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THOS. E. HARRISON, President,
in the Chair.

No. 1,411.—“The Erosion of the Bore in Heavy Guns, and the means for its prevention; with suggestions for the improvement of muzzle-loading projectiles.” By CHARLES WILLIAM LANCASTER, Assoc. Inst. C.E.

IN all the important issues involved in the international relations of the comity of nations, the great questions of the day, nay even the very interests and maintenance of peace, would seem, now more than ever, to be inextricably associated with the development and perfection of the means and appliances of war, the *personnel* and *matériel* of armies and navies. With the former this Paper is only indirectly concerned, in so far as the extension of military hosts, counted and enrolled by millions, throughout the continent of Europe, involves increase of armaments, such as small-arms and artillery; but with the latter, the *matériel* of war, it has more especially to deal, and in particular with the important arm of artillery, ordnance, and heavy guns. The introduction and development of novel means of defence, such as iron-plated armour and backing for vessels of war and for forts, even the revival of the centuries-old question of earthworks and their efficiency and endurance, all of which mark the current time, invest the standing issue of arms *versus* armour with an ever-present interest and importance, intensified in rapidly increasing degree at every stage of advance in the size and construction of what are becoming emphatically “heavy” guns. In connection therewith are questions of endurance, efficiency, and reliability, which press for early, if not immediate, solution.

The considerations set forth in this Paper, with their inferential solution, derive their origin primarily in the adoption, by the authorities of the British War Department, of muzzle-loading in preference to breech-loading guns, and of a particular system of rifling. It becomes, therefore, essential, for the sake of argument, to accept the situation, although this involves a *petitio principii*, viz., that the decision is correct, a point which may be regarded as open to doubt.

One of the greatest difficulties encountered in the practical working of the muzzle-loading guns of the British service has unquestionably been the rapid and injurious erosive action on the bore, due to the heated gases, generated by the ignition and explosion of the powder, finding vent on the upper side of the projectile, by the windage or difference of diameter between the calibre of the piece and the projectile, an allowance absolutely necessary to render muzzle-loading feasible.

The magnitude of this evil is demonstrated by the fact, that the gun is disabled after a comparatively small number of rounds, and consequently has to be inverted, in order that what was previously the lowest part of the periphery of the bore should be turned uppermost, the eroded part assuming the lowest position; and subsequently, after the new portion has in its turn undergone erosion, the gun can only be rendered available for further service by being re-tubed, with a new A-tube or steel lining.

But this does not represent the full extent of the evil; for long before the necessity arises for turning the gun, or re-lining it with a new steel tube, its shooting power and accuracy have been materially deteriorated by the erosion of the bore, and the concomitant wearing away of the arrises of the grooves, or angles of the rifling, which are the first parts attacked by the heated gas, and the friction of the studs in centring the projectile, and in imparting the spin or rotation on its polar axis. Moreover, all the facts on record tend to establish the principle, that the extent of this injurious action, for greater areas of bore, increases more rapidly than the size of the gun, and the weights of powder-charge and projectile respectively.

The nature and extent of this prejudicial effect by erosion have excited the serious consideration of the British authorities. The remedial devices and appliances hitherto proposed have assumed, in the main, two distinct forms:—(1) The coating of the projectile, wholly or partially, with a soft metal envelope, such as lead, which would, when subjected to the explosive action of the powder, be squeezed out, so as to fill the bore and take the rifling; and, (2) The application of certain accessories, attached to, or separate from, the projectile, such as discs, gas-check rings, or wads of metal or other suitable material; which, being flattened out or expanded by the pressure, would attain the same end, *i.e.*, a temporary enlargement of the projectile, but at its base only, thus taking the rifling, filling up the bore, and arresting the forward rush of the gases by the windage. The former of these expedients is represented in the systems of lead-coated projectiles

of Mr. Jeffery and of Mr. Bashley Britten. Both of them gave sufficiently satisfactory results, so far as regards the primary object of their introduction, for the evil effects of erosion disappeared, just as in a breech-loading gun; but it was found that other disadvantages were entailed. In fact, so long as the powder-charges were limited to a maximum of $\frac{1}{10}$ th of the weight of the projectile, the practice was good; but, with higher powder-charges, such as the modern full and battering charges, extending to from $\frac{1}{4}$ th to $\frac{3}{4}$ th of the weight of the projectile, the more energetic action distorted or blew off the lead on the base of the projectile, in jagged pieces, so as seriously to affect the accuracy and range of the shooting, and to create danger by the consequent stripping.

