UNCLASSIFIED

AD NUMBER
AD389296
CLASSIFICATION CHANGES
TO: unclassified
FROM: confidential
LIMITATION CHANGES
TO: Approved for public release, distribution unlimited
FROM: Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; AUG 1963. Other requests shall be referred to Army Materiel Command, Washington, DC 20315.
AUTHORITY
USAMDRC ltr, 3 May 1976; USAMDRC ltr, 26 Aug 1976

THIS PAGE IS UNCLASSIFIED

UNCLASSIFIED

AD 381 216L

CLASSIFICATION CHANGED
TO: UNCLASSIFIED
FROM: CONFIDENTIAL
AUTHORITY:

USAMDRC Ltr, 3 MAY 76

UNCLASSIFIED

SECURITY MARKING

The classified or limited status of this report applies to each page, unless otherwise marked.
Separate page printouts MUST be marked accordingly.

CONFIDENTIAL

AMC PAMPHLET **AMCP 706-215**

AD 389296

RESEARCH AND DEVELOPMENT OF MATERIEL

ENGINEERING DESIGN HANDBOOK

AMMUNITION SERIES

FUZES, PROXIMITY, ELECTRICAL

PART FIVE (U)

See inside back cover for information on previous publications.

HEADQUARTERS U. S. ARMY MATERIEL COMMAND **AUGUST 1963**

This material contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Sec 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

attn: AMCRD-TV
Wash, D.C. 20315

CONFIDENTIAL

GROUP 3
Downgraded at 12 year intervals; not automatically declassified.

HEADQUARTERS
UNITED STATES ARMY MATERIEL COMMAND
WASHINGTON 25, D. C.

20 August 1963

AMCP 706-215(C), Fuzes, Proximity, Electrical, Part Five (U), 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)

FOR THE COMMANDER:

SELWYN D. SMITH, JR.
Brigadier General, USA
Chief of Staff

OFFICIAL:

Pruett
R. O. DAVIDSON
Colonel, GS
Chief, Administrative Office

ENGINEERING DESIGN HANDBOOK

AMMUNITION SERIES

FUZES, PROXIMITY, ELECTRICAL

PART FIVE (U)

CONSISTING OF

CHAPTER 7-13

FOREWORD

The Ammunition Series is part of a group of handbooks covering the engineering principles and fundamental data needed in the development of Army materiel, which (as a group) constitutes the Engineering Design Handbook Series.

Fuzes, Proximity, Electrical comprises five numbered Parts, each of which is published as a separate volume and assigned an Army Materiel Command Pamphlet (AMCP) number. Arrangement into Parts and Chapters, with Chapter titles, is as follows:

AMCP 706-211(C), *Fuzes, Proximity, Electrical—Part One (U)*
- Chapter 1 —Introduction
- Chapter 2 —Philosophy of Fuze Design
- Glossary
- Index

AMCP 706-212(S), *Fuzes, Proximity, Electrical—Part Two (U)*
- Chapter 3 —VHF and UHF Radio Systems

AMCP 706-213(S), *Fuzes, Proximity, Electrical—Part Three (U)*
- Chapter 4 —Microwave Radio Systems

AMCP 706-214(S), *Fuzes, Proximity, Electrical—Part Four (U)*
- Chapter 5 —Nonradio Systems
- Chapter 6 —Multiple Fuzing

AMCP 706-215(C), *Fuzes, Proximity, Electrical—Part Five (U)*
- Chapter 7 —Power Supplies
- Chapter 8 —Safety and Arming Devices
- Chapter 9 —Components
- Chapter 10—Materials
- Chapter 11—Construction Techniques
- Chapter 12—Industrial Engineering
- Chapter 13—Testing

The purpose of these handbooks is twofold: (1) to provide basic design data for the experienced fuze designer, and (2) to acquaint new engineers in the fuze field with the basic principles and techniques of modern fuze design.

These handbooks present fundamental operating principles and design considerations for electrical fuzes and their components, with particular emphasis on proximity fuzes. Information on mechanical fuzes, and other general information on fuzes, is contained in AMCP 706-210, *Fuzes, General and Mechanical.*

As indicated by the Table of Contents, the arrangement of material is primarily topical. This permits ready reference to the area in which the user desires information.

Some subjects are covered in considerable detail, whereas others are covered only superficially. Generally, the amount of coverage is an indication of the state of development of a system. There are exceptions to this, however. For example, although the section on optical fuzing is comparatively extensive, this type of fuzing is not as far advanced as other methods of fuzing. Much of the information in this section, however, is based on an unpublished report. Rather than risk the loss of this information, and to disseminate it more widely, the information is included in these handbooks.

A Glossary is included in which terms that are unique to the fuze field, or that have special meaning in the fuze field, are defined.

References at the end of a chapter indicate the documents on which the chapter is based. They also furnish additional sources of information.

Titles and identifying numbers of specifications, standards, regulations and other official publications are given for the purpose of informing the user of the existence of these documents, however, he should make certain that he obtains editions that are current at the time of use.

Defense classifications are indicated for chapters, paragraphs, illustrations and tables. The degree of classification of the contents of each illustration or table is indicated by the appropriate initial symbol immediately preceding the title. In the case of classified illustrations or tables the classification of the title itself is indicated by appropriate initial symbol immediately after such title.

CONFIDENTIAL

These handbooks were prepared under the joint direction of the Harry Diamond Laboratories (formerly Diamond Ordnance Fuze Laboratories) and the Engineering Handbook Office, Duke University. Text material was prepared by Training Materials & Information Services, McGraw-Hill Book Company, Inc., under contracts with both of these organizations. Material for text and illustrations was made available through the cooperation of personnel of the Harry Diamond Laboratories. The operation of the Engineering Handbook Office of Duke University is by prime contract with the U. S. Army Research Office, Durham.

Comments on these handbooks should be addressed to Commanding Officer, Army Research Office, Durham, Box CM, Duke Station, Durham, N. C.

Per
Allen Black
originator
Duke U

CONFIDENTIAL

PREFACE

Part Five of this handbook contains Chapters 7 through 13. A Table of Contents for all Parts is also included. The Index and a Glossary, defining terms that are unique to, or that have special meaning in, the fuze field are included in Part One. Chapter 7 discusses the various types of power sources used in fuze design. Chapter 8 presents fuze safety concepts and describes the design of safety and arming devices. Chapter 9 gives a brief treatment and refers the reader to other literature concerning detonators and fuze components. Chapters 10, 11, 12, and 13 cover materials, construction techniques, industrial engineering, and testing, respectively.

TABLE OF CONTENTS

Paragraph *Page*

PART ONE

CHAPTER 1 (C) INTRODUCTION

CHAPTER 2 (C) PHILOSOPHY OF FUZE DESIGN

PART TWO

TABLE OF CONTENTS (cont'd)

Paragraph *Page*

CHAPTER 3 (S) VHF AND UHF RADIO SYSTEMS

TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (cont'd)

PART THREE

CHAPTER 4 (S) MICROWAVE RADIO SYSTEMS

TABLE OF CONTENTS (cont'd)

PART FOUR

TABLE OF CONTENTS (cont'd)

Paragraph *Page*

CHAPTER 5 (S) NONRADIO SYSTEMS

TABLE OF CONTENTS (cont'd)

Paragraph *Page*

TABLE OF CONTENTS (cont'd)

CHAPTER 6 (C) MULTIPLE FUZING

TABLE OF CONTENTS (cont'd)

PART FIVE

CHAPTER 7 (C) POWER SUPPLIES

CHAPTER 8 (C) SAFETY AND ARMING DEVICES

TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (cont'd)

Paragraph *Page*

CHAPTER 9 (U) COMPONENTS

CHAPTER 10 (U) MATERIALS

CHAPTER 11 (U) CONSTRUCTION TECHNIQUES

TABLE OF CONTENTS (cont'd)

CHAPTER 12 (U) INDUSTRIAL ENGINEERING

TABLE OF CONTENTS (cont'd)

Paragraph *Page*

CHAPTER 13 (U) TESTING

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (cont'd)

LIST OF TABLES

CHAPTER 7

(C) POWER SUPPLIES

7-1 (U) REQUIREMENTS FOR FUZE POWER SUPPLIES

An existing power supply seldom meets the requirements of a new fuze. Power supplies must usually be designed for specific fuze applications. Five basic requirements for all fuze power supplies, however, are as follows:

(1) Electrical. The power supply must provide electrical energy having certain current and voltage characteristics for a given period of time. Current and voltage requirements vary with the fuze design. Activation time (the time interval required for the power supply to reach its specified voltage and current rating after initiation) and active life are important considerations. Both of these vary depending upon the application. For example, artillery projectiles require power supplies that activate quickly, but their active life is measured in seconds. A short activation time is usually not required in long range guided missile fuzes, but an active life measured in minutes is generally needed. In some cases, activation time can be taken advantage of and used as an arming delay for safety.

(2) Size and Weight. Usually a power supply must fit into a very small space and its weight must not exceed a prescribed limit. Space and weight requirements are a function of the weapon and vary widely. Severe restrictions are usually placed on the size and weight of power supplies used in motar, artillery, and similar type projectiles. The restrictions placed on guided missile power supplies are usually less stringent.

(3) Environmental. The power supply must withstand the shock, vibration, ambient pressures, and temperatures to which it will be exposed in storage, transportation, and use. Operation in the −65° to 160°F range is normally required. Shock and vibration requirements are usually governed by the weapon's flight characteristics.

(4) Shelf life. The shelf life of a power supply is of great importance. To be of any value, a fuze power supply must furnish the required electrical energy on demand after many months or years of storage. Generators or reserve-type batteries are essential to meet this requirement. A reserve battery is inert during storage and is not activated until functioning of the weapon is desired. The shelf life of commercial active or ready-type batteries is too short for use in most fuze applications. Reserve-type batteries for fuze applications must be stored with the electrolyte in place. The electrolyte is generally in an inert state or is kept separated from the battery cells until the missile or projectile is launched. Reserve-type batteries in which the electrolyte is added just prior to launching a missile or projectile are unsuitable for fuze applications.

