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RESEARCH AND DEVELOPMENT OF MATERIEL

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ENGINEERING DESIGN HANDBOOK

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AMMUNITION SERIES
SECTION 6, MANUFACTURE OF METALLIC COMPONENTS OF ARTILLERY AMMUNITION

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UNITED STATES ARMY MATERIEL COMMAND
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AMCP 706-249, Section 6, Manufacture of Metallic Components of Artillery Ammunition, forming part of the Ammunition Series of the Army Materiel Command Engineering Design Handbook Series, is published for the information and guidance of all concerned.

(AMCRD)

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PREFACE

This handbook is the last of six handbooks on artillery ammunition and forms a part of the Engineering Design Handbook Series of the Army Materiel Command. Information concerning the other handbooks on artillery ammunition, together with the Table of Contents, Glossary and Index, will be found in AMCP 706-244, Section 1, Artillery Ammunition--General.

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SECTION 6

MANUFACTURE OF METALLIC COMPONENTS OF ARTILLERY AMMUNITION

INTRODUCTION

6-1. Objectives in Design. Design of components of artillery ammunition seeks to accomplish objectives set forth in requirements of service. Design and the expedients of available material and manufacturing methods must be correlated to minimize drain on stockpiles and man-hours in times of emergency. Principal metals employed for a round of artillery are (1) steel for the shell, (2) brass for the cartridge case, and (3) copper for the rotating band. Steel is also employed successfully for certain types of cartridge cases.

6-2. Reasons for Use of Steel and Brass. The low cost of steel and its ready adaptability to a wide variety of specifications, especially those for strength and hardness, virtually rule out any other material from consideration, as far as the shell is concerned. Cartridge brass, despite its higher cost, owes its traditional employment chiefly to the ease with which it may be drawn into a thin-walled case, its resistance to corrosion, and its successful performance of the function of obturation.

6-3. Selection of Manipulative Techniques. Means employed to cause metals to assume the desired form include (1) casting in a mold; (2) squeezing and drawing, either hot or cold; and (3) machining. Selection of one or more of these techniques, in an appropriate sequence, is governed by considerations of both cost and adaptability. Thus, while it would be possible to machine a large shell out of a solid bar, it is cheaper to forge hot and finish on the lathe. Similarly the easiest way to make a cartridge case is (1) to blank out a disk from rolled strip, (2) to cup it and, (3) by successive draws and intermediate anneals, to extend the metal into a long, cylindrical thin-walled container having the necessary combination of plasticity and resilience to expand with the gun tube at the instant of firing, and to retreat sufficiently to render withdrawal easy. A method of manufacturing cartridge cases by spiral wrapping of sheet steel is also coming into increased use.

6-4. Progress in Manufacturing Techniques. Use is being made of the techniques of powder metallurgy for the manufacture of rotating bands and other parts that lend themselves to this method. Use of cold extrusion methods promises a superior shell body, having the required physical (including fragmentation) characteristics, from a slug which exceeds the weight of the finished carcass by only a few percent. However, throughout the period including the First and Second World Wars, a few changes which could be regarded as radical departures from pre-existing practice took place. Cartridge case manufacture is still more or less unchanged, although the labor of handling components has been greatly reduced. A noteworthy forward step in the case of high-explosive shell was the forge finish of the cavity. This saved much expensive machining.

6-5. Casting Versus Forging of Steel Shells has attracted the attention of many ordnance engineers. The principal resistance to casting high-explosive shells arises from a justifiable skepticism about the integrity of the finished article. Cast steel, except under high hydrostatic heads, is especially prone to blowholes on account of its relatively high melting point, as compared with cast iron. Centrifugal casting has been proposed but never seriously considered. Tank hulls, however, were successfully cast during World War II and the possibility of casting high-explosive shell with the aid of shell molds cannot be overlooked.

6-6. Influence of Hot Versus Cold Work on Steel. In hot-forging, as distinct from cold-working, the temperature of the steel always exceeds the critical range. Hence, the microstructure of the steel is austenitic. No amount of deformation while in this condition injures the steel in any way; on the contrary, it improves it. Cold-worked steel can always be distinguished from hot-forged stock, under the microscope, by the appearance of the grains. Cold-working tends to elongate the grains whereas hot work breaks up the large crystals, which tend to form at elevated temperatures, into a fine grain of normal polyhedral pattern. However, if steel is subjected to tension while at forging heat, the amount of elongation to which it can be subjected without cracking depends upon the cleanliness of the steel. Dirty steel (including high-sulfur steel), if extended sufficiently under the rolls, may exhibit cracks.

6-7. Hot Work Produces Satisfactory Shell. The familiar pierce-and-draw process of manufacturing steel shells subjects the steel to far less risk of cracking from overextension than the rolling down in the mill. Manufacture of shell forgings by hot work is an eminently satisfactory method. It does entail, of course, the machining of the exterior of the forging and the removal of a considerable quantity of steel. The latter is conserved by circulation through the open-hearth furnances as scrap.

6-8. Influence of Cold Work on Physical Properties of Steel. The principal results of cold work are a considerable increase in tensile strength and a large loss in ductility. Yield strength increases as the cross section is decreased. With reductions of 30 to 70 percent, it is at least 90 percent of the tensile strength; and for greater reductions, yield strength and tensile strength may for all practical purposes be the same. Figure 6-1 shows the stress-strain curves of cold-worked, low-carbon steel. Figure 6-2 shows the influence of carbon content on the gain in tensile strength arising from cold work.

6-9. Extrusion for Shell Manufacture. Steel, especially low-carbon steel, can, it is now known, be made to flow under sufficient pressure into the form of an artillery shell or cartridge case and to acquire, in the process, the required physical properties. Under favorable circumstances pressures of over 200 tons—many times in excess of the yield strength of the steel — may be applied without fear of rupture. Also, deep-drawing operations characteristic of cartridge case manufacture may be

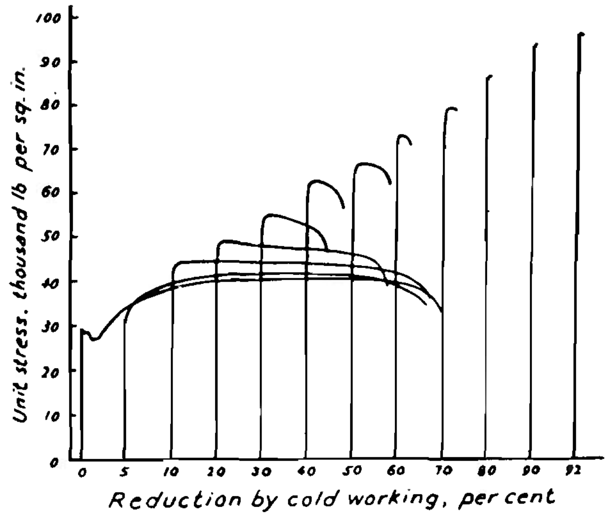


Figure 6-1. Stress-strain curves of cold-worked, low-carbon steel

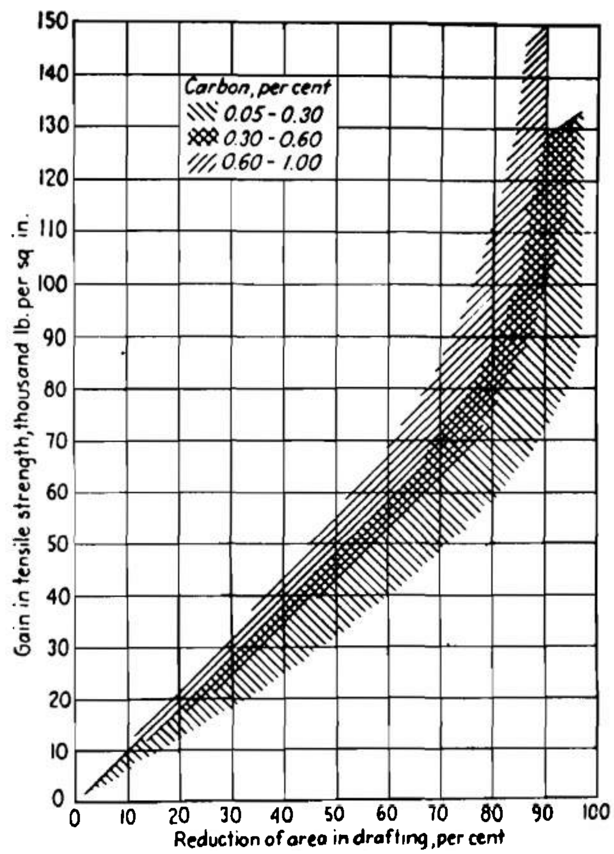


Figure 6-2. Effect of cold working on the tensile strength of carbon steel, gain in tensile strength versus area reduction

carried out to the extent of a 55 percent reduction, an amount far in excess of normal limits.

6-10. Advantages of Extrusion over Forging. Among the advantages claimed for extrusion are (1) the enhancement of physical properties, by cold-work, beyond the requirements of the specifications for steel shell; (2) the elimination of heating facilities for forging and heat treatment; (3) the avoidance of a resort to critical alloys. Manganese content is greatly reduced, savings up to 50 percent being indicated. Further, there appears to be a remarkably low percentage loss of steel in cold extrusion. For example, a 75-mm shell weighing 8.9 pounds starts with a 9.22-pound slug. The key to successful operation lies in the proper application of zinc phosphate to the surface of the shot-blasted and pickled slug and successive squeezes. The metal phosphate acts as a "host" to the sodium stearate soap lubricant to avoid sticking and tearing of the component against the extrusion tools.

6-11. Steel Used Early in World War II. Shells were forged from a steel known as X-1340, which had the following composition: carbon, 0.35 to 0.45 percent; manganese, 1.35 to 1.65 percent; phosphorus, 0.45 percent maximum; sulfur, 0.075 to 0.15 percent. These are relatively high percentages of manganese and sulfur. High manganese content was originally intended to secure the required physical properties (on cooling from forging temperature) without subsequent heat treatment, manganese being a hardener. The amount by which 0.01 percent manganese increases the tensile strength varies with the carbon content from 100 to 500 psi. The increase in the yield strength is somewhat more than this, 50,000 psi, accompanied by good ductility, being easily attained with manganese in excess of 1.0 percent, provided the cooling is rapid and uniform. While the physical requirements were met in the smaller shells, difficulty was experienced with the 155-mm on account of the higher ratio of volume to heat-robbing surface. This accounts for the decision of the Ordnance Department to adopt a steel with lower manganese content and to obtain the required mechanical properties by heat treatment. This action also saved considerable quantities of manganese, which was in short supply, and simplified the work of the forge by eliminating air-blast cooling; however, the work in the machine shop was increased.

6-12. Objections to High Sulfur Content. Reduction of the manganese content of the steel would have necessitated a reduction in the sulfur in any event, since there is a limit to the amount of sulfur with which manganese will combine to form manganese sulfide and thus rid the steel of the more objectionable iron sulfide. Lower percentages of sulfur were desirable, however, for other reasons. First, manganese sulfide is almost completely insoluble in solid iron. Consequently, when the iron solidifies manganese sulfide is present in the mass of metal as discrete particles. These particles, if present in large quantities, as a result of excessive sulfur, may have a deleterious effect on the ductility and impact resistance of the steel. In general, as far as steel for shells is concerned, high sulfur content was believed (1) to contribute to nonuniformity in quality; (2) to be responsible for transverse weakness and red shortness, giving rise to longitudinal cracks at the open end of the shell; and (3) to occasional surface defects. High sulfur content does, however, promote free machining. But above all other considerations, the presence of large quantities of high sulfur shell-steel scrap (crop ends, scrap forgings, lathe chips, etc.) was a menace to the quality of other steels in the mill whose sulfur contents were normal.

6-13. Steels Used After World War II. Steel which replaced the older X-1340 had the following composition: carbon, 0.60 percent maximum; silicon, 0.15 to 0.35 percent; manganese, 1.00 percent maximum; sulfur, 0.06 percent maximum. Maximum percentages of residual ingredients were given as follows: nickel, 0.35 percent; chromium, 0.30 percent; copper, 0.25 percent; together with the proviso that the sum of the percentages of nickel, chromium and copper must not exceed 0.50. This steel had no noticeable influence on the amount of work required in the forge shop. There was a noticeable absence of any tendency to crack, especially at the open end of the forging. The work of the machine shop, however, was increased.

6-14. Prevailing Shell Steel Specifications. The chemical requirements of shell steels, as of 17 February 1953, are shown in table 6-1.

Grades WDSS 1 and 2 are used for the most part for 60-mm and 81-mm mortar shell forgings; also for the 57-mm recoilless gun shell. The other grades cover all calibers from 37-mm to over 155-mm, in which the yield strengths vary from 60,000 psi to 80,000 psi. All shell steel is made by the basic open-hearth process to fine grain practice, silicon 0.15 to 0.30 percent. Bessemer steel never has been acceptable for shell bodies because of its low notch toughness, especially at subzero temperatures. The current specification for hot-forged artillery shell is identified as MIL-S-10520C (ORD).

Table 6-1

Steel no.	Carbon percent	Manganese percent	Phosphorus percent	Sulfur percent	Silicon percent
WDSS 1	0.14-0.20	1.00-1.30	0.040 max.	0.08-0.13	0.10 max.
WDSS 2	0.28-0.34	0.60-0.90	0.040 max.	0.050 max.	0.15-0.30
WDSS 3	0.60 max.	1.00 max.	0.040 max.	0.050 max.	0.15-0.30
WDSS 5	0.65 max.	1.00 max.	0.040 max.	0.050 max.	0.15-0.30
WDSS 6	0.55 max.	1.00 max.	0.040 max.	0.050 max.	0.15-0.30
WDSS 7	0.65 max.	1.30 max.	0.040 max.	0.050 max.	0.15-0.30

In the above steels, incidental elements shall not exceed the following: nickel, 0.25 percent; chromium, 0.20 percent; copper, 0.50 percent; molybdenum, 0.06 percent.

6-15. Shapes From Which Shell Forgings Are Made. The modern hot-forged shell blank starts as a billet, parted off from round stock or square stock with rounded corners. In the familiar pierce-and-draw process, the square-stock type has the advantage (more fully discussed elsewhere) of imposing less severe duty on the punch, since lateral movement of the steel takes place as the die pot is filled, thus limiting the extent of rearward extrusion.

6-16. Specifications. Military specification for shell steel covering the compositions shown in the table above are the following.

Federal. QQ-M-151 — Metals: General Specification for Inspection of.

Military. MIL-M-11266 — Macroetch Test and Macrographs of Steel Bars; MIL-M-12286 — Macroetch Test and Macrographs for Resulfurized Steel Bars, Billets and Blooms.

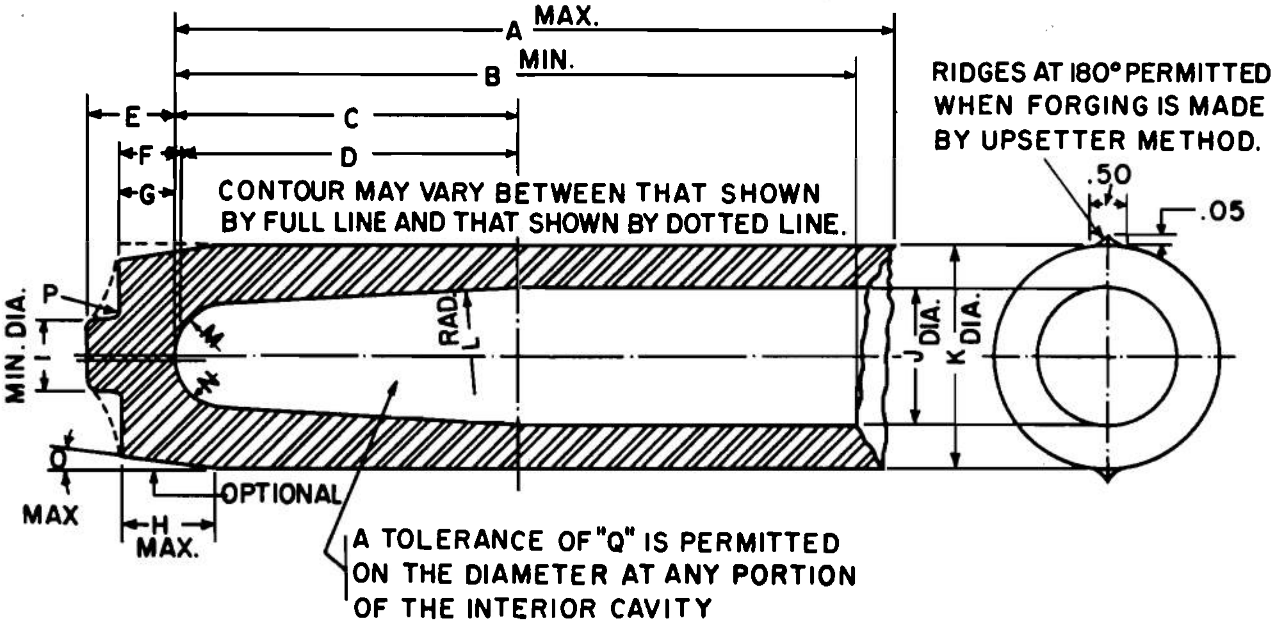
Standard. Military, MIL-STD-129 — Marking of Shipments.

These specifications (1) cover the quality of the steel; (2) indicate permissible variations for check analysis; and (3) deal with the matters of internal soundness, (4) extent of the discard from the top and bottom of the ingot, (5) identification by heat number, and (6) surface condition. They also exhibit permissible variations from size and straightness; and deal with sampling, inspection, and test procedures. Notes are also appended on preparation for delivery and ordering data.

6-17. Shapes and Dimensions of Shell Forgings. Figure 6-3 gives information on the shape and dimensions of forgings for 75-mm, 90-mm, and 105-mm shell. These data were laid down for World War II manufacture. The dimensions shown were standardized at a time when the Ordnance Department purchased shell forgings from prime contractors. Later on, when shell machiners purchased shell forgings directly from the forge plants, no fixed outside dimensions existed. In consequence the same shell forger made shell forgings to different dimensions at various times, or even at the same time, if he had orders from several shell machiners. The desirability of saving weight caused changes in these dimensions to the point where they lost their original significance. Cavity sizes, of course, persisted, since the cavity was finished in the forge, apart from the small amount of material removed by shot blasting.

6-18. Billet Separation. The great majority of shells are forged from single or double slugs parted off from the main billet or bar. Separation may be effected in various ways, especially by (1) shearing, (2) sawing, or (3) flame cutting; (4) "nick and break" was also widely used. The first three do not permit effective inspection of the separated surfaces for secondary pipes, cracks and holes. Breaking does, but slivers and rough breaks occasionally mask holes and cracks. Moreover, steel breaks at times with a loose sliver which is not easily detected if it lies flat against the broken surface. Such a sliver would end up as a sliver in the cavity and be detected on shot blasting, causing rejection of the forging.

For shearing, the bar must be heated to at least 80°F to avoid shearing cracks. Even so, if the slugs are not delivered to the furnace within a few hours or days at the most, cracks may develop unless the steel has been heated to 200°F. Among the methods available for



SIZE	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
75mm.	13.125	11.35	5.51±.20	5.48±.20	1.36	1.11	1.08	1.4	1.06	2.13	3.28±.06	24	.8	.47	8°	.1	±.02
90mm	14.0	12.30	6.30-	6.11±.20	2.15		1.43	1.5	1.25	2.55	3.92±.08	4	.8		6°	.1	±.025
105mm	19.0	15.5	8.45±.20	8.80±.20	2.25	1.65	1.30	2.0	2.00	3.30	4.55±.10	18	1.25	.5	8°	.25	±.025
155mm	26.50	23.0	10.42±.25	10.10±.25	2.80	1.90	1.58	3.0	2.50	4.84	6.60±.10	43	1.75	1	8°	.25	±.035

DIMENSIONS OF SHELL FORGINGS

Figure 6-3. Dimensions of shell forgings

separation of the slugs from the bar, shearing is the cheapest. However, shearing of rounds is limited to 3 inches diameter, although somewhat larger squares are sheared. Nicking and breaking is the cheapest method for large shells. Sawing and flame cutting give square ends that make it easier to set the slug upright on the rotary hearth of the heating furnace.

