the copper plug would keep pace with the increase of pressures, and would register any momentary excess of pressure due to the compression of the head of a surging gaseous column, arrested at the end where the crusher gage was. M. Vieille put the rectified curves into four classes, typical case being illustrated in Fig. 1. Of these, *a* is the case in which the copper plug was compressed regularly to a normal value, *b* in which the deformation rose to a normal value by steps, *c* in which an abnormal deformation was produced by steps, and *d* in which an abnormal crushing was attained at once. Selecting illustrative data from the experiments, the following table shows plainly the value of uniform distribution of explosives in long tubes.

Powder.	Density of Loading.	Indicated Pressure, Pounds per Sq. Inch.	Class of Trace.	Conditions of Loading.
A	0.075	10,000	a	Uniform distribution.
	0.075	10,000	b	Collected at firing end.
	0.075	10,000	b	" " " "
	0.1	15,800	a	Uniform distribution.
	0.1	32,950	c	Collected at firing end.
	0.1	36,400	c	" " " "
	0.1	31,850	c	" " both ends.
	0.1	34,850	c	" " " "
	0.1	34,500	c	" " one end.
	0.2	35,400	c	" " " "
B	0.2	29,500	a	Uniformly distributed.
	0.2	66,800	d	Collected at firing end.
	0.2	51,300	c	" " " "
	0.2	49,300	c	" " " "
C	0.2	29,300	b	" " " "
	0.25	38,300	b	Results normal with uniform distribution in previous tests.

Double pressures mean readings from both gages. Single readings from gage opposite firing end.

Previous experiments in much shorter *épreuves* (2 to 6 inches in length and 1 to 2.5 inches in diameter) had disclosed no difference in pressures with uniform and ununiform dispositions of explosives varying widely in their quickness. The tests in the long

épreuves revealed another state of affairs, as indicated in the above table. Up to a certain low limit of density of loading, increasing with the slowness of the powder, variations in the placing of the charge made little or no change in pressures. Above those limits the collecting of the charge at one end, or of equal parts at both ends, caused deformation of the copper plugs much in excess of that given by the case of uniform distribution at the same density of loading. This occurred with powders *A* and *B*. It would have taken place with *C* if the strength of the apparatus had permitted a higher density of loading. Referring to the pressure curves, all cases of uniform disposition were included in type *a*, showing that the pressure was developed regularly. Below the density of loading limit ununiform conditions gave curves of type *b*, in which the pressure rose to a normal value by successive steps. Above that limit ununiform distribution produced generally curves of type *c*, showing a development of abnormal pressure by several steps, and occasionally of type *d*, representing abnormal pressure in one step. A study of a large number of experiments of this nature led M. Vieille to the conclusion that "for densities of loading above the limiting values the crusher-gage coppers suffer excessive deformations, which demonstrate the existence of real excessive pressures, due to condensations resulting from the arrest at the ends of the chamber of the gaseous mass in rapid motion."

M. Vieille went further into the nature of this wave action, and experimented with the *épreuve* suspended freely, and with crusher-gages whose pistons were too heavy to respond to the momentary pressures due to condensation at the end of the tube of the moving gaseous column. A careful review of the matter led him to formulate the opinion that wave action was possible in large rifles when certain conditions coincided. The influence of ununiform distribution of the charge above certain densities of loading depending upon the quickness of the powder has been noticed. The universal practice in ordnance matters is to employ high densities of loading, much above these limits. The influence of length of powder chamber has been indicated by the difference in results obtained in short and long *épreuves*. This refers to the absolute length, and not to relative length in comparison with the diameter. The prevalent custom of igniting the charge is by means of a primer placed in the breech block, whose explosion, acting on the priming charge, would tend to set up some motion in an axial direction and contribute to pressure irregularity. This is borne out by some firings made in 1891 at Sandy Hook in two 3.2 field guns similar in all respects except that one had a radial vent for ignition of the charge, while the other had an axial vent. Loading conditions were the same, and black moulded powder used in these firings.