(5) Reliability. This is a critical requirement. Because of the tactical importance of assuring proper functioning at the right time, the power supply must approach 100% reliability.

7-2 (U) TYPES OF POWER SUPPLIES

The two broad classes of power supplies used in fuze applications are generators and batteries. Generators are operated by mechanical means. They may be wind-driven, gas-driven, spring-driven, or may be operated by the inertial forces of setback. Piezoelectric generators have also been used in fuze applications.

Batteries may be broken down into two broad categories: active or ready batteries and reserve batteries. Active or ready batteries are generally used for mine fuzes only. For other fuzing applications reserve-type batteries are preferred. For fuze applications, the entire battery must be in one container and must be capable of remote activation.

All batteries, except radioactive, generate power by electrochemical processes. The electrolyte may be either a solid or a liquid. The electrolyte in a thermal battery is a solid inert material which contains no water. It becomes active when heated to about 300°C. Reserve-type aqueous batteries have a solution of some chemical in water with the liquid solution hermetically sealed in a separate container until operation of the battery is desired.

7-3 (U) GENERATORS

7-3.1 (U) WIND-DRIVEN GENERATORS (Ref. 1)

Wind-driven generators can be used to provide power for fin-stabilized bomb, rocket, and mortar fuzes. Basically, the generators convert part of the kinetic energy of a projectile into electrical energy and thus eliminate the requirement for stored energy. Other advantages of a wind-driven generator are low cost, safety, and the fact that it withstands repeated testing. Its main weakness lies in the exposure of its moving parts. A wind vane may become fouled or damaged, or a shaft may be bent.

Direct-current type wind-driven generators are not feasible. Slip rings and brushes develop serious electrical noise problems, and, also, speed-voltage relationships are hard to regulate.

The alternator-type wind-driven generators overcome these defects. Electrical noise is reduced since the alternator does not require slip rings or brushes. The alternator also provides a reactance that can be used to obtain sufficient voltage regulation.

Typical mortar fuze and bomb fuze generators are shown in Figures 7-1 and 7-2, respectively. The mortar fuze generator delivers 2.75 watts and operates between 20,000 and 80,000 rpm. The bomb fuze generator delivers 40 watts when operating at 40,000 rpm.

Wind-driven generators reached a satisfactory stage of development and were produced in large numbers up until about 1948. They have now been superseded by reserve-type, electrochemical power supplies. A detailed discussion of this type of generator is given in Reference 2.

7-3.2 (U) GAS-DRIVEN GENERATORS (Ref. 3)

A typical gas-driven generator system consists of a solid propellant charge, an ignitor, a housing containing a nozzle, a turbine, an alternator, and rectifier, filter, and regulating networks. Systems that run from 10 to 90 sec and generate 50 to 100 watts of power have been designed and operated successfully. Probably the most successful gas-driven generator is used in the Navy's Sidewinder missile (Ref. 4). The Sidewinder power supply generates pneumatic power to drive torque motors for guidance in addition to providing electrical energy. The Sidewinder alternator is 1.5 in. in diameter and 1.5 in. long and has a useful output of 60 watts at 6,000 cps. The original Sidewinder power supply was required to run 10 seconds. This was later extended to 20 sec, and a system that will operate 1 minute was under development when this text was "frozen"; 1961.

Electrical components for gas-driven generating systems are easily designed. There are

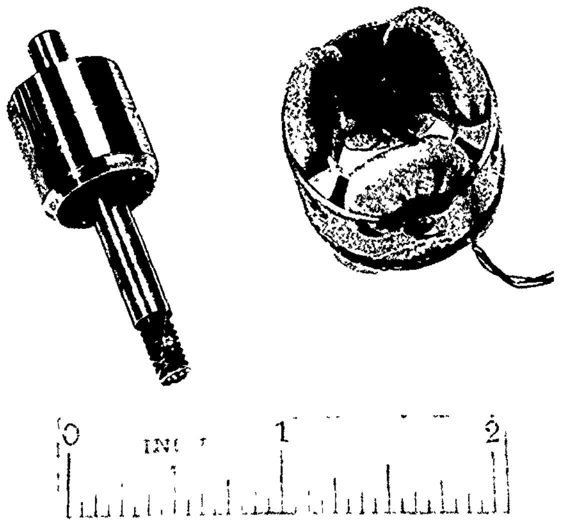


Figure 7-1 (U). Typical Wind-driven Generator for Mortar Fuzes

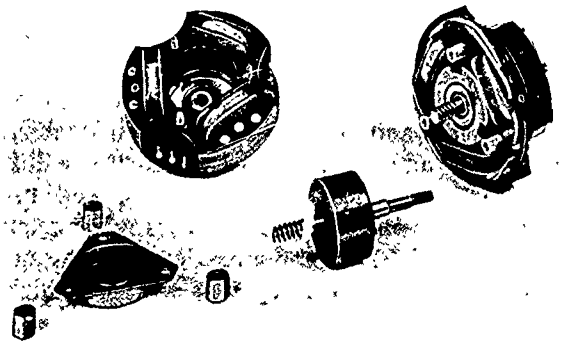


Figure 7-2 (U). Typical-driven Generator for Bomb Fuzes

difficulties, however, in obtaining propellants that will burn evenly, provide constant pressures, and burn at low rates over the temperature range of −65° to 160°F. Until considerable improvement takes place in propellants, the gas-driven power supply system has no particular advantage over other systems. For short operational periods (less than 5 minutes) the thermal battery is less complex and more reliable, although it cannot be tested nondestructively under load. For operating periods of 10 to 20 minutes, the reserve alkaline primary battery appears a better choice. Although the gas-driven alternator and its regulating circuits may be tested nondestructively, the propellant cannot. As far as weights and volumes are concerned there is little difference between thermal batteries, the reserve alkaline primary battery, and the gas-driven generator.

7-3.3 (U) PIEZOELECTRIC GENERATORS

Some crystalline substances such as barium titanate generate electrical energy when under pressure or stress. In certain cases, it is desirable to take advantage of this fact for fuzing projectiles. Piezoelectric power generation is covered in more detail in Chapter 5.

7-3.4 (U) INERTIA GENERATORS

An inertia generator consists basically of an Alnico magnet enclosed within a coil of many turns of fine wire. At setback the magnet is rapidly ejected from the coil and generates a voltage across the terminals of the coil. The voltage is applied across a capacitor to provide power to operate a fuze. This type of device was abandoned primarily because a suitable release mechanism, which would prevent the fuze from becoming accidentally armed if it was dropped, became too complicated.

7-3.5 (U) SPRING-DRIVEN GENERATORS

Spring-driven generators were investigated primarily for use with electrostatic fuzes. Energy produced by releasing a cocked spring drove a rotor for about 0.1 sec. Operation of the rotor developed a voltage that was used to charge a capacitor, which was then used to provide power for fuze circuits. This type of device was abandoned for the same reason as the inertia generator (paragraph 7-3.4).

7-4 (C) BATTERIES

(U) There are two broad categories of batteries: active (sometimes called ready) and reserve. In an active battery, electrochemical action is always taking place, whether the battery is in storage or operational use. In a reserve-type battery, however, no electrochemical action occurs until the time the battery is used. The electrolyte is distributed to the cells then, or is maintained in inactive form until activation is required.

Active batteries deteriorate rapidly at high temperatures; operate poorly, if at all, at low temperatures; and have a very limited shelf life. In addition, switches are usually required to provide safety when they are used. On the other hand, reserve batteries operate over a wide temperature range, have an excellent shelf life, and provide a high degree of safety. For this reason, they are used in almost all fuzing applications. An exception to this is mine fuzing. Reserve-type batteries are one-shot devices; that is, they cannot be activated, turned off, and then reactivated at some later time, which is required in most mine fuze applications. Also, mine fuze batteries usually require a much longer active life than can be provided by reserve type batteries.

7-4.1 (C) BATTERIES FOR GUIDED MISSILE APPLICATIONS

(U) Batteries for guided missile applications are generally required to deliver high power and have a relatively long active life. An active life of 1 to 3 minutes is typical, but in some applications an active life of 20 minutes or more is required. The following paragraphs discuss two types of batteries: the thermal battery and the silver oxide-zinc battery. Both are used in many present-day fuzing applications. Another type, the liquid ammonia battery, which is relatively new and appears to have direct application to guided missiles, is also discussed.

7-4.1.1 (C) Thermal Batteries (Ref. 5)

Thermal batteries are a rugged, efficient, and reliable reserve power source. They consist basically of a combination of primary voltaic cells with each cell having a negative electrode, a positive electrode, and an electrolyte. Negative electrodes are usually made of magnesium or calicum; positive electrodes of nickel and silver. A thermal battery contains no water. The electrolyte is a solid material such as lithium chloride, potassium chloride eutectic, or the equivalent bromide eutectic. The electrolyte is carried in Fiberglas or asbestos tape that also separates the electrodes of the cell. During storage the electrolyte is in an inactive solid state. When heat is applied to the electrolyte, and it reaches a temperature between about 275° and 375°C, it becomes a liquid ionic conductor. A complete thermal power supply contains an integral source of heat that is inert until required for operation. One way of providing heat is to surround the individual cells with a pyrotechnic material.

Several actions take place in a typical thermal power supply to produce useful voltage and current. An electric match initiates the power system, and in a matter of milliseconds the pyrotechnic paper is ignited. A few tenths of a second later combustion is complete, and sufficient heat is transferred to the voltaic cells so that the electrolyte is fused. As internal resistance is reduced, terminal voltage increases, and useful current can then be drawn from the supply. Since the action of the heat source is irreversible, any pretesting for performance of the completed unit is precluded. This is the main disadvantage of thermal batteries.