6-19. Billet Scale and Descaling. Shell steel bars, when delivered to the forge, are covered with a light scale and occasionally with rust. The amount of scale formed and its nature vary with furnace heating time, temperature, and the composition of the shell steel and of the furnace atmosphere. Scale is abrasive and ruins tools and dies. A nonretentive scale is desired, that is, one that can readily be knocked off in its entirety. Scale on a round slug can be cracked off with an end squeeze; another method employs serrated rolls. Water jets driven by high pressure (2,500 psi) are effective without appreciable cooling effect. A thin skin only is affected in the second or so of contact between high-pressure water and the steel. Reheating of the thin, cooled skin by the heat in the body of the slug is rapid.

6-20. Shell Forging. The apparently simple process of forging a shell from a heated slug is actually beset by many pitfalls. Modern techniques have grown out of extensive development. Earlier and more direct methods centered about forcing a punch into a round slug previously raised to forging heat and placed in a die or "pot" which it fitted loosely. The metal rises around the punch, much after the fashion of drawing on a heavy steel glove. The load on the punch under these circumstances is very severe, and its life is short. The surface of the punch deteriorates rapidly, giving rise to rough cavities which have to be machined. "Wash" heating of the slugs (hasty heating causing steep temperature gradients from the hot exterior to the cooler interior) forces the punch to run to the side, producing "thick-and-thin" forgings, difficult to machine and wasteful of steel.

Punches are now made of alloy steel and are lubricated. The load on the piercing press is reduced by performing the forging process in two steps. First a cup is formed in the press; this cup is then mounted on a mandrel and pushed through a series of ring dies of gradually diminishing size to draw out the body of the forging.

Possibly the most significant change between the two World Wars has been the use of round-cornered squares in place of rounds for the slugs. The load on the punch is reduced, since lateral flow of the steel to fill the die reduces the amount of backward extrusion, as well as the work required to change the shape of the slug to that of a cup.

6-21. Objectives in Shell Forging. The effort to produce accurate, minimum-weight shell forgings arises from the necessity of saving steel. During a war, shells are manufactured in astronomical quantities, and demand on steel capacity is correspondingly heavy. The return of scrap and chips to the mills reduces the load on the blast furnace, and is a necessary part of the material requirement of the openhearth. Transportation is another factor. Tools need be conserved. Power used in the machine shop is less if only a thin roughing cut has to be made. Weight may be saved at the outside diameter, also on the length and on thickness at the base. But enough metal has to be left to make sure that a high percentage of forgings will "clean up" during rough turning without leaving any black spots.

Several distinct improvements have been successful: (1) the so-called French extrusion process, in which a plunger moving downwards within a cylindrical die extrudes the slug over a punch which sits upright with its nose within the die; (2) use of mechanically operated presses, such as bulldozers and upsetters; (3) application of cross rolls (familiar in the manufacture of seamless tube) to the extension of the cup produced by the piercing press; (4) the "one-shot" process, in which the base of the die drops downwards under a controllable pressure, thus minimizing rearward extrusion of the steel and relieving the load on the punch.

6-22. The One-Shot Method. Figure 6-4 illustrates diagrammatically the progressive stages in the one-shot piercing process that is credited with producing smooth, satin-like cavities. The profile of the piercing punch must, of course, be that of the cavity in the shell. Since the ordinary high-explosive shell has a fairly large length-to-cavity diameter ratio, the piercing punch is much longer and more slender than the punch required for the more familiar double-operation sequence of pierce and draw. Provision of a retreating base in the die averts the limitations encountered when shells were pierced in one go.

In the one-shot process, friction between the exterior of the slug and the die tends to hold the forging against the die walls, while the punch makes its way into the interior of the slug, extending it as the base of the die drops when the thrust upon it exceeds a predetermined adjustable value. Slug temperatures must be high and heating should be uniform if "run-out" of the long and relatively slender punch is to be avoided. A modification of the one-shot process calls for the use of a second press where the bottom of the forging is set.

Figure 6-5 is a diagrammatic cross-section through a "one-shot" press. The piercing punches are fastened to a turntable which is indexed 90° after each piercing operation. This gives the punches a chance to cool off and to be lubricated for the subsequent operation. After the first turn through a right angle, the punch which has just been at work is sprayed with oil. Another quarter turn and it is immersed in oil. A third quarter turn and it is in the inspection position. The means whereby the base of the die (marked "resistance pin") descends as the pressure upon it exceeds a predetermined pressure are clearly in evidence. This relief pressure is adapted to the variable resistance of shell steel at forging heat to change of shape; and to variations in the frictional resistance of the interior of the die with wear. Punches in this operation have to be carefully guided, as indicated by the extensive punch guide on top of the die.

6-23. Hydraulic Piercing for Subsequent Drawing. In the process described in the preceding paragraph, the entire action takes place in the piercing die unless a second operation to set the bottom of the forging is used. The greatest

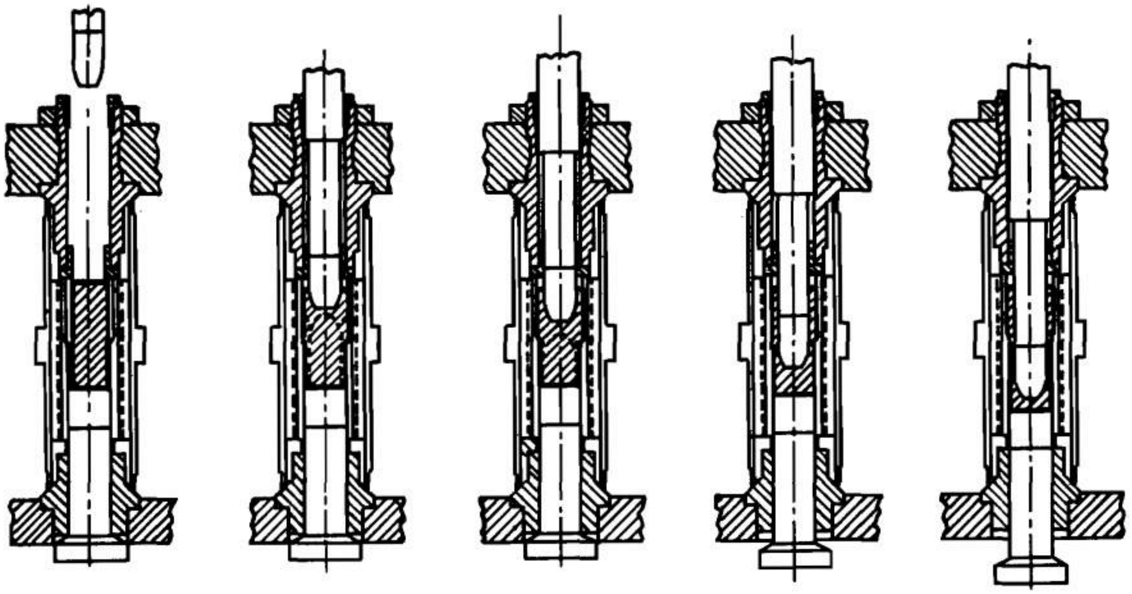


Figure 6-4. Progressive stages of one-shot piercing method

part of high-explosive shell manufactured during World War II, however, was forged in two major operations, the "pierce" and the "draw". Many minor variations of the piercing or "cupping" operation appeared. Sometimes the die pot was inverted, the punch entering from below, partly to facilitate the removal of scale but principally to secure concentric entry of the punch. If a cylindrical or prismatic slug is placed in a tapered die set upright, it tends to rest against one side of the die, causing eccentric entry of the punch. There is less liklihood of this happening in the case of an inverted die. Figure 6-6 shows the arrangement of the tools of a hydraulic press for inverted piercing.

6-24. Round Versus Square Slugs. During World War II the use of round stock for shell slugs was restricted, on account of its higher cost as compared with round-cornered square billets. But there is less rearward extrusion, that is, flow of metal in the direction opposite to that of punch travel. In fact, in the early use of the round-cornered square it was hoped to avoid rearward extrusion (with its consequent erosion of punch and die) by making the area of the original square equal to that of the final annulus. Actually the slug is shortened by the pressure of the punch until friction between die and slug takes hold and lateral displacement supervenes. Finally the excess metal in the die extrudes rearward toward the end of the piercing stroke.

The maximum square is determined by the consideration that the steel displaced from the cavity by the punch must be sufficient to fill the four segments between the billet and the die; otherwise the forging would not fill the die. If S is the measure of the side of the square and r the radius of the corner, then for equality between the area of the original round cornered square and the final annulus

$$S^2 = 3.222rS + 2.45\ r^2 = 1.375d^2$$

6-25. Drawing After Piercing. Figure 6-7 exhibits a typical draw bench with solid ring dies. As previously indicated, the forge work required to produce a shell is divided between the piercing press and a subsequent draw. The drawing operation may be carried out on a mandrel which pushes the cup through a series of ring dies of successively smaller diameter. Instead of solid rings, rollers may be used; or humped rolls may be employed for the purpose,

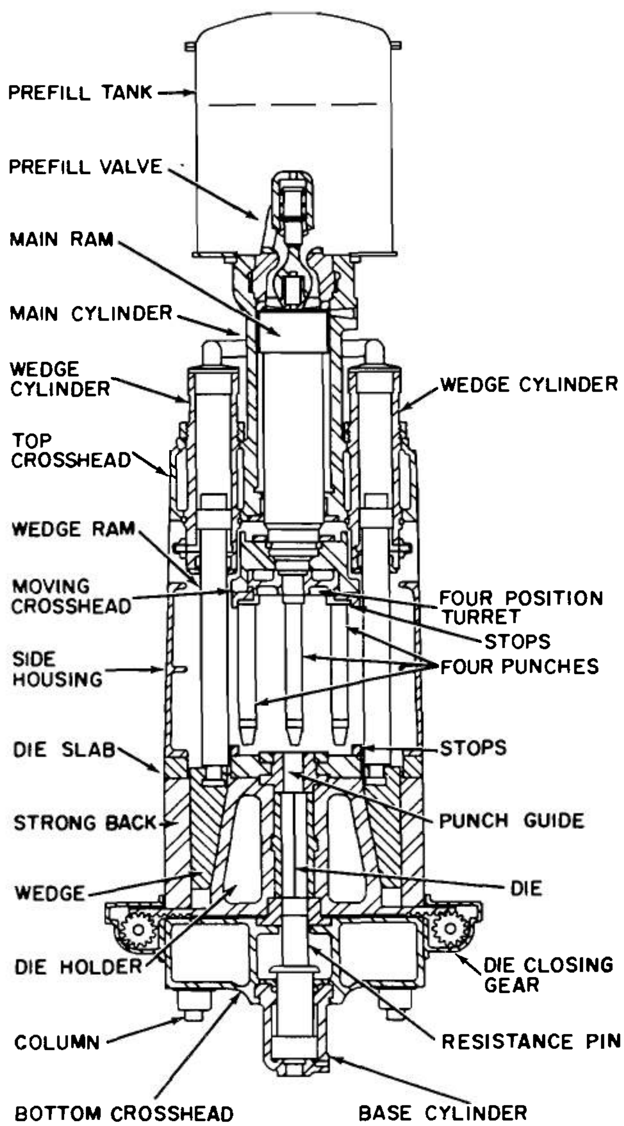


Figure 6-5. One-shot press

as shown in figure 6-8. While the shape of the piercing punch is determined by the experience of the tool designer, the profile of the draw-bench mandrel must, of course, be that of the cavity in the shell. Likewise the diameter of the last ring die is determined by the diameter of the shell, that is, it must not be less than this. Actually, of course, sufficient metal must be left on the outside to "clean up" on machining. The cavity is merely shot-blasted, and little metal is removed in the process.

6-26. The French Extrusion Method of forging shell foreshadows the modern techniques of cold extrusion which will be described later. The principle is illustrated in figure 6-9. A slug, raised to forging heat, is placed in the die (B). The punch (C) then moves forward to cause flow through the annular space between the die (B) and the mandrel (A), the action being continued until the desired base thickness of the forging is secured. The process can be readily carried out on a bulldozer. This simple method of forging high explosive shell attracted less attention during World War II than it merited, partly on account of the uncertainty concerning the outside diameter of the forging. Some care is necessary in the adjustment of the relative axial position of the die (B) and the mandrel (A), and consequently of the characteristics of the annular orifice between them, to ensure satisfactory performance.

6-27. Progressive Piercing on the Upsetter. The origin of the force that does the work in forging a shell from a slug is a matter of little moment, granted that adequate force is available. A hydraulic press produces a steady thrust, but a crank and flywheel combination produces a variable thrust. The thrust may be as great near the dead center as the several parts of the machine will withstand, but it declines rapidly toward crank positions at right angles to the dead center.

Given a sufficiently powerful press, the job of forging a shell should apparently be completed at one heavy stroke; nevertheless, a series of operations is necessary, if for no other reason than that the energy capacity of the system per revolution of the flywheel is a limiting factor. The sequence is best interpreted by reference to figure 6-10, entitled "Upsetter Forging With a Collar." In brief, the bar, one end of which has been heated while the other serves as a tong hold, is pushed against a stock gage and gripped by the closing dies. In the first push (not shown in the diagram) the punch upsets the end of the bar and splinters the scale. Thereafter, the stock is pushed forward to the gage a second time after turning through 90°. Subsequent events may be followed from the diagram. After each thrust of the pitman carrying the head in which the punches are mounted, the

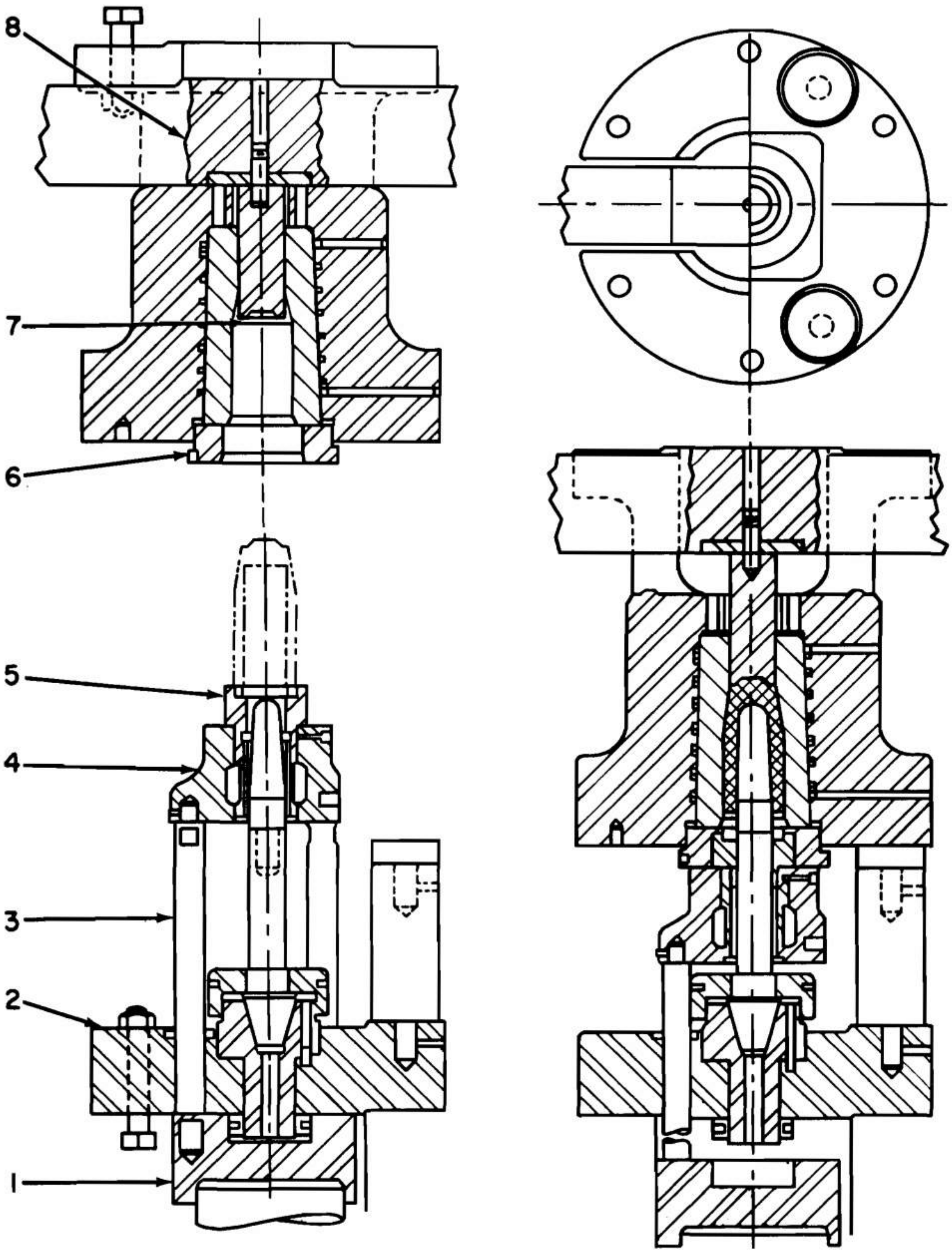


Figure 6-6. Hydraulic press tools

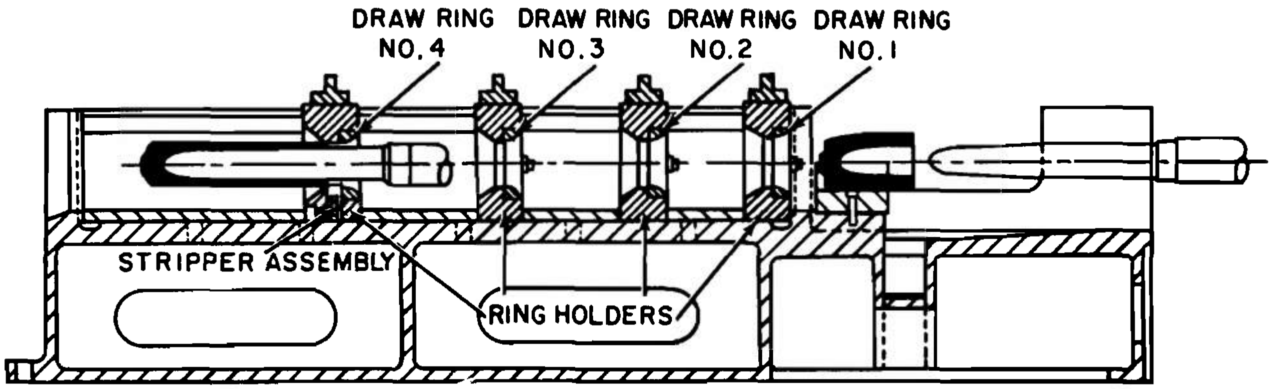


Figure 6-7. Draw bench

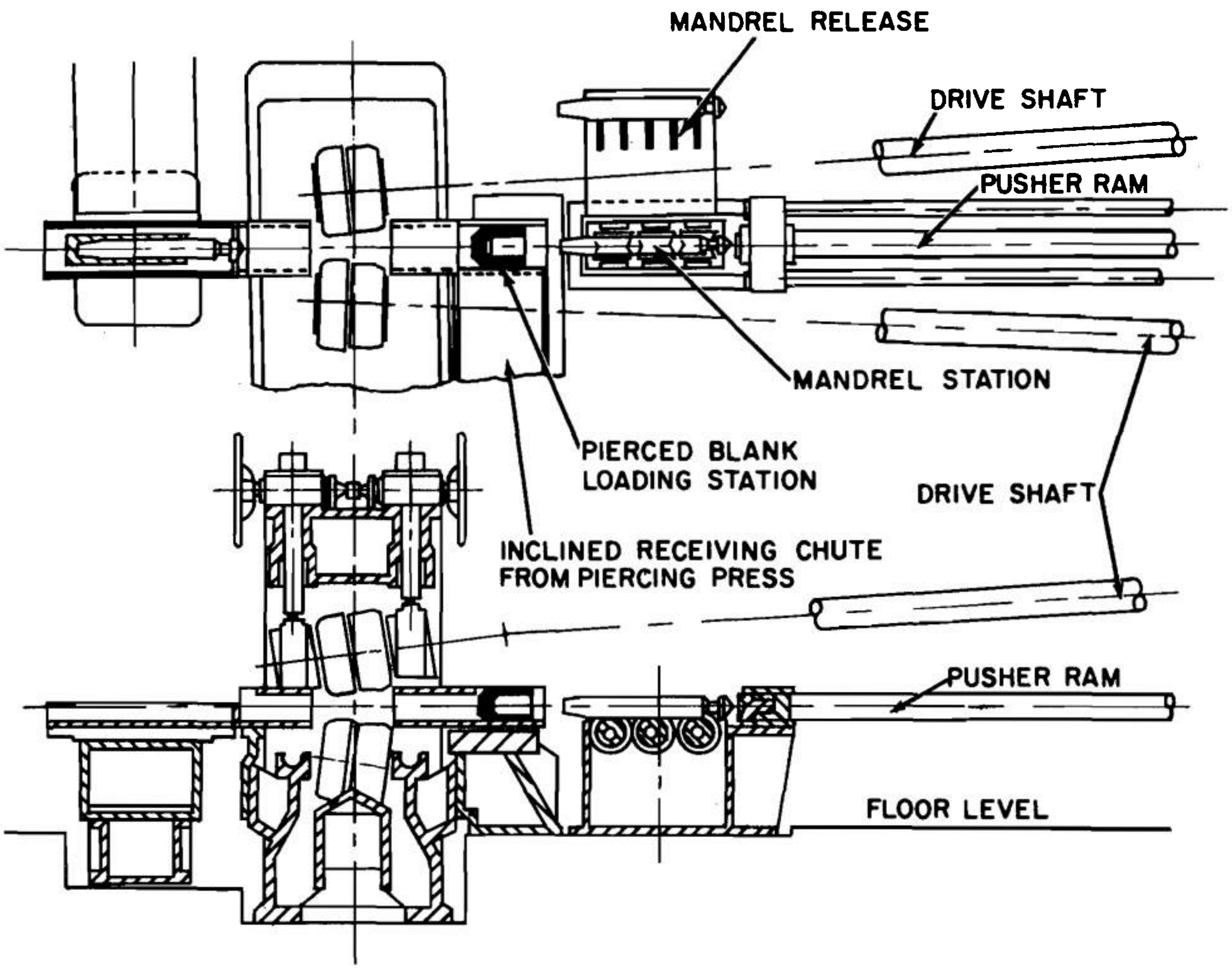


Figure 6-8. Cross rolling mill

split die opens, one half moving under toggle action to enable the operator to transfer the stock from one impression to the next below. In this way the final form of the forging is reached. Round or square stock may be used in the upsetter. The latter has the advantage of being readily gripped in the dies, despite reasonable variations in size.