Charge.	Pressure.	
	Axial Vent.	Radial Vent.
3 pounds 5 ounces.....	26,450	32,500
3 " 6 "	37,600	32,450
3 " 7 "	41,300	33,600
3 " 7 "	38,400	31,000
3 " 8 "	39,500	34,350

It will be seen at once that axial ignition gave rise to higher and more irregular pressures than did radial ignition, confirmed by further tests with black and smokeless powders.

It would appear that wave action may find an origin in these conditions: Length of chamber, high density of loading, end ignition, quickness of powder, and ununiform distribution. The first three of these attend every firing of the large rifles of the day, and it may possibly be that the system of gaseous products of explosion is always on the verge of some degree of wave action that other causes may change, according to their nature, into mere irregularities or large and dangerous jumps in the pressure at the breech of the gun and extending more or less into the chamber.

Capt. Stuart noticed that abnormal pressures occurred with brown powder in the tests at Sandy Hook usually with reduced charges. Full charges were fixed to extend the length of the chamber, but smaller charges were generally reduced in length and not in diameter, providing thereby another favorable condition for wave action. Loading regulations were put into force then at Sandy Hook, designed to secure uniform distribution and regularity of inflammation of the charge. The Chief of Ordnance of the United States Army was able to report a year and a half later: "The occurrence of excessive wave pressure, frequently experienced in the earlier stages of our tests of brown powder, has been practically overcome."

Smokeless powders are at one disadvantage compared with brown prismatic. Any accidental variations in conditions that give rise to an abnormal pressure jump will carry it further with smokeless than with brown powder, for the rate of emission of gases increases more rapidly with the pressure in the former than in the latter. The relation in question is

$$V \propto P^x$$

in which *V* is the velocity of combustion of the powder at any pressure *P*, and *x* an exponential constant depending upon the powder used. M. Vieille has given these experimental values for *x*: Brown prismatic powder, 0.45; black powder, 0.55; smokeless powder of 50 per cent. military gun-cotton and 50 per cent. nitroglycerin, 0.55; smokeless powder of 50 per cent. soluble nitrocellulose and 50 per cent. nitroglycerin, 0.60; and smokeless powder entirely of military gun-cotton, 0.66. Furthermore, in a gun the action is a multiplying one. Some variation causes an irregular jump in the pressure; this increase makes the powder burn faster and deliver a large amount of gas. This additional increment of pressures increases still further the rate of emission, and so each reacts on the other until the movement of the projectile or the destruction of the gun relieves the pressure. This will indicate the complexity of the smokeless powder question. That article we must have. It involves the drawback just stated. On the other hand, a more uniform product is possible in commercial manufac-

ture. Then, again, in smokeless powders the introduction of nitroglycerin in quantity gives one with a lower rate of emission exponent, manufactured more rapidly and cheaply and having far higher ballistic properties than a guncotton powder. But nitroglycerin means a high degree of erosive action at least, while many contend that it introduces a dangerous mechanical stability into powders and generally lay any trouble with a nitroglycerin powder to its presence. It is indeed a puzzling matter.

To revert to the accident at Sandy Hook, it would seem reasonable that, if the inner jackets of the chamber show no signs of a general dangerous stress, wave action may be safely considered as the cause, coupled possibly with some weakness in the breech system of this particular rifle. If the chamber exhibits plainly that an excessive pressure existed throughout it, wave action must still have a prominent consideration, but the physical condition of this lot of powder enters into the case. Multiperforated powder can be badly made just as well as any other powder. Commercial methods may sometimes diverge from good practice. In 1897 the United States navy rejected 835,700 pounds of brown powder in getting 699,847 pounds of satisfactory powder. Badly warped and cracked multiperforated powder would not redound to the credit of the system through the results secured in firings. Shipments of cordite have been rejected on these grounds.