No one thermal battery can satisfy all requirements over the wide range of missile applications. Physical and operating characteristics for several thermal batteries are given in Table 7-1. Some of the batteries listed were not designed specifically for guided missile applications: however, they indicate the variety of thermal batteries available.

Important characteristics to be considered when selecting thermal batteries for fuzes are activation time, active life, temperature, ruggedness, voltage, current, and size and weight. A brief discussion of each follows.

7-4.1.1.1 (U) Activation time

A thermal battery is normally inactive because of the inert containment of the electrolyte. To activate it, an initiating force is required. Primers, electric matches, or internal starters are the usual activating agents.

The time required to activate a battery varies from a few tenths of a second to several seconds. In general, the greater the permissible activation time, the longer the battery life. Small batteries are activated in about 1 sec or less, larger ones take from about 2 to 8 sec.

7-4.1.1.2 (U) Active life

The maximum life of present thermal batteries is about 10 minutes, although a life of about 15 minutes is considered feasible. The active life of the average battery is largely controlled by thermal rather than chemical considerations. The space available for thermal insulation is, therefore, important for a long-life battery.

7-4.1.1.3 (U) Temperature

Thermal batteries perform satisfactorily in the −65° to +160°F temperature range providing the battery activation temperature reaches 400°C (752°F) or higher. Over a given temperature range, one particular operating temperature generally gives the most efficient performance. This operating temperature can be obtained by varying the heat input of the battery, and in this manner optimum performance can be attained for either very low or very high environmental temperature ranges.

7-4.1.1.4 (U) Ruggedness

Thermal batteries are inherently rugged since they have no moving parts and do not rely on the displacement of materials. Some thermal batteries withstand more than 10,000 g. With proper construction, all thermal batteries can withstand normal vibration and shock environments.

7-4.1.1.5 (C) Output voltage

An individual thermal cell produces an output voltage of between 1 and 3 volts. The battery voltages available are multiples of the single cell voltage. This in turn is not infinitely variable. There are discrete levels, depending upon the battery system used. Thermal batteries with voltages up to 2,500 volts have been produced. Overall weight and bulk considerations make it impractical, however, to attempt higher outputs.

TABLE 7-1 (C). Operating and Physical Characteristics of Typical Thermal Batteries (U)

Voltage (volts)	*Current (amperes)*	*Activation Time (seconds)*	*Active Life (seconds)*	*Initiation Method*	*Size (inches)*	*Weight (pounds)*
1.5		0.33	15	Primer	0.5 x 0.5**	
1.5 150 *	0.450 0.012	2.0 5.0	45	Inertia Match	1.62 x 1.59**	0.28
1.5 145 * 8.5	0.450 0.012 0.0001	0.5	20	Primer	1.35 x 1.62**	0.25
6.0	5.0	1.5	30	Primer	1.62 x 1.31**	0.44
6 28 * 6	4.5 4.5 4.5	8.0	480	Electrical	5.69 x 3.69 x 6.38	10.0
12	20.0	0.3	1	Primer	1.62 x 1.0**	0.20
28	4.5	0.8	60	Electrical	3 x 3**	1.34
350	0.090	1.0	60	Electrical	3.48 x 3.0**	1.56
600	0.001	1.0	180	Electrical	3.19 x 1.62**	0.57

* Single package
** Diameter of cylindrical package

The noise produced by thermal batteries is quite low compared to that produced by conventional batteries. Thermal batteries with outputs of 600 volts produce a noise level of about 10 mv; conventional batteries produce this noise level at outputs of about 150 volts.

Thermal batteries lasting about a minute have a voltage regulation of ± 5%, which is satisfactory for fuzing applications. Similar data for batteries with longer active life are not currently available.

7-4.1.1.6 (C) Output current

Low voltage, short-life cells have been designed that are capable of supplying up to 100 amperes. The present B-type thermal batteries can provide up to 100 milliamperes. Figure 7-3 shows the current behavior for a compact, lightweight thermal battery that measures only 2-1/2 in. in diameter and 1 in. high and weighs only 5 ounces. The battery produces a peak discharge current of 10 amperes with a reasonably flat response (within 0.1 volt). Activation times to reach the operating voltage of 1.8 volts is about 5 sec; the battery life is about 1-1/2 minutes.

7-4.1.1.7 (C) Shelf life

The storage characteristics of thermal batteries are better than those of any other type battery for fuze applications. Tests indicate that hermetically sealed thermal batteries normally remain in good condition for at least four years. Thermal batteries in storage deteriorate very little unless they are subject to a temperature of 250°F or more. In actual storage this temperature rarely occurs.

Two views of a hermetically sealed thermal battery before and after use are shown in Figure 7-4. Pressure seals prevent chemical reactions with atmospheric constituents during storage.

7-4.1.2 (U) Silver-Oxide Zinc Batteries (Refs. 6, 7)

Silver-oxide zinc reserve batteries provide a primary power source for surface-target guided missile fuzes. They are an alternate to thermal batteries and should be considered for low-voltage, high-power applications. Their volume efficiencies are 5 to 10 times greater than those of other batteries, but since their capacity decreases rapidly below 30°F, they require integral heating units for operation at low temperatures. Silver-zinc cells deliver about 60 w-hr/lb and 3 w-hr/in.^{3}. Cell voltage under load is 1.5, whereas maximum current density is about 2.5 a/in.^{2} of projected plate area.

Silver-zinc batteries may be activated by an electrical command signal and have an active life of a few hours at normal temperatures. The shelf life of reserve-type silver-zinc batteries is believed to be greater than five years.

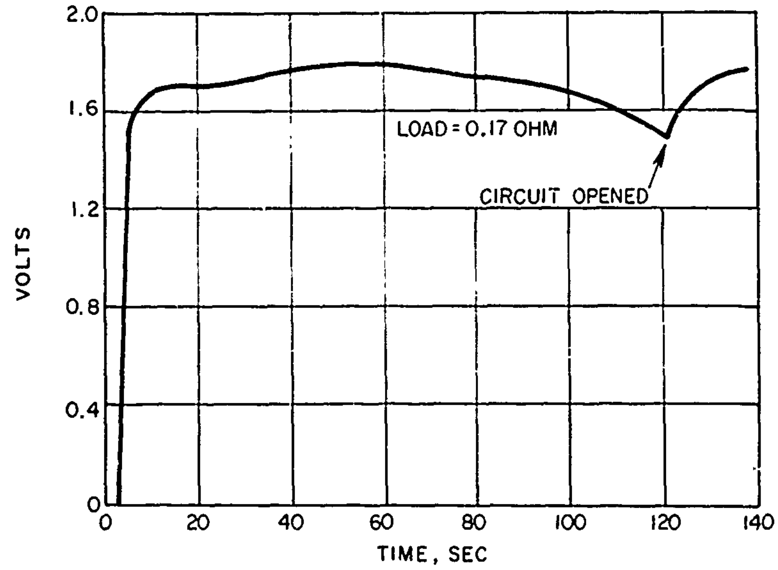


Figure 7-3 (C). Thermal Battery Current Behavior Curve (U)

