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Explosive Metal Forming

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Abstract

This study will be concerned with investigating the development of equipment and instructional materials to teach a unit of explosive metal forming in a high school Industrial Arts class. The study will be specifically concerned with: (1) dies and dies blanks for explosive forming, (2) physical phenomena such as velocity, pressure forces, etc., generated in the explosion, (3) technical and laboratory activity content regarding explosion forming, and (4) to prepare a final written report.

EXPLOSIVE METAL FORMING

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the Non-Thesis Master of Arts Degree

by
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Chapter 1

THE PROBLEM AND DEFINITION OF TERMS

During the past two decades explosive forming method has been initiated and has grown into a widely used process of metal forming manufacturing.

This process grew because it was imperative to find newer and more efficient methods of fabricating metals, especially the newer alloys, which are now being used in the space age.

Basically, explosive forming method refers to a technique that forms metal to die shape by explosive impact. The explosive charge is a form of stored energy that can be released to move the metal into shapes that cannot otherwise be economically produced any other way. The explosion of the charge instantaneously generates a higher pressure and the metal will glow like a liquid.

It is felt by the writer that a unit in explosive forming method would be a good unit to be taught in Industrial Arts, and this process provides an opportunity to develop experiments, such that could be used in teaching classes and would enrich the curriculum of Industrial Arts.

The writer's previous knowledge of explosive metal forming was limited, until attending a class demonstration about this process that was a tremendous motivator in order to increase his knowledge.

Statement of the Problem

This study will be concerned with investigating the development of equipment and instructional materials to teach a unit of explosive metal forming in a high school Industrial Arts class.

The study will be specifically concerned with: (1) dies and dies blanks for explosive forming, (2) physical phenomena such as velocity, pressure forces, etc., generated in the explosion, (3) technical and laboratory activity content regarding explosion forming, and (4) to prepare a final written report.

Importance of the Study

It is important that Industrial Arts teachers keep abreast of the new and rapidly developing processes in industry and to see that they are introduced into their classes; because Industrial Arts is a field within the educational system which has as one of its major objectives instilling within the students an awareness of modern industrial practices. Explosive forming is a new and important metal forming process in the aerospace industry; it resulted from the necessity of inventing new ways of working metals.

Through this research it is hoped the writer will be able to gain enough knowledgeable experience to basic understanding of techniques used in explosive metal forming.

Limitations

The study of explosive metal forming covers a wide range of topics. To gain a thorough knowledge of all mechanics used in it requires a thorough understanding of mathematics, physics, mechanics and metalburgy.

Since this study is written to serve the general needs of high school students, the discussion of explosive metal forming is limited to the found data from experiments. How does the form of the dies affect the form of the workpiece, and how does the pressure develop in the process? However, it is difficult to design an explosive close chamber for high explosives. The reason the open chamber was chosen is that it is a much safer unit.

The thickness of the blank used in the experiment is limited to 18 guage aluminum.

Definition of Terms

Selected terms were defined so the reader would have a common understanding of the way in which they were used in this report.

High Explosive. These explode with a rapid detonation such as dynamite, TNT, RDX, composition C-3, composition C-4, and PETN and EL-506.

Low Explosive. These explode with slow detonation such as black powder and smokeless powders.

Closed System. It is an explosive system that contains the forces of the explosives.

Contact Operation. Explosive forming in which the explosive charge is placed in direct contact with the work.

E. M. F. Explosive Metal Forming. It is a method of changing the shape of various kinds of metals by means of shock waves set up by an explosive charge under desired conditions.

Free Forming. In this type the forming is performed without dies or with open end dies.

H. E. R. F. This term means high energy rate forming, and the metal is formed into a die with very high pressure in the duration of a microsecond.

Explosive Shape. It refers to the shape of the explosive used and can largely determine its effect on the piece to be produced.

Standoff. It is the distance between the explosive charge and the piece to be produced.

Transfer Medium. It is the medium used in order to transfer the pressure generated for the explosive charge.

Open Dies. It is a female half of a die.

P. E. T. N. It is a high explosive used in this process. It means Pentaerythritol Tetranitrate.

Chapter 2

HISTORICAL INFORMATION

Perhaps the Chinese people were the first civilization that used explosives because there is certain evidence that they made black powder several hundred years before the Christian era.

The Arabs also were supposed to have used gun powder in the Thirteenth Century.

History tells that the philosopher Roger Bacon wrote an essay about how to make black powder, but the application of the black powder to the gun was not accomplished until 1313, and the black powder became a useful element for military purposes.

Black powder was used successfully in the exploration of mines in Hungary and tin mines of England in 1627.

In 1675 the first production plant for the making of black powder began its operation in Massachusetts; and in 1780 French industry produced a good quality powder through the scientific contributions of Berthelot and Lavosier.

In 1802 E. Leuthere Irenee Du Pont, specialist in the powder manufacturing came to the United States and began the commercial manufacturing of black powder near Wilmington, Delaware.

In Italy, 1846, the discovery of nitroglycerin, which is the most important ingredient in the production of high explosives, was made. When this explosive was developed, the industrial safety used for production was very poor. In fact, a lot of accidents occurred in the manufacturing plants and in transportation; this generated a restrictive legislation.

In 1863 nitroglycerin was absorbed into Kieselguhr, diatomaceous earth thus converting the sensitive liquid into a solid for less hazardous production. The material in this form was called dynamite by its inventor, Alfred Novel.

In 1965 the Russians launched their Sputnik I and touched off widespread interest in revolutionary methods of forming metals. The Sputnik I generated a vigorous action in governmental agencies. The aeronautical industry in the United States was ordered to find a solution to the forming of complex metal parts necessary for missile industries. Explosive metal forming was the answer for this question:

> The first application of explosive metal forming was undertaken in the manufacturing of industrial fans by Kansas City's Moore Company, twenty three years ago. In 1953 Olin Mathieson became interested, by 1955 was going great guns at its Winchester and Western Division in a search for new techniques to which such packaged propellants as blank cartriges and explosives could be applied.[1]

The importance of Olin Mathieson's work had been to cut down drastically on the number of separate operations necessary for producing stainless sound suppressors for the Boeing 707.

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[1]"Explosive Forming," American Machinist, (December 29, 1958), pp. 47.

Chapter 3

TECHNICAL INFORMATION

EQUIPMENT USED IN EXPLOSIVE METAL FORMING

The basic setup for explosive forming method consists of: (1) Energy Source, (2) Transfer Medium, and (3) Dies.

Energy Source

TNT (trinitrotoluene). It is a military explosive and is used as a standard (with a rating of 1.00) in measuring the power of other explosives. It can be detonated at 22,600 feet per second. TNT is insensitive to shock even though it may be detonated by a rifle bullet.

P. E. T. N. (pentaerythrite tetranitrate). When P. E. T. N. is founded pure, it melts at 141.3 C. and its crystals have a density of 1.765 gramos/cc. It may be slightly soluble in water and is nonhygroscopic although wetting it tends to desensitize. This is a military explosive also. Special loadings of P. E. T. N. are founded commercially in sheet explosive and in detonation fuse. Its explosive power has an equivalent of 170 percent of TNT. This explosive can be easily stored live, but should be kept dry for most consistent results. Its detonation velocity is 27,200 ft/sec. P. E. T. N. is not toxic, since it is nearly insoluble in water. But small doses of it taken internally causes a decrease in blood pressure and larger doses cause dyspnea and convulsions.

