General Design of Gun System

火炮、自动武器专业英语

主　编　王惠源
副主编　张鹏军　曲　普

国防工業出版社
National Defense Industry Press

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内 容 简 介

本书采用英文较全面地介绍了火炮、自动武器系统工作原理以及主要机构结构形式。全书分为三部分,涉及轻武器、火炮、弹道学方面的知识。本书系统地介绍了火炮、自动武器的工作原理,闭锁机构,供弹机构,击发机构,反后坐装置,炮架,内弹道学和外弹道学基本知识。本书力求专业知识的系统性和完整性,将基础理论和武器结构融为一体,附有大量典型武器机构原理图,具有一定的知识深度和广度。

本书可作为相关高等院校武器系统与工程、武器发射工程专业本科生双语教学和专业英语教材,亦可作为火炮、自动武器、弹药工程、兵器发射理论与技术研究生以及相关专业技术人员参考用书。

图书在版编目(CIP)数据

火炮、自动武器专业英语/王惠源主编. —北京:国防工业出版社,2014.3

ISBN 978-7-118-09107-6

Ⅰ. ①火... Ⅱ. ①王... Ⅲ. ①火炮-英语 ②自动武器-英语 Ⅳ. ①H31

中国版本图书馆 CIP 数据核字(2014)第 033537 号

※

国防工業出版社出版发行

(北京市海淀区紫竹院南路 23 号 邮政编码 100048)

北京奥鑫印刷厂印刷

新华书店经售

*

开本 787×1092 1/16 **印张** 17¼ **字数** 401 千字

2014 年 3 月第 1 版第 1 次印刷 **印数** 1—2000 册 **定价** 34.00 元

国防书店:(010)88540777 发行邮购:(010)88540776

发行传真:(010)88540755 发行业务:(010)88540717

前　言

进入 21 世纪，随着计算机技术、信息化技术、新材料、新能源技术、微电子技术、光电技术等一大批高新技术的发展，推动了军事领域的深刻变革，也进一步推动了常规兵器的发展。相关专业人员需具备查阅外文文献、及时跟踪国外技术发展动态的能力。

为了满足高等学校武器系统与工程、武器发射工程专业本科生专业基础课双语教学和专业英语教学的需求，本书结合作者多年的教学经验，并在广泛收集国外英文教材和技术资料的基础上，综合了自动武器、火炮和弹道学的内容，阐述了武器系统设计的基本概念、构造原理和作用过程。本书将基础知识和武器结构融为一体，确保专业知识的系统性、完整性，有助于培养学生阅读英文文献获取专业知识的能力。

全书内容均采用高质量英文素材，由于教材信息量大，没有给出中文注释，涉及到的专业词汇可以借助专业辞典。

全书分为三个部分，主要内容如下：

第一部分为轻武器篇，包括第 1 章至第 10 章的内容，系统地阐述了轻武器的基本组成、结构特点和工作原理。第 1 章较详细地介绍了枪械身管的类型、结构、安装方式及膛口装置的类型及其特点等。第 2 章至第 8 章着重介绍了自动步枪、机枪的自动机组成、自动方式和自动循环过程。第 9 章介绍了自动步枪、机枪供弹机构，重点分析了弹匣供弹和弹鼓供弹的结构特点和工作原理。第 10 章详细介绍了自动步枪、机枪击发和发射机构的类型、结构特点、工作原理及各种典型击发和发射机构的应用。

第二部分为火炮篇，包括第 11 章至第 14 章的内容，系统介绍了火炮系统的组成，炮身、炮闩、反后坐装置、炮架等结构和工作原理。

第三部分为弹道学篇，包括第 15 章至第 17 章的内容，简单介绍了经典内弹道学和经典外弹道学的基本概念和理论。

三部分具有一定的独立性，教学实践中，可以根据学时和专业方向，对教学内容进行选择。

本书第 1 章至第 6 章由王惠源教授编写；第 7 章至第 10 章由张鹏军编写；第 11 章至第 14 章由曲普编写；第 15 章至第 17 章由邢杰编写；全书由王惠源教授统稿。