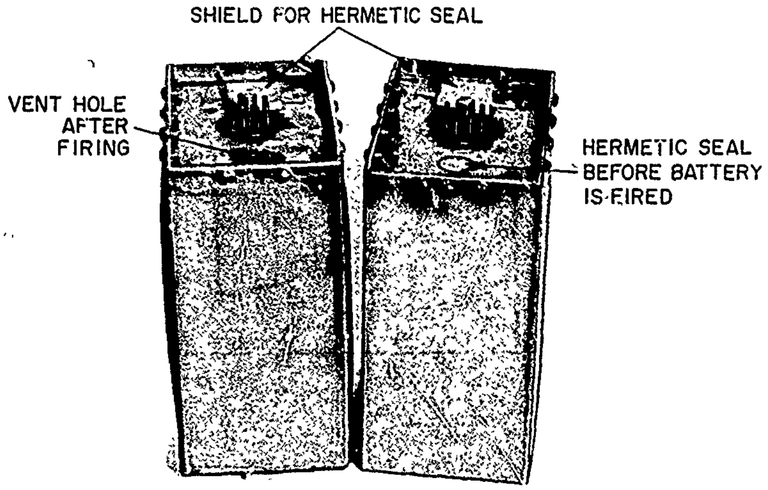


Figure 7-4 (U). Thermal Power Supplies with Pressure Sensitive Seals

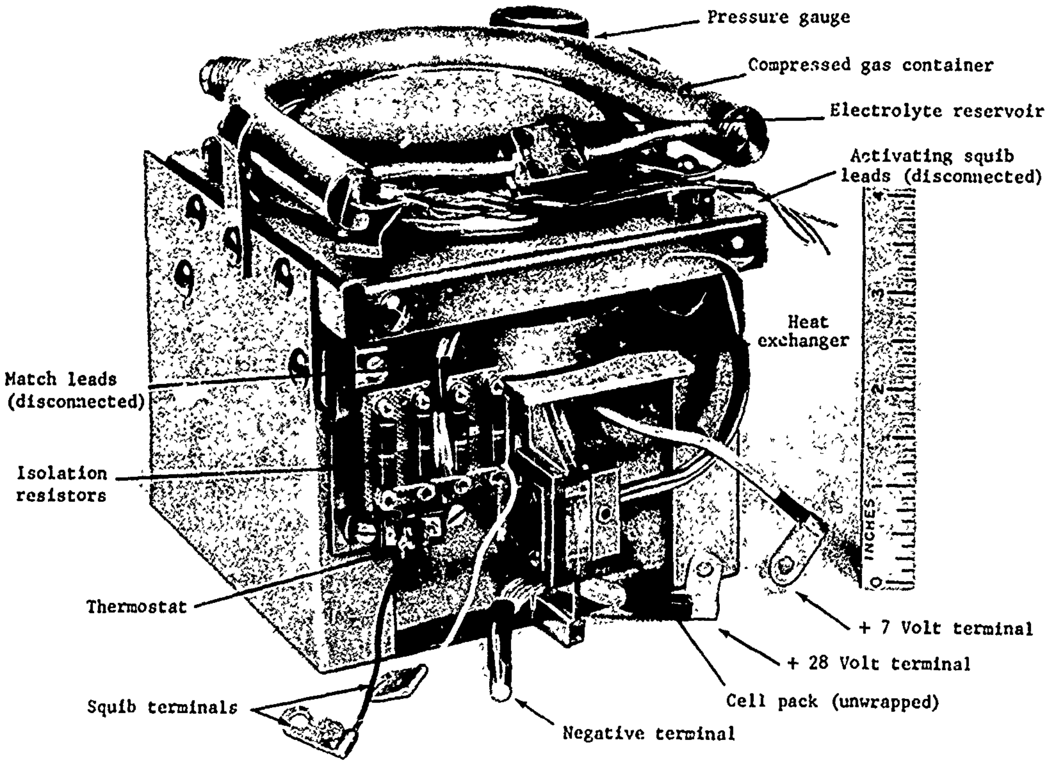


Figure 7-5 (U). PS-502A Silver-zinc Power Supply

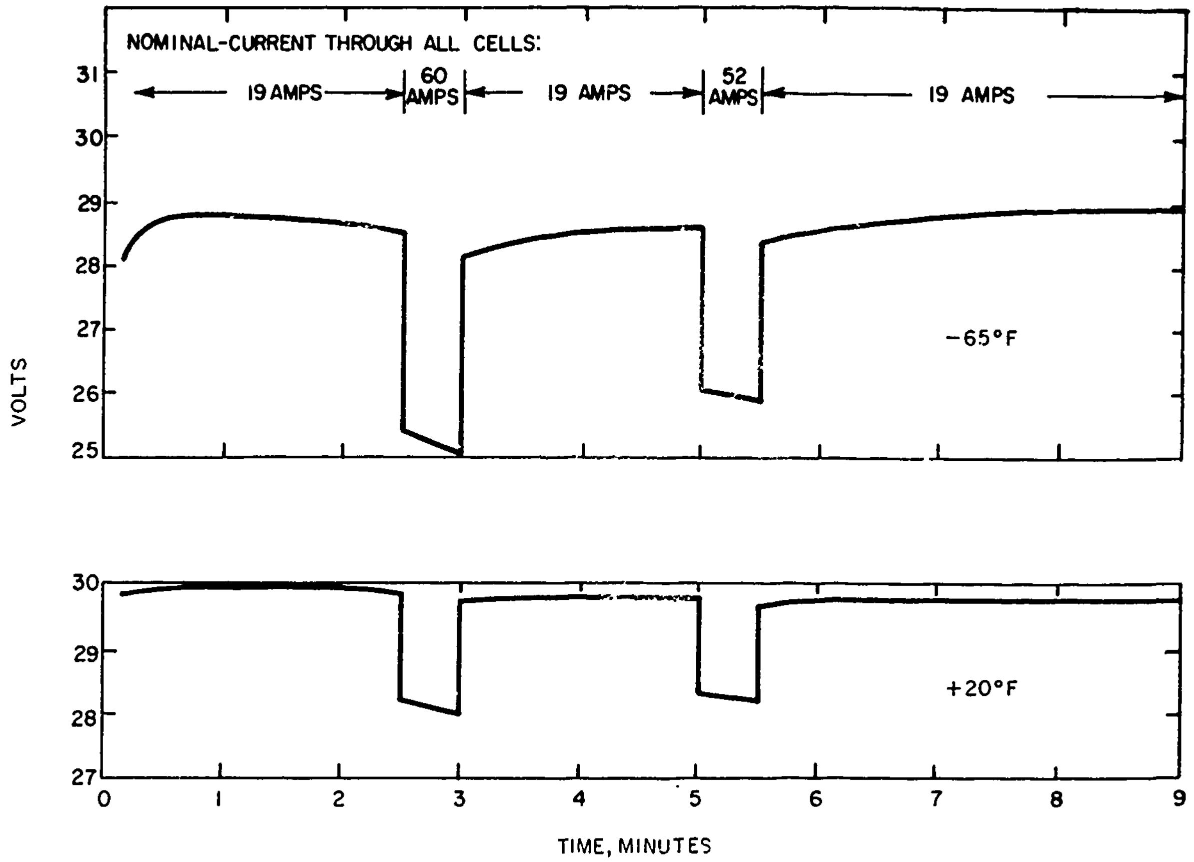


Figure 7-6 (U). Performance of Silver-zinc Power Supply Under Heavy Current Drain (−65° and +20°F)

Figure 7-5 shows the PS-502A silver-zinc power supply developed for guided missile application. The supply is about the size of a 6-in. cube, and weighs about 12.5 lb. It is a 28-volt battery and delivers up to 60 amperes with less than a 4-volt drop in output voltage throughout its operating range of —65° to 165°F. The performance of the battery under heavy current drain is shown in Figures 7-6 and 7-7.

The operation of the silver-zinc power supply is shown in Figure 7-8. An initiating command fires two squibs which release pressurized nitrogen gas into the electrolyte reservoir, forcing the 31% water solution of potassium hydroxide electrolyte through the heat exchanger and into the cell pack. Twenty cells, connected in series, are filled through a common manifold. Air within the cells is not bled off but is compressed by the influx of potassium hydroxide. The back pressure equalizes the volume entering each cell and makes resistance to flow uniform.

The heat exchanger contains a heat powder which releases about 40,000 calories in less than 0.5 sec to warm the electrolyte when the power supply is activated at low temperatures. If ambient temperature at the time of initiation is below 25°F, a thermostatic switch between the signal-input terminals and two electric matches is closed, allowing the command signal to initiate the squibs and matches simultaneously. The matches, in turn, ignite the heat powder, which warms the electrolyte passing through a copper tube to the cell pack. The cells can deliver full power in 1 to 10 sec.

Although relatively complex and expensive, the power supply is made of noncritical materials. Its reliability is high, and it can be activated by a low-energy command signal. Present design efforts are directed at decreasing the

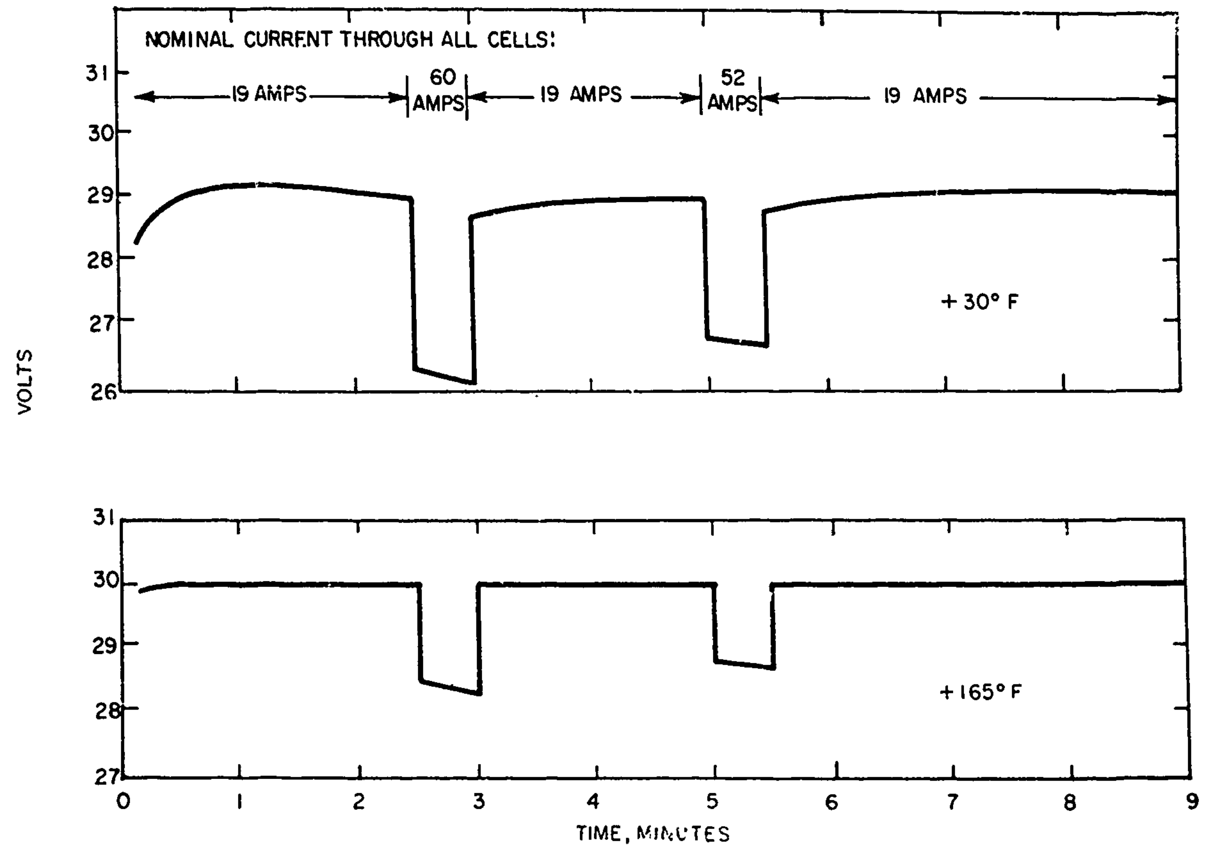


Figure 7-7 (U). Performance of Silver-zinc Power Supply Under Heavy Current Drain (+ 30° and — 165°F)

complexity, cost, and weight of the unit and eliminating the need for heat for low-temperature operation.