RDX (cyclltrimethuleno-trinitramine). This explosive melts at 204.1 C. and has a crystal density of 1.815. RDX may be cast or pressed to obtain higher densities. This explosive is primarily a military explosive, but may be used in combination with a number of other explosives or binders in commercial forms. Different types of detonating fuses are loaded with this explosive. This explosive is slightly soluble in water and is nonhygroscopic. Its sensitivity to detonation is decreased when it is wet. The equivalent explosive power of RDX is 170 percent of TNT and its velocity detonation is 27,400 ft/sec. It is not toxic, and cleanliness is the only precaution prescribed.

NG Nitroglycerin. Nitroglycerin is the primary explosive in a number of dynamites. The pure state of Nitroglycerin is a colorless liquid and extremely sensitive to impact. The Nitroglycerin has no application in its pure state and in explosive forming operation extreme care is required. It has a detonation rate of 25,200 ft/sec. and it has an explosive power of 185 percent of TNT. It is stable at common temperatures and low solubility in water posses. It does not cause corrosion in contact with metals, and any contamination in the explosive may cause rapid decomposition. Nitroglycerin is easily absorbed through the skin into the circulatory system and its vapors inhaled are absorbed by the blood. The symptom is a severe headache. The workers in constant contact with it usually develop an immunity that can be maintained only by almost daily contact.

Composition C-3 and C-4. These are plastic explosives which may be molded by hand into the desirable shape. The C-3 explosive is a mixture of about 77 percent RDX and 23 percent explosive platicizer, containing mononitrotoluene. It is a yellowish putty-like solid that has a density of 1.60 gramos/cc. Composition C-3 is less sensitive to impact than RDX and about equal in sensitivity to impact as TNT. It has a detonation rate of 25,000 ft/sec. and it is 115 percent power than TNT. It is slightly hygroscopic to the extent of 2.4 percent but its power is unaffected by immersion in water.

Composition C-4 is less sensitive to impact than C-3. It has a detonation rate of 26,400 ft/sec. and contains a TNT power equivalent of about 120 percent. It can be easily stored and is not toxic so that no special precautions need be used in handling it.

These two explosives have been used in explosive forming operations because they can be easily shaped by hand to any configuration and size of charge.

Detasheet A and C (EL-506). Detasheet is primary (P. E. T. N.) explosive combined with other ingredients to form a tough, flexible sheet which is supplied in sizes of 10" by 20" sheets. It is available from Du Pont. There are several different compositions even though the C series is preferred due to its greater flexibility and long shelf life before drying out and becoming brittle. Detasheet is waterproof and may be used in direct contact with charges or can be cut and shaped to the desired charge size for standoff operations.

There are several thicknesses of sheets with loading up from ½ gramo/in^2 in the C series. Several layers of the sheets may be placed together in order to construct the charge size required. This explosive should be ignited only with special high-powdered caps since it is rather insensitive. This becomes even more critical when the thickness of the sheet explosive is reduced. The explosive may be glued onto a backup material for charge shaping if desired. An all-purpose adhesive which can be used is Minnesota Mining and Manufacturing Company Adhesive CTA-11. This explosive is the safest on the market commercially, but it is expensive. It was developed for use in operations of explosive forming.

Its velocity detonation is 23,600 ft/sec. for type A and 23,000 ft/sec. for type C.

MFXP Explosive. This is a putty-type explosive which can be hand molded in different shapes. It is available from Hercules Powder Company. This explosive requires a No. 8 cap for consistent detonation and has a detonation rate of 21,000 ft/sec.

Aerex Liquid Explosive. This is made for use in explosive forming method and is manufactured by Aerojet-General Corporation. The principal feature of this explosive is that it is stored as two separate liquids, neither of which is explosive by itself. The explosive charge is made by mixing both liquids in correct proportions. The explosive charge takes the form of the container; plastic or glass containers should be used.

Its detonation rate is 22,000 ft/sec. and has 80 percent of the power of TNT. A solid Aerex explosive is now available; it is made by mixing the same liquids, but with the addition of ammoniun nitrate to obtain a solid. These are not expensive explosives.

Detonating Fuse. The Primacord is called detonating fuse. It is easy to shape by hand in the desirable form, and for this reason it is extensively used in explosion forming manufacturing. This explosive consists of a small filament of explosive material, normally P. E. T. N. or RDX, with a protective coating of plastic. It is sensitive to water and the ends should be protected when an underwater operations may be performed. When a role of this explosive is stored for some time, the ends of a roll can suffer damage.

It is a requirement that the Primacord will be cut with a knife, because if it is cut with a pliers a buildup of the explosive can occur in the joints of the pliers and cause an accident later. Primacord may be used for connecting separate charges or may be used as the charge itself.

Mild Detonating Fuse (M. D. F.). It is a series of explosives available in charge loading between 20 and 1 grain per foot. When it is necessary to get consistent detonation with an explosive charge, it is used to place the charge inside of a metallic shield which is made from lead. This explosive is used in explosive forming manufacture when a small charge is required.

Transfer Medium

The purpose of transfer medium is the connecting link between the explosive charge and the workpiece. The energy developed from the explosive charge is transmitted in the form of a shock wave and it changes with the characteristics of the explosive and medium. The most common medium is air and water, but water is preferred because of its reduced compressibility.

Dies

A die is a tool used to produce forgins and sheetmetal stampius. There are two main kinds of dies, the cutting dies and the forming dies. In explosive forming manufacture it is most used forming dies, which dies are designed to shape metal parts and are used in operations involving bending, flanging, beading, drawing, etc. Dies used in explosive metal manufacture operations are made from different materials such as:

Heat Treated Alloy Steel Dies. These kinds of dies are very expensive to make, but will form a lot of parts from hard materials to close tolerances.

Ductile Iron Dies. Ductile iron is easily machined. The surface can be case hardened to withstand firing.

Kirksite. These types of dies have been extensively used for explosive forming manufacturing because of their reclaimability. This zinc alloy has a compression strength of 75,000 psi, but its tension strength is 35,000 psi. It is a good production die material for shallow doms; but its use is limited for forming only ductile materials like aluminum, magnesium, and copper, which do not require high loading to form.

Concrete Dies. This material is used for large explosive forming dies, and its compressive strength is approximately 30,000 psi. It is necessary to reinforce that kind of die because its tension strength is very poor. Its disadvantages are: (1) a long cure time is required in order to get the full strength of concrete, and (2) it cracks easily and eventually becomes useless.

Plastic Dies. The plastic dies are used for limited production of parts when tolerances are not critical. It is extensively used for making aluminum pieces which have a tolerance of ± .03". The dies must be enclosed in a metal case to prevent flow and fracture, and it is necessary to use the exact explosive charge because heavy charges will overform the part and possibly fracture the die.

Plaster Dies. It can be used for one shot dies for forming ductile metals. The die should be encased in a metal box and the surface of the die well coated with a solid film lubricant to prevent galling. It is necessary to smooth the forms with large radii and exact explosive charge and pressure distribution even over the die surface because the die is destroyed at first shot.

Thin Dies. This development in explosive forming metal is based on the principle that the resistance of water displacement is dependent on the rate of displacement.

In this case the dies are suspended edgeways in the water rather than resting on tank bottom. The explosive charge is placed facing the part on a charge holder. A vacuum is drawn between the blank and the die. Then, when the charge is detonated, the blank is moved into the die at high velocity and the excess of energy is transmitted to the die, which, in order to move, must be displaced by water at the same rate. Pressure of water on the back of the die is equal to the explosive pressure on the front during a few milliseconds that is required to form the piece.

Types of Dies

There are three principal kinds of dies design: (1) Free Forming Dies, (2) Bulkhead Forming Dies, and (3) Cylinder Forming Dies.

Free Forming Dies. Figure 1 shows the free forming die. In this case sometimes the free forming is made without die or it is used with an open-end die.