6-28. The Effect of Water Sprays on Hot Forgings lies in the extent to which the hot forging is cooled. With modern shell steels, no injury results as long as the outer layers remain above the critical temperature; however, if surface cooling is continued until the temperature falls to the "blue heat" (around 700°F), the deformability of the steel becomes low; steel tends to fracture at this temperature like cast iron. Ordinarily this does not happen. Even the hydraulic descaling of the slug with cold water under a pressure of 2,500 psi appears to have no injurious effects. In any case,

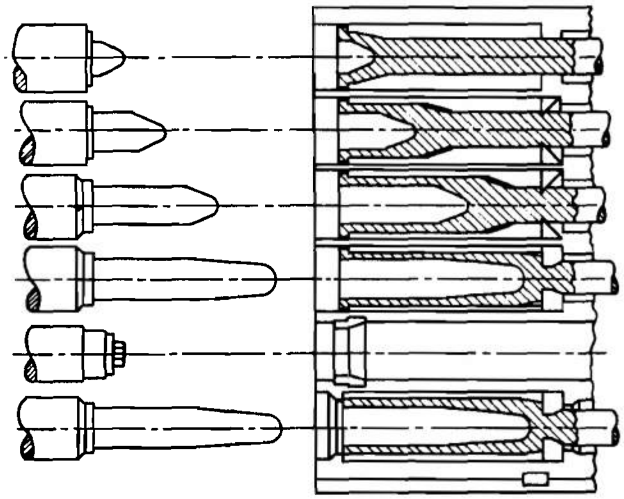


Figure 6-10. Upsetter forging

even if fine hair-like cracks should form on the outside of the forging, any injury from water would be removed in rough turning.

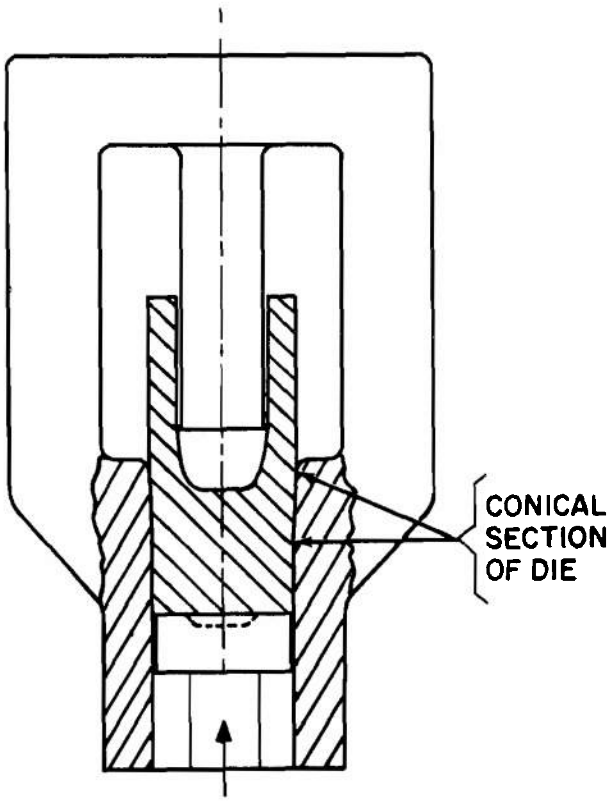


Figure 6-9. French extrusion process

Cracks in the cavity would be more serious, both because of the greater difficulty of observation and on account of the small amount of metal removed by shot blasting. Careful investigation, in cases where water was freely sprayed in the cavity for periods in excess of normal, failed to reveal any cracks from this cause.

6-29. Economics of Shell Forging. The cost of producing a usable shell forging is the sum of many minor and a few major items. These include the cost of the steel, freight, unloading, billet separation, transportation to furnace, heating, descaling, forging, cooling, inspection, hospitalization, and loading. Coupled with these costs are those for supplies, such as fuel, refractories, material for tools, packings, lubrication, overhead in the form of interest, depreciation of buildings and equipment, insurance, taxes, management and other forms of indirect labor; all of these must also be included in cost appraisal.

In making an appraisal of the different techniques of forging shell, the method which proves most economical for one size of shell may not be the cheapest for another. For example a 75-mm HE shell forging is most economically made on the upsetter; the upsetter, however, is the most expensive method of making the 105-mm.

6-30. Comparative Study of Shell Forging Methods. Certain considerations other than cost enter into the selection of equipment to forge shell. These are (1) what type of equipment is best adapted to rapid conversion on the outbreak of war; (2) what forging equipment should be immediately available, without conversion, if urgent necessity should arise; (3) the degree of skill required in any given method, since a process than can be operated by unskilled labor has the advantage of a quick start.

An ASME study on "The Forging of H.E. Steel Shells" tabulates the various items of cost entering into the manufacture of 720,000 shells by various methods, for four different sizes of shells, namely, 75-mm, 90-mm, 105-mm, and 155-mm. The figures relate to 1943. In the final analysis no large differences, with one or two exceptions, exist among the various methods. Total cost divided by number of shells results in the following average dollar values of the four shell sizes:

For the 75-mm shell forging,
577,500/720,000 = $0.81
90-mm shell forging,
877,800/720,000 = $1.22
105-mm shell forging,
1,188,600/720,000 = $1.65
155-mm shell forging,
3,443,000/720,000 = $4.78

Slug weights for these shell sizes were, approximately, 19, 30, 42, and 128 pounds, respectively. The costs per pound of forged shell are:

4.3 cents for the 75-mm
4.1 cents for the 90-mm
3.9 cents for the 105-mm
3.7 cents for the 155-mm

Certain items, such as real estate and buildings, taxes, burden, overhead, and other more or less fixed expenses, are not included in these figures.

6-31. Inspection of Shell Forgings. Forgings are inspected for soundness and adherence to dimensions. Inspection procedures fall into the following categories:

1. Inspection for Soundness.
   - Soundness of base
   - Seams and slivers
   - Scoring or roughness of cavity
   - Scale pits
   - Gas pockets or blisters
   - Torn cavity
   - Tear drops
   - Cracks in nose end after nosing
2. Inspection for Adherence to Dimensions.
   - Outside diameter
   - Diameter of cavity
   - Length of shell (clean metal)
   - Thickness of base
   - Eccentricity
   - Ovality
   - Length of taper in cavity
   - Ballooning of cavity (double nose)

6-32. Inspection Before Heating. The principal defects encountered in the slug are (1) unsoundness of the center caused by pipe; and (2) surface seams and laps. Pipe is an unusual extension of the cavity which forms under the upper crust as the ingot cools and shrinks. This defect is usually removed by cropping in the mill; but incomplete removal may cause unsound cores and basal porosity. Shells are protected against premature detonation from this cause by a rolled steel plate, welded to the base. Experiments to determine the possibility that basal porosity will cause detonation within the gun tube indicate that the risk is very small. It is, however, a chance that cannot be taken. Pipe is detected by sawing and macroetching the ends, and sometimes the middle, of the bar. Billets 5 by 5 inches, or larger, are particularly subject to unsoundness, hence the ends of each slug are usually examined.

6-33. Inspection After Forging. Inspection after forging is done before the forging has cooled. The principal checks are made for concentricity and thickness of base. This is followed by a cold inspection prior to machining. "Tear drops" and "torn cavities" arise from the same cause. The melting point of the steel skin in the cavity is lowered by the addition of the carbon in the graphite lubricant used on the punch, and may liquefy in flakes or globules which weld themselves to the wall of the cavity. The bond is not secure. The shot blast sometimes removes the flakes and the tear drops may be chiseled out.

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6-34. Sequence of Operations in the Machining of Shells. The following operations are normally performed on the shell after it comes from the forge:

1. Shot blasting of cavity
2. Cutting to length
3. Centering
4. Rough machining
5. Heating for nosing
6. Nosing
7. Heat treatment
8. Testing for hardness
9. Shot blasting
10. Nose boring
11. Finish turning of body
12. Removing boss
13. Finishing of base
14. Rough turning of band seat
15. Finishing of band seat (including waving or knurling)
16. Nose tapping
17. Bourrelet finishing
18. Nose notching
19. Cleaning of band seat
20. Banding
21. Band turning
22. Degreasing
23. Fastening of base plate
24. Painting
25. Checking for dimensions after each operation

6-35. Preparation for Machining. After shot-blasting the cavity to remove scale, the excess length is cut from the mouth of the forging and a centering hole for the tailstock center is drilled in the base. The cutting-off operation is usually done by sawing or by flame-cutting on a cradle of slowly revolving rollers. The torch is placed inside the shell, so that the flash is thrown to the outside where it is removed in rough turning. For 155-mm shell and above, flame cutting is more economical than sawing. Since the cavity of the shell is not machined, it is necessary to locate all machining operations therefrom. The centering hole is drilled while the forging is mounted on an arbor which rotates counter to drill rotation. This arrangement gives a better guarantee of concentricity than rotation of either shell or drill alone.

6-36. Rough Machining the Outside of the Shell. (See figure 6-11.) Rough machining is carried out on a special, single-purpose lathe, designed to mount an optimum number of carbide cutting tools working simultaneously. The shell is gripped internally by the expanding pads of a heavy arbor, while its base rides in the live center of the tailstock. The greater the number of tools, with given feed and depth of cut, the tighter must be the grip between arbor and shell.

6-37. Nosing. The open end of the rough-machined shell is closed in and the ogive formed by a large vertical press capable of exerting pressures of 150 to 400 tons. The body of the shell is well supported by a chuck during the operation. Fuze thread diameter is the same for all high-explosive shell, from 75-mm to 240-mm; therefore, the open end of the largest shell must be deformed about three times as much as the smaller calibers to produce the same size fuze hole. As a result, 155-mm shell and up are hot-nosed, while the 75-mm to 105-mm can be cold-nosed.

6-38. Heat Treating. The critical temperature of shell steel lies between 1,400 and 1,450°F. All portions of the nosed shell forging must be heated above this critical temperature and quenched. In order to achieve maximum hardness prior to tempering, coupled with a mimimum of distortion, the cooling rate of the inside and outside, during quenching, must be as near the same as practical. In order to make sure that the critical temperature has been reached, the temperature is brought up to about 1,500 to 1,525°F. For quenching, oil is preferred to water, which is more drastic in its cooling action and hence more liable to produce cracks. The quench is followed by tempering, that is, reheating the shell to some temperature below the critical range to soften and toughen the steel. Tempering temperatures usually range from 1,000 to 1,250°F.

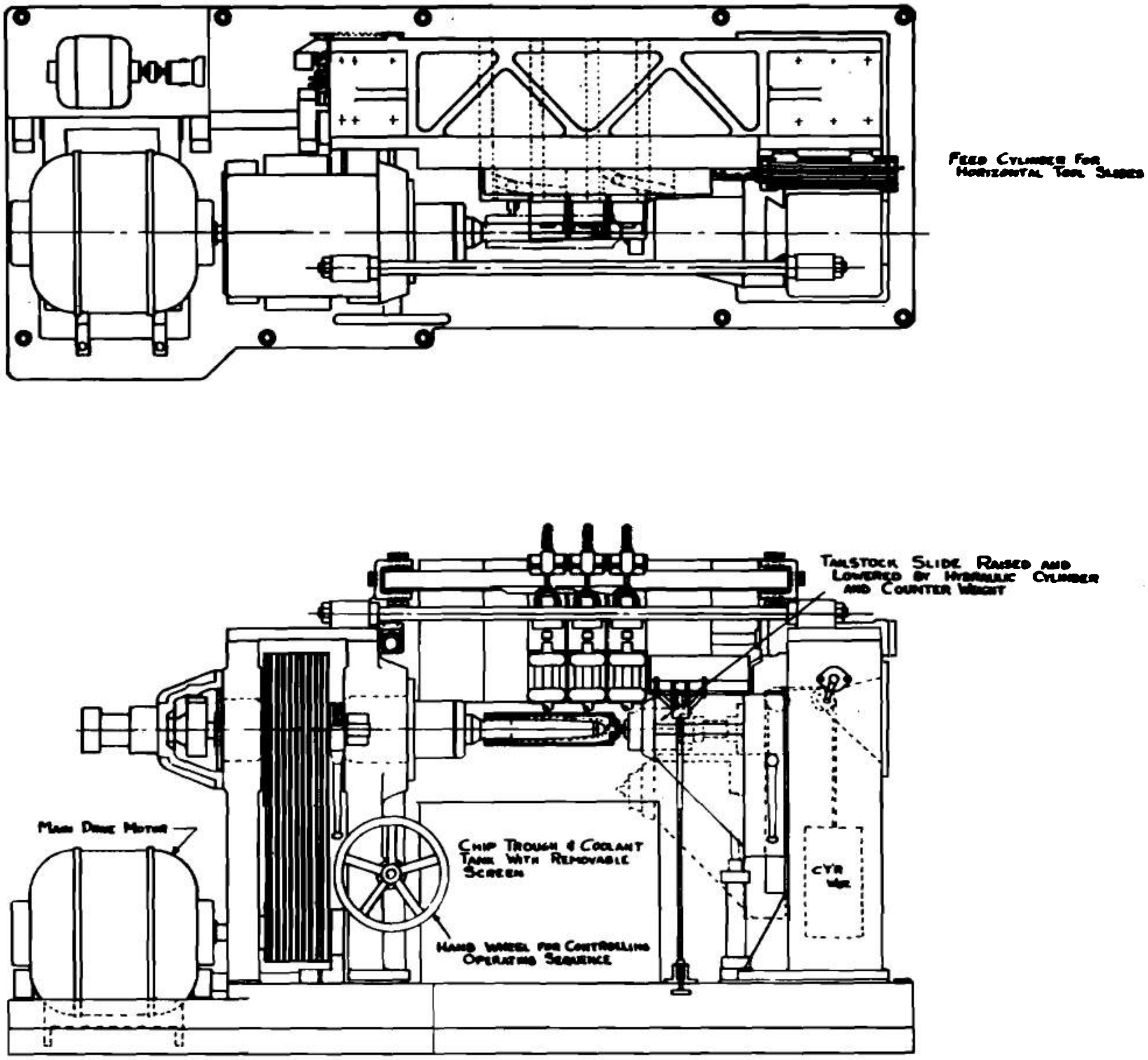

Figure 6-11. Lathe for rough turning

6-39. Testing for Hardness. The temperature at which shells are tempered is determined primarily by the necessity for meeting specifications for physical properties. The higher the temperature, the softer the steel and the lower the tensile strength. There is an approximate relation between tensile strength and hardness (tensile strength = 480 x Brinell hardness). Therefore, after tempering, the shell is Brinell-tested for hardness. The lowest permissible Brinell hardness is determined by the minimum tensile stress specified; the highest permissible Brinell hardness is established by consideration of machining difficulties. Unsatisfactory shells are returned to the heat-treating department.

6-40. Shot Blasting. After heat treatment, the cavity is cleaned by shot blasting in order to remove any scale formed during heat treatment, thus preparing the cavity for painting.

6-41. Finish Machining. (See figure 6-12.) To prepare the shell for finish machining, the nose of the shell is bored, reamed, and faced to provide a surface for chucking. The shell is mounted in the finishing lathe between an expanding driver head, which grips the nose bore, and the tailstock center, on which the boss in the base of the shell rides.

Because of its effect on exterior ballistics, close tolerances are specified for surface roughness. The maximum roughness permitted by the Ordnance Department is 250 microinches.

The machining setup is similar to that used for rough machining (paragraph 6-34), although a lighter lathe may be used.

6-42. Finishing the Base. After completing finish-turning of the shell, the boss on the base is removed. It may be sheared off; sawn by a metal saw, or abrasive wheel; or cut off in the lathe. An end mill is also occasionally employed. The removal of the boss in the lathe may be coupled with the finishing operation on the base.

6-43. Machining the Band Groove. Grooves with radial sidewalls can be machined by a forming tool, which leaves circumferential ridges in the bottom of the groove and finish-machines a portion of the shell adjacent to one side of the groove. These ridges are later converted into sharp projections by knurling rollers with hardened teeth. Grooves with undercut sides and wavy ribs require somewhat different treatment. The groove is first opened up with a radial feed to the depth of the top of the ridges. Clearance is then cut at the sides of the rectangular groove. Undercutting of the sides of the groove and machining of the wavy ribs by a waving tool may be done simultaneously.

6-44. Nose Tapping. Cutting the thread in the nose of the shell to receive the fuze is most frequently done with collapsible tapping heads. However, milling cutters may be used. These

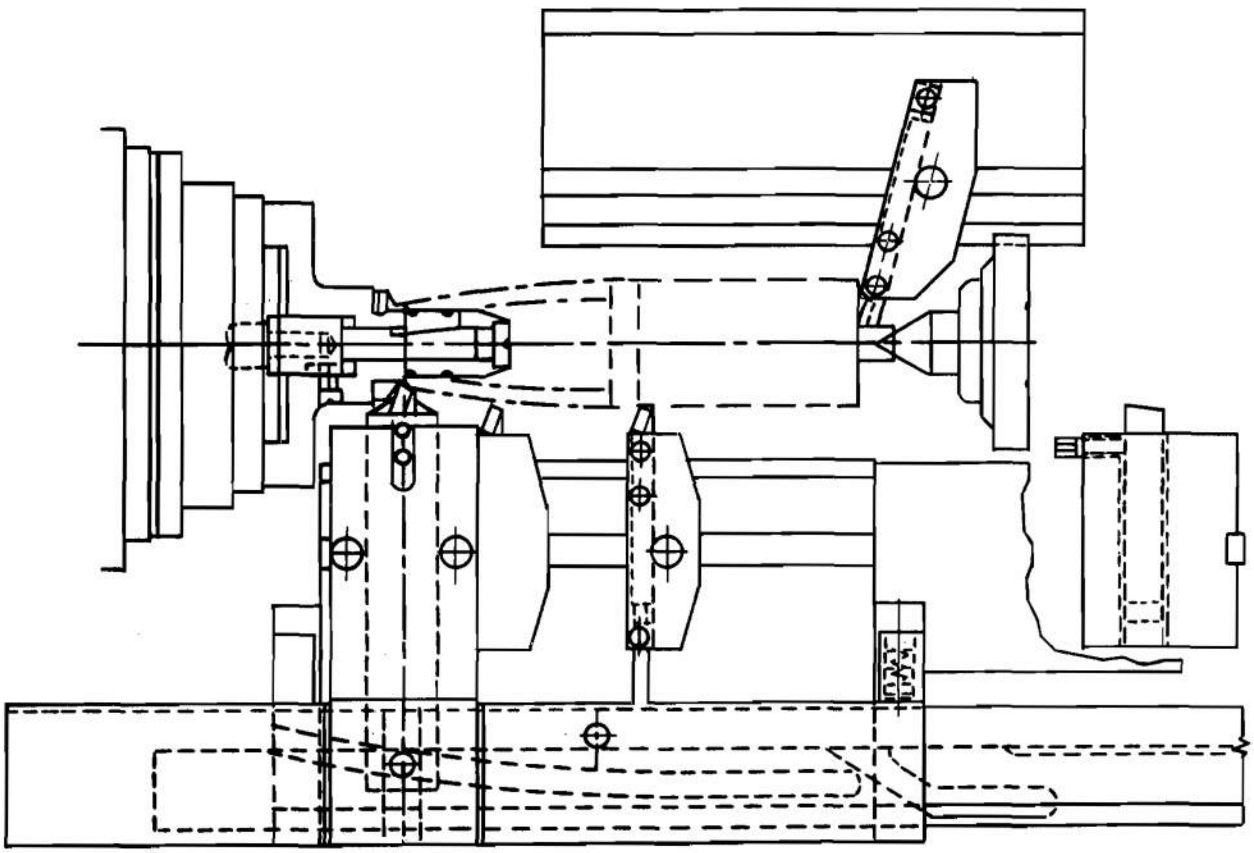

Figure 6-12. Tooling setup for turning

enter the bore, are then advanced to cut, and are traversed axially through a distance equal to the pitch of the thread, while the shell rotates once. Tapping may be done on a standard tapping machine; a multistation machine may also be used.