Let us examine multiperforated powder as regards uniformity and regularity, as these bear upon the starting of wave action. The general formula may be varied to produce powders running from a pure guncotton to a 60 per cent. nitroglycerin basis. In addition to the incorporation in the usual mixing machine, the ingredients are further mixed and kneaded thoroughly on rolls. From the press the powder issues in rods having exactly the cross section imposed by the forming die. Good practice in manufacturing insures that the shrinkage in drying is small and regular, this shrinkage occurring with all powders made with solvents. It is less in multiperforated powder than in other powders, and is distributed through at least three burning thicknesses in place of the one thickness of solid grains. The final dimensions of grains are completely in the control of the manufacturer, and accordingly all working details contribute to a maximum uniformity of powder. Matters still favor it in the gun. The gravimetric density of the grain is greater than with any other shape; that is, a given weight of multiperforated powder of any formula, with a given least dimension, will occupy more volume than the same weight made up into any solid grain with the same least dimension. Under these conditions more multiperforated powder can be used for a given pressure than is possible with the other powders. The natural result is that the chamber is more fully filled by the charge, and the danger of ununiform distribution through accident obviated to that degree. An essential point to regular pressures is regularity of inflammation of the powder by the priming charge. For this condition the multiperforated grain is ideal, since the perforations of the grain and the air spaces between the short cylinders afford an easy path for the igniting gases to penetrate and start simultaneous combustion throughout the entire charge. Latinal and cubical grains are sadly lacking in this respect, and their firing records testify to it. The mechanical integrity and structure of the grain rests here, as in other powders, with the personal equation of the factory. The company that developed the powder in question used the most trying formula, and yet every lot delivered gave a satisfactory account in guns, running from the 6-pounder rapid-fire gun to the 12-inch rifle, exciting comment by its remarkable uniformity and regularity of action. Another word in regard to the Hiram Maxim theory of internal explosion of the grains. Were it true nothing but solid rods are permissible. Yet nobody objected to brown powder with its central hole, or to short tubular smokeless powder. The short grains afford easy passage for the gases of internal combustion in their initial dimensions, and combustion increases the area of the passage as the square of the linear enlargement, while the burning surface is growing only in direct ratio. The best testimony of the erroneousness of the theory is given by some grains in the possession of Dr. R. C. Schüpphaus.

After a firing in the 3.2-inch field gun of a somewhat slow multiperforated powder, the pressure being 30,000 pounds, grains were found in the sand in front of the gun burned out perfectly, so that the circular perforations were almost tangent. Though quite fragile, they were perfectly intact. Another sample is an extra slow powder fired in an 8-inch rifle at 15,000 pounds pressure. It is burned up about half and in first-class condition. Again, after a firing in an 8-inch rifle at 35,000 pounds pressure, I picked up many of the curvilinear rods formed by the burning out of powder with circular perforations. Their heights were all uniform, and equal to the original heights less twice the burning thickness, as was to be expected from the combustion at both ends. I regret that the absence of Dr. Schüpphaus does not allow photographs of the grains mentioned, but the SCIENTIFIC AMERICAN ARMY SUPPLEMENT contains one of the grains partly burned at 5,000 pounds pressure.

Stretching down across the State of Iowa, commencing at the Minnesota line, lies a belt of counties which in the future may be rightly named the Egypt of Iowa, says The Rockford (Iowa) Register. The territory included in this belt is from 100 to 150 miles in width, and embraces what were known as the slough lands of the State in an early day—a region prolific in tall blue joint grass, frog ponds, small lakes, and possessing a black gumbo soil of unsurpassed fertility and durability. In the pioneer days men starved out in the effort to here grow a crop, the excess of moisture in the soil defeating their best efforts. Ditching, tilling, and cultivation have changed this condition, and today the world does not possess a more productive and fertile region. While the slopes and hills of the valley land bordering our great rivers already show marked evidences of exhaustion, this Egypt of the central black lands is coming to its own, and its marvelous productiveness is just beginning to be appreciated. As between the white farm on the hills and the black farm in the territory referred to, there is an immeasurable difference.

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