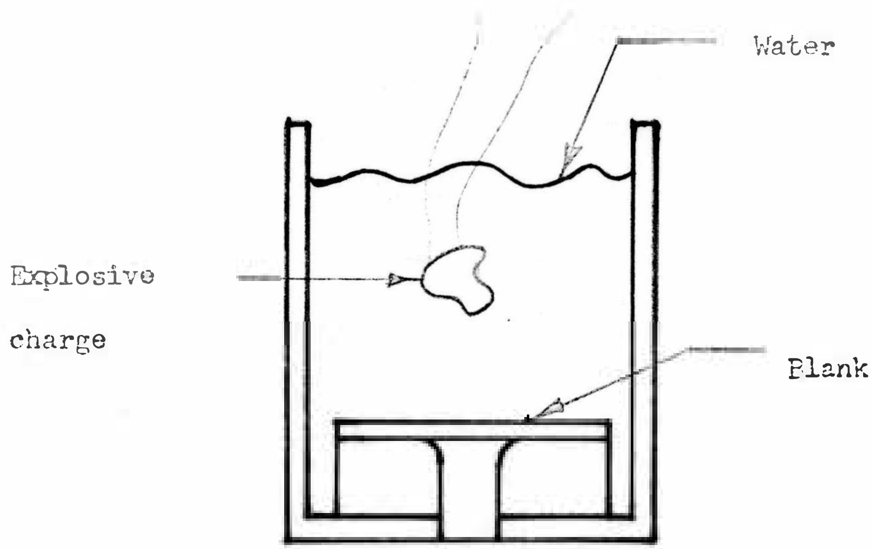

Figure 1. Free Forming Die

Figure 2 shows The Bulkhead Forming; this required a formed die, sealled off from the water that carries with the shock waves.

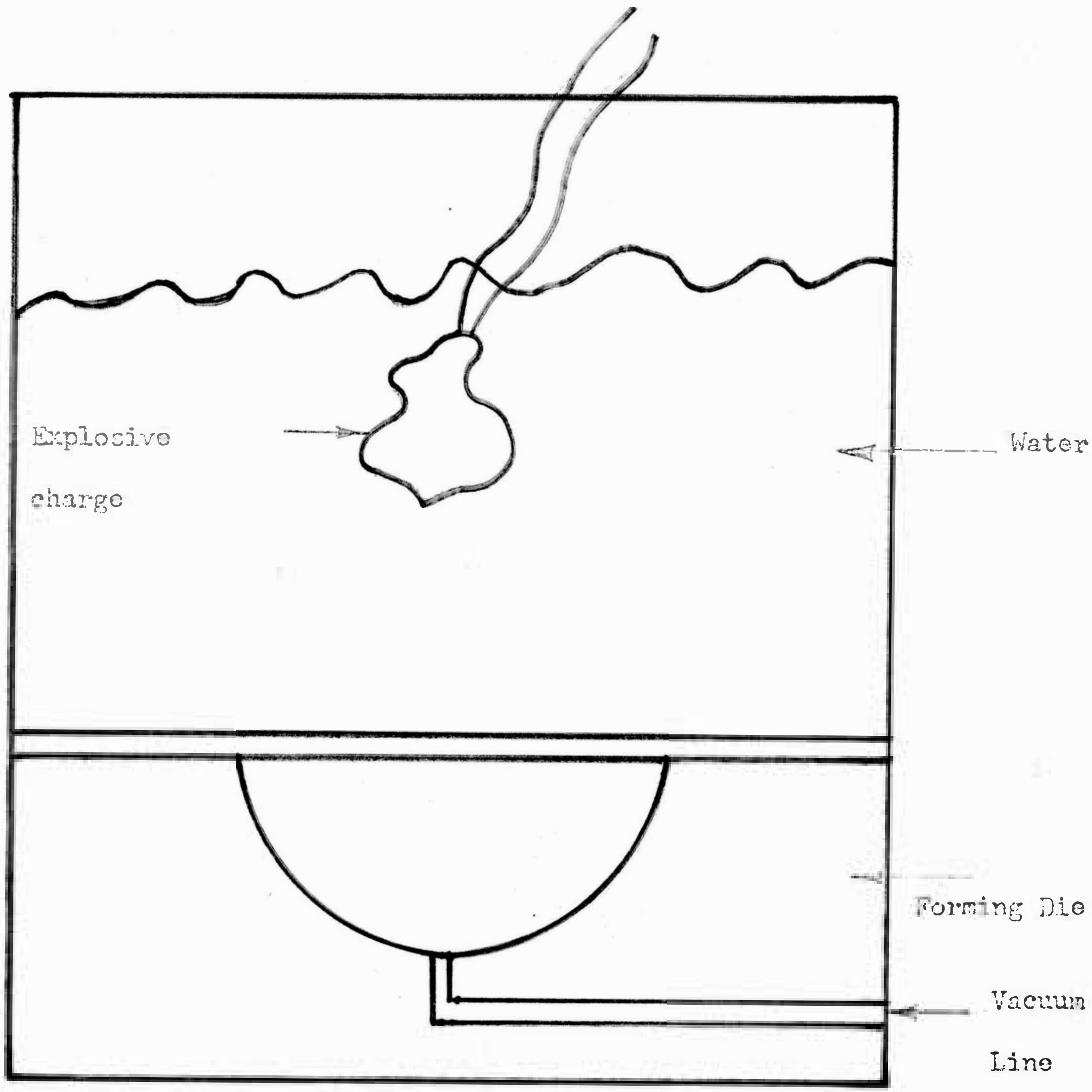

Figure 2. Bulkhead Forming

Figure 3 shows a Cylinder Forming. It pushes the work radially into a shape die, and is often applied to form special tubing.