6-45. Finishing the Bourrelet. In order to maintain the close tolerances of bourrelet diameter in mass production with unskilled help, the bourrelet is usually finished by centerless grinding, although many machiners prefer a shallow cut in the lathe with a very fine feed.

6-46. Nose Notching. Staking notches are required in some shells but not in all. These notches may be cut by various means, the most common being milling. One or several milling cutters may be used. If several are used the cutters rotate continuously, the shell being pushed up against a stop governing the proper depth of cut.

6-47. Cleaning the Band Seat. The presence of chips or other trash may interfere with the proper seating of the band. The seat is therefore cleaned thoroughly with a steam jet, or by wiping with a rag which has been wet with carbon tetrachloride. A very thin layer of oil or grease does not interfere with tight banding.

6-48. Banding. The proper mounting of the driving band on the shell is of considerable importance, since the tightness of the band affects the ballistics of the shell. The band, made of gilding metal, copper, or iron, should fill the band groove completely, without clearance; and exert pressure against the shell both radially and against the sides of the groove. Banding is commonly done on a multicylinder hydraulic press (figure 6-13), or a toggle joint press (figure 6-14) known as a tire-setter, in which a number of jaws are thrust radially inward against the band, squeezing it into place. Banding may be done cold on shell up to and including 240-mm. For larger sizes the band is heated to around 1,500°F before application to the shell. In general it must be set sufficiently hard so that when the pressure is released, and in the case of hot banding the band is cool, the shell springs back more than the band. If this condition is not fulfilled the band will be loose. Shell may also be banded by forcing through a die (figure 6-15). For thin-walled shell, welded overlay bands are often used.

6-49. Band Turning. After having been set, the rotating band is machined to the specified size and shape. Bands without grooves may be finished with a single point tool; those with grooves are usually finished on a lathe with a form tool. Milling with a profiled cutter is also practiced. Since gilding metal is comparatively soft, it tends to spread beyond the confines of the groove during the banding operation; hence trimming tools must be provided in the machining set-up.

6-50. Washing and Degreasing. High-explosive shells are painted to protect them against rust. The surface is prepared by washing and degreasing. This consists of an alkaline wash, followed by a rinse and an acid wash. The alkaline solution dissolves the grease. It is not allowed to dry on the shell because the salts may react with the explosive in the cavity, and for this reason is removed by flowing water in the rinse tank. For the acid wash, the solutions which are used contain phosphoric acid, which (1) produces a surface to which paint adheres exceptionally well, and (2) forms a complex phosphate coating which protects the steel against rusting.

6-51. Fastening the Base Plate. Since premature explosion may result from cracks, sponginess, pipe, or holes in the base of the shell, a rolled steel plate is mounted on the finished base of the shell. This base plate may be (1) welded on; (2) caulked with a lead ring; or (3) peened in place. The preferred method in this country is resistance welding, either with the wheel or the cam-operated, reciprocating type of spot welding electrode.

6-52. Methods of Weight Control. For various reasons, including tool wear, variation in the size of the forge-finished cavity, lubrication, and (in large shells) temperature during the nosing operation, the weight of the shell would vary beyond prescribed limits if means of weight control were not used. Among available methods of control are (1) the adaptation of the outside diameter of that region of the rough-turned shell which undergoes deformation during nosing; (2) adjustment of the distance between base and nosing die; (3) alteration of the thickness of the base within prescribed

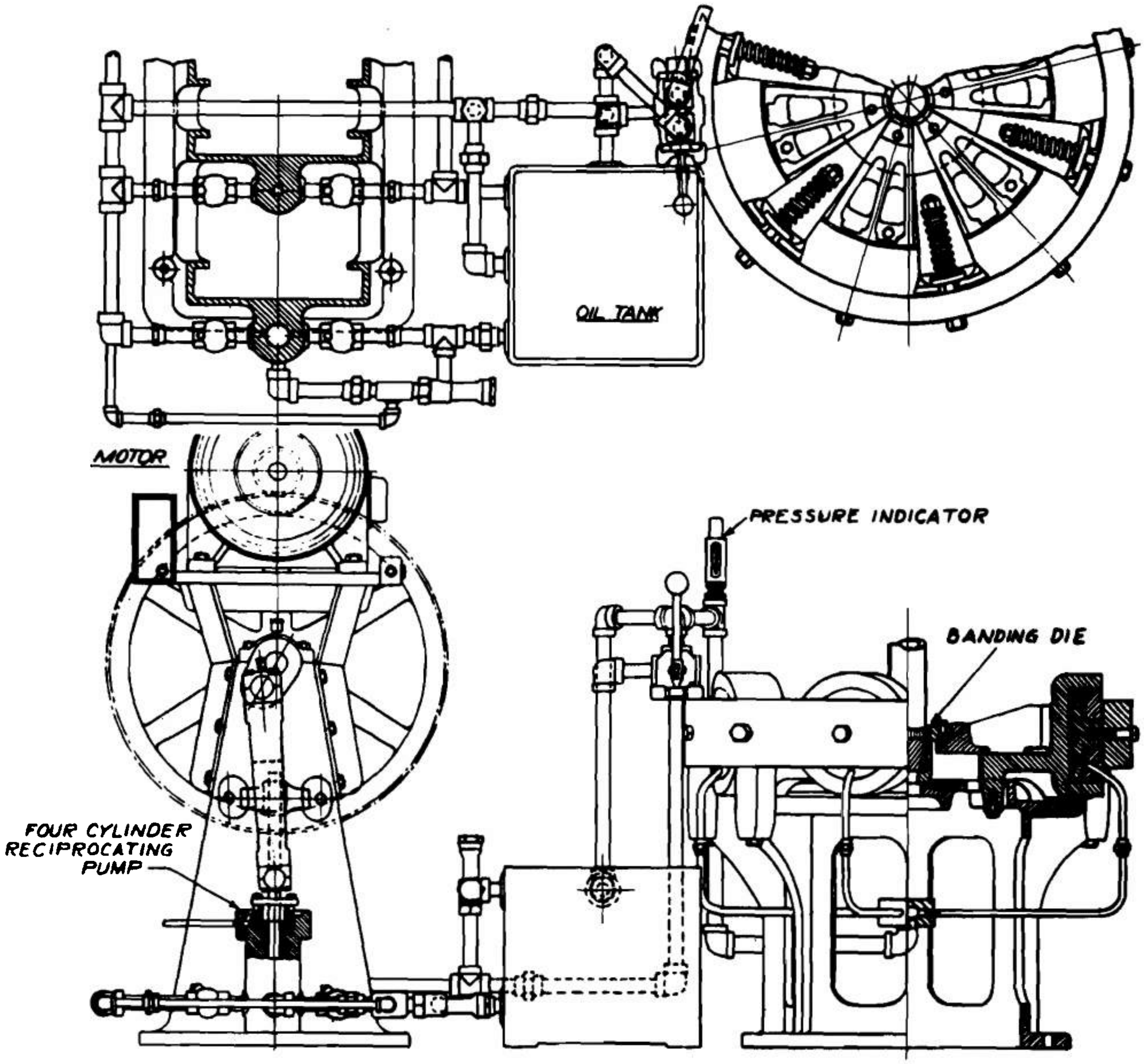

Figure 6-13. Hydraulic banding press and pump

tolerances; and (4) reduction of wall thickness by removing metal from the cavity. As a last resort, (5) a thin cut may be taken from the center section of the ogive. This procedure is not recommended.

6-53. Marking. The Ordnance Department requires that all shells be stamped before painting, in accordance with precise instructions as to which items are to be marked, on what part of the shell the stamp is to be placed, and the size of letters and numerals. Two methods are in common use. In the first the stamps are pressed into the shell while at rest; while in the second, the stamps are mounted in the circumference of a wheel which rolls them in, as in a knurling operation.

6-54. Hospitalization. In the course of manufacture a few shells slip through which will not pass inspection. If the body is oversize, the shell can be remounted in the lathe for remachining. Likewise, the ogive may be reprofiled. Other hospitalization operations include refacing the nose and retapping. A faulty center may cause the shell to "run out," that

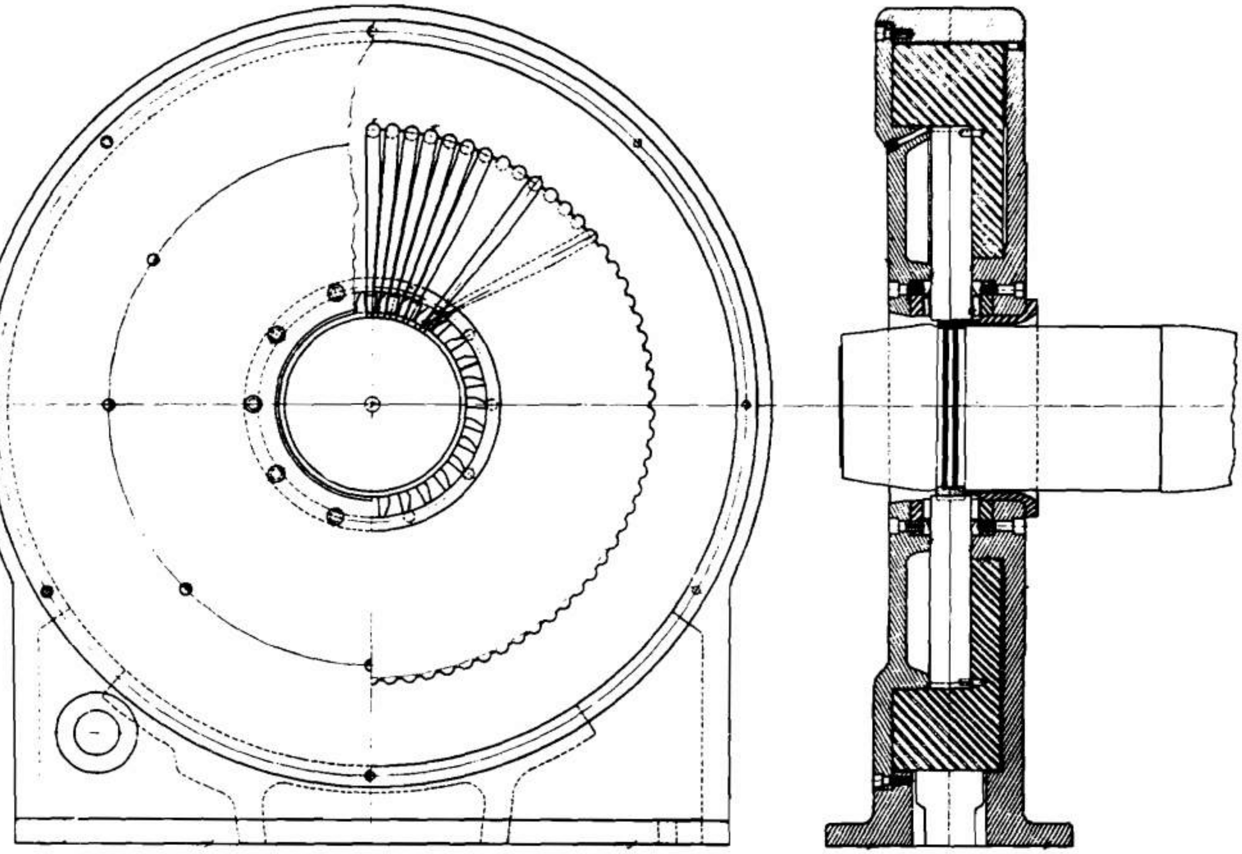

Figure 6-14. Toggle joint banding machine

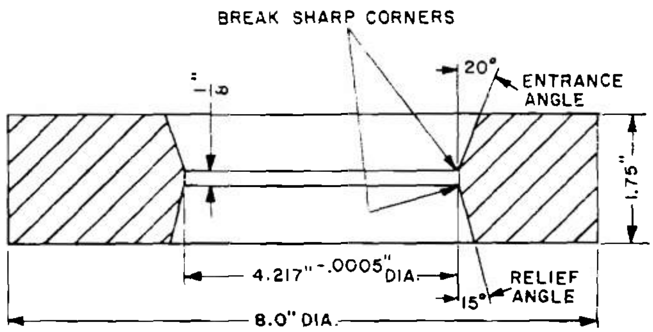

Figure 6-15. Banding die

is, fail to clean up and show forging scale after machining. The faulty center may be welded up and redrilled. During nosing, non-uniform lubrication may cause the nose near the tip to be thicker on one side than on the other. This may be corrected by machining out the irregularity with a boring bar and skiving tool. If heat treatment is unsatisfactory, it may be repeated. Debanding and rebanding is another function of the shell hospital. Surface finish may be improved by the application of a fast moving abrasive band.

6-55. Painting. Except for the rotating band (sintered iron excepted) and the threads in the nose, all parts of the shell must be painted prior to shipment. Spraying is almost universally used. The paint applied to the cavity has an asphalt base and is acid proof. The band is covered by a protector which may also support the shell during the operation. The threads are closed off by a plug which may serve to suspend the shell.

6-56. Inspection. During manufacture the shell is inspected both by the manufacturer and by Government inspectors. The manufacturer inspects at frequent intervals, such as after the forgings have been received, after rough-turning, and after nosing; while Government inspection is limited to three points in the production line: (1) before application of the band and base plate; (2) before painting; and (3) after painting.

The principal function of inspection is to check on size and shape. For this purpose gages — wherever possible, of the "go" and "not go" type — are provided. Visual inspection of the shell is mandatory at frequent intervals; concentricity is checked, tests of physical properties are made, and the base plate struck a sharp blow with hammer and chisel to be sure that it is secure. Finish is checked by comparison with a standard block or by means of a measuring device. Paint coverage, both outside and inside, is examined visually.

6-57. Cold Extrusion of Shell. A process for cold-forming shell by extrusion has recently been developed in this country. By the use of extremely high pressures, steel slugs are extruded into finished shell with a minimum of machining operations and waste material. The process consists of the following operations:

1. Preparing the slug
2. Sizing the slug
3. First extrusion — first hit
4. First anneal
5. First extrusion — second hit
6. Second anneal
7. Second extrusion
8. Third extrusion
9. Extrusion to length
10. Expansion of the bourrelet and drawing through
11. Nosing
12. Stress relief anneal
13. Machining
14. Inspection and marking

The following paragraphs describe the cold forming of the 105-mm HE shell as practiced by the Mullins Manufacturing Corporation. The procedures followed by other manufacturers for machining this size or other sizes of shell may differ in detail, but the overall process is the same.

6-58. The Preparation of the Slug. (See figure 6-16a.) A slug 4 11/16 inches long is sawn from a 5-inch diameter C-1012 steel bar. Each slug is chamfered, on both ends simultaneously, in a deburring machine, and the sawn faces are buffed to a smooth finish. The slug is washed in a solution of sodium orthosilicate and dried in a hot air circulator. In preparation for the next operation, the slug is then (1) pickled in sulfuric acid, (2) rinsed, (3) phosphate coated, (4) rinsed again, (5) neutralized, (6) lubricated, and (7) dried.

6-59. Sizing the Slug. (See figure 6-16b.) The slug is sized under a pressure of 900 tons by a punch in a die. This produces a reduced lower end in the shape of a conical frustum, designed to center the piece in the next die; and a shallow depression or "dimple" on top. This dimple centers the slug with respect to the punch in the next operation. The sized slug is 5.115 inches in diameter over the upper cylindrical portion; and 5.77 inches in overall length. Before moving to the next operation, the slug is again phosphate coated and lubricated as described in the preceding paragraph.

6-60. Extrusion. (See figures 6-16c through 6-16f.) The first extrusion operation is carried out on a 1,500-ton press; the actual pressure required is 1,100 tons. The press has a 36-inch stroke, and a 48-by-48 inch bed. It is powered by two 200 horsepower motors. Maximum oil line pressure is 2,460 psi. The bar, after this "first hit," has a cylindrical cavity 3.320 inches in diameter and 4.08 inches deep. The outer diameter has increased to 5.123 inches, except where it tapers to the nose. The overall length has been increased from 5.77 inches in the sized slug to about 7.4 inches. Following washing and drying, the component is inspected for seams which, if they occur, are ground out. If the seams are too deep, the piece is discarded. The steel is then annealed at 1,450°F to remove the effects of strain hardening. After annealing, the piece is again phosphate coated and lubricated. A "second hit" deepens the cavity, cabbages the nose, and further extends the piece to about 7.9 inches, without change in the exterior diameter. A third extrusion pushes the rounded nose of the punch deep into the tapered lower extremity, lengthens the body to 8.8 inches, and develops the boat-tail. The annealing, pickling, phosphate coating, and lubrication are repeated, and the second and third extrusions are performed at pressures of 650 tons and 580 tons, respectively.