薄玉成教授、高跃飞教授分别审阅了本书部分内容并提出了宝贵意见，在此表示衷心感谢。

在本书的编写过程中，引用和参考了许多英文文献资料，在此向原作者表示感谢。

感谢国防工业出版社的大力支持，感谢中北大学教务处的支持。

由于本书内容广泛，涉及多方面的知识，书中疏漏与不当之处在所难免，恳请读者批评指正。

编者

2013 年 7 月

Contents

Part Ⅰ Small Arms

Chapter 1 Barrels

Purpose

The purpose of the barrel is to impart velocity and direction to the bullet. It must withstand the high pressures and temperatures that are developed each time the weapon is fired. The rear of the barrel locates the cartridge and the front part is used for the expansion of propellant gases that impart velocity to the bullet. In rifled weapons the barrel also imparts spin to the bullet by using helical grooves machined into the bore. The main dimension of a barrel is its caliber which is the dimension of the bore before the rifling grooves are machined. Barrel length is an important parameter because it affects the muzzle velocity of the bullet: the longer the barrel, the higher the muzzle velocity.

Barrel Construction

The barrel comprises an independent block, referred to as the barrel group, which consists of the following parts:

- Barrel.
- Receiver.
- Barrel supports.
- Barrel attachments.

The barrel is fitted into the receiver, which closes the barrel bore from the end of the cartridge chamber and serves to position the bolt, to which the firing loads are transferred. For automatic weapons the barrel breech is formed by the closing bolt, or breech block, which is connected to the receiver when firing. Thus, the receiver supports the bolt and transfers the force of the propellant gases to it. Barrel supports serve to mount and locate the barrel in the weapon. The mounting may be either fixed or a sliding design. For small caliber weapons the mounting is fixed and the supports serve to hold and support the weapon. Barrel attachments consist of a variety of components, the most important being:

- Muzzle brakes.
- Recoil increasers.
- Flash hiders.

- Noise suppressors (silencers).
- Muzzle deflectors.
- Gas blocks (gas operated weapons only).

Barrel Types

Small arms are fitted with either monobloc or compound barrels. Monobloc barrels are made of one piece of material whilst composite barrels consist of a monobloc barrel with an insert fitted to protect the breech end from wear. The barrel has a major effect on the construction of the whole weapon. The basic requirements are:

- Required strength at maximum operating load.
- High rigidity to minimize vibrations.
- Maximum straightness.
- Concentricity between inner and outer diameters.
- Adequate service life.
- Optimum mass for strength and stiffness.
- Low manufacturing costs.

Barrel Bore

The barrel bore is the internal part of the barrel with a tapered opening at the breech to house the cartridge and to guide the bullet during firing. The bore has the following parts as illustrated in Fig. 1.1.

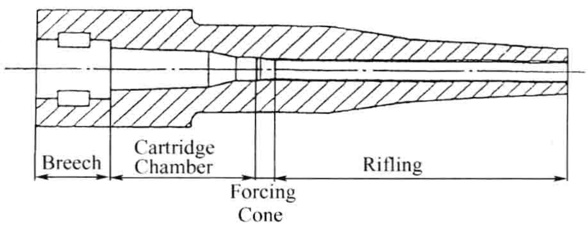

Fig. 1.1 Basic Parts of the Barrel Bore

The barrel bore is symmetrical about the longitudinal axis and diminishes in diameter towards the forcing cone. The rifled section is usually parallel.

Cartridge Chamber

The cartridge chamber serves to house the cartridge in the barrel. The cartridge case seals the rear end of the barrel and prevents the propellant gases leaking from the breech end when the weapon is fired. The layout and shape of the cartridge chamber depends upon the design of cartridge. Each part of the cartridge chamber follows the shape of the cartridge case. However, radial and axial dimensions of the cartridge case differ from that of the chamber by the amount of clearance between them as shown in Fig. 1.2.