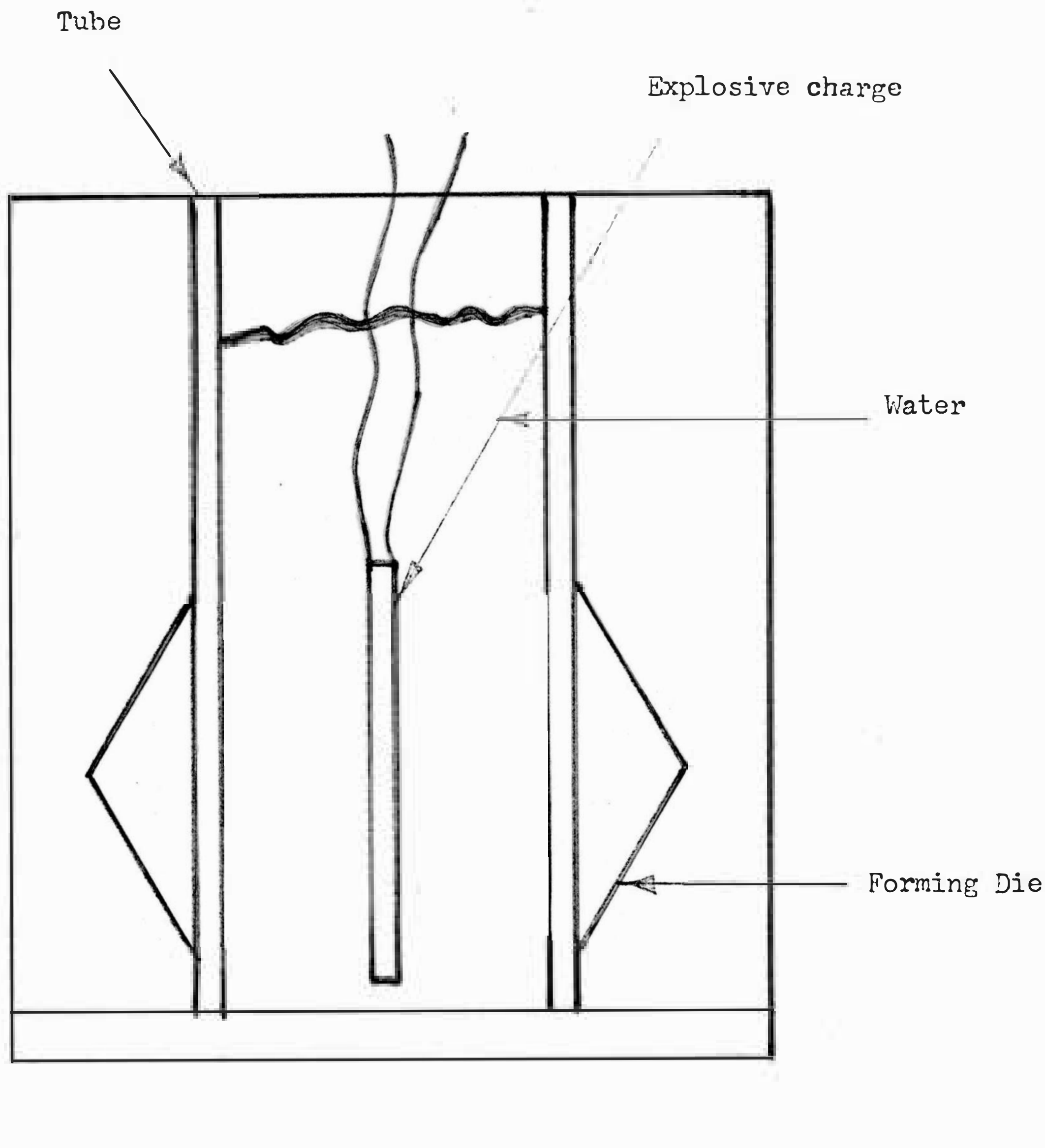

Figure 3. Cylinder Forming

Chapter 4

EXPLOSIVE FORMING

Explosive metal forming is a technique that forms metals to die shape by explosive impact. When the explosive charge is detonated, two types of energy were generated. One of these is the shock wave, which travels about the speed of sound, the other is the pressure wave generated by the gas bubble. The shock wave reaches the workpiece before the pressure wave. Figure 4 shows one equipment used in this process.

The difference between shock-working and the conventional press-working is the speed with which energy is delivered to the metal being worked.

> According to Lockheed Aircraft Corporation, explosives provide velocities of 4,000 to 25,000 feet per second. A high speed press might operate at 150 feet per second. As a consequence of high velocity the energy is poured into the work at a greater rate than the work can dissipate it, hence the metals molecules are jumping and the metals have the characteristics of a viscous fluid.[2]

Free Forming Expand Tubes

Figure 5 shows how high explosives can be used in order to develop a high energy inside the tubes with the purpose of enlarging tubes. The metal tube is filled with water and the explosive charge is placed into the tube, thus the tube is sealed with ends plugs. The whole assembly is immersed in a water tank and detonated by an electric detonator. The wall thickness of the tube decreases and its length increases.

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[2]"Revolution in Metalforming," American Machinist (November 17, 1958), pp. 123.