The United States Government is reported to have made successful and satisfactory practice with lead-coated projectiles from heavy guns; but records are wanting to show with what proportion of weight of powder-charge to projectile these results have been obtained; and there is nothing to warrant the conclusion that it has gone beyond that above named, *i.e.*, $\frac{1}{10}$ th—especially as these trials were conducted with cast-iron guns.

In reference to the latter class of preventive devices, many and various gas-check rings, and the like, have been tried. The earliest was that invented by the Author in January 1851 (Plate 4, Fig. 1). This consisted of a flat disc of felt, attached to the base of the projectile by a central screw, 0.75 inch in diameter, held in place by a corresponding exterior plate of iron, through which the screw passed, thereby compressing the felt between the two metals. Although this, like the lead-coating, was efficacious in preventing the forward escape of gas, and the consequent erosion; yet it was similarly defective, in that the discs of iron and felt became violently detached during the flight of the projectile, thus introducing elements of difficulty and danger—as for instance, in the case of firing over troops. It should be noticed that this was long antecedent to the trials of lead-coated projectiles in 1865. In 1854 the Author applied a somewhat similar system to the projectiles for the oval-bore or Lancaster gun (Fig. 2). An oval galvanised iron cup was charged into the gun before the projectile. This cup was 0.35 inch thick, and 2 inches deep at the side, furnished at the rear with a corresponding disc of felt, 0.75 inch thick, secured by a wrought-iron plate, 0.03 inch thick, and a screw. This separate metallic wad was held to be objectionable, as introducing complications into the operations of loading the gun, and as being dangerous in firing over troops and boats.

The next device, in order of date, meriting particular notice, was that of Captain Blakely, about the year 1865, for use with the Blakely gun. This consisted of a disc of copper, with a projecting rim (*i.e.*, dished) on the rear, attached by being cast on or screwed to the base of the projectile, which was provided with radiated, sunk, or recessed prismatic ribs (Fig. 3). The copper disc was flattened out on the explosion of the charge, filling up the majority of the numerous shallow grooves of the Blakely gun; but, just as in the cases already cited, large portions of the copper disc were detached and thrown off during the flight of the projectile, to the manifest danger of outlying troops (Fig. 4).

There is little or nothing worthy of mention in other inventions of this class until a much more recent date; with the exception, perhaps, of the *papier-mâché* wads proposed by Major Bolton, Assoc. Inst. C.E. But these, like their predecessors, when subjected to the test of high charges, failed; particularly with regard to their primary object, as gas-checks.

Major Lyon, R.A., proposed a composite appendage to the base of the projectile. This consists mainly of a copper cup, dished out to the rear, and attached by an iron clamping screw; the interval between the rounded edges of the projectile and the copper cup being filled with a wrought-iron ring, or annular washer, of suitable shape. There are two forms or modifications (Figs. 8 and 9), differing simply in the relative or proportionate widths of the copper cup and of the iron clamping screw-head; which latter in one case assumes the form of a flanged cover. A somewhat similar form of attachment, emanating from the Royal Gun Factory at Woolwich (Fig. 7), consists in securing the copper cup to the base of the projectile by a dozen screws. Another complication of wedges and rings, &c., of different metals, of an elaborate character, is represented in several varieties in Figs. 11, 12, and 13. There are, indeed, many and various forms wherein this principle may be developed; but the differences are so minute and unimportant, and the action and effect so similar, that they may all be classed together.

The latest outcome of the search after an effectual remedy, for the acknowledged evils of bore-erosion in muzzle-loading guns, was the official trial at Shoeburyness in 1873 of gas-checks, as applied to the service projectile, upon three different systems; viz., those of the Elswick Ordnance Company, of Major Maitland, R.A., (of the Royal Gun Factory), and of the Author.