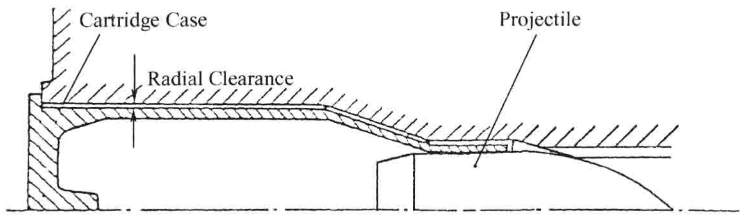

Fig. 1.2 Clearance between Case and Chamber

The longitudinal shape of the cartridge case is designed for easy loading and extraction of the cartridge case after firing. The cartridge case and chamber are conical in shape with clearance between the chamber and the cartridge. For a rimmed round, positioning is achieved by squeezing the cartridge case rim between the barrel and the breech as shown in Fig. 1.3. A disadvantage with rimmed rounds is that the protruding rim causes weapon feed problems. Also, when the breech block closes there is a hard impact against the barrel. For rimless cartridges there is a longer distance between the breech block and the seating point as shown in Fig. 1.4. Rimless cartridges cause the fewest feed problems; consequently this is the most widely used design for cases. An additional advantage of rimless cases is that the impact by the breech block is reduced when it closes.

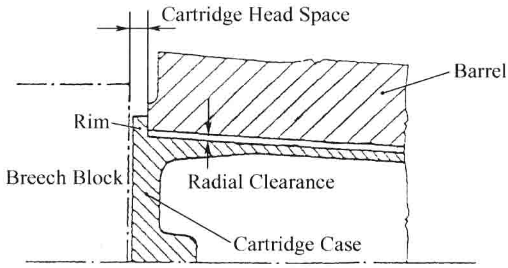

Fig. 1.3 Positioning of a Rimmed Round in the Chamber

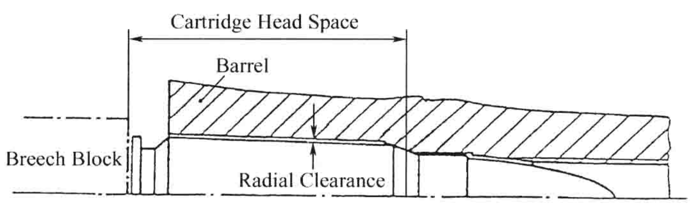

Fig. 1.4 Positioning of a Rimless Cartridge in the Chamber

The distance between the breech block and the seating point of the cartridge case in the chamber is known as the cartridge head space. For the weapon to function correctly it is important that this dimension is correctly maintained. If the cartridge head space is too short the breech block will not fully close. If it is too long the cartridge will not be fully supported during firing and the case will be distorted, causing extraction problems.

The reliable extraction of fired cartridge cases is very important to the operation of automatic weapons. A method of easing the problem is to provide the chamber with longitudinal grooves, known as fluting, which allow propellant gases to enter between the chamber wall and cartridge case and thus facilitate extraction of the cartridge case.

Forcing Cone

The forcing cone is designed to provide smooth engraving of the bullet jacket by the rifling grooves. When the jacket of the bullet is fully engraved, the bore of the barrel is fully sealed. The forcing cone is the place of greatest wear in the barrel and has a major effect on the service life of the weapon. When the forcing cone is excessively worn, the accuracy of the barrel decreases because of variations and reductions, in muzzle velocity.

Rifling Profile

With the exception of shot guns, all small arms barrels are rifled, the purpose of the rifling being to impart spin to give the projectile gyroscopic stability. In cross-section the rifling appears as a number of lands and grooves as shown in Fig. 1.5. The actual profile of the rifling may be rectangular or trapezoidal. Although a rectangular profile is most often used, a trapezoidal profile may be encountered, as shown in Fig. 1.6. The barrels of most small arms are made by cold hammer forging or extrusion and the trapezoidal profile is easily formed by these methods.