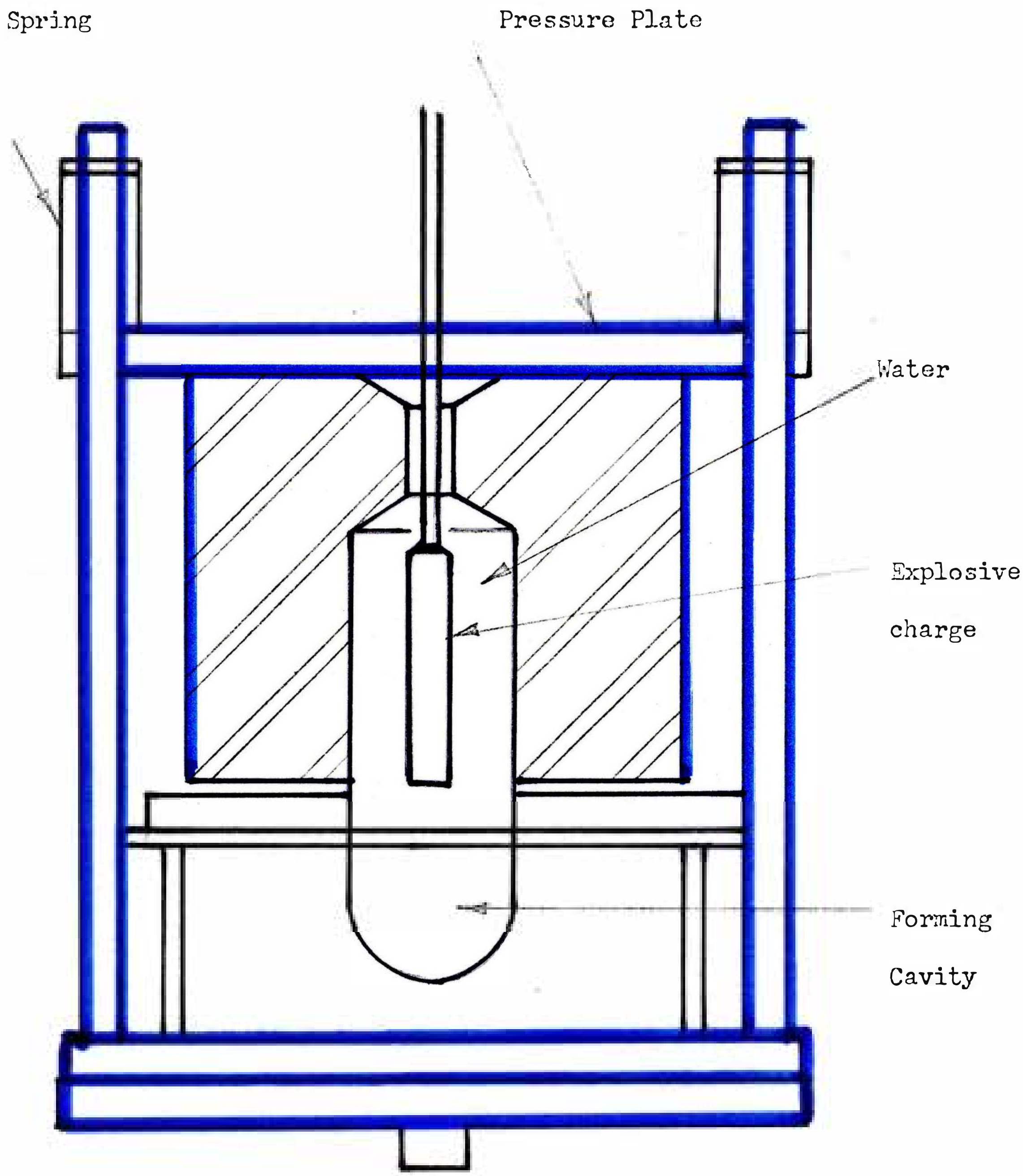

Figure 4. Equipment Used in Explosive Metals Forming

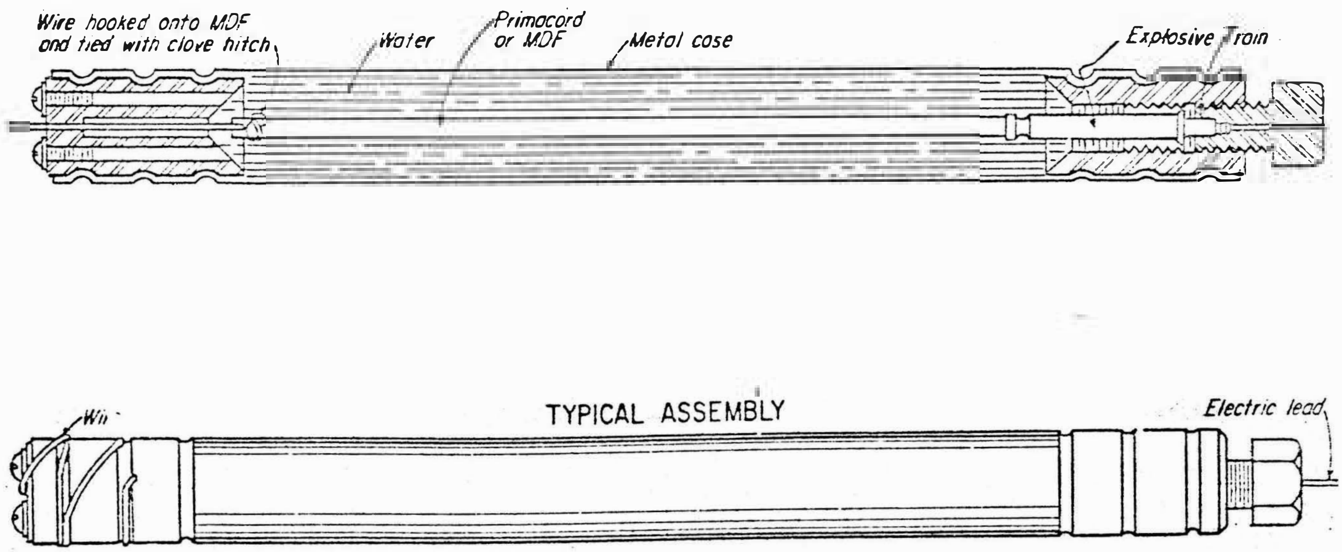

Figure 5. Free Forming Expand Tubes

Other similar experiment was performed for a perfect process that shall streighten and expand rocket-booster cases 18 inches in diameter and 11 feet long with tolerances of ± 0.02 were met.

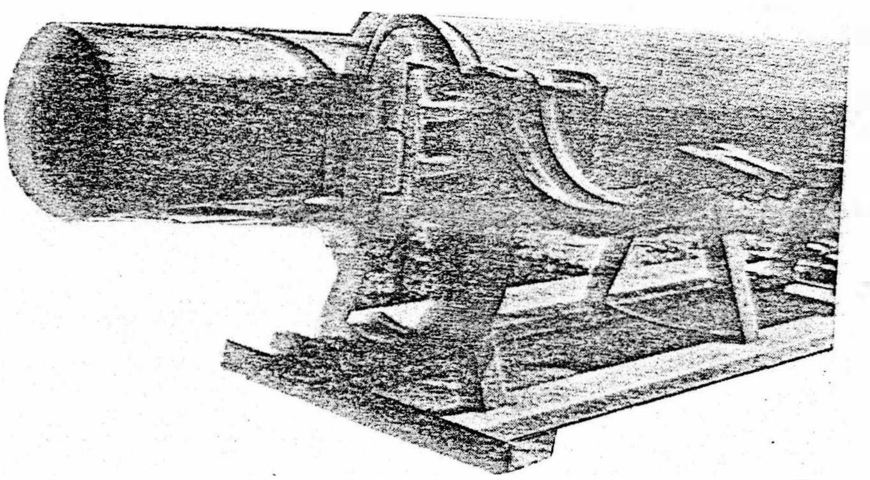

Figure 6. Expand Tube Die

Forces in the Explosion

The principal characteristic of the explosive charge is developed a great pressures in mileseconds, for this reason they are usually detonated in open systems. The explosive metalworking operations shall be divided in two groups, depending on the position of the explosive charge in relation to the workpiece. In the first group the charge is placed a determined distance from the workpiece and the energy from the explosion is transmitted through the medium, air, water and so on. This method is called standoff.

Table 1 shows the results of one experiment conducted for "Explosive Forming Laboratory - Burban".[3]

Table 1. Free-Forming Tests in Water with Three Gallon Steel Container at 6 Inch Standoff - 6 Inch Hemispherical Die - 6AL-4V Titanium

Data #	Explosive Weight (Grams)	Average Workpiece Thickness (Inches)	Condition	Draw Depth (Inches)	Remarks
1	6	0.028	Annealed	1.36	
2	7	0.026	Annealed	1.56	
3	10	0.027	Annealed	1.78	
4	12	0.026	Annealed	--	Shattered
5	10	0.061	Annealed	1.04	
6	16	0.060	Annealed	1.15	
7	18	0.062	Annealed	1.60	
8	16	0.061	Heat Treat	1.13	
9	17	0.060	Heat Treat	1.23	
10	17	0.056	Heat Treat	1.86	Fractured

[3] U. S. Department of Commerce, High Energy Metal Forming, Technical Report, 60-7-588, (October 1960), pp. 67.

In this table it can be observed ten items numbered from 1 to 10, the weight of the explosive charge, the thickness of workpiece, condition of material and the draw depth in inches. It is important to know the weight of the explosive because an excess of it can destroy the workpiece, and a few weight of it cannot perform the work. Figure 7 shows the equipment used for this experiment.

In the second group the explosive charge is placed in direct contact with the work and the generated pressures is about 4,000,000 psi. This tremendous pressure is only restricted by the surface of the workpiece. The disadvantage of the contact method is the danger in using such high force to perform the work.

The explosive charge may be used in open die forming under water, but in close die work careful measurements are necessary so as not to exceed the strength of the die. A formula for calculating safe pressure:

$$Pm = \frac{K\ (W/1/3)\ X}{R}$$

W = peak pressure

R = distance from the charge in feet

X = a constant for that explosive

K = a second constant for that explosive[4]

Importance of Explosive Charge Shape

With the RDX or P. E. T. N. pellets, the pressure obtained at explosion is inversely proportional to the cube of the distance between

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[4]Charles Honeywell, "High Energy Rate Forming," (Unpublished report at Morehead State University, 1967), pp. 5.