The Elswick Ordnance Company proposed to screw on to the

conical base of the projectile a wrought-iron cup or disc, having a ring in front, and being lead-lined and encircled with a ring of lead. On the explosion of the charge, the lead was driven up the inclined plane of the truncated diverging cone, whereby it was expanded so as to fill the bore. But in practice the lead was rent and driven forward in advance of the projectile, so as to injure the studs, and create elements of danger by the detached ragged pieces; and, consequently, its efficiency as a gas-check was materially impaired at the very outset.

Major Maitland's proposition differed from most of its predecessors in being an adjunct or accessory, not an attachment, to the projectile; and it is accordingly called by its inventor a metallic wad (Figs. 14, 15, 16). This is a ring of copper, nearly pure, and therefore soft, having only about 1 per cent. of alloy. The base of the projectile, ordinarily flat, was turned down at the centre and periphery so as to leave a sunken plane surface with an undercut annular projection or ring, standing above it to the height of 0.25 inch, and having a width of 0.7 inch at the base, increasing to 1.02 inch at the upper side. On the side adjacent to the base of the projectile the copper wad is flat, but there is an annular recess corresponding to and fitting over the projecting ring. The width of the copper ring forming the wad is 2.52 inches, and it is dished, outside of the recessed ring, on the outer rear side, to a total depth or thickness, on the external edge or rim, of 0.75 inch; that on the inner edge being 0.5 inch. It is also provided with projecting studs corresponding to the grooves of the rifling. The pressure, on the explosion of the charge, forces the soft copper into the undercut bevels of the ring on the base of the projectile, so as to attach the copper wad to the shot, in the majority of instances. As a gas-check Major Maitland's metallic wad fairly secures the object aimed at; but, apart from the questions of the weight and cost of this form of appliance, it is open to the objection that the operation of loading is more complicated, inasmuch as the wad is charged into the gun separately from the projectile.

The third system is that of the Author (Fig. 19). In this case the base of the projectile was turned down on the outside and recessed to receive, first, a corresponding ring of soft metal, and, secondly, a ring of wrought iron. When the charge was exploded, the effect was to drive forward the wrought-iron hoop, thereby squeezing out the softer metal and filling up the bore, thus cutting off the forward rush and escape of the heated gases. Being limited by the Select Committee to a trial of one

metal only, out of three alternative metals suggested, the soft metal ring was at that time made of an alloy of lead and tin, the compressing ring being of wrought iron. The result showed that the composition was of too soft a nature, as there was a tendency for it to be blown forward along the outside of the projectile, thus diminishing the action and efficiency of this contrivance as a gas-check. Moreover, some of the wrought-iron rings, being defective in the weld, had not strength to resist the great strain. If a trial had been allowed of the alternative proposal, a ring of soft copper, with a compressing ring of steel, the Author is of opinion that the result would have left nothing to be desired. In corroboration of this opinion it may suffice to quote the statement of Sir William Armstrong, C.B., M. Inst. C.E., during the discussion, last session, of the Paper on "Gun-Carriages and Mechanical Appliances for working heavy Ordnance," by Mr. G. W. Rendel, M. Inst. C.E.¹ Sir William Armstrong then described an arrangement, adopted by Captain Andrew Noble (late R.A.), which had been found perfectly effectual in the 12-ton gun, as follows:—"A steel ring was fitted upon the back of the shot in such a manner as to have a travel of about $\frac{1}{2}$ inch. The force of the explosion drove the ring home, and in doing so crushed a copper hoop between the shot and the sides of the bore, by which means the copper entirely filled the grooves, just as in the case of the breech-loader they were filled with the soft metal coating of the projectile. In that way the gun was perfectly gas checked, and by the same apparatus the necessary rotation was produced." This, it is to be noted, was some time after the Shoeburyness trials above referred to. Nothing could be more emphatic and convincing than the public testimony of Sir W. Armstrong to the efficiency of the original proposal of the Author.