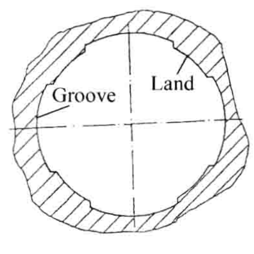

Fig. 1.5 Land and Groove Profile of Rifling Grooves with a Square Section

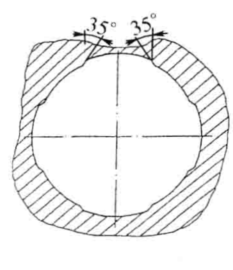

Fig. 1.6 Trapezoidal Rifling Cross-Section

The width and depth of the grooves are usually the same along the entire barrel length. The angle of twist of the rifling is usually constant for small caliber weapons and is choose to stabilize the bullet both for a new barrel and one that is worn. It is normally expressed as the length of one complete turn in mm. The twist rate at the muzzle and the muzzle velocity determine the spin rate of the bullet.

The accuracy of the weapon is considerably affected by the muzzle of the barrel which affects the flow of propellant gases around the bullet as it leaves the barrel. It is essential that the end of the muzzle is perpendicular to the barrel axis. The internal edge of the muzzle is usually rounded with a greater radius than the groove depth. For barrels requiring maximum accuracy, such as sniper rifles, the muzzle end is counter bored several calibers in depth, which results in a cylindrical cavity of a diameter which is greater than the diameter of the bullet. This provides constant gas flow around the bullet as it leaves the muzzle.

Barrel Mounting and Guides

The barrel is attached to the weapon by the breech end to the breech casing and barrel supports. In weapons with fixed barrels, the receiver group and the weapon casing are the same and one of the main parts of the weapon. On weapons with a recoiling barrel the barrel is attached to the receiver group which locates the barrel in the weapon casing. The breech blocks and bolt recoils together with the barrel in the breech casing. The receiver group has at least one guide, usually to the rear as shown in Fig. 1.7.

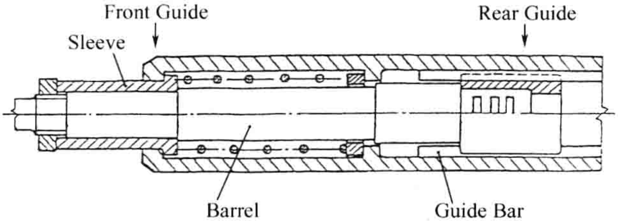

Fig. 1.7 Typical Barrel Arrangement for a Recoil Operated Weapon

The front guide is positioned directly on the barrel. The torque acting on the barrel caused by the bullet spin is resisted by the receiver group guide or by a special guide bar which meshes with the breech casing recess. The barrel may be fixed or have a quick change facility. Fixed barrels are usually attached to the weapon by a screw thread on the outside of the breech end of the barrel.

Barrels of machine guns with a high rate of fire can become excessively hot. Usually there is a facility to change the barrel for a cold one on the battle field. The method of attaching quick change barrels to the weapon can be of the following design:

- Cotter joint.
- Ribbed joint (bayonet joint with straight ribs).
- Interrupted thread.

The quick change joint is usually referred to as the barrel nut. A cross wedge bears against a lug on the barrel or it passes through the cross groove on the barrel as shown in Fig. 1.8. The bevel of the cross wedge presses the barrel into the receiver group. It is locked in position by

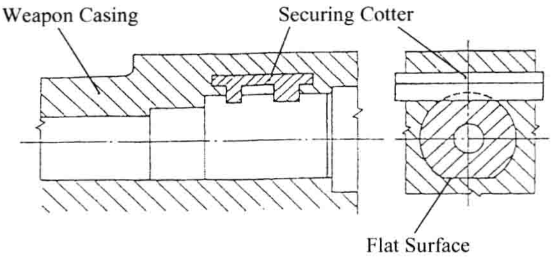

Fig. 1.8 Cotter Joint for a Quick Change Barrel

means of a nut or spring-loaded pin.