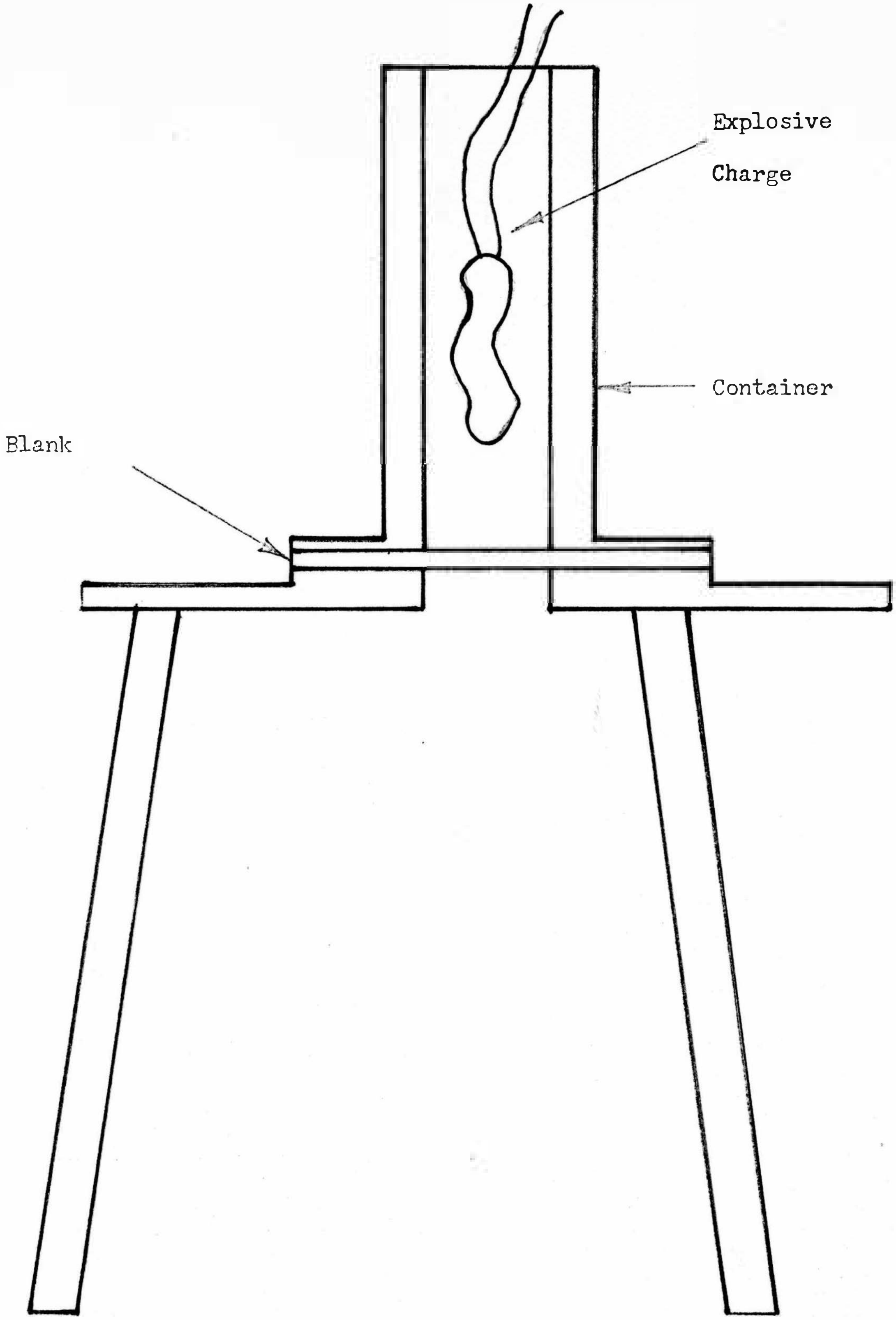

Figure 7. Free Forming Tool

the charge and the surface of the work.[5] With explosive cords or cylindrical forms (Primacord) the pressure are inversely to the square of the distance between the work and the charge.[6] Pressure develops with sheet explosive, decrease in direct proportion to increase standoff distance.

An indication of the pression used in explosive metal forming may be had from the following figure, Figure 8. In this figure the readers can see how the pressure drops as the result of increased distance from the explosive charge to the surface of the workpiece according to the shapes of charges.

Metal Used in Explosive Metal Forming

In this process it is possible to use most kinds of steels, including stainless compositions, titanium and its alloys, and many aluminum alloys are formed with explosives. The fascojet 1000 and AMS 6434 and 4340 have been explosively formed successfully although they still present problems in conventional forming. High nickel and high chrome steels have been formed from 0.040 to 0.500 in. For practical purposes most metals are in annealed state because they form easier and do harden when formed.

Perhaps there are no limitations on the thickness, size or strength of material to be formed. The frontier seems to be the ability of the explosive forming installation, to withstand the shock of the increased amount of explosive needed for producing bigger parts.

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[5]"Explosive Forming," American Machinist (June 15, 1959), pp. 132.

[6]Ibid.

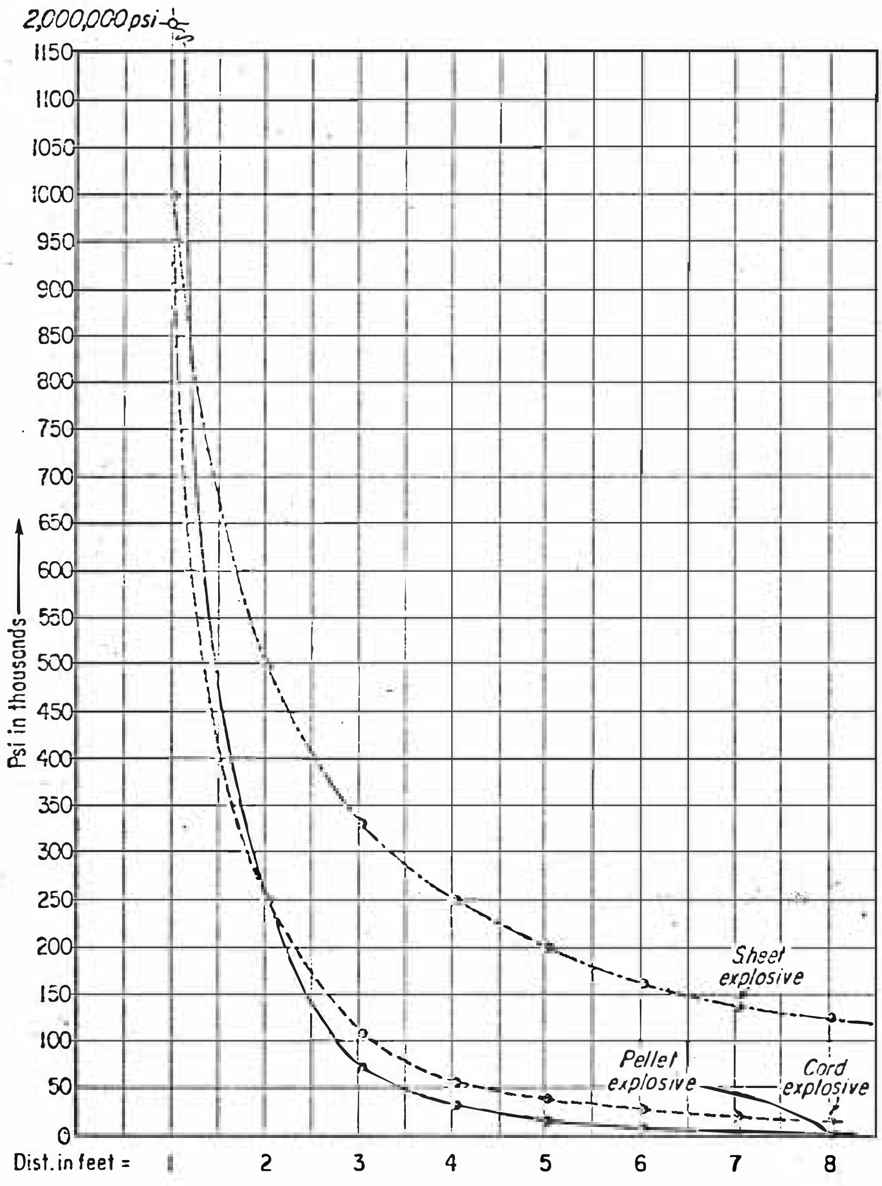

Figure 8. Pressure Drop

The Effect of the Explosive Forming Over the Properties of Materials

The effect of the instantaneous pressure generated by the explosive charge on the properties of materials is not quite known.

One theory states that when the metals are subjected to an impulsive load, the metals suffer a phase during which it behaves as a fluid, and while in this fluid condition, forms to the shape of the die. During the explosion, the metal undergoes severe plastic deformation. The metal behavior was sutdied by means of mathematical analogy based on a fluid model.

Some researchers with the use of microestructural techniques and high-speed photography revealed that the metals retain their ordered state during deformation and at no time during deformation does it assume the disordered state of a liquid. The metal suffered severe plastic demormation, which is caused by shear mechanisms that result in grain-boundry distortion, slip, and shock twinning.