Nevertheless, the subject is not exhausted, as fundamental principles, relating to the combined action and effect of gun, projectile, and powder, are either overlooked or ignored in all such really limited proposals for gas-check appliances, which are simply adjuncts or attachments to the base of the projectile.

A brief comparison, between the muzzle-loading and breech-loading systems, is essential to show what further remedial devices have been suggested, and indeed are necessary, as preventive auxiliaries, before the muzzle-loading system of gun and projectile can be fairly regarded as developed to its greatest perfection. In

¹ *Vide Minutes of Proceedings Inst. C.E.*, vol. xxxviii., p. 127.

the breech-loading system there is no erosion, because the projectile being inserted from the rear into a chamber specially adapted for the purpose, and being provided, partially or wholly, with enveloping rings or hoops of soft metal, is made to fit the bore of the gun at the breech. This it does with such exactness, that there is practically no windage throughout the entire length of the cylindrical portion of the projectile, which, therefore, is concentrically aligned with the bore. The action of the explosion is thus limited to the breech-piece and chamber, which are renewable. The endurance of the gun is therefore practically maintained. Thus the Russian 11-inch Krupp breech-loading guns fired 800 rounds without any appreciable deterioration, the weight of projectile being 481 lbs. and of charge $82\frac{1}{2}$ lbs. of prismatic powder. But the muzzle-loading projectile, when charged into its gun, lies at the breech end, on the lower side of the bore, and the surplus area of windage is concentrated in a crescent-formed opening on the upper side, above the projectile, with double the amount of mean windage at the highest point: thus presenting to the heated gases evolved on explosion an outlet of least resistance, through which they rush with the power and effect of a gigantic blowpipe.

It has been shown, by recently published experimental researches and determinations of Captain Noble and Professor Abel, that the temperature evolved on the explosion of gunpowder is about 2,200° centigrade, equivalent to nearly 4,000° Fahrenheit. But of this temperature only 3 per cent. (66° centigrade or 151° Fahrenheit) is communicated to an 18-ton gun; while the tension of the resulting combustion products is represented by a normal pressure of 6,400 atmospheres, or 42 tons to the square inch, and exceptional pressures up to 66 tons per square inch with the 12-inch 35-ton gun have been recorded. This will account for the destructive action on the upper portion of the periphery of the bore. Subsequently the action of the explosion takes effect upon the projectile, which, as it gathers way, is temporarily raised into a central position in the bore, by the aid of the rifling; whence necessarily results, in the stud system, a rapid and unequal wearing away of the edges of the grooves at a particular point on the leading side. This injurious effect is attended by a 'wobbling' motion of the projectile, which becomes intensified as the grooves get worn, setting up a progressive deterioration in the shooting, and detracting from the quality of the practice. Now the gas-check appliances, upon the systems described, acting solely at the base of the projectile—admitting, for the sake of argument, their efficiency as gas-checks—in no way diminish this prejudicial

'wobbling,' but rather tend to aggravate it by their partial operation. The essential point is to provide a similar appliance at the head of the projectile, so as to give the means of assimilating the position and conditions of the muzzle-loaded projectile in the bore, before firing, to those of the breech-loaded projectile.

The only proposal yet brought forward, having this object in view, is that of the Author, as illustrated in Fig. 17, where provision is made for an expanding ring, to centre the projectile in the bore and fill up the windage, both at the front and at the rear of the projectile. At the rear, the base of the projectile is turned down at the periphery, undercut and recessed to receive a soft metal ring, behind which is inserted a compressing ring of wrought iron or steel. The expansive action of the explosion drives the compressing ring forward, and squeezes out the soft metal radially, so filling the bore and grooves. In the front of the projectile, at the base of the ogival head, a similar ring of soft metal is affixed, in an undercut recess, provided with a series of channels leading forward, so as to crop out on the curved periphery of the ogival head. These channels are filled at the same time with the soft metal from the ring, and are so arranged as to correspond in number and to take into the 'lands' and grooves of the rifling. When the initial movement is given to the projectile, these columns of supply of excess soft metal, to which the same velocity cannot be simultaneously imparted without distortion of form, run back or are 'upset.' The volume of metal in the front ring is thus increased all round the projectile, being upset and squeezed out, so as to fill up the bore and the rifling, and at the same time effectually to centre the projectile from the 'lands' or cylindrical portion of the bore. In this way the bearing is practically elongated, the shot steadied, and all the advantages in position and initial conditions are given which are now the attributes of the breech-loaded projectile only.