6-61. Extrusion to Length. (See figure 6-17.) Up to this point the operations on the slug are comparable, in many ways, to hot forging; but at this point the action becomes less familiar. Extrusion to length, cold, is not done on a draw bench. The piece is forced to flow through the annular space between the nose of the extruding punch and the die, so that the shell "runs ahead" of the punch. This action may be

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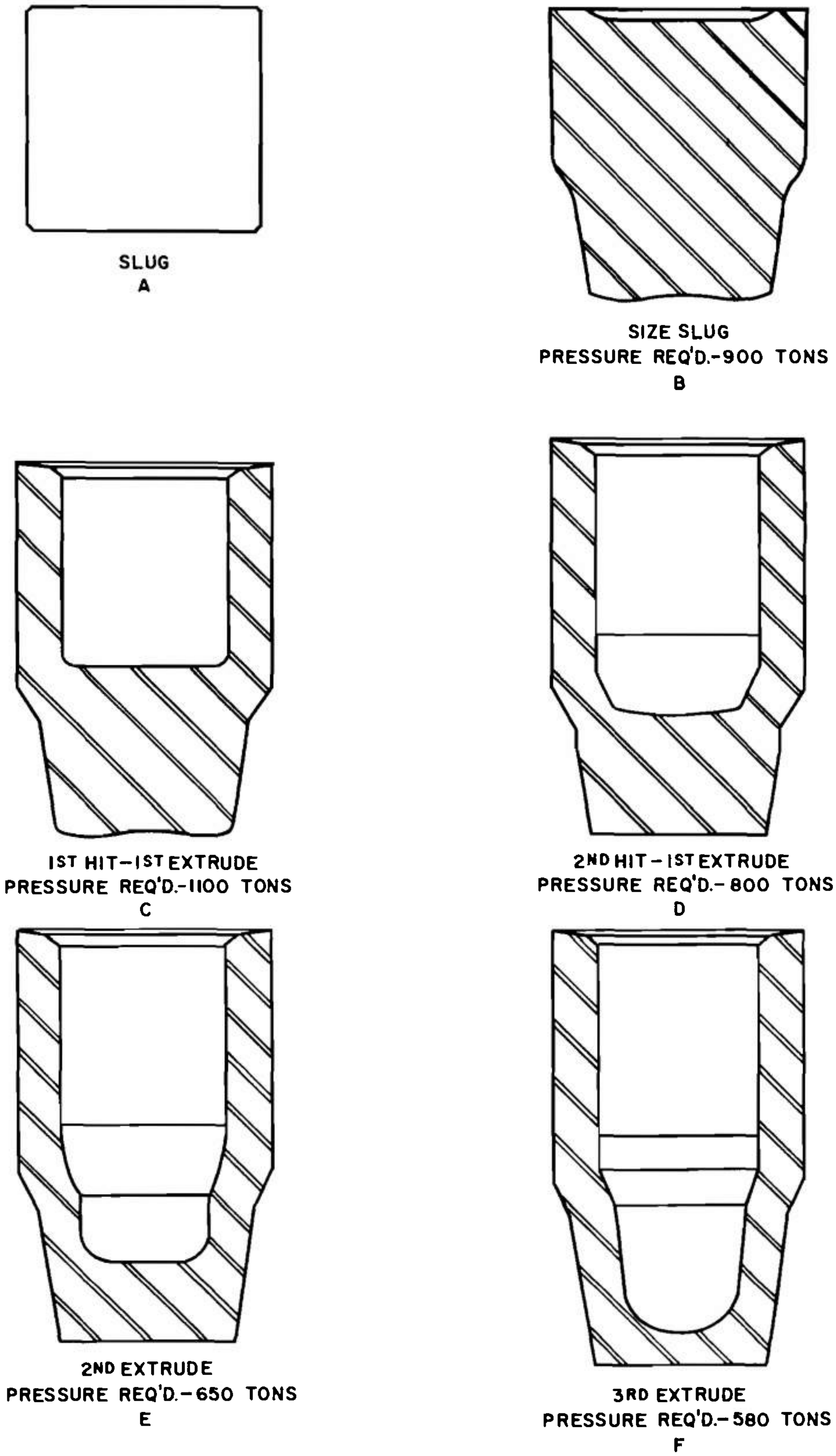


Figure 6-16. Slug

likened to any extrusion process in which a plunger forces the metal through a formed die. The cylindrical enlargement of the punch body acts as the plunger; the annular space between the nose of the punch and the restricted region of the die constitutes the formed die. This operation requires the usual coating and lubricating preparation of the component. In addition, a lubricant consisting of molybdenum sulphide and oil is smeared on the shoulder of the piece at the press. The total pressure required for extruding to length is 650 tons. The shell, as it comes from the press, has been extended to a length of 15.16 inches; its external diameter reduced to 4.09 inches; and the inner to 3.185 inches.

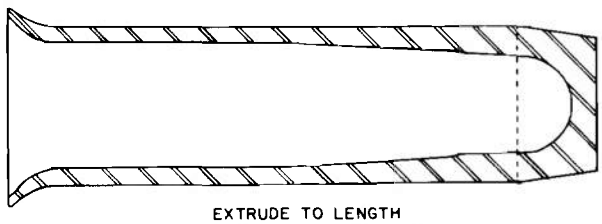


Figure 6-17. Slug, extrude to length

6-62. Expanding the Bourrelet and Drawing Through. (See figure 6-18.) The previous operation left the carcass with a boat-tail and a body which tapered by a few thousandths of an inch toward the expanded lip left by the extrusion die. It is necessary to expand the body to produce the bourrelet. This is accomplished by thrusting a punch of appropriate profile into the cavity of the shell. While the shell remains on the punch, the bourrelet is sized and the flared lip of the shell is straightened by drawing through a die. The expansion of the bourrelet requires about 175 tons; the subsequent sizing, about 125.

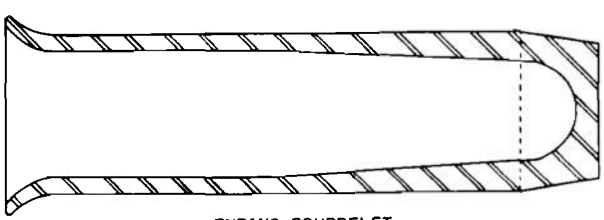


Figure 6-18. Expand bourrelet

6-63. Nosing. (See figure 6-19.) This operation, similar to the cold-nosing of hot-forged shell, is conducted in a 500-ton mechanical press. The shell sits in a lower, retaining die, while the nosing die descends upon it and forms the ogive. Enough metal must be gathered in the process to render nose reaming and tapping possible. The shell is then washed, rinsed, dried, and given a stress relief anneal at a temperature of 850°F.

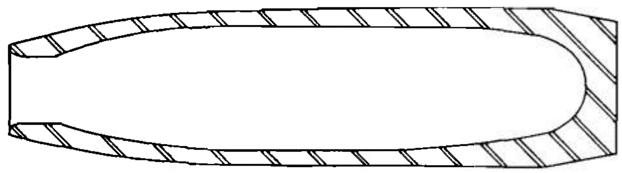


Figure 6-19. Final nose reduce

6-64. Machining Operations. After the cold-forming operations, the following machining is done: (1) the nose is bored, faced, and chamfered in preparation for threading; (2) the band seat is cut and knurled; (3) the bourrelet is ground; (4) the rotating band is pressed into the seat; (5) the band is turned and trimmed; (6) the staking notches are cut; and (7) the base plate is welded on. These various machining operations are similar to those already described for hot-forged shell (paragraphs 6-34 through 6-56). The small number and relative simplicity of the machining operations on the cold-formed shell, as compared with a hot-forged carcass, is impressive.

6-65. Laboratory Tests. From each lot of 20,000 shells, two are picked at random, and tests carried out on the steel of the shell body and on the gilding metal. The yield point of the steel is in the neighborhood of 73,000 psi; the elongation 18 percent; and the reduction of area about 64 percent. Typical results of tests on the band give tensile strengths of about 38,000 psi with a 20 percent elongation, and somewhat greater than this with a 21 percent elongation. Each shell used for these laboratory tests is also checked for hardness. Rockwell B hardness numbers range from about 86 to 96.

6-66. Inspection in Process of Manufacture. After the slug has been sawn from the bar, there is a 100 percent inspection for weight;

and one slug from the first bar cut of each new heat is macroetched and tested for hardness. Following sizing, every 150th shell is given a profile check. After each of the first three squeezes, the shape and base thickness of the shell are determined; also the size of the boat-tail. After extrusion to length, body diameter is checked with a snap gage; also overall length; and lip thickness with a ball point micrometer. Since surface defects may show up after expansion to swell the bourrelet, every 15th shell is inspected visually. After nosing, the bourrelet diameter, body diameter, nose diameter, eccentricity of the nose, inside diameter of the nose, thickness of the base, and the size of the boat-tail are gaged. Visual inspection for defects, with the aid of a light to view the cavity, is extensive, reaching 100 percent at two points. After boring, facing, and chamfering the nose, the diameter of the bored hole, overall length, nose diameter, and angle of chamfer are gaged. After the machining of the band seat, there is a 100 percent check of the width of the band seat, its diameter, the diameter of the recess at the rear of the band seat, and the position and angle of the boat-tail with respect to the band seat. After grinding, a snap gage is applied to the bourrelet. After threading, the thread gage is used in every 5th shell. Gages are also provided for inspection of the rotating band and its position on the shell. The final inspection, which follows the welding of the base plate, includes the application of a "Multichek Gage" to the shell diameter at seven points, from nose to rear bourrelet. After painting, the shells are given a 100 percent visual inspection, both inside and out. All shells are then passed through the forward bourrelet ring gage. In combination with previous inspection measurements, this last-mentioned inspection serves as a check on the thickness of the paint.

6-67. Government Inspection and Marking. Following final inspection by the plant, Government inspectors pass upon batches of 83 shells on a pallet. Shells released from inspection are marked, then washed, bonderized and dried, the cavity brushed out and painted in readiness for packing.

6-68. Comparison of Hot Forging with Cold Extrusion of Shell.

a. Use of Strategic Material. Cold extrusion requires a steel with a low manganese content. Since manganese is a strategic material, this represents an advantage over forging, which requires a high manganese steel.

b. Use of Steel Making Facilities. The cold extrusion process uses a billet which is much closer to the weight of the finished shell than that used for forging. The scrap resulting from the forging process must be reprocessed. This represents an additional load on the steel making facilities. This advantage of cold extrusion may be offset if the percentage of rejects from the production line is greater than the percentage resulting from forging.

The steel required for cold forging demands must be much freer from nonmetallic inclusions and, since physical properties are obtained by work hardening, must have a more carefully controlled composition than that which is needed for forging. It is not known whether or not our present facilities could supply the tremendous amounts of this high quality steel which would be needed during wartime.

c. Machining Operations. Cold extrusion eliminates rough machining and finish machining of the body of the shell, as well as bourrelet finishing. The remaining machine work is light, compared with these two operations.

d. Total Number of Operations. Although the cold extrusion process eliminates several of the machining operations required by forging, it requires eight press operations as compared with three for forging. In addition, cold extrusion requires a rather complex lubrication operation before each press operation. Hot forging requires that the shell be brought to forging temperature before each press operation; however, cold-forged shell must be heat-treated several times during the forming operation in order to maintain required physical properties. In all, approximately twenty-five operations are required for cold extrusion versus twenty-two for forging.

e. Cost of Plant. Because of the extremely heavy, high-pressure extrusion presses required, the cost of a plant for cold extruding of shell is considerably greater than that for a forging operation. A further disadvantage is that heavy-press time is usually at a premium in time of war.

6-69. Compromise Method of Shell Forming. The principal advantage of cold forming is that the weight of the completed shell is within a few ounces of the weight of the slug from which it is formed. By contrast, the weight loss resulting from the extensive machining which accompanies the hot-forging process may run as high as 50 percent. The principal disadvantage of cold forming is that the 1,500-ton presses required for the first extrusion process are extremely expensive and at present are not readily available.

A compromise method of forming, which would make use of the advantages of cold forming while at the same time eliminating this major disadvantage, has been proposed. This method would employ hot forming to make the first draws and cold forming for the subsequent operations.

6-70. Difficulties Involved. The difficulties involved in this process are that (1) an extremely even heating of the billet is required to prevent run-out of the punch, and that (2) some means must be provided to either prevent the formation of scale or to eliminate it completely after it has formed. Large scale testing of this compromise method is now under way at Frankford Arsenal.

6-71. Introduction. The following paragraphs describe the manufacture of the 75-mm shell, HEP, M349, as practiced by the Chamberlain Corporation. Procedures followed for other shell or by other manufacturers may differ in detail, but the basic process is the same.

The M349 includes three components: (1) a shell body fitted with a rotating band, (2) a base plug, and (3) a gasket (figure 6-20). The base section in the neighborhood of the rotating band is relatively heavy. The side wall tapers from the base to about a tenth of an inch at the nose. The base is threaded to receive the plug.

6-72. Development. The HEP shell has an unusual profile which is poorly adapted to standard forging cold-forming techniques. The interior protuberance, required to accommodate the rotating band, makes it impossible to withdraw a forming punch. Machining of the cavity would be a difficult operation. Quite early in the experimental work on this shell, trouble was experienced with loose rotating bands caused by the difficulty in seating the band on the thin wall. Attempts were made to make the band an integral part of the shell body; failing that, a welded overlay of copper was used.

6-73. Experiments With a Two-Piece Body. At first, the body of the HEP shell was made in two parts. The nose was a cold drawn ogive made from cold rolled 1030 steel. This was then brazed to the body. As chamber pressures were increased to secure higher muzzle velocities, the shell tended to bulge at the brazed joint. Thickening the shell in this region was tried and abandoned because of reduction in the effectiveness of the round. Heat treatment to harden the steel in the neighborhood of the joint was out of the question, since it would have destroyed the brazed joint. A single-piece, thin walled shell appeared to be the only answer.

6-74. Present Manufacturing Method. The process starts with a disk shaped blank, or "slug," of fine grained, spheroidized, mild steel (FS 1030). The blank is cleaned, phosphate-coated, and lubricated. Figure 6-21 shows the sequence

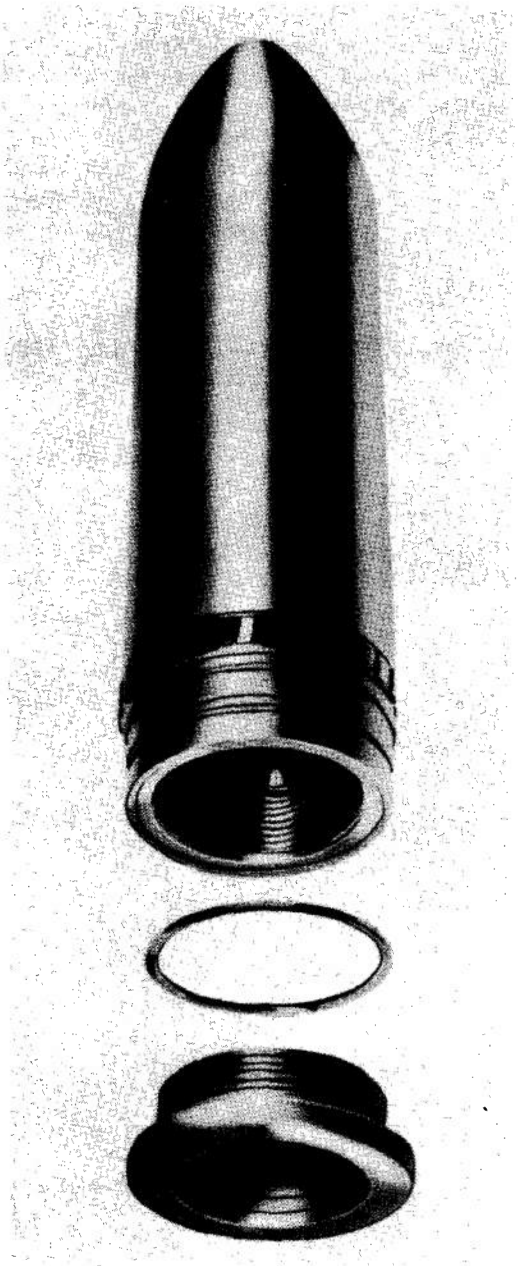


Figure 6-20. HEP shell

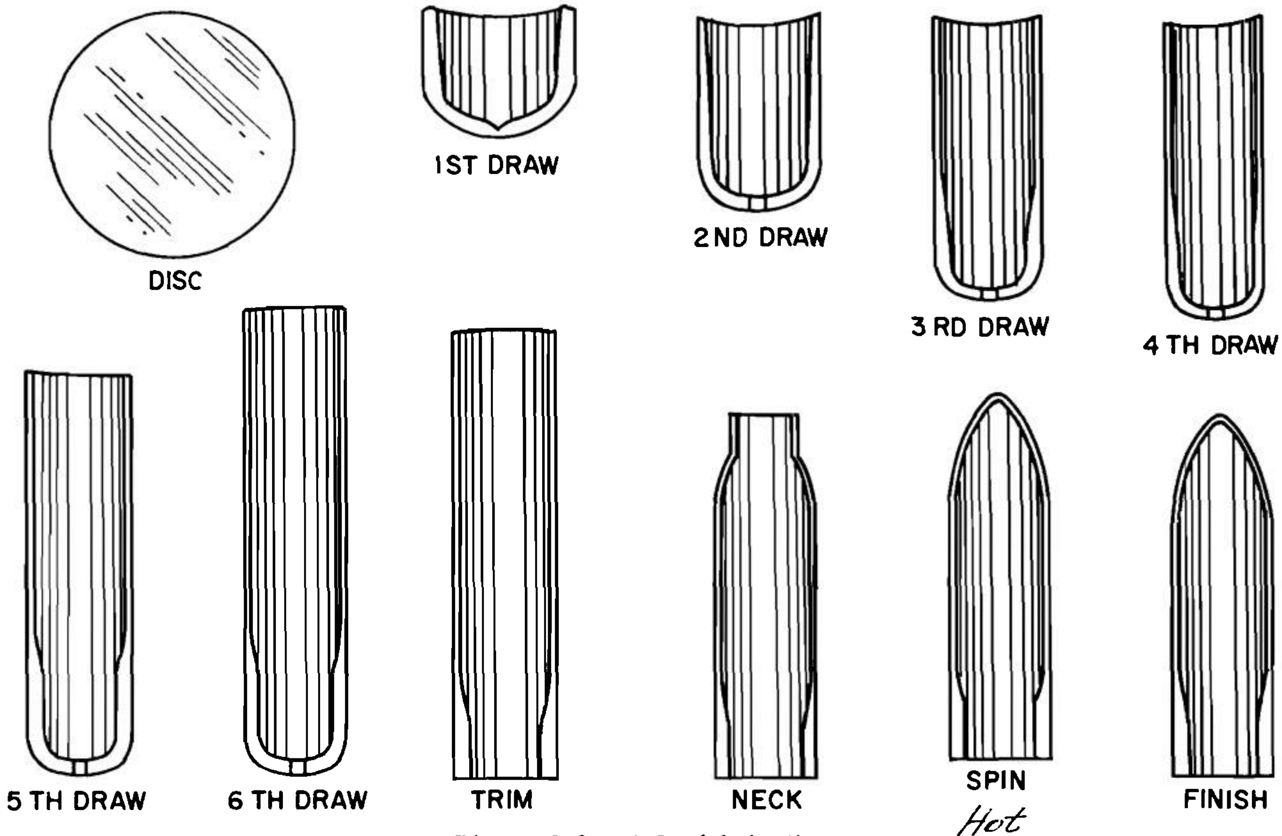


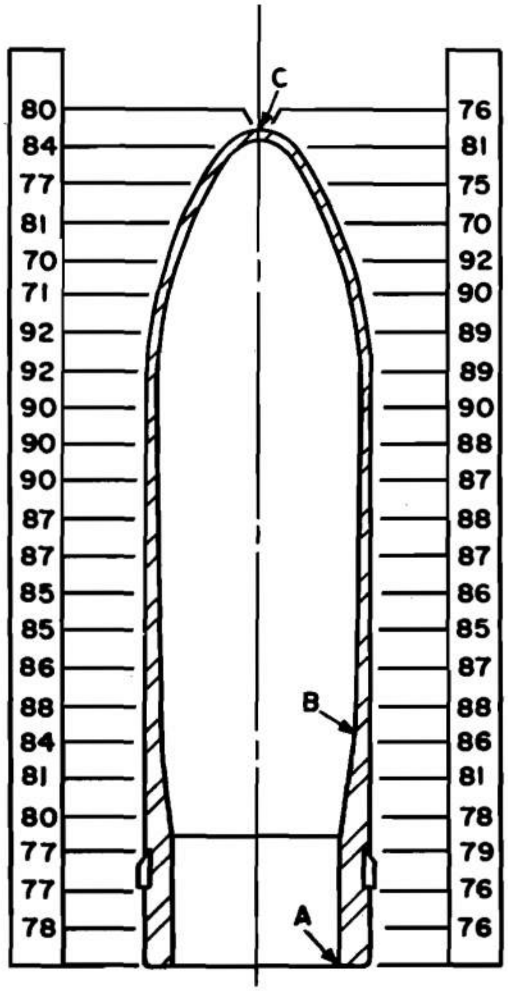
Figure 6-21. HEP fabrication

of the draws. Note that the thickness in the original cup is largely maintained in the draws. The punches have reduced noses which draw the body into the thin-walled extension of the lower region of the tube. After each of these operations, the component is annealed at 1,250°F, just below the lower limit of the critical range, for 45 minutes. The spheroidized structure is retained while the hardness, induced by cold work, is removed.

6-75. Cutting Off the Base. After the final draw the piece is again annealed and given one more draw. The base, closing the tube, is cut off, leaving an open ended "can" which is trimmed to length. The open mouth is closed into an ogive as follows: (1) the thin walled end is nosed, leaving a smaller open mouth; (2) a mandrel is inserted in the shell, and bears upon the partially closed nose; (3) the shell is rotated in a lathe and an oxyacetylene torch is played upon the partially formed ogive until welding heat is reached. A stellite-sheathed nubbin is moved in on the cross slide, working the hot wall of the shell around the profile of the mandrel to a tit on the nose. The tit is removed in the finish grind.