Chapter 5

THE EXPERIMENT

Equipment

The equipment used in the experiment consist of: (1) Explosive chamber, (2) Die block, (3) Primacord, (4) Vacuum pump, (5) Blasting wire, and (6) Detonator device. This equipment was found in the Industrial Arts Department except for two dies, those were constructed for the writer.

Water was used as the shockwage medium and was placed into a plastic bag. The use of a plastic bag in order to contain the water was observed by the writer in one demonstration conducted for Dr. James La Rue. It is an easy method to hold the water without sealing the die block to the base of the explosive device. Figure 9 shows the equipment used.

The explosive charge consisted of eleven inches of Primacord because it is a safe explosive and was easy to obtain.

Safety Procedure

The blasting caps are packed in a separate container and are not carried or stored with the explosive charges. The electrical blasting caps are shorted at the end of the leads to prevent stray current from setting them off. To insure safe handling, the shorting device on the cap is not cut off until the charge is placed in the waterfilled chamber. The charge is immersed into the water, the shorting

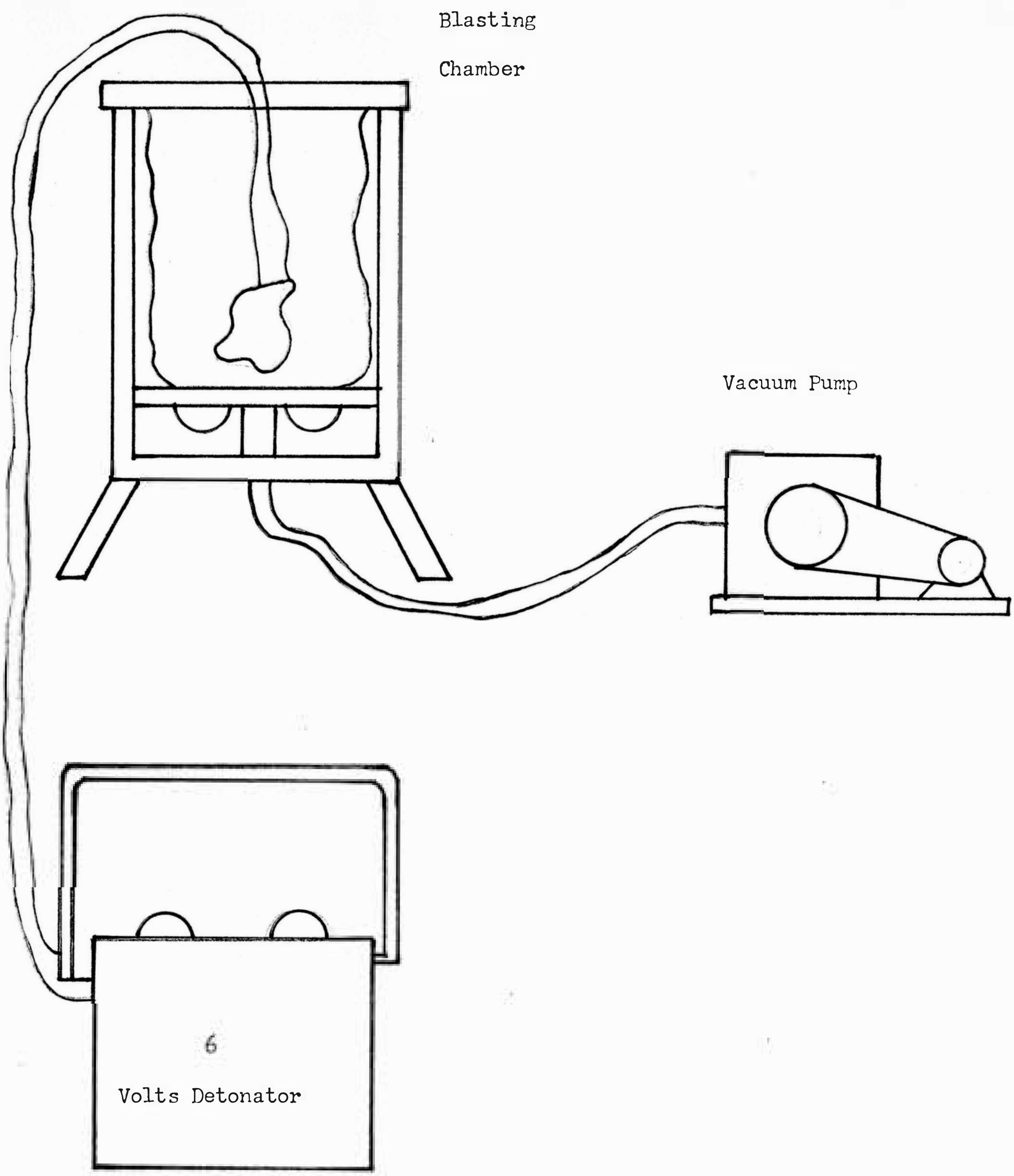

Figure 9. Equipment Used in the Demonstration

ends are cut off and the detonating wire is hooked up to the blasting cap. The detonating wire is not plugged into the detonating box until all is hooked up and ready to blast.

The blank was held on the die and this assembly was placed in the bottom of the chamber. The vacuum hose was connected to the chamber, and the plastic bag was placed in the chamber and filled with water. A wooden support was placed over the top of the chamber. The Primacord was placed three inches from the bottom of the chamber.

The cap leads are then cut, stripped and attached to the detonator leads. In the experiment 18 gauge aluminum blank was used with a charge of eleven inches of Primacord, the experiment was successful.

Chapter 6

INSTRUCTIONAL UNIT

The following unit is designed to present to the student a concept of what explosive metal forming is and how it fits into the industrial processes of today.

Objectives

1. At the end of the unit the student will be able to identify the different kinds of explosive charges used in explosive metal forming.

2. The student will be able to identify different kinds of equipment used in this process.

3. The students will be able to recognize safety precautions in conjunction with the use of explosive metal forming.

Course Outline

A. Introduction to unit.

   1. The difference between conventional and explosive metal forming process.
   2. Historical development of explosive metal forming.
   3. Industries utilizing explosive metal forming.

B. Technical aspects of explosive metal forming.

   1. Types of explosives.
   2. Forces and pressure.
   3. Shape of the charges.

6. Properties of metals.

7. Types of dies.

8. Economy of this process.

9. Safety precautions.

Teaching Class Method

Perhaps the most effective method for this class is a teacher demonstration, but the demonstration can be helped with a film, inquiry sheets, and class participation.

Evaluation

1. Written examinations.

2. Student's success in the application of the knowledge related to this matter.

3. Teacher's observations.

Chapter 7

SUMMARY

The explosive metal forming is perhaps one of the most revolutionary concepts in manufacturing technology since the advent of the space age.

The explosive metal forming has been discussed. The major points of consideration have been: die design, explosive charges and equipment, in order to find the best way for the industrial application.

Prospects for the technological future finds explosive metal forming in the center plans.

The aeronautical industries find they must utilize explosive metal forming in order to compete in machining and accuracy.