7-4.1.3 (U) Liquid Ammonia Batteries

Liquid ammonia batteries are being investigated as this is being written (1961). They appear to have excellent low-temperature operation characteristics, and may be suitable for fuze application. No further information is available at the time of this writing. Ammonia-vapor batteries have been investigated (Ref. 8), but they do not appear suitable for fuze applications.

7-4.2 (C) BATTERIES FOR ROTATING PROJECTILES

(U) Rotating projectiles, such as antiaircraft projectiles, field artillery projectiles, and many rockets, use reserve-type aqueous batteries almost exclusively. An aqueous battery is one in which the electrolyte is in liquid form during both storage and operational use. Carbon-zinc batteries and lead-lead dioxide batteries are the two main types used in rotating projectile applications.

A typical battery is shown in Figure 7-9. As in all batteries of this type, the electrolyte is contained in a glass or plastic ampule. When a projectile is fired, the ampule is broken by a setback-operated device, or in applications where the projectile experiences low setback force, by a mechanically-operated spin breaker. As the projectile spins, centrifugal force distributes the electrolyte between the plates, thus energizing the battery.

The battery shown in Figure 7-9 uses half plates. Other types of batteries have been constructed, however, using radial plates, involute plates, and annular plates.

Typical characteristics of aqueous batteries used in rotating projectile applications are discussed in the following paragraphs.

7-4.2.1 (C) Operating Temperature

The operating range of carbon-zinc batteries is from about +10° to +120°F. The lead-lead dioxide battery operates over a range of about −40° to +160°F. Both types will operate at temperatures lower than the minimum temperature specified, although degradation of performance will result. Activation time will increase greatly as the operating temperature decreases below the minimum operating temperature; output voltage, active life will decrease.

7-4.2.2 (C) Activation Time and Active Life

Activation time for both types of batteries is a function of temperature. Within the temperature limits of the batteries, however, activation requires about 0.2 sec. Rotating projectiles normally do not require a long active life. Both types of batteries can be made with an active life of a few seconds up to about 120 sec.

7-4.2.3 (C) Voltage and Current Capacity

The A section of a typical aqueous battery produces about 1.4 to 1.7 volts and can provide a maximum current of about 1 ampere. The B

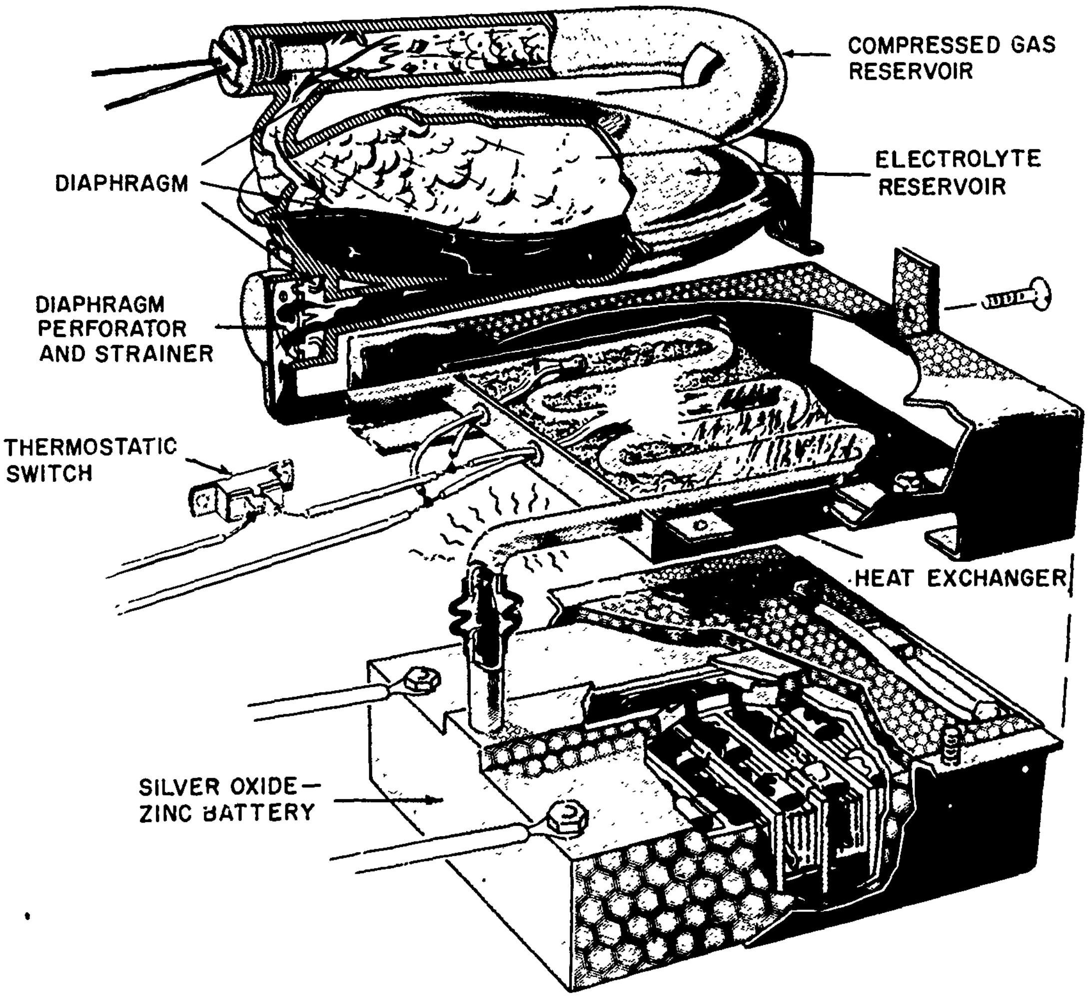


Figure 7-8 (U). Operation of Silver-zinc Battery

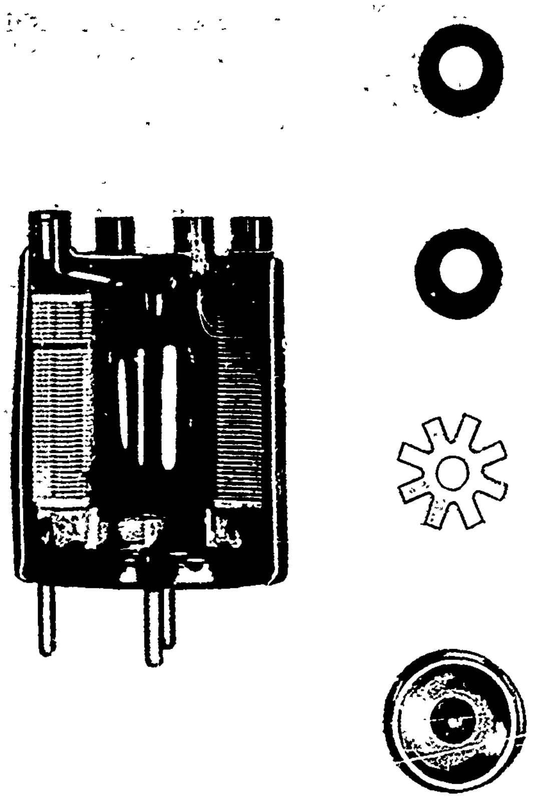


Figure 7-9 (U). Typical Aqueous-type Battery for Rotating Projectiles

section is usually required to produce about 90 volts for most applications at a maximum current of about 20 milliamperes. For the C section, a voltage of —6.5 volts is typical at a maximum current of about 10 milliamperes. Actually, voltages and currents considerably higher than these can be obtained by connecting more cells. The size of the battery, however, becomes an important factor as more and more cells are connected.

7-4.2.4 (C) Noise

Electrical noise generated within the battery ranges from about 1 to 25 millivolts. For most batteries however, it is less than 5 millivolts.

7-4.2.5 (C) Minimum Spin and Setback Required for Activation

The minimum spin required for proper diffusion of the electrolyte is about 25 rps. For batteries that are initiated by setback, a minimum setback of approximately 1600 g is required to break the ampule containing the electrolyte. For batteries equipped with spin breakers no setback force is required to break the ampule.

7-4.3 (U) BATTERIES FOR NONROTATING PROJECTILES

Nonrotating projectiles, such as mortar projectiles and bombs, generally use thermal batteries to provide fuze power. Thermal batteries used in nonrotating projectile applications are characterized by small size, fast activation time, and short active life. They are of rather low power, when compared with thermal batteries used in guided missile applications. Thermal batteries are discussed in detail in paragraph 7-4.1.1.

7-4.4 (C) BATTERIES FOR LAND MINE FUZE APPLICATIONS (Ref. 9)

Batteries considered for fuzes of this type must meet certain stringent conditions. They must supply voltage over a wide range of temperature, have a long shelf life, and be able to supply ample energy for days, and sometimes weeks or months, after the fuze has been armed. Wherever possible, fuzes are designed to use a passive detector, i.e., a continual power supply is not required by the sensing and firing elements.

The energy required from the battery is extremely small. A hundred to a thousand ergs is all that is necessary to initiate firing of the explosive charge. Circuits can be designed that connect only the insulation of the fuze as a load on the battery. Thus, the drain is only a little greater than that normally flowing through the insulation of the battery itself. The effect of moisture on the insulating properties of the components does become a serious problem. It can be solved by proper plotting, seals, and metallic vapor barriers. Essentially then, the life of a battery is the primary consideration. In addition to supplying this minute current, it needs only to maintain a charge on a capacitor with a very high insulation resistance. The following paragraphs discuss some of the batteries considered for mine fuze applications. All are of the active type since, at this time (1961), reserve-type batteries do not appear suitable for this fuze application.