6-76. Finishing. Following these shaping operations, (1) the shell is ground to meet surface finish requirements; (2) the base is faced and recessed; (3) the band is welded to the body; (4) the band, which is to be pre-engraved, is broached; (5) the base is tapped; (6) the shell is tested hydrostatically and with air; and (7) it is cleaned, phosphate-coated, and painted, outside and in. After loading, the base plug which carries the fuze is screwed into the shell base. The copper gasket between plug and body guarantees tightness.

6-77. Hardness Testing. Because of the method of functioning of the HEP shell, it is important that the hardness be accurately controlled. Figure 6-22 exhibits the results of a typical Rockwell B hardness check.



ROCKWELL PATTERNS
327

ELONGATION 11% (IN 2")
YIELD POINT 58,000 P.S.I.
ULTIMATE 70,770 P.S.I.

ELONGATION 14% (IN 2")
YIELD POINT 59,000 P.S.I.
ULTIMATE 71,890 P.S.I.

Figure 6-22. Typical hardness check

6-78. Introduction. Armor-piercing shot may take a variety of forms. They may be made (1) with or without a cavity, (2) ogival- or truncated-nosed, (3) capped or uncapped. Any combination of these choices is also possible.

The following paragraphs describe the manufacture of the 37-mm AP shot, M51, as practiced by the National Pneumatic Company. The processes which this capped monobloc shot go through are applicable to other types of shot also. Differences in size and shape of shot will modify the procedures, but they will remain basically the same. A major difference exists in the case of shell with cavities — in this case the rough forging must first be made by the pierce-and-draw process — but these shell are at present obsolescent.

6-79. Steel Specifications. WD-4150 electric furnace steel, manufactured to Ordnance specification 57-107-D (with the exception that the carbon range is 0.52 to 0.57 percent) is used for this shot. The structure must be at least 50 percent lamellar pearlite. The composition of this steel is given as: carbon, 0.52 to 0.57 percent; manganese, 0.60 to 0.90 percent; phosphorus, 0.025 percent; sulfur, 0.025 percent minimum; silicon, 0.15 percent minimum; chromium, 0.80 to 1.10 percent; molybdenum, 0.20 to 0.30 percent. Jominy tests are required in order to ensure hardenability to the specified 79 to 82 Rockwell A. The steel is melted in 50-ton Heroult electric furnaces and poured into 16 1/2 in. square, big end up, molds, fitted with hot tops. After slow cooling to avoid checks and flakes, the ingots are stripped, reheated, and rolled down to 4-inch square billets. Following slow cooling, the billets are pickled, surface conditioned, then reheated and rolled down to rounds 1 and 17/32 inches in diameter. These are annealed to reduce the hardness to 183 to 212 Brinell, and machined to diametral limits of 1.453 to 1.459 inches. A sample is taken from the top of each ingot after it is rolled into the 4-inch square billets. Disks, cut from the samples, are hydrochloric-acid etched and then examined, by both mill and U. S. Army Ordnance inspectors, for internal defects, including segregations, pipe, checks, and flakes.

6-80. Manufacturing Techniques. Figure 6-23 shows the first sequence of operations on the bar stock. Each operation is performed by one spindle of an automatic screw machine, indexing 105 pieces per hour and running at 258 rpm. The machined bodies are fed into a centerless grinder which brings the bourrelet to limits of 1.4475 — 1.4485 inches; and the region in rear of the band seat to 1.436 — 1.439 inches. The nose is then profiled on a six-station screw machine. The sequence is shown in figure 6-24. The shot is then degreased and a number stamped on the base to identify the lot and, if necessary, the heat from which each shot was made.

6-81. Heat Treatment. The shot are heated in a radiant-tube, reducing-atmosphere furnace. The atmosphere, fed from a separate generating unit at a temperature of 1,580°F, flows from the discharge end of the furnace forward to the loading end, where the gases burn, preheating the shot in the process. The shot are oil quenched at 140 to 180°F. They are then placed in a batch-type furnace, where they are tempered for four hours at 325°F. After tempering, the shot are allowed to stand for 72 hours, after which they are hot-and-cold water tested to determine whether or not they will crack. One shot from each heat is cut through the center (as shown in figure 6-25) and checked for hardness at the points indicated; 79 to 82 Rockwell A is required. The microstructure of the hardened shot consists of highly refined martensite. Following the hot-and-cold treatment, the shot are air-blast dried, inspected for surface defects, and shot blasted preparatory to matching with caps.

6-82. Specifications of Steel for the Caps. The composition of the steel for the caps is: carbon, 0.90 to 1.00 percent; silicon, 0.40 to 0.65 percent; tungsten, 3.75 to 4.25 percent; sulfur, 0.025 percent maximum; manganese, 0.45 to 0.65 percent; chromium, 0.70 to 0.90 percent; vanadium, 0.30 to 0.40 percent; phosphorus, 0.025 percent maximum.

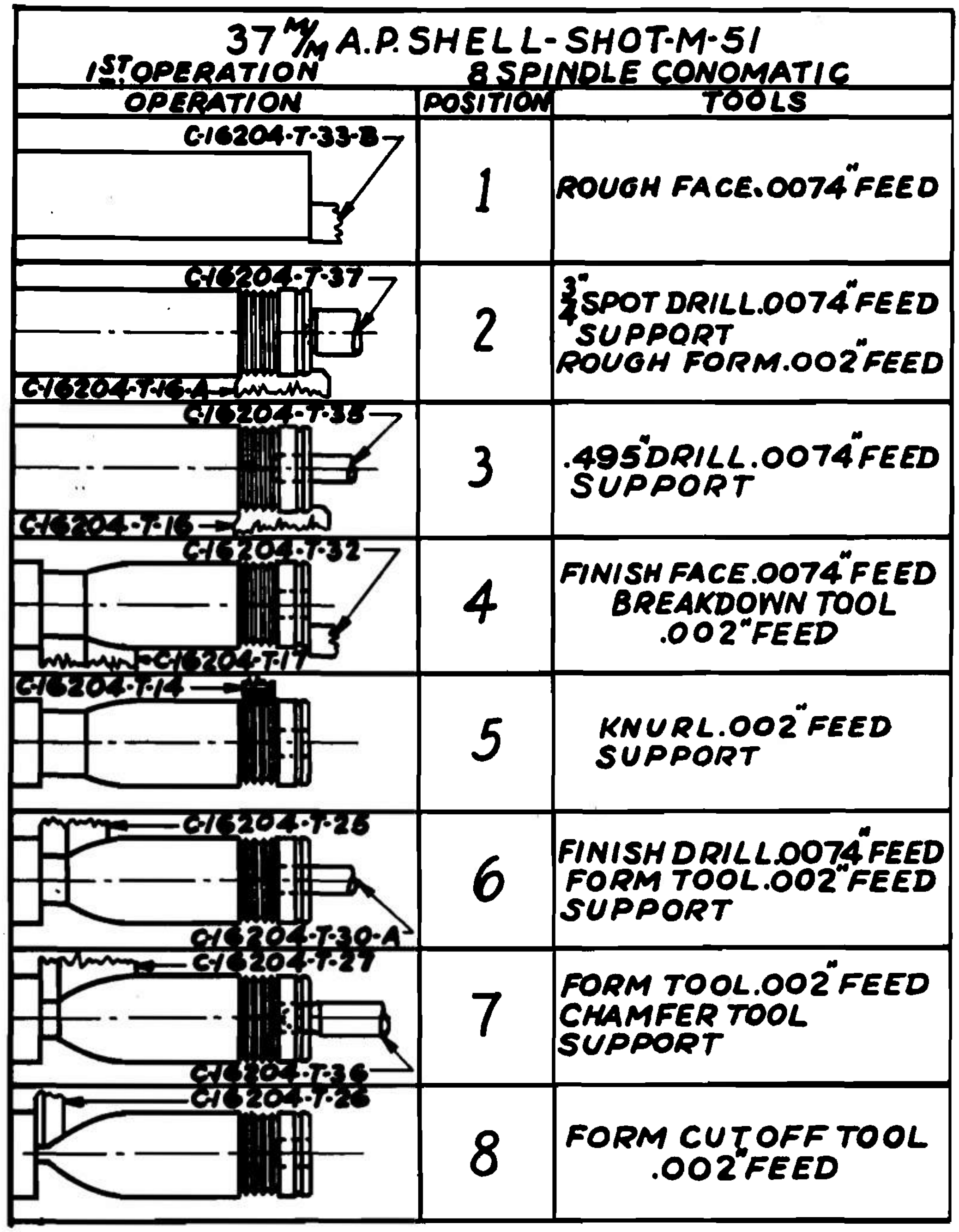


Figure 6-23. Preliminary operations, AP shell

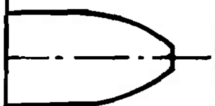
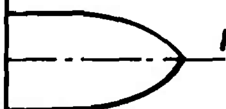
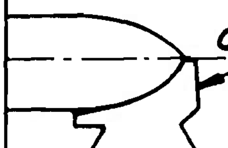
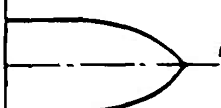
37 M/M A.P. SHELL-SHOT-M-51 2ND OPERATION NEW BRITAIN MODEL 61		
OPERATION	**POSITION**	**TOOLS**
 INSERT AND EJECT	6	
 C-16204-T-1	1	FORM NOSE .0054" FEED
 NO WORK	2	
 C-16204-T-13-A	3	ROUGH FORM .0018" FEED
 C-16204-T-13-A	4	FINISH SKIVE .0038" FEED
 NO WORK	5	

Figure 6-24. Nose forming

37 M/M A.P. SHELL-CAP-M-51

1ST. OPERATION — 8 SPINDLE CONOMATIC

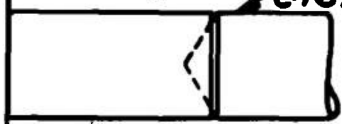
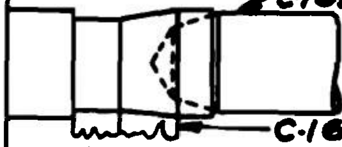
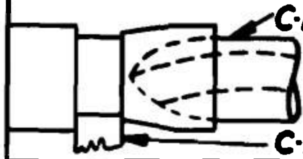
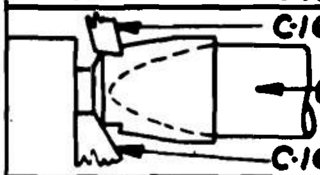
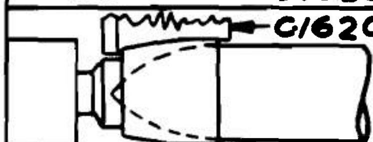
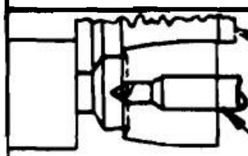
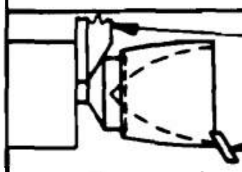
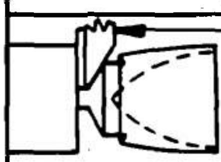
OPERATION	POSITION	TOOLS
 C-16202-T-81	1	1½" SPOT DRILL .0046" FEED
 C-16202-T-82 C-16202-T-2	2	1¼" DRILL-SPECIAL GROUND .0046" FEED FORM TOOL .0018" FEED
 C-16202-T-11 C-16202-T-3	3	FORM TOOL .0018" FEED 1⅛" DRILL-SPECIAL GROUND .0046" FEED
 C-16202-T-19 C-16202-T-14 C-16202-T-67	4	UNDERCUTTING TOOL .002" FEED ROUGH REAMER BREAK DOWN TOOL .0018" FEED
 C-16202-T-6 C-16202-T-14	5	ROUGH FORM TOOL .0004" FEED FINISH REAMER .0046" FEED
 C-16202-T-7 C-16202-T-105	6	FORM TOOL .0023" FEED FINISH REAMER .0046" FEED
 C-16202-T-8 C-16204-T-9	7	FORM TOOL .0023" FEED REVOLVING SUPPORT .0023" FEED
 C-16202-T-21	8	CUT OFF .0023" FEED

Figure 6-26. Cap operations

All bars must be thoroughly annealed to 240 Brinell maximum. They are turned and ground within limits of 1.431 inches and 1.435 inches. A disk is cut from one bar of each heat and checked for surface decarburization and structure.

6-83. Machining Operations. Figure 6-26 shows the sequence of machining operations on the cap. These are carried out on an 8-spindle automatic screw machine which indexes 85 pieces an hour at a spindle speed of 168 rpm. On an automatic lathe, the cap is then faced off at the point where it is cut off from the bar in the screw machine. It is then notched at two points, 180° apart, and threaded for the windshield.

6-84. Heat Treatment. The caps are heated in an induction furnace to approximately 1,625°F and oil quenched at 140 to 180°F. Periodically a cap is cut as shown in figure 6-27 and checked for hardness at the points indicated. After hardening the caps are cleaned, drained, rinsed, and blown dry. After drying the caps are shot blasted.

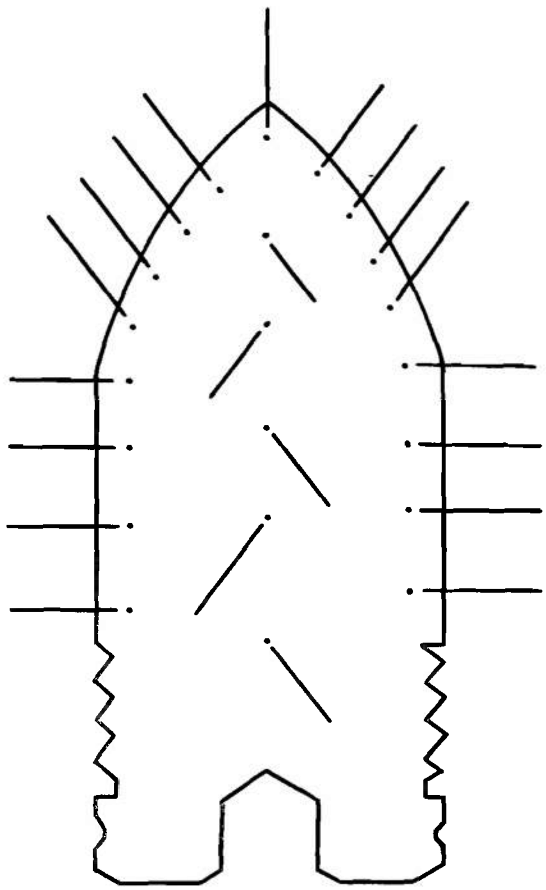


Figure 6-25. AP shot profile

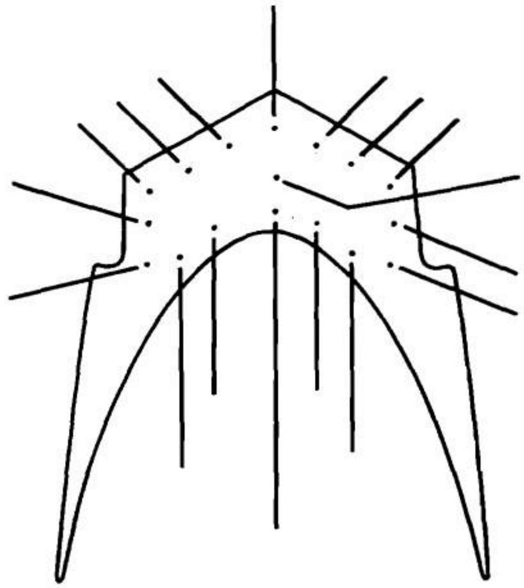


Figure 6-27. Cap profile

6-85. Matching and Soldering. After shot blasting, each cap is matched with a shot body upon which it must spin perfectly without excessive clearance. The cap remains on the body until ready for soldering. This is done by placing the bodies and the caps in an oven at 385°F. The caps are fluxed and tinned, the body is inserted in the cap and rotated slightly to center it, and the solder is allowed to set. The capped shot is then washed, the excess solder is trimmed off, and the shot checked for concentricity of the cap threads with the bourrelet and the tracer hole. A magnaflux test is applied to check for cracks.

6-86. Finishing Operations. The capped shot are washed, and buffed with a wire buffer. The shot are then banded and the band is machined. Care must be taken to clean the copper out of the relief groove and to see that the tracer hole is clean. The finished shot are given a final wash prior to inspection, which includes gaging of the band, relief groove, body diameter, depth of tracer hole, and weight. The bands are then stencilled with the Government lot number and the manufacturer's lot number and type. The band and the threads which engage the windshield on the nose of the cap are masked and the shot are sprayed with lacquer and infrared dried. After drying the thread protectors are removed and the shot are packed with their windshields, for shipment.

6-87. Components. The HVAP shot is made up of a tungsten carbide core, a steel-banded aluminum body, an aluminum nose piece, a steel base, and an aluminum windshield. These parts are assembled to provide a light projectile with an extremely hard dense core which is highly effective against armor plate.

6-88. The Body. The body of the shot is a hollow, aluminum-alloy cylinder, approximately two diameters long. A bourrelct of seamless steel tubing is pressed on the forward end of the aluminum body, and machined to ride on the lands of the rifling of the gun and prevent balloting. The forward portion, just beyond the bourrelet, is threaded to receive the aluminum-base alloy windshield, and the same size of thread is provided at the rear of the body for the attachment of the steel base. The outer surface of the body is finish machined and the interior is bored out to a diameter slightly under 2 inches, to within 1 inch of the front end. This forward portion is threaded internally for the installation of the nose piece, an aluminum-alloy die casting in which the point of the tungsten carbide core rests.

6-89. The Base. The base is a steel forging made from FS1314, FS1010, FS1020, or FS1315. It closes the rear end of the body of the shot, to which it is screwed and staked. The outside of the base is machined with a groove for the rotating band and for the attachment of the cartridge case. A tapered recess in the rear of the base provides a tolerance in machining to enable the weight of the shot to be held within specified limits. A hole in the bottom of this recess permits the attachment of a tracer.

6-90. Windshield. The windshield is a thin walled, die-cast, aluminum-alloy cone which is screwed to the body. It streamlines the shot and locates the center of gravity of the projectile to the rear of the center of buoyancy, in the interest of stability in flight.

6-91. Assembly. This aluminum nosepiece, which engages the point of the tungsten carbide core, is screwed up and tightened to 150 pound-inches of torque. The core is then inserted and the base screwed and staked.

6-92. Introduction. Tungsten carbide cores are presently used in both HVAP and HVAPDS shot. Although they are quite expensive, no satisfactory substitute has been found as of this date. Their manufacture, similar to the process followed for the production of commercial tungsten carbide, is described in the following paragraphs.

6-93. Tungsten Carbide. Of the two tungsten carbides, only the monocarbide is used for manufacturing cemented carbides. This is prepared either by heating a mixture of tungsten powder or tungsten oxide, with a calculated amount of carbon powder in a hydrogen atmosphere, containing carbon; or by heating tungsten powder or oxide in a carburizing atmosphere. The carbon powder may be lampblack or sugar carbon.

6-94. Milling and Blending. After the carbide has been formed, it is carefully crushed, milled and screened. Compositions of the various commercial grades are prepared by selecting measured quantities of the binder metal (cobalt) and the carbide, or carbides, and blending the mixture by ball milling. This can be done either wet or dry.

6-95. Compacting and Sintering. Prepared powders are formed into shape for use either by cold pressing, followed by sintering; or by hot pressing, during which the pressing and sintering are done simultaneously. The material is pressed into hard steel molds, at pressures of from 5 to 30 tons per square inch, depending on the size and shape. Sintering is performed at 1,400 to 1,500°C. (2,550 to 2,730°F) for from 30 to 60 minutes, in a protective atmosphere of hydrogen, containing sufficient carbon to prevent decarburization; or in a vacuum. During the sintering operation, the material goes through a plastic stage as a result of the formation of a eutectic, between the cobalt and the carbides, at approximately 1,350°C (2,460°F), thus wetting the carbide particles that do not dissolve. This eutectic becomes the cementing material, surface tension drawing the particles together. After cooling, the sintered product has its final properties.

6-96. Introduction. The following paragraphs describe the manufacture of the 120-mm brass cartridge case, M24, as practiced by the Chase Brass and Copper Company. While the methods used by other manufacturers may differ in detail, the process described may be considered typical.