The ribbed joint has both ribbed and smooth sectors along the barrel circumference and the barrel beds into the breech casing as shown in Fig. 1.9.

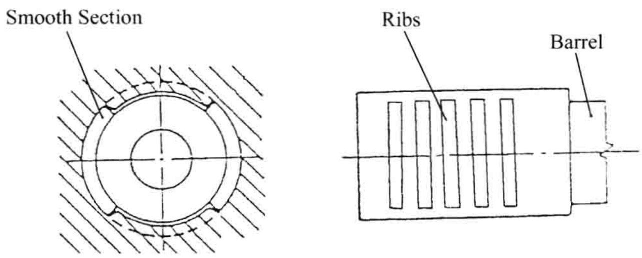

Fig. 1.9 Ribbed Joint for a Quick Change Barrel

The ribbed and smooth sectors are usually between two and four in number. One sector has several cross ribs with a rectangular profile. The interrupted thread joint is identical in design except the ribs are in the form of a thread. This design makes it possible to press the barrel towards the breech block: to join the barrel to the breech casing, the barrel is placed with its threaded sectors into smooth sectors of the breech casing and rotated to lock the two together; to provide for precise positioning of the barrel, the receiver group is equipped with supports in the form of spigots before and after the joint. A ratchet is usually provided to prevent the barrel from working loose.

Barrel Heating

This topic is covered in Chapter 2—"The Introduction to Operating Mechanisms".

Barrel Wear

When a gun is fired, a complex set of conditions occur in the barrel that mechanically and thermally stress the bore which eventually lead to the barrel wearing. Barrel wear reduces weapon performance and once performance fails below the required level it is replaced. The service life of a barrel is usually set by the number of rounds it has fired. The condemnation criteria for barrels are set by:

- Reduction in muzzle velocity.
- Increase in dispersion.
- Onset of bullet instability.
- The weapon becomes a danger to the user.

A common cause of barrel failure is by an obstruction, the most common of which are cleaning rods or cleaning materials. Mud or snow in the barrel can also form an obstruction. The common effect of firing a gun with an obstruction in the barrel is to cause the barrel to burst. Another possible cause of catastrophic barrel failure is that of fatigue. This is a highly unlikely mode of failure mechanism in modern military small arms, although it has been known to occur in weapons produced under war time conditions where the quality control of the barrel materials was not as stringent as in peace time conditions.

Barrel wear is usually greatest in the rifling lead because of the impact of the bullet onto the forcing cone. Chemical reactions between the burning propellant and the surface of the barrel produce cementation and nitration of the surface in the form of layer 0.05 – 0.1mm thick. Erosion of the bore by the propellant gases appears as a washing away of the bore surface. Erosion effects increase as the bore become hotter. The hottest part, the forcing cone is particularly exposed to erosion effect. Wear causes the forcing cone to move forwards in the bore which results in greater bullet insertion depth and a resultant reduction in the muzzle velocity of the bullet. The burning propellant has several effects on barrel wear. It causes a high thermal gradient at the surface of the barrel; this leads to high thermal stresses that result in a network of cracks on the bore surface, and forms the basis of mechanical wear and erosion. Also, heating of the barrel results in a decrease in material strength that leads to lower resistance to erosion and abrasion. The cyclic character of heating and cooling of the surface layer can lead to mechanical and thermal fatigue resulting in the development of cracks and a reduction in the resistance to wear. Wear is not distributed uniformly along the barrel. The most critical region of wear is the forcing cone and beginning of rifling up to about the point of maximum pressure. Maximum wear is usually at the beginning of the full depth of the grooves. There follows a region of medium wear that lies near the point of maximum pressure. In the middle part of the bore, the wear is small and uniform.