7-4.4.1 (C) Radioactive Batteries (Ref. 10)

Radioactive batteries have direct application to mine fuzing. They can be used to maintain the charge on a capacitor and, if sufficient time is available, the battery can be used to charge the capacitor directly. They can also be used as long interval timers to provide sterilization of mine fuzes. Interval timers have been constructed to measure time intervals of a few hours to many days.

There are other possible fuzing applications of radioactive batteries: to provide power for electrostatic fuzes; to provide self-destruction in many types of fuzes; and to provide arming delays.

Radioactive materials, decaying through an alpha or beta emission process, eject particles that carry an electrical charge. A radioactive battery is essentially a device that provides for the collection of these charged particles and permits utilization of the accumulated electrical energy.

In its simplest form, a radioactive battery consists of an electrode coated with active material, separated by a dielectric from another electrode which traps and accumulates the charged particles. It can be considered as a selfcharging capacitor, or as a voltage or current source, with the maximum voltage and total charge being determined by the amount and type of radioactive material used, the size of the electrodes, the dielectric material used, and the electrical leakage of the battery and its associated circuits.

For maximum efficiency, radioactive batteries require an active material as a point source of radiation, suspended by an insulated lead in the center of an evacuated sphere. Under these conditions, all emitted particles reach the collector, and a potential difference between the insulated lead and metal sphere would develop at a rate dependent upon the rate of emission of the charged particles. For ruggedness and simplicity of construction, however, it is considered impractical to use either a vacuum dielectric or a spherical shape. Available batteries are cylindrical with polystyrene as the dielectric material. Strontium 90 (SR^{90}), which has a 25-year half-life, is used as the radioactive material.

Radioactive batteries have many important advantages. They are small in size, light in weight, and SR^{90} is plentiful since it is a byproduct of pile operation. Other components of the battery are easily assembled and are relatively cheap. Units can be mass produced with few facilities and little cost for special tooling. Radioactive batteries are rugged enough to withstand 20,000-g acceleration. They have no moving parts or voids, and the only activation problem is one of switching. Other advantages are that the rate of radiation changes only with time, and the power supply is independent of both pressure and temperature, except as the dielectric is affected.

Radioactive batteries also have a number of disadvantages. The ability of dielectrics to withstand radiation for long periods has not been proven, and the deteriorating effect of aging and temperature variations on dielectrics is considerable. Since SR^{90} has a half-life of 25 years, there is a 50% reduction in current at the end of 25 years when it may be needed for use. Due to the low current drains permissible, all circuit elements must have high leakage resistance (10^{11} ohms or better). Since the unit is normally used with a charged capacitor, the problem of premature functioning requires safety devices. Another disadvantage is the question of the tactical use of radioactive material in any significant quantity, as well as the use of the battery adjacent to other radioactive materials.

7-4.4.2 (C) Zamboni Pile

A Zamboni pile battery consists of a layer of paper on one side of which is a thin layer of aluminum and on the other side a mix of manganese dioxide, carbon, aluminum chloride, and a very small quantity of water and ethylene glycol. Discs are cut from a sheet of paper so treated and stacked one upon the other. Approximately 1.1 volts is obtained from each of these discs. When stacked together to give a pile two inches in height, a battery of over 200 volts is obtained. The batteries promise to give very long shelf life because they are exceedingly dry, but they are incapable of supplying heavy currents. In mine fuze circuits, however, there is no requirement for a heavy continuous current, and thus it is permissible to use batteries of the Zamboni type.

Zamboni piles have been tested under various conditions and appear to maintain their open circuit voltage down to temperatures that will be encountered in operation. However, there is some doubt because of the high internal impedance of the Zamboni piles at low temperatures that they can deliver even the small current required for some mine fuze applications. Provisions would have to be made to maintain the standby current drain from the Zamboni pile to a negligible value to keep the 395A gas triode tubes, which are used extensively in mine fuzes, in a sensitive state.

7-4.4.3 (C) Mercury Batteries (Ref. 9)

Commercially available mercury cells having a shelf life from 5 to 10 years and capable of supplying ample energy over the temperature range likely to be encountered could be used in mine fuze applications. However, their cost appears to be excessive. A possible method of overcoming this high cost is to employ an inductive "kick-back" circuit to obtain high voltage from a single mercury cell.

Inductive kick-back is accomplished by connecting the cell in series with an inductance and a vibration-operated switch, such as the reed or seismometer systems described in paragraph 5-11. Under the influence of vehicle-produced vibrations, the switch closes and opens establishing and then breaking a current in the inductance. The current decay in the inductance produces a high voltage, with a peak value approximately equal to the ratio of the resistance across the inductance and the resistance in the inductance proper. Therefore, the external resistance must be large in comparison to that of the inductor. Several hundred volts can be produced across the inductance with a source having an e.m.f. of only 1.3 volts.

If a capacitor and rectifier with a high back resistance are connected across the coil, high voltage energy can be stored in the capacitor. This capacitor then functions in the same manner in fuze operations as it would in conjunction with a Zamboni pile.

(U) REFERENCES

1. G. L. Scillian, *Miniature Alternators for Proximity Fuzes,* Paper, Symposium on Auxiliary Power for Guided Missiles, Report CES 212/4, Volume II, OASD Research and Development, 5-7 February 1957. (CONFIDENTIAL)
2. *Radio Proximity Fuze for Fin-Stabilized Projectiles,* Report of NDRC Division 4, Vol. I, Office of Scientific Research and Development, 1946.
3. G. L. Scillian, *Gas-Driven Alternators for Fuze Power,* Report TR-813, Diamond Ordnance Fuze Laboratories, 9 March 1960. (CONFIDENTIAL)
4. L. Lorant and N. Johnson, *Sidewinder Turbine-Driven Generator.* Paper, Symposium on Auxiliary Power for Guided Missiles, Report CES 212/4, Volume II, OASD Research and Development, 5-7 February 1957. (CONFIDENTIAL)
5. This section based on:

   Thermal Batteries, Technical Report-155, Diamond Ordnance Fuze Laboratories, Dept. of the Army, 14 March 1955.

   Thermal Batteries, Report 13/7-93R, National Bureau of Standards, Ordnance Components Section, Ordnance Development Division, 11 December 1950. (CONFIDENTIAL)

   Reliability in Thermal Power Supplies for Guided Missile Fuzes (C) DOFL Report R22-57-7, Diamond Ordnance Fuze Laboratories, Dept. of the Army, 14 August 1957. (CONFIDENTIAL)

   Evaluation of a 350-Volt Thermal Battery for Guided Missile Fuzing Applications (C), Technical Report TR-401, Diamond Ordnance Fuze Laboratories, 13 November 1956. (CONFIDENTIAL)

   Development of Thermal Power Supply for Surface-Target Fuzing Applications (C), Technical Report TR-169, Diamond Ordnance Fuze Laboratories, 3 May 1955. (CONFIDENTIAL)
6. *Reserve Primary Power Supply Development for Fuzing and Warhead Applications on the Redstone Missile,* Report TR-523, Diamond Ordnance Fuze Laboratories.
7. *An Automatically Activated Silver-Zinc Power Supply for Radar Fuzes,* Report TR-665, Diamond Ordnance Fuze Laboratories, 6 February 1959.
8. *Application of Ammonia Vapor Activated (AVA) Battery Systems to Guided Missiles Power Supplies,* Eastman Kodak Company, Apparatus and Optical Division, Paper presented at Symposium on Auxiliary Power for Guided Missiles, Report CES 212/4, Office of Assistant Secretary of Defense. (CONFIDENTIAL)
9. A. G. McNish, et al., *Research and Development for Influence for Land Mines and Accessories,* Report 5A-161, Diamond Ordnance Fuze Laboratories, 30 September 1952. (SECRET)
10. N. Kaplan, *The Radioactive Battery and Its Possible Ordnance Applications,* Report 13-4-40R, Diamond Ordnance Fuze Laboratories, 12 September 1953. (CONFIDENTIAL)

CHAPTER 8

(C) SAFETY AND ARMING DEVICES

8-1 (U) INTRODUCTION

A safety and arming (S & A) device is a transfer device between the fuze and warhead. It keeps the warhead safe until detonation of the explosive charge is desired and then arms the fuze by providing a reliable path for transmitting the firing impulse. The safety and arming device is not the sole determinant of safety; it is a component of an overall safety system, which includes the explosive warhead. Generally, the warhead is made relatively insensitive, thus the probability of spontaneous detonation in an expected environment is very low (Ref. 20).

An explosive charge is considered safe when its fuze is safe. A fuze is safe (or unarmed) when the S & A device places a physical barrier in the fuze explosive train so that detonation of the sensitive element (usually the primer) is confined in such a way that the detonation will not be transmitted to the explosive train. An explosive charge is not safe when a fuze is armed. A fuze is armed when the S & A device has removed the physical barrier between the sensitive element in the fuze and the explosive train, and detonation of the sensitive element can be transmitted through the explosive train to detonate the main explosive charge. There are a few instances in which space or other exigencies have precluded the use of physical barriers in the explosive train. In such cases the electrical initiating circuit may be disconnected or the firing pin blocked to prevent initiation of the explosive train in the safe condition.

An S & A device may malfunction in one of two ways. It may arm a fuze too soon, or it may fail to arm a fuze in time for effective detonation of the explosive charge and cause either a hangfire or a dud.

To assure proper operation, it is desirable that a fuze have at least two independent safety and arming devices, a primary and a secondary device. This is not always practicable, however.

A desirable feature in the design of S & A devices is the "no-stored-energy" concept. This concept states that no primary safety and arming device should depend for its operation on cocked springs, explosive motors, or other kinds of energy stored prior to projectile flight, although such devices may be used to perform auxiliary functions. To prevent arming before launching, arming energy should come from forces or conditions that occur during launch or after the projectile is in flight. These forces and conditions must be such that they are not duplicated in transportation, handling, storage, and pre-launching operations. Sometimes the "no-stored-energy" concept must be ignored, but then extreme care must be exercised in the details of design, especially with regard to such factors as stress, corrosion, and creep of springs and stability of chemicals.