The cartridge brass is 70 percent copper and 30 percent zinc. It is rolled to a thickness of 0.820 to 0.835 inch, and annealed to a grain size of 0.075 to 0.150 mm. The upper and lower surfaces of the rolled strip are scalped, leaving a finished thickness of 0.790 to 0.805 inch. The strip is blanked to disks, which are then cupped and drawn four times, with intermediate washing, annealing, pickling, trimming, and lubrication. The job is completed by heading, saltpeter annealing, tapering, machining, and final edging. For the drawing operations, highly polished tungsten carbide dies are used, and are dry-soap lubricated. Heading, which proved troublesome because of tool breakage, is performed by means of a two-piece die, with a ring shrunk around an insert. Care is to be taken in handling the case to avoid dents and the consequent risk of excessive folding during tapering. A chrome flash is used on the tapering dies to avoid deposit of brass film.

6-97. Blanking and Cupping. (See figure 6-28.) The blanks are sheared in a knuckle-joint mechanical press from strip 14 inches wide. Twelve to thirteen disks, 12.18 inches in diameter and 0.80 inch thick, are cut from each strip, giving a scrap loss of about 40 percent. The disk is then pushed through a die by a punch to form a cup 8.260 inches in diameter and about 5 1/8 inches long. This cupping operation reduces the thickness of the metal in the bottom of the cup very slightly, while drawing it down to 0.613 around the lip.

6-98. Drawing. (See figures 6-28 and 6-29.) After having been annealed and pickled, the cup is drawn out in four successive operations and two "edgings," or mouth trimmings, to a closed-end tube 32 3/16 inches long, with side walls which taper to a thickness of 0.042 inch and a head whose thickness is approximately the same as that of the original disk. The outside diameter is uniform at 7.004 inches. The first of these draws takes a 250-ton hydraulic press; the second calls for 200 tons; while the third and fourth require 100 tons. The case is edged between the third and fourth draws, instead of merely after the final draw, to remove the "ears" or uneven mouth which are thought to be caused by "thick and thin," or eccentricity of the original cup. This causes the metal to tend to draw out more in one place than another. Considerable force is necessary to strip the draw from the punch; if not cut off, the points of the ears would burr over.

6-99. Heading. (See figure 6-30.) In order to form the head of the case and to secure the desired physical properties, i.e., a hardening induced by cold work, the metal in the closed end of the draw is upset in a powerful hydraulic press. Two steps, each requiring a maximum thrust of 2,700 tons, are used. The heading tools consist of the punch, a built-up 'post' or support within the case, and a die around the head to control its shape as the punch squeezes the metal radially outwards. The post consists of 15 spacers, held together with a tie rod. A built-up support, rather than a solid post, is used because of the relative ease with which these spacers can be heat treated to obtain the toughness and strength required to support the heavy punch load, as well as the flexibility in adjusting the height of the post. The die is supported by a shrink fit ring.

6-100. Tapering. (See figure 6-30.) In preparation for tapering, a vent hole is drilled in the head in order to release the air which would otherwise be trapped inside the case by the liquid saltpeter used for the semi-anneal prior to tapering. In order to help guarantee success in the tapering operation, the mouth of the case is chamfered inside and out. The edge must be free of burrs, dents, and chatter marks which might start a crease. In the manufacture of this case, tapering is the most troublesome operation. The case is thrust into the tapering die by a 150-ton hydraulic press, and removed

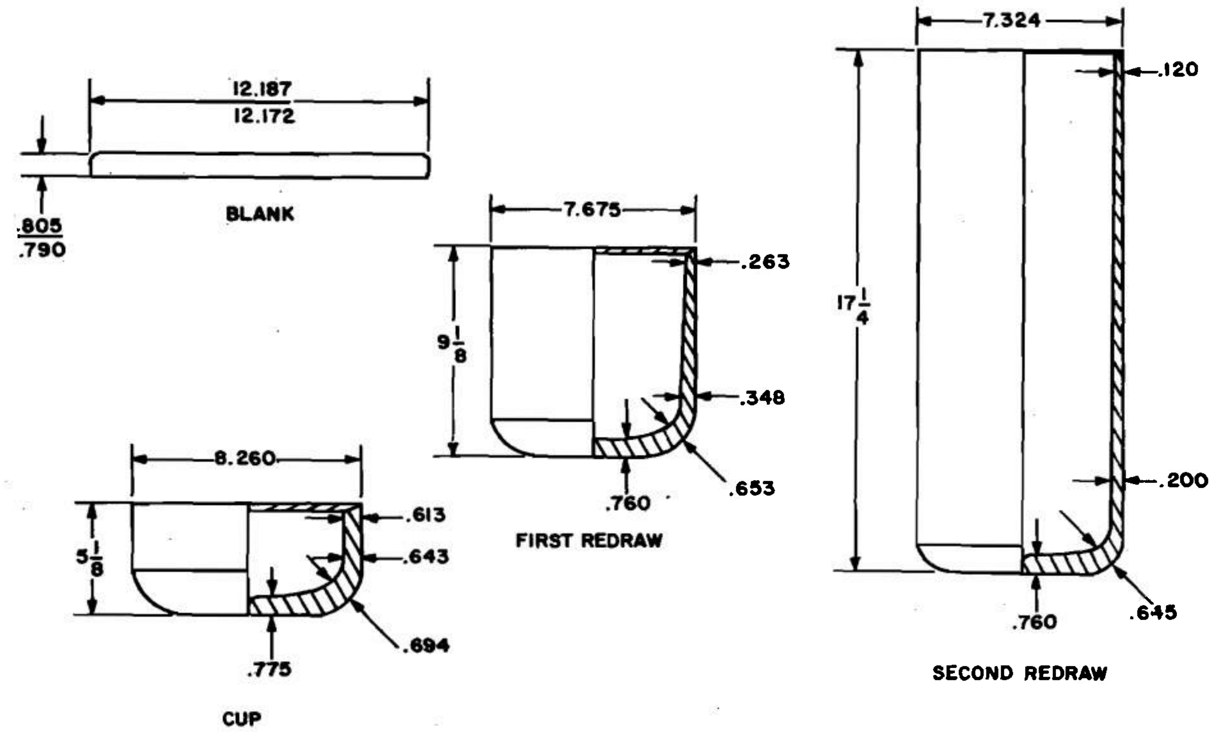


Figure 6-28. Cartridge case process drawing

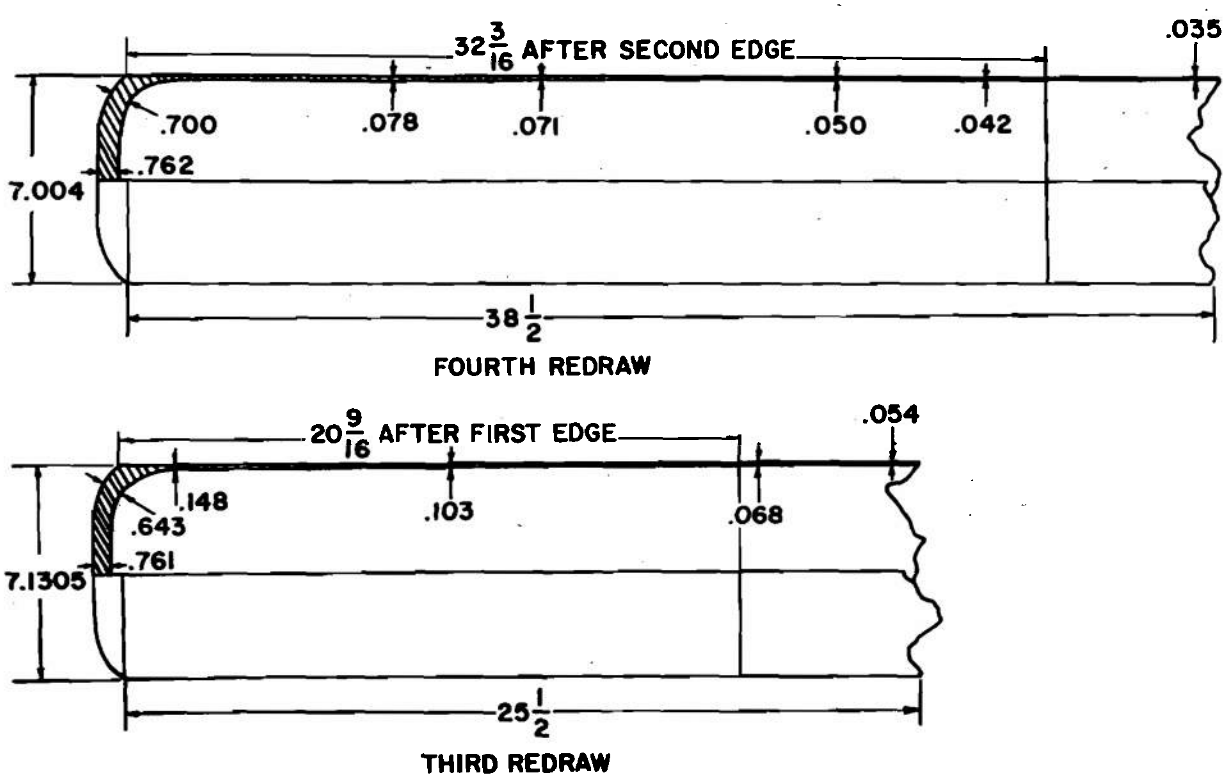


Figure 6-29. Cartridge case process drawing

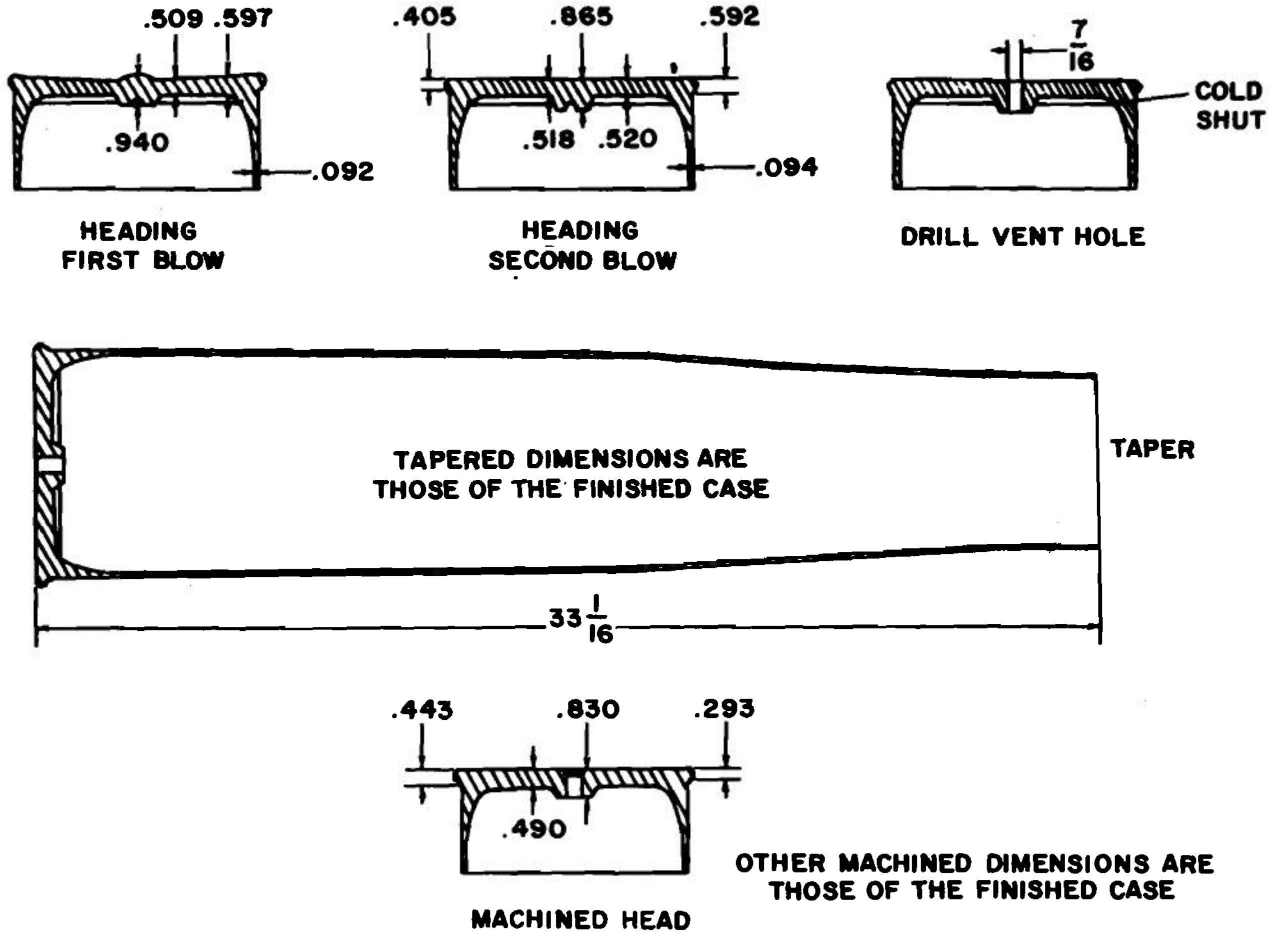


Figure 6-30. Cartridge case process drawing

by a 25-ton knockout. This case has three different diametral tapers. Accordingly, to simplify grinding and reduce toolmaking costs, the die is made in five sections. Metal properties required for successful tapering are (1) a mouth soft enough to withstand reduction; (2) a body which is strong enough to resist the thrust of the tapering punch and sufficiently rigid to prevent the formation of pleats. Adequate lubrication, to promote the flow of metal in the die, must be present.

6-101. Head Machining and Stamping. (See figure 6-30.) The case is firmly clamped in a collet chuck and the head is machined in three operations. The hydraulic knockout used to remove these cases from the tapering die tends to distort the head, hence, the customary practice of machining the head prior to tapering is not followed. The case is finished to length by a contour cutter, which chamfers the inside and outside in one operation. Stamping, by means of a drop hammer, concludes the machining sequence. It is done after final inspection and identifies the case as to manufacturer, year of manufacture, lot number, and the name and designation of the component.

6-102. Annealing Operations. Reducing-atmosphere, gas fired furnaces are used for the process anneals. Temperatures are held at 1,250°F on all draws except the last, which is 1,150°F. Total time in the furnace is 70 minutes for the cup and 60 minutes for the draws. When it is necessary to soften only a portion of the case, saltpeter anneals are used. The case, after heading, is immersed for 2 minutes, mouth down, to a depth of 14 to 14 1/2 inches. In the mouth anneal, the saltpeter is held at around 875°F; only about 5 inches of the case are immersed. After stamping, the finished case is given a low-temperature, stress-relief anneal, at about 530°F, to relieve the locked-in stresses which have been held responsible for season cracking.

6-103. Inspection Procedures. Plant inspectors have a schedule of dimensional checks which are made at various stages of manufacture.

Government inspection, in addition to checks of size and shape, involves certain physical and chemical tests. Under exposure to certain atmospheres, cartridge brass will "season crack" if residual stresses are present. In order to determine whether the stress-relief anneal has removed these locked-in stresses, two cases from each lot of 5,000 are cleaned in nitric acid, rinsed, and immersed in a solution of mercurous nitrate. After vaporizing the excess moisture, a mercury deposit is left on the case. Any crack, which under normal conditions would have appeared in five years, will develop under this test. A litmus-paper test is performed to determine the presence of residual acids or bases on the interior or exterior surfaces of the case. If no change in color of pieces of red and blue litmus paper occurs, after 30 seconds of application to the surfaces, they are assumed to be neutral. A test for cold shuts (fold-ins), at the interior radius of the head, is carried out on one case per lot. A radial section is cut from the base, polished, and nitric-acid etched. The excess acid is washed off and the specimen immersed in ammonium persulfate to accentuate the grain. Microscopic examination then determines the depth of the cold shut. This may not extend beyond tangents drawn to the interior of the base and the sidewall, so that they intersect. Rockwell B hardness should vary from 35 near the mouth to 88 in the region of the head, with an intermediate value of 64 at 23.5 inches up from the head.

Proving ground tests require that

1. The case must enter the chamber of the gun freely.
2. No flutes or cracks shall appear after firing.
3. Obturation must be satisfactory.
4. Extraction must be easy.

6-104. Steel for Cartridge Cases. Most steel artillery cartridge cases have the following composition:

	Percent
Carbon	0.25 to 0.35
Manganese	0.60 to 0.90
Phosphorous	0.040 max.
Sulfur	0.045 max.
Silicon	0.10 max.

The carbon content is determined by the physical properties required in the lower sidewall. The steel is spheroidized before the cupping and precupping operations, in order to increase the amount of deformation the steel will stand without fracture. The cold work to which the case is subjected during manufacture increases the hardness, the ultimate strength, and the yield strength so much that it is necessary to process anneal. The recrystallization temperature at which the effects of prior cold working are completely eliminated is approximately 1,050°F.

6-105. Steel Blanks. (See figure 6-31.) The steel cartridge case starts as a precut disk or blank of the prescribed dimensions. The ideal blank would be smooth on both sides and free from all surface imperfections. Since such perfection is impossible, surface defects are classified as those which iron out and those which do not. Among the latter are notches, which, during the drawing operations, may become stress raisers. Disks having surface blemishes may be salvaged by grinding.

6-106. Preparation for Cupping. The blanks are (1) rinsed to remove soap which may have been picked up from the conveyor workholders; (2) washed in an alkali cleaning solution to remove oil and dirt; (3) given a rinse with trisodium phosphate to remove the cleaner and promote uniform soap coating; and (4) soapcoated. This is done in one continuous operation. Many lubricants, such as oils, greases, and graphitized compounds have been tried as lubricants for the drawing operations, but it has been found that the intense pressures of the tools during the cold-working operations broke through the lubricating films and caused excessive friction. A layer of soap is easy to apply, remains intact during the forming and drawing operations, and can be removed with hot water.

6-107. Precup and Cup. (See figure 6-31.) The first drawing operation in the manufacture of the steel cartridge case is the cup which forms the head and first few inches of the sidewall. This was formerly done in one operation, but the common occurrence of fracture of the cup, especially when 0.30 percent carbon steel was used, caused operation to be divided into two stages. Following the first of these, the "precup," an inspection determines whether there is any sign of a rupture or potential rupture. If none is observed, the precup is placed in the cupping die and the punch carries the component through the die, ironing out the sidewalls. Finished cups are inspected for evidence of "tool loading," that is, the incipient or actual welding of steel particles from the cup to the die, punch, or stripper fingers. This may be caused by an inadequate soapcoat, which leaves bare spots.