Hard chromium plating of the bore, with a plating thickness up to 0.05mm is commonly used on small arms. This can double the barrel life when the weapon is fired under the most severe firing cycles. Stellite liners are fitted to the breech end of the barrel in certain sustained fire medium machine guns and considerably increase the barrel life of these weapons.

Chapter 2 Introduction to Operating Mechanisms

General

Small arms can either be powered internally, with the source of energy provided by the propellant, or externally by an electric motor or hand cranking. A small arm is, in effect, a single cylinder internal combustion engine, of which the bullets form a series of expendable pistons that are thrown out of the barrel (or cylinder). The propellant gases are also expelled from the muzzle, some of them at considerably greater velocity than the bullet itself. The greater the proportion of charge mass to bullet mass in a round, the greater is the significance of the propellant gases in the momentum balance of the weapon system.

Distribution of Energy

As has been indicated already, the means whereby the energy of a small arm round is distributed can vary considerably. However, some items can fairly easily be quantified, using the normal laws of mechanics and thermodynamics. These are:

- A bullet can be weighed, its muzzle velocity measured and its forward kinetic energy calculated. Spun bullets also have rotational energy, but this is usually negligible.
- Heat is transferred to the barrel from the high temperature propellant gases and by the friction of the bullet passing up the bore. The total heat loss can be calculated, based on the mass of the barrel and other heat affected parts, their specific heats and on the temperature rise.
- Recoil energy can be determined by using a ballistic pendulum, on which the weapon can be freely suspended. The height to which it swings when a round is fired is proportional to the free recoil energy of the weapon.
- The input of energy from each round depends on the mass of propellant burnt, in grams, and its specific energy, in Joules per gram.
- The energy imparted to the muzzle gases as blast and heat cannot be directly measured. However, as this represents the balance of the energy losses from the system, it follows that:

Muzzle Gas Energy = Propellant Energy Input − (Bullet Energy + Barrel Heat + Recoil Energy)

As a very approximate guide, the distribution of propellant energy for a small arm can be taken as:

Kinetic Energy of Bullet	30%	Heat to Barrel, etc.	30%
Muzzle Gas Energy	nearly 40%	Recoil Energy	0.1%

The very small proportion of the whole that becomes evident as Recoil Energy is noteworthy.

Efficiency

The efficiency of a small arm is expressed as, $\frac{\text{Bullet Muzzle Energy}}{\text{Propellant Energy}} \times 100\%$

This usually gives, for high velocity weapons, approximately 30% efficiency which compares poorly with the output of petrol engines (35%), diesel engines (38%) and power stations (40%).

The Operating Cycle

Regardless of whether a small arm is manually operated, self loading or automatic, in general, a number of functions must occur for each round and these constitute the cycle of operations:

- A round must be fed, normally from a magazine or belt.
- The round is chambered.
- A firing mechanism is cocked.
- The breech is locked.
- The round is fired by the firing mechanism.
- The breech is unlocked.
- The breech is retracted, the return spring compressed and the empty case extracted.
- The empty case is ejected.

Variations in the Cycle

The basic cycle can be modified, after due thought, to suit particular needs. As examples, some blow back weapons are never locked, but rely on either the inertia of a heavy bolt, or on intentional mechanical disadvantage, to keep the breech closed whilst pressures are high. For a weapon firing ceaseless ammunition, there should be no need to extract or eject an empty case, although provision would need to be made for misfires or unloading.

Locking

Rounds fired in small arms generate very high pressures for very short times. Such pressures, if uncontrolled, could either damage the weapon, or the firer. Therefore it is normal to design into a weapon a means whereby the bolt, or breech block, can be held against the chamber end of the barrel before the pressure becomes dangerously high and removed immediately it has dropped to a safe low level. The most common forms of locking are achieved either with devices that tilt. go past-top-dead-centre, have locking lugs, or rotate serrated bolts. Once such a device is "locked" no amount of pushing on the bolt head will open it.