Although safety and arming devices vary widely in appearance and in method of operation, most of them fall into two broad classes: mechanical and electrical. Some that do not fall clearly into these two classes are fluid operated devices, barometric devices, thermal devices, and chemical eroders.

This chapter discusses basic design requirements for S & A devices used in electronic fuzes. It supplements the material contained in Ordnance Corps Pamphlet ORDP 20-210, *Fuzes, General and Mechanical* (Reference 1), which covers basic arming principles and various types of arming devices generally suitable for use in projectiles, bombs, and rockets. The reader should be thoroughly familiar with the information contained in Reference 1 before using this chapter.

Besides the general safety and arming requirements common to most fuzes, additional requirements are sometimes specified for electronic fuzes. Special safety or arming requirements vary, depending upon the size and type of warhead, function of the weapon system, and the launch environment. Warheads with a large lethal radius not only require a very large separation distance before arming, but also require that the probability of premature function be extremely small; usually less than 1 in 10^5 or 10^6. This may dictate the use of multiple independent arming devices operated in series to provide such safety reliability. Also, weapons for defense of civilian centers often require an "intent to launch" feature to insure non-arming in the event of accidental launch.

As in the case of the mechanical fuzes discussed in Reference 1, there is not one best criterion for making the arming decision for all weapons. For example, elapsed time may be the most convenient measure of separation distance following bomb release; missile velocity may be both a sufficient and a required criterion for arming a low-acceleration rocket; and minimum velocity plus elapsed time might be required for a mortar fuze. For arming sequences similar to the last-mentioned, which is performed in two stages, the system may be said to be committed to arm when the launch conditions are satisfied.

Quite often, the arming system in an electronic fuze is required to delay arming beyond the time required for safety. This may be to minimize early functions, to decrease the effect of enemy countermeasures, or to conserve the life of a battery. For some special warheads, it may be required that the arming functions, which are usually the closure of switches, be programmed in a given sequence rather than occurring at once.

8-1.1 (U) DESIGN REQUIREMENTS FOR SAFETY AND ARMING DEVICES

Basic design requirements for an S & A device are as follows:

(1) The device must operate reliably. Reliability in S & A design (as in all ammunition design) has a very special meaning. It means thousands of devices working well for a few seconds or minutes, rather than one device working well for 10,000 hrs.

(2) The device must positively lock fuze elements in the safe position and in the armed position.

(3) The device should not remain in the partially armed position. If any combination of forces and conditions partially arms the device, the device should return to the safe position when these forces and conditions are removed.

(4) In the safe position, the device must block the explosive train so that if the sensitive explosive is detonated, other explosives in the train will not be detonated.

(5) The device must withstand all forces and conditions to which it may be subjected in launching and in flight.

(6) The device must withstand the rigors of transportation and handling as designated in the following tests:

a. Jolt Test, MIL-STD-300.
b. Jumble Test, MIL-STD-301.
c. Forty-foot Drop Test, MIL-STD-302.
d. Transportation and Vibration Test, MIL-STD-303.
e. Jettison Tests, MIL-STD-307 (8) (9) (10).
f. Accidental Release Test, MIL-STD-311.

(7) The device must function throughout a temperature range of −65° to +160°F. after being subjected to the Temperature and Humidity Test, MIL-STD-304.

(8) The device must pass the Salt Spray Test, MIL-STD-306.

(9) The device must have a shelf life of 20 years. All materials in contact with each other must be mutually compatible. Materials used must be corrosion and fungus resistant. Devices used with nuclear weapons must not be adversely affected by radiation.

(10) The device must be as small and light in weight as possible.

(11) The shape of the device must be such that it will fit into the assigned space.

(12) The device must be as simple as possible in design. It should contain a minimum number of parts, and it should not require parts such as unlinked pins or balls that may be easily omitted in assembly.

(13) The device must usually be adaptable to mass production and be safe and economical to manufacture.

(14) The device must be versatile. It must be adaptable to changes in fuze and missile design.

(15) Indicators must be incorporated to show handlers whether or not a fuze is armed.

(16) It must be impossible to assemble an armed fuze to (or insert one into) an explosive charge.

Many of these requirements conflict with one another. Certainty of action at the proper time, safety, and compatibility of materials complicate design and manufacture and add to the cost of making the device. Size and shape are determined by available space; weight is governed by the weight allowance of the fuze. When feasible, adoption of a standard shape, size, and weight and use of the same device in fuzes for all projectiles of a given class affords economy of manufacture. Design compromises implicit in "trade offs" that must be made to satisfy overall system requirements should be very carefully analyzed.

8-1.2 (U) SAFETY AND ARMING DEVICES FOR MISSILE FUZES (Ref. 2)

Characteristics of S & A devices for guided missile fuzes are based on the required characteristics of the missile in which the fuze is used. Most of the design requirements previously covered apply; however, their relative importance changes. Because of the increased cost of the weapon and its much greater damage capability, safety and reliability must be emphasized. Size, weight, shape, simplicity, long shelf life, adaptability to mass production, and economy of manufacture become relatively less important.

Safety requires that the probability of premature arming of a guided missile must be very much less than that of devices for less powerful projectiles. The probability of premature arming must be extremely low (10^{-6}, 10^{-7}), while a dud rate of 10^{-3} is tolerable. In some missile designs, there must not be any chance of premature arming, and only a negligible chance of a dud. To meet such requirements the designer must compromise between the following two contradictory facts:

(1) The chance of premature arming decreases with the number of independent steps (each having a given chance of failure) that must be completed to arm the device.

(2) The chance of a dud increases as the steps (each having a given chance of failure) required for arming increase.

An S & A device will remain safe, or unarmed, as long as any one step in the arming cycle is not completed, and the device will be a dud if any one of the steps is not completed as designed.

A feel for the relations involved can be obtained from the following oversimplified examples. When the probability of premature arming must be less than 1 in 1,000,000 and three independent steps are to be completed in series for arming, then the probability that each step will be completed prematurely must be less than 1 in 100 ($100 \times 100 \times 100 = 10^6$). With only two steps in the arming cycle, the probability that each step will be completed prematurely must be less than 1 in 1,000 ($1000^2 = 10^6$). When the chance of a dud must be less than 1 in 100,000 each step for a 3-step arming cycle will have to have a failure rate of less than 1 in 50; and each step for a 2-step arming cycle will have to have a failure rate of less than 1 in 350. Performance reliabilities of this order are hard to attain and even harder to prove because of the large number of controlled tests required. This subject is treated more rigorously in Reference 21.

8-1.3 (U) DESIGN FACTORS FOR GUIDED MISSILE S & A DEVICES

Before designing an S & A device for a missile, a designer must have the following information:

(1) Dynamic characteristics. Axial forces caused by axial acceleration and deceleration during missile launching and flight, as well as side thrust forces resulting from lateral acceleration, must be known, as must the vibration and shock forces caused by booster and sustainer ignition and aerodynamic disturbances. With knowledge of the size and duration of axial acceleration forces, the designer can derive acceleration-time relationships to establish an arming sequence over a given time and distance. Inertial forces of axial acceleration and deceleration can be used to trigger certain actions in the device, and the device can be designed strong enough to withstand the forces

of lateral acceleration, vibration, and shock. For air-to-air or air-to-surface missiles used by naval aircraft, the device must also withstand the special shocks of catapulting and arresting the aircraft.

(2) Missile environmental temperatures. The temperatures resulting from all internal and external conditions must be known. High temperatures caused by skin friction, propellant burning, and heat generated by internal electronic devices may affect temperature-sensitive circuits and materials with high temperature coefficients. Special temperature-resistant materials, temperature-compensated circuits, and special packaging may have to be used.

(3) Minimum and maximum arming times and distances. These are specified in the military characteristics of the missile.

(4) Size, shape, and weight. These are determined by the available space and the weight allowance for the S & A device, the location of the device in the missile, and the type of warhead used in the missile.

(5) Explosive components. Most S & A devices contain explosives, which when properly aligned, complete the fuze explosive train. These essential parts of the device create a very serious compatibility problem. Typical explosives are a detonator, tetryl lead, and a booster. The explosive train is loaded in the S & A device and laboratory tested before being tested in high explosive warheads.

(6) Handling and storage safety requirements. Completed S & A devices must pass the 300-series of Military Standards tests (paragraph 8-1.1). These tests cover jolt, jumble, drop, transportation vibration, extreme temperatures, humidity cycling, and salt spray.

8-2 (U) MECHANICAL SAFETY AND ARMING DEVICES

Pins, rods, bearings, wires, foil, detents, springs, rotary devices and clockworks are some of the many mechanical devices used to arm a fuze, to permit a fuze to arm, or to transmit an arming signal. The choice of a type for a particular application is usually based on its operating principle, although other factors such as available space and economics, for instance, play important roles in selection.

8-2.1 (U) DEVICES BASED ON DEFORMATION OF MATERIALS (Ref. 3)

When the setback force during launching is much higher than any forces encountered during transportation and handling, it may be used to deform material which, when deformed, permit a fuze to arm, perform the actual arming, or provide an arming signal. Cost, environment, and space limitations govern whether the material used is a plastic, a metal, or a ceramic. Materials may be loaded in tension, compression, or shear. They may be ruptured, stressed beyond the elastic limit, or stressed and allowed to recover their original shape or position. Some plastics have special recovery characteristics after strain. For example, lucite when stretched 3% returns to 2% deformation rapidly, to 1% in about 2 msec, and to zero after another 4 msec, providing a cheap but crude time delay unit.

Wires, pins, and foil are the most common elements that are ruptured to function. Punching through controlled thickness of these elements or shearing their specially designed cross sections are some of the methods used to rupture them.