6-108. Process Anneal. The cold work on the cup distorts the ferrite grains and greatly increases the strength and hardness of the steel, while at the same time drastically reducing the ductility of the steel. Before any further work can be done the cup must be annealed by heating above the recrystallizing temperature (that is, by heating to around 1,150°F and holding at this temperature for five minutes). Until recently no attempt was made to control the atmosphere of the annealing furnace, thus avoiding the formation of scale. Hence it has been necessary to "pickle" the cups in order to remove the scale. While the use of a controlled atmosphere does not entirely obviate the necessity of pickling, the amount of scale formed is considerably reduced; as is the pickling time. Capital investment in a controlled-atmosphere furnace is about 50 percent greater than in an air-atmosphere furnace, and there is still some uncertainty about the ultimate advantage

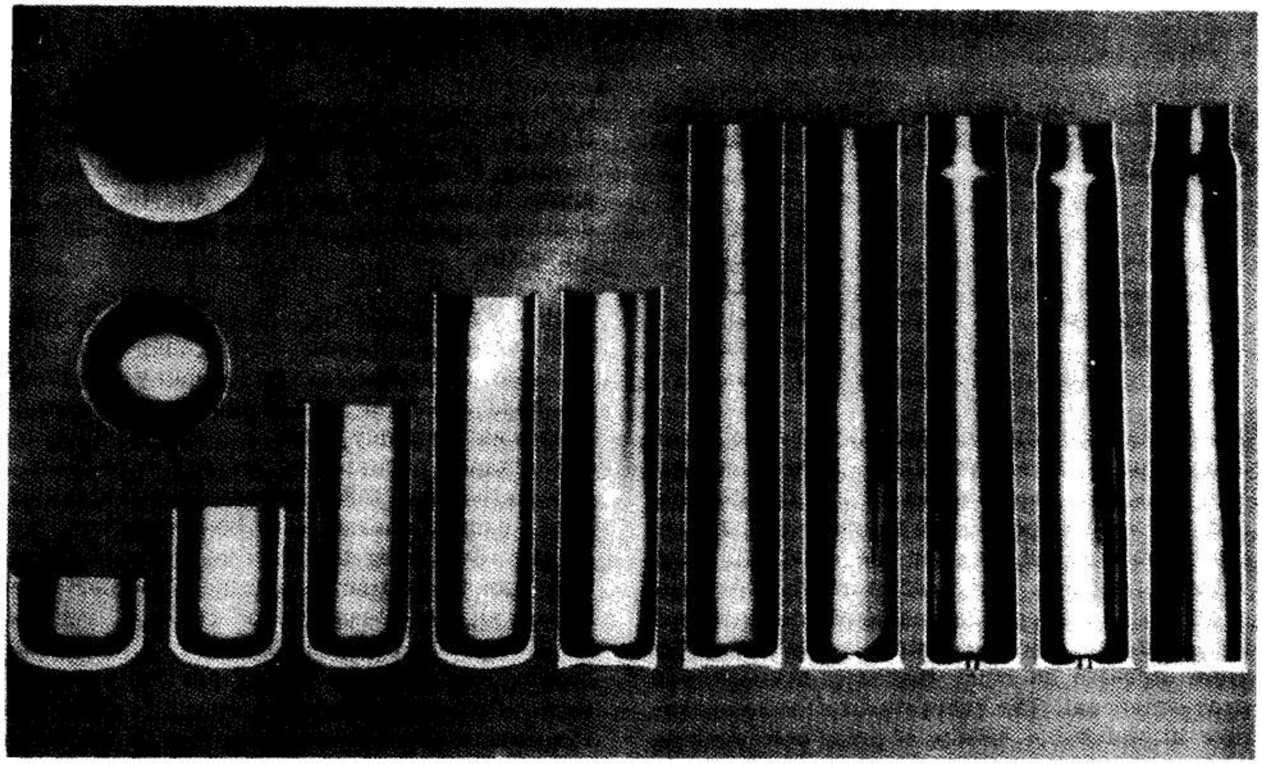


Figure 6-31. Progressive drawing of forming and machining operations required to manufacture a typical steel cartridge case, from the blank to the finished case

of scale control. Since the presence of soapy film on the components during annealing would produce hard scale deposits, which would be difficult to remove in the pickling bath, the cups are thoroughly washed to remove all soap prior to annealing.

6-109. Drawing. Prior to drawing (figure 6-31), the cups are phosphate coated and then soap-coated. The phosphate acts as a host to the soap, which is used as a lubricant to prevent metal-to-metal contact during the drawing operations; the latter progressively reduce the thickness and length of the sidewall. The number of draws required depends on the total reduction in wall thickness from cup to finished case. Each draw is designed to produce a reduction of approximately 40 percent, which is the maximum that can be sustained without causing excessive variation in the thickness, or a fracture, of the sidewall. Consecutive draws may be made without intermediate lubrication if the total reduction is limited to 70 percent.

6-110. Trimming. Between draws the mouth of the case is trimmed to eliminate "dead metal," which develops because, during the draw, the outer surface of the case elongates more than the inner surface. Hence the lines of grain flow curve inward near the lip of the case and show end grain on the inside of the case. This weakens the steel, and may cause circumferential rupture. Another purpose of the trim, particularly after the final draw, and before and after tapering, is to secure uniformity in the length of the sidewall. Trimming is done both by a nibbling operation, which shears the surplus metal in a series of strokes of a cutter while the case is mounted on a mandrel; and by a rotary trim before the taper. The rotary trim produces a burr-free edge; the shearing action of the nibble trim produces burrs which necessitate a mouth ream to prevent scratching of the chrome plating of the punch during the subsequent draw. If the steel is process annealed, there is very little risk of trouble except in the case of consecutive drawing.

6-111. Prehead and Final Head. (See figure 6-31.) Cold-worked steel is much more "notch sensitive" than brass; therefore, all stress raisers must be eliminated, especially from the internal radius of the head. Actual cold shuts in this area may be tolerated in brass cases, but in a steel cartridge case, ballistic failure could result. The steel cartridge case is headed in two operations. The preheading operation, by gathering metal at the center of the head and at the periphery, redistributes the metal in the head of the case to facilitate the formation of the primer boss and the flange during the final heading operation. Preheading is done by a heavy squeeze in a hydraulic or knuckle-type press between a stationary post and a die mounted on the face of the ram of the press. Final heading forms the flange of the case and the primer boss, and shapes the entire interior of the head. Heading is a critical operation, since roughness of the internal radius of the head may raise the stress in the steel during firing to a point where the head separates from the body.

6-112. Piercing the Primer Hole. Using a mechanical press, the primer hole is pierced in the boss of the cartridge case. Piercing at this stage makes it possible to finish-machine the primer pocket during the machining of the head. Formerly, the primer hole was pierced after the taper trim. This necessitated the use of air vent tubes in the salt pot used for the taper stress relief. These air vent tubes permitted the escape of the air from the inside of the case when the cases were dipped, mouth down, into the molten salt; the trapped air escapes through the primer hole. Following the piercing operation the case is passed through a combination wash and pickle machine, where the soapcoat, phosphate coating, and incidental rust are removed and the case is thoroughly dried preparatory to heat treatment of the sidewall.

6-113. Sidewall Heat Treatment. The amount of elastic recovery of the cartridge case after firing depends primarily on the elastic limit of the steel in the sidewalls. If the elastic limit is low, there will be more plastic deformation and consequently a smaller recovery. Since it is difficult to develop the requisite mechanical properties in the sidewalls of the steel case, especially the critical region near the head, by cold work alone, this portion is induction hardened and tempered. The induction coil raises the case to a temperature of 1,700 to 1,800°F. This is followed by a quench with large volumes of water, preferably applied to both inside and outside of the case.

6-114. Magnetic Hardness Test. To check on the heat treating, all cases are tested for hardness in a magnetic hardness comparator. A standard case of known hardness is mounted in one induction coil while the case under test is inserted in a similar coil. The standard coil and the test coil form two arms of a Wheatstone bridge. If the magnetic characteristics (dependent upon hardness) of the case under test differ from the standard, the bridge will be unbalanced and an output voltage will appear.

6-115. Heat Treatment in Preparation for Tapering. The cold work in the final draw raises the hardness of the case to around 96 Rockwell B, but at the same time materially reduces the amount of deformation the steel can withstand as a result of further cold work. Since the tapering of the cartridge case imposes severe strains on the steel of the sidewall, heat treatment is required. To obtain maximum increase in percentage elongation without appreciable loss of hardness, a temperature between 1,000 and 1,050°F is required. If the temperature is allowed to rise to 1,050°F, recrystallization takes place and the steel loses much of its hardness and yield strength. The case is therefore immersed, up to the region that was hardened by induction heating, in a salt pot at 1,020°F. It is held there, mouth down, for a period of four or five seconds.

6-116. Tapering. (See figure 6-31.) Following the low-temperature stress relieving operation, pickling for the removal of scale, and the application of a coat of soap to the outside for lubrication, the case is tapered. This operation develops the final contour of the body section by forcing the case into a tapered die in a vertical hydraulic press. Not all cases successfully withstand this treatment. Among the resultant defects are (1) "fluting," a waviness of the sidewall arising from inadequate stress relief, failure of the soapy lubricant, or the plugging of the air relief vents in the die; (2) "wrinkles," an aggravated form of fluting; (3) collapse of the body of the case, often caused by a ragged mouth giving rise to high localized stress; (4) scoring by the tapering tools; and (5) stretcher strains, a pattern of Lueder's lines sometimes observed on the surface of soft steel subjected to cold work. Stretcher strains indicate that stress relieving has been overdone; the temperature has risen above 1,050°F, recrystallization of the steel has taken place, and the hardness of the body may be below specifications.

6-117. Machining Operations on the Head and on the Mouth. (See figure 6-31.) The cartridge case is thoroughly washed and dried, so that it can be held securely during machining. It is then inspected and defective cases are rejected before machining. The head of the case, the flange, the shoulder, the primer hole, and the mouth of the case are finish machined on a special lathe, which may be of one of two types: (1) a single-spindle, center-drive lathe, or (2) a multi-spindle machine. The single-spindle machine is preferred because of lower initial cost and greater convenience. The cold-worked structure of a steel cartridge case presents difficulties in machining. The material is exceedingly tough and produces long, stringy chips which are hard to handle. Following machining, the cases are 100 percent inspected for size and shape. The mouth of the case is then resized to the correct dimensions by holding the case in a special fixture and forcing a sizing plug into the mouth to a depth of one inch. The case is tapered slightly undersize, and then resized after machining, in order to insure its passing the chamber gage inspection.

6-118. Mouth Anneal. The last production operation on the case prior to application of the protective coating is a mouth anneal to increase the ductility of the steel. This is done for two reasons: (1) unless relieved, the high yield and low percentage elongation characteristic of cold work may cause the mouth to split on firing; (2) if the case is attached to the shell by crimping, softening of the mouth is essential. Every half hour, a mouth-annealed case is removed from the production line and given a Rockwell test at five points in the annealed zone to determine whether the hardness meets specifications.

6-119. Government Intermediate Inspection. After all manufacturing and washing operations have been completed in preparation for the application of the protective coat, Government inspectors make the final acceptance gaging of the case. Inspection before coating not only avoids damage to the coat, but in the event that a lot is rejected it obviates the need to remove the varnish or zinc plating before reprocessing. Government intermediate inspection procedure involves inspection of cartridge cases in sublots of approximately 2,000 cases. Acceptability of each sublot is determined from an inspection of about 100 cases from each. If the first samples from a sublot contain more defects, of any kind, than permitted by standard sampling inspection tables, a second sample, twice the size of the first, is taken and inspected for the class of defects which were the cause of resampling. If the defects of the second sample are too numerous, the entire sublot is rejected.

6-120. Protective Coatings. Two types of protective coatings are used on steel cartridge cases, zinc, or phenolic varnish. Zinc is prescribed by the Navy and varnish by the Army. The cases are prepared by removing scale, formed during the mouth anneal, as well as shop dirt and any traces of machining oil. The varnish coat is uniformly applied by dipping. After dipping, the coat is air dried prior to baking, in order to avoid thin or bare spots resulting from flow of the varnish on first contact with the heat of the oven. The phenol formaldehyde resin varnish specified for this service bakes by polymerization at a temperature of 400°F. The varnish case is tested by pouring 3 liters of Ottawa sand upon the inclined sidewall through a vertical tube, 3 feet long, located 1 inch from the case. The area abraded must not exceed a specified limit. The baking at 400°F also serves as a low-temperature stress relief which protects against rupture during firing, but does not appreciably lower physical properties. Cases which are to be zinc plated are stress-relief annealed after the taper but before plating. Before zinc coating, the case is cleaned electrolytically in an alkaline bath. After rinsing, and an acid dip to neutralize all traces of the alkali cleaner, the outside and inside of the case are plated to a thickness of 0.00015 to 0.00020 inch.

6-121. Final Inspections. These are made both by the manufacturer and by the Government. The inspection by the manufacturer is primarily visual. Scratches, cuts, dents, laminations, and other blemishes cause the case to be set aside for possible salvage. The inspector is also on the lookout for coating defects, including blisters, unevenness of varnish coat or zinc plate, and bare spots. A recheck of hardness, in the magnetic comparator, is also made to make sure that no case slips through without being properly heat-treated. The final Government inspection is similar to the intermediate (paragraph 6-119), except that this time 300 samples are selected from a lot of not over 25;000 cases. Included in the Government's final inspection is a Rockwell hardness test applied to 10 cases per lot; failure of 1 case in the group is cause for rejection of the entire lot. The manufacturer may request that a second group of 10 be selected. Another failure means rejection of the lot without further appeal.

6-122. Head Stamp and Packing. The head of the cartridge case is stamped by the manufacturer with the lot number, the component, the code designation of the manufacturer, and either the Ordnance bomb or the Navy anchor to signify acceptance of the lot. Two percent of the stamped heads are then checked with a special head thickness gage to insure that the stamping ridges are not excessive and that the head has not been distorted. The finished cases are then packed in corrugated paper cartons for shipment.

6-123. Introduction. The following paragraphs describe the manufacture of the trapezoidal-wrapped steel cartridge case, 120-mm, M24E1, as practiced by the Murray-Ohio Corporation. The methods described are typical of the manufacture of this type of case.

In order that this type of cartridge case may be the equivalent, in all respects, of the standard brass case, the following characteristics must be maintained:

1. Stable dimensions, with emphasis on the region of engagement with the gun, head engagement, and datum diameter
2. Uniform internal volume, to accommodate the exact quantity of the charge
3. Good obturating quality
4. Free and uniform ejection
5. Resistance to weathering effects of the elements.

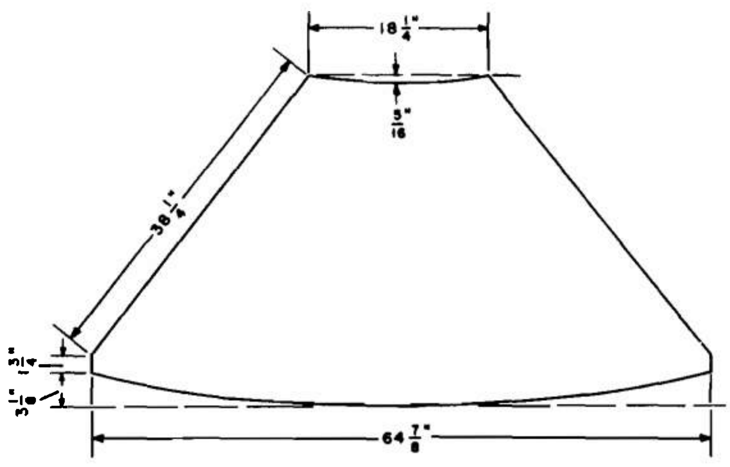


Figure 6-32. Body layout

6-124. The Body of the Case. This is made from standard mill tolerance steel sheet (SAE 1008) sheared and trimmed to a trapezoidal blank (figure 6-32). The blank is rolled into an open-ended, tapered cylinder, and expanded by hydraulic pressure against the walls of a die, and tack-welded at top and bottom. The wrapped sheet comes from the rolls rather loose, with the upper and lower edges of the trapezoid forming the mouth and the base, respectively, so that there is a single wrap at the mouth and several wraps at the base. Before wrapping, the sheet is washed and varnished on both sides. Since the varnish has a tendency to age harden, the sheet is worked immediately after baking.

6-125. Rough Rolling and Expanding. The trapezoidal sheet is rough rolled in a specially built machine. One end of the long lower edge of the sheet is entered between the first and second rolls. These are backed up by a third roll, which turns the sheet around into a tapered cylinder. The "wrap-up" is then lowered into a die over a rubber bladder. After the die is sealed, hydraulic fluid pressure at 15,000 psi presses the bladder against the interior of the case and expands the case against the walls of the die. A well-defined offset at the lap seam (in other words, a smooth closure on the outside of the case) indicates good workability of the metal. Following expansion, the bodies are tackwelded at the top and at the bottom of the seam with a 1/4-inch long bead to hold the case to its expanded size through the subsequent spinning operation, which turns over the lower lip of the case to fit into the head.

6-126. Spinning the Lower Lip. A six-jawed collet chuck, carried by a lathe spindle, closes the coiled body upon an expanding mandrel. An air-operated pusher head, mounted on the lathe tail stock, is used to push the work into the collet. A motor-driven mechanism on the lathe carriage causes a flanging roller to move over a series of fixed paths, which progressively form the flange in a series of "passes." The collet is provided with an ejection arrangement, which pushes the work forward as the collet opens and permits its ready removal from the spinning lathe. For some types of cartridge case, the flanging may be done prior to expansion, instead of afterwards, as in this case.

6-127. Completion of the Assembly. The base, or head, of the case is burnt out from SAE 1545 steel plate which is ground and machined, then fastened to the body (figure 6-33). The several parts of the head assembly are enameled and baked to protect against corrosion and weathering.

6-128. Advantages of Wrap-Up Cases. Wrapped cartridge cases date back to an 1869 U. S. patent. Apparently the problem of sealing led to abandonment in favor of the drawn case, for which hydraulic press capacity had to be provided. The wrapped case does not require these presses. Recently, the development of the sheet-metal industry and the expansion of steel sheet capacity has paved the way for the solution of the major problems of design and production. These are principally the flanging of the lower lip and the expansion and locking of

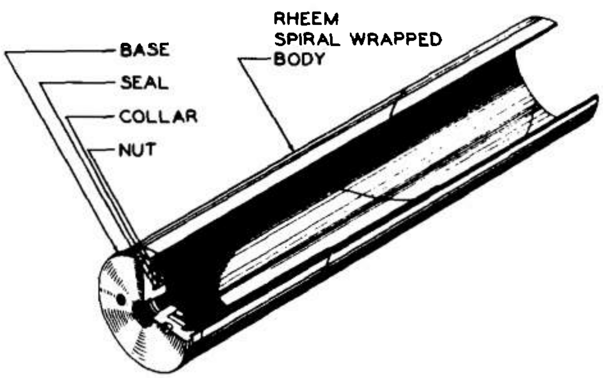


Figure 6-33. 120-mm case assembly

the case itself. The other processes involved in this method are not fundamentally complex.

6-129. Facilities. The initial cost of production-line machines for wrap-up cases is small compared with that for cup-and-draw. They are not highly specialized, and are to be found in many sheet-metal works. Less space is required, hence production lines for trapezoidal-wrapped cases can be set up, in dispersed areas, in a very short time. Since no heat treatment is required anywhere in the process, the expensive furnaces, with their exacting controls, are eliminated. Hardness checking is not necessary, and the highly qualified inspection personnel normally required for this service are not needed. In general, since the wrapped case is made from standard rolled sheet, requiring little attention to avoid minor imperfections, the care which is exercised to avoid tiny flaws or undersurface imperfections (causing ballistic failure) in the drawn case is unnecessary. Thus inspection costs are held to a minimum.

6-130. Performance. Experience in the Korean war demonstrated the acceptability of the wrapped case. The only malfunctions reported concerned certain undesirable characteristics of the nitrocellulose lacquer coatings. This has since been corrected. The flexibility of this case gives it an advantage over the drawn case, especially those drawn from steel. The spiral seam, acting as an expansion joint, enables it to fill the chamber without rupturing. The multi-component construction of this case offers advantages in salvage. Since the base is fastened to the body by simple threaded attachments, battle salvage of the bases (which represent a substantial portion of the manufacturing cost of the complete case) is a definite possibility. Being flat, they are easily shipped. The body could also be shipped flat, or merely regarded as expendable.

6-131. Inspection. Body steel is checked for thickness and hardness. After rough rolling, the body is visually examined for flutes, and to see that no leaf extends more than 1/8 inch above mating leaves. Bases are spot checked for blemishes after grinding. Government inspection includes the normal size and shape gage checks.

6-132. Introduction. The manufacture of perforated cartridge cases (figure 6-34), used in recoilless weapons, is similar to the method used for the manufacture of any drawn case, with the following exceptions.

1. The perforations are punched prior to the final tapering.
2. After the final tapering, the inside of the case is shot-blasted to insure a smooth interior.
3. The inspection procedure includes a check for alinement of the perforations.

6-133. Perforating. In the earlier stages of development of this type of cartridge case, the holes were drilled. This practice was too slow for quantity production, and has since been supplanted by multiple punching along the longitudinal axis. The case is supported internally by a sliding wedge and anvil, which are expanded by air pressure after insertion in the case. The case rests in a shoe, or cradle, during the punching operation to enable it to be indexed for successive rows of perforations. A complete row of punches descends at a single stroke and punches the holes through the die buttons in a die holder on the anvil. A blast of air blows the chips out of the anvil through a chip receiver pipe. An automatic indexing device then turns the case and moves it longitudinally in order to stagger the rows of holes.

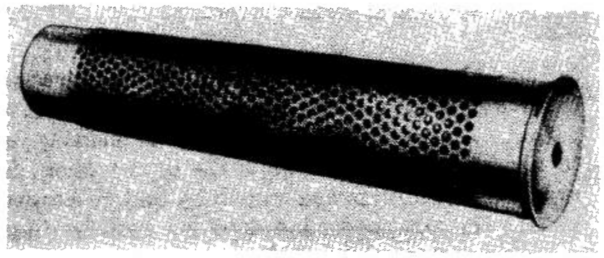


Figure 6-34. Perforated cartridge case

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