As a modification of this method, also part of the invention, the rearmost expanding ring may be acted on, in lieu of the compressing ring of hard metal, by columns of supply, filled with soft metal, and communicating directly with the hindmost soft metal ring. These columns of supply yield readily to the impulse of the pressure in their rear, and are driven forward upon the ring, expanding it so as to fill the bore.

It is obvious that by establishing correct proportions between the bore, the windage, the expanding ring, and the supply columns, the degree of expansion may be regulated with nicety and exactness, so as precisely to compensate for and fill up the windage;

thus efficient centring and gas-check action may be attained, without excess of soft metal, causing friction and stripping. This system has been tried abroad, with satisfactory results.

It would seem, nevertheless, that all the known facts tend to the conclusion, that the system of gas-checks, however varied in detail, or however fully developed, should properly be regarded only in the light of remedial devices, having for their primary object, and even for their limit of utility, the mere palliation of certain defects inherent to the combination of gun, projectile, and rifling as adopted. Further, the seat of these inherent defects may, the Author considers, be clearly assigned to the grooves, which, by breaking up the continuity of the otherwise smooth and even surface of the bore, and by offering projecting and recessed angles to the action of the heated gases, afford points of vantage whereon these gases can seize with concentrated effort and effect. Furthermore, the modern development of artillery, resulting in the manufacture of heavy ordnance of enormous weight, calibre, and, above all, cost, never previously contemplated, supplies a valid argument against the perpetuation of any such system as that involving the necessity of renewing, at frequent intervals, the steel lining, or A-tube of the gun, or even only of turning and re-venting the piece; inasmuch as in all such cases the gun must be sent back to the Royal Arsenal, from the ship or station where it has been disabled, seeing that the machinery, the skilled labour, and the other means available for such work exist at Woolwich only.

But whatever may, hereafter, be the efficacy or superiority of the various gas-check appliances, the primary and radical defects of grooved guns and studded projectiles will always remain. Accepting such ordnance as being for the present established in the British service, the Author has sought only to provide the means of diminishing, as far as may be practicable, their attendant defects. All reasoning, however, on the known premises leads to the inference, that the fundamental requirement is a simpler system of rifling the bore of the gun, whereby the smoothness and continuity of the interior may be preserved, while at the same time the necessary spin or rotary motion may be effectually imparted to the projectile. This, the Author ventures to submit, has been attained only by his own invention, known as the oval-bore gun and projectile; and his conviction is that, if fully developed and fairly tried, this system will completely satisfy and fulfil all the conditions of the problem, combining a perfect gas-check and efficient centring with unsurpassed accuracy, high

initial velocity, low trajectory, long range, and satisfactory powers of endurance.

It is not intended to enter into the arguments or history of this old and long-standing controversy, and of the trials by the Select Committee, made several years ago. But a careful examination and comparison of the official photographs will suffice to show that, from whatsoever cause it may arise, the erosive action of the powder on the oval-bore is trifling; whereas, under precisely similar conditions, it entirely disables the ordinary Woolwich rifled gun.

If, then, the principle of muzzle-loaded projectiles, which has been persistently approved by the authorities in this country, is to be enabled to hold its own, and if muzzle-loading guns are to retain their place as the equals of breech-loading guns, the existing faulty and unmechanical system of rifling, with a grooved bore and studded projectiles, on which in the end the whole question turns, must be discarded in favour of a simpler and better system of rifling for gun and projectile, such as the oval bore, a conclusion which can be established on grounds both of economy and efficiency.

The Paper is accompanied by a series of diagrams and photographs, from which Plate 4 has been compiled.