Pressure and Time

In a self-loading gun obtaining its power from the pressure developed by the burning propellant, the duration of time when this power can be safely tapped is limited. A curve plotting the pressure in the bore against time for a typical small arm is shown in Fig. 2. 1.

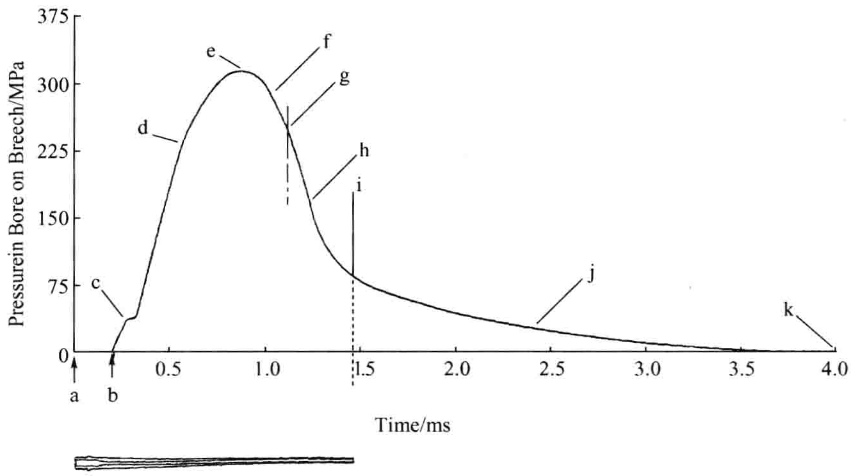

Fig. 2. 1 Pressure/time Curve

Sequence of Events

The sequence of events, as shown in Fig. 2. 1 is:

a. The striker hits the cartridge cap.

b. There is a, delay before the ignition sequence starts. A tiny quantity of highly sensitive explosive detonates to produce a flame, which ignites the outer surface of the propellant.

c. Pressure rises inside the cartridge case until it is sufficient to blow the bullet out of the mouth of the cartridge. Considerable resistance is encountered as the bullet engraves in the rifling. This occurs approximately 0. 3ms after cap strike.

d. The propellant produces gas faster than the volume behind the bullet increases and therefore the pressure rises rapidly.

e. At this point the highest pressure is reached.

f. The velocity of the bullet is now so great that the increase in volume behind the bullet is growing faster than the propellant can fill it and so the pressure now drops.

g. The propellant is all burnt.

h. The bore behind the bullet remains full of hot gas that expands adiabaticaily

i. The bullet emerges from the muzzle, and some of the gases overtake it. Pressure in the bore remains relatively high. Although the bullet is moving in the bore of the rifle for only just over one millisecond, it may reach a velocity of 1000m/s at the muzzle. Maximum accelerations are of the order of 1,500,000m/s^2, so the set back forces are enormous, sufficient to distort a lead-filled bullet to fill any cavities in the bore.

j. For a further 2 or 3ms pressure continues to drop in the bore. Only at this stage would it be safe to unlock the bolt of the weapon so that advantage could be taken of the blow back pressure remaining on the base of the cartridge.

k. The pressure in the bore drops to ambient. The entire duration from cap strike to this point is only about 4ms. Dead time follows before the next round is fired, with no pressure other than ambient in the bore. During this period, the working parts of the mechanism perform the operating cycle, using energy transferred to'them whilst there was still pressure in the bore. This energy is in the form of kinetic energy that is used to push the working parts of the weapon to the rear. At the same time energy is transferred to the return spring ready for it to push the working parts back to their forward position.