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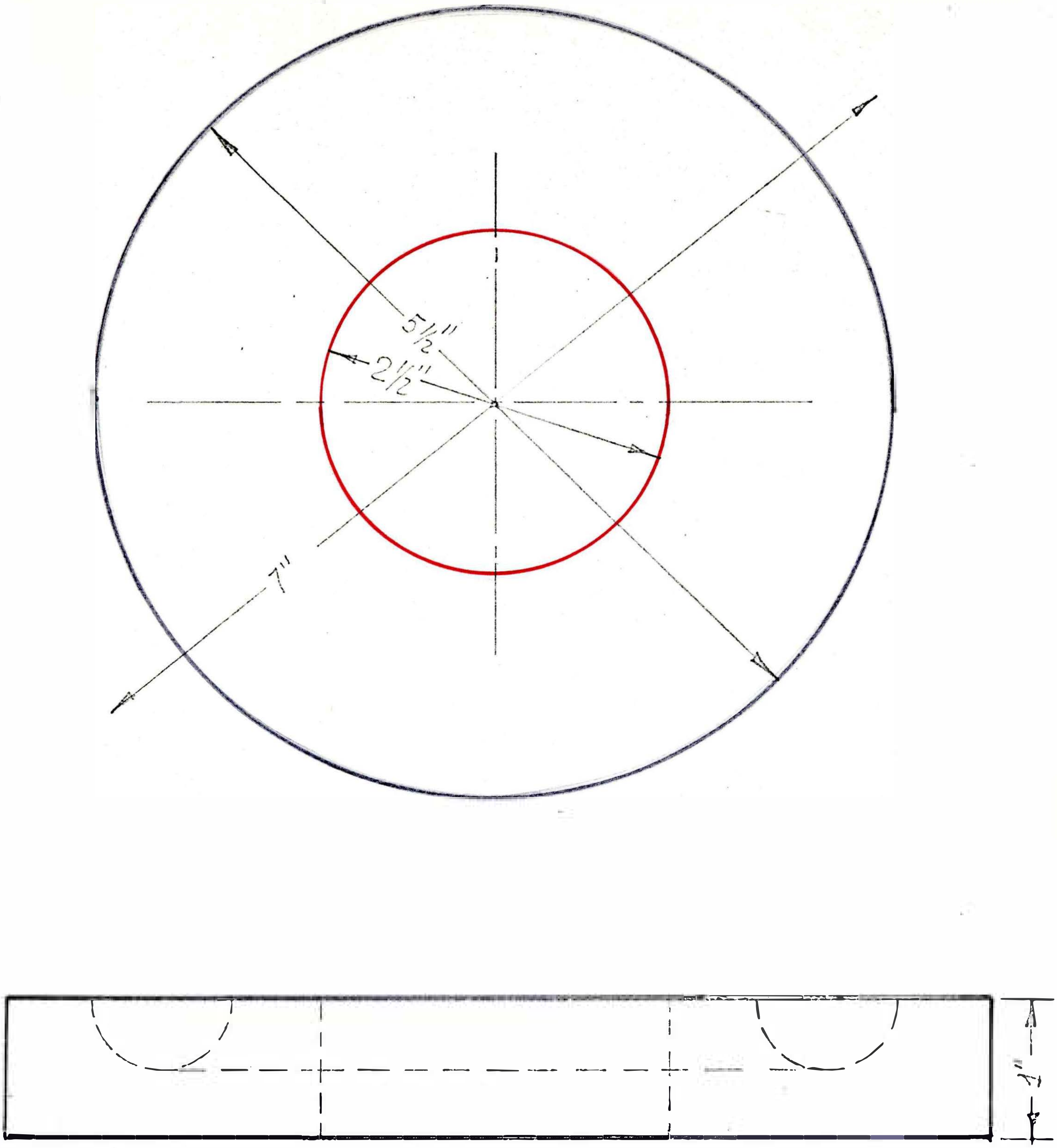
APPENDIXES

APPENDIX A

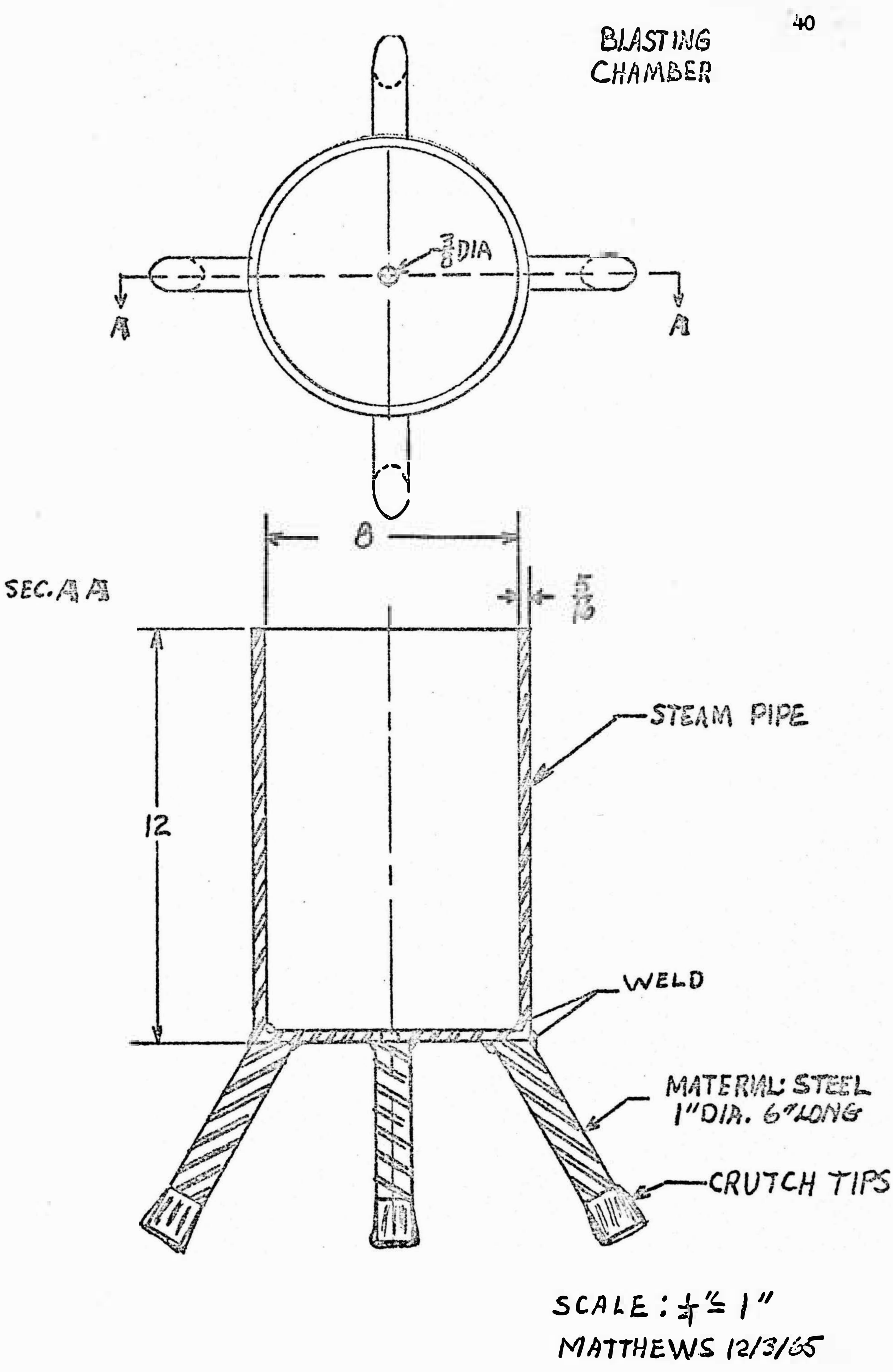
Forming Die



Forming Die

APPENDIX B

Blasting Chamber


BLASTING
CHAMBER
7/8 DIA
A
A
8
SEC. A A
5/16
12
STEAM PIPE
WELD
MATERIAL: STEEL
1" DIA. 6" LONG
CRUTCH TIPS
SCALE: 1/4" = 1"
MATTHEWS 12/3/65