Obturation

Cartridge Case Obturation

Current conventional small arms all use cartridge cases to provide obturation at the breech end of the barrel until pressure has dropped to a safe low level. The part played by the case in the reliable working of an automatic weapon is shown in the much exaggerated sequence of diagrams in Fig. 2. 2. Although drawn, for demonstration, with a rimmed case, the reasoning that follows would equally apply to a rimless round:

- The cartridge is loaded into the breech, and the breech block closed. Because of manufacturing tolerances and possible temperature differences between gun and round, some clearance must be provided between the round and the chamber and between the round and the breech face. This is called "set back" or "cartridge headspace". The arrow depicts the striker hitting the cartridge cap, but before any pressure rise inside the cartridge.
- The propellant ignites, pressures rise to a low level (L). Until the bullet leaves the mouth of the case, (shot start), the cartridge does not move, but as the bullet moves into the rifling so the case pushes backwards against the breech face, thus increasing the clearance between the case and the chamber. With low pressure also in this clearance, thus on both sides of the case wall, there is no reason for the wall to move. Momentarily there may be a tiny pressure rise outside the breech, but it is insignificant, due to a very short duration.
- Pressure inside the cartridge case rises rapidly to a high (H) level, and the bullet starts to accelerate down the bore. Around the outside of the mouth of the case there is also high pressure so, apart from compression of the mouth, there is no tendency for movement. Down the outside of the case , however, there is a pressure drop due to baffling in the constriction and when the pressure outside the case has dropped to a sufficiently low level, the differential between H and L is sufficient to bulge the case outwards against the chamber wall.

• Forward of the bulge in the case wall baffling becomes complete, and the case obturates forward towards the mouth, to form a complete seal between itself and the chamber wall. With a typical H of over 300 MPa (20tons/in^2) the frictional force between the case and a dry chamber wall will be so great as to approximate "welding" the front end of the case to the wall. If the breech block were removed before this "weld" was broken, the back of the case would be ripped off the front by the pressure on its base, and the separated case would cause a gun stoppage.

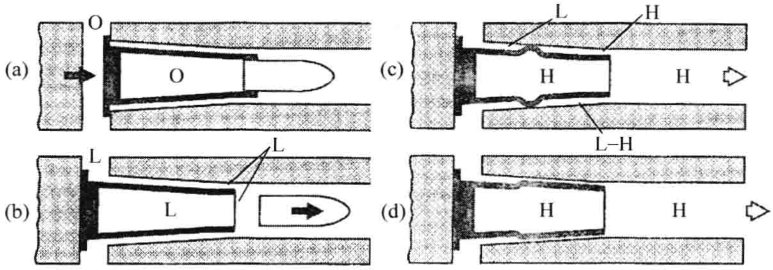

Fig. 2. 2 Sequence of Cartridge Case Obturation

The sequence just described varies in degree with the pressure of rounds and with the tightness of fit of the bullet in the case mouth. The higher the pressure of the round, the further forward it will obturate, which explains why very short stub cases are suitable for high pressure tank guns; but not for low charges in field artillery. If a field gun is fired with initially clean cartridge cases; it will be found that the outside of the cases remain clean when fired on high-charge, indicating obturation near the case mouth, but are burnt black near the base of the cartridge wdien fired on the lower charges.

Other Methods of Obturation

In another method of obturation the barrel and bolt are held together to. give a good seal. However, such a system is very prone to wear and erosion and becomes rapidly unusable. In the case of rotating chambers such as Revolvers, Aden/Mauser aircraft cannon, and the German Gll caseless system, other methods need to be found to seal the gap between the bolt and barrel. In Figs. 2. 3. 1(a), (b) and (c), the two mating surfaces are held together by the pressure provided by a ramp on the rear of the rotating chambers. This method can be used for increasingly powerful Revolver handguns, but is not sufficient for more high powered rounds or weapons with high rates of fire. Figs. 2. 3. 2(a) and (b) can only be used on slow firing weapons, usually cannon. Such methods are not used today because of the need for a different form of ammunition and the long stroke movement needed. Fig. 2. 3. 3 is the method used in the Aden/Mauser Aircraft Cannon with rates of fire between 1000 and 2000 rpm. It is also used in the H&K Caseless G11. The higher the pressure, the more the two surfaces are pressed together to give a good seal.