8-2.2 (U) DETENTS

Detents are catches, pawls, dogs, or clicks used to lock or unlock sliders or rotary devices. They must be designed with great care to insure proper operation, to prevent damage to mating parts and to prevent accidental unlocking due to shock.

8-2.3 (U) SPRINGS

Springs provide a convenient source of stored energy that remains essentially constant over the 20-year shelf life required for fuzes (see "no-stored-energy concept discussed in paragraph 8-1). They also act as restrainers for various parts of a fuze, such as detents, pins, balls, and rotors.

Flat leaf, flat spiral, and helical coils are three common types of springs, and all are used in fuze arming mechanisms. The flat leaf spring is a thin beam that has tensile and compression stresses when it bends. The flat spiral spring is a leaf spring wound into a spiral. The helical coil spring is a wire coil in which a shear stress is induced when the coil is deflected.

Reference 1 discusses the motion of masses of springs and gives elementary spring equations. It also describes fuzes that contain spring-loaded components.

8-2.4 (U) SLIDERS

Fuze components, such as interrupters, lock pins, detents, and similar devices, which move without rotating or without the aid of roller or ball bearings, are called sliders. Their use reduces manufacturing costs because large tolerances are permitted.

Because sliders have open bearing surfaces, they are more vulnerable than rotating devices to jamming caused by dirt and corrosion. In rotating devices the bearing surfaces are covered and protected to some extent. Sliders are also subject to cocking when clearances are large, and to galling or gouging where corners are sharp.

Sliders are moved by springs, inertial forces such as setback and creep, or centrifugal forces. They may travel along, normal to, or at an angle with the missile axis. They are usually held in their initial position by springs. Sliders are discussed in detail in Reference 1.

8-2.5 (U) ROTARY DEVICES

Some arming devices are pivoted so that they can rotate through a specified angle. Rotation may be caused by setback, creep, or centrifugal forces, by the air stream, or by unwinding springs. The axes of the rotating members may be parallel to, perpendicular to, or at an angle with the missile axis.

The disk rotor, the centrifugal pendulum, the simple plunger, the rotary shutter, the ball rotor and a ball cam rotor, sequential events setback devices (setback leaves), and clockwork are common rotary devices. Design data for these devices are given in Reference 1. Supplementary data for sequential events setback mechanisms and clockworks are given in the following paragraphs.

8-2.6 (U) SEQUENTIAL EVENTS SETBACK MECHANISMS (Ref. 4)

Sequential events setback mechanisms, commonly called setback leaves, provide safety by discriminating between sustained firing setback and momentary setback caused by poor handling. These mechanisms refer to any arming system employing interlocking elements that must be moved in a particular sequence by a firing acceleration to accomplish a particular final motion. Thus, as shown in Figure 8-1, leaf 1 must rotate counterclockwise through an angle θr_1 to permit motion of leaf 2; leaf 2 must then rotate counterclockwise through an angle θr_2 to release leaf 3; and leaf 3 must then rotate counterclockwise through the angle θr_3 to permit counterclockwise motion of the arming rotor. Motion of the arming rotor through 90 degrees is the particular final motion desired in this case. Note that motion of the *n*th leaf cannot occur unless all previous n—1 elements have been rotated through their release angles. Each element must have some restraining torque, usually a spring, so that motion can occur only when some reasonable minimum acceleration is applied.

Leaves are not limited to rotary motion but can be elements moving linearly. Only rotary leaves will be discussed here as they are by far the most prevalent. Final motions are not limited to rotating arming rotors but can include starting clocks, clocking switches, starting thermal power supplies, etc.

8-2.6.1 (U) Applications, Advantages, and Limitations

Setback leaves can be used as a primary safety device in all high-velocity, nonrotating projectiles that are launched with acceleration. There are limitations depending on the degree of safety required by the military characteristics and the intrinsic nature of the round. For example, a HVAR rocket is launched at accelerations as low as 20 g and as high as 80 g, depending upon the launch temperature of the propellant. If a fuze must have, for example, 300 ft safe arming distance, then setback leaves are impractical because of the nature of the requirements. To delay arming for 300 ft of acceleration would require either large, massive leaves or an extraordinary number of small leaves.

When leaves cannot be used as primary safety devices because accidental accelerations can reproduce firing accelerations, they can be used in conjunction with a pull-pin or some other environmental force or forces peculiar to the round. The greatest advantage of setback leaves is that they use the one large force that is common to all projectiles—firing acceleration. In some fuzes, it is the only practical force available.

For rounds that must be safe to dispose of after delivery by a malfunctioning parachute, when the impact velocity may be as great as 160 ft/sec and bouncing may occur, it is necessary that the setback leaves shall prevent arming at firing velocities nearly twice the maximum impact velocity. This safety factor takes into account the effect of bouncing and the fact that no setback-leaf system integrates a full firing acceleration.

8-2.6.2 (U) Equations of Motion

Figure 8-2 shows the major parameters of one element in a setback-leaf system. Assuming that θ is positive when the center of gravity is above the line drawn through the pivot and perpendicular to the direction of acceleration, the differential equation of motion is

$$I\ddot{\theta} = -maA(t)\cos\theta + S(\theta) + F \qquad (8\text{-}1)$$

where

I = moment of inertia of the leaf about the pivot

θ = angle (radians) that the pivot-center of gravity line makes with the line perpendicular to the direction of acceleration

m = mass of leaf

a = distance of the pivot to the center of gravity of the leaf

$A(t)$ = applied acceleration as a function of time t

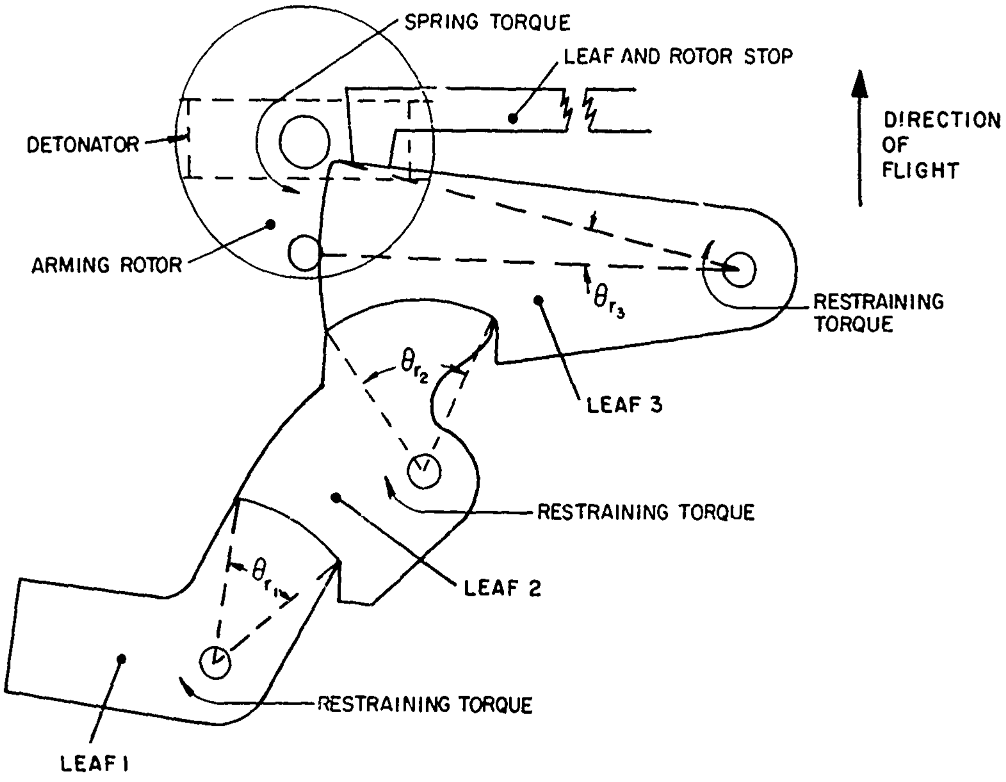


Figure 8-1 (U). Typical Setback-leaf System

$S(\theta)$ = spring torque as a function of angle θ

F = friction torque (coulomb — always directed to oppose motion)

The initial conditions are at

$t = 0$

$\theta = \theta_o$

$\dot{\theta} = 0$

If T is the time for the leaf to move into position to permit the next element to move, then the final boundary condition for t equals T is

$\theta = \theta_o - \theta_r$

where

θ_o = initial θ (radians) at time $t = 0$

θ_r = release angle (radians)

$S(\theta)$ can usually be written in the form $b - c\theta$, where b and c are nonnegative constants. F is usually taken to be a constant for simplicity.

It is usually best to solve Equation 8-1 numerically because $A(t)$ is usually a complicated function of time. If $A(t)$ is a constant, A, such as would occur in centrifuge time-testing, then a first integral is immediately obtained, simplifying numerical solutions:

$$(1/2)I\dot{\theta}^2 = -maA(\sin\theta - \sin\theta_o) + (b+F)(\theta - \theta_o) - \frac{C(\theta^2 - \theta_o^2)}{2}$$

The value of T can be obtained by solving this equation. All of the constants must have a subscript, n, for the nth leaf, and if there are L leaves the total time for operation, τ, is given by

$$\tau = \sum_{n=1}^{L} T_n \qquad (8\text{-}2)$$

To determine whether or not a particular acceleration function, $A(t)$, will operate the mechanism, it is necessary to compute each T_n by Equation 8-1 and sum as indicated by Equation 8-2. The initial conditions for the nth leaf are at

$$t = \sum_{i=1}^{n-1} T_i$$

$\theta = \theta_{o_n}$

$\dot{\theta} = 0$

8-2.6.3 (U) Equations for Minimal Velocity Change for Operation

The principle of operation of setback leaves is that firing accelerations must be sufficiently high and last for a sufficient length of time to operate all the leaves. Accidental accelerations, however, must be able to operate only some (but not all) of the leaves, due either to a lack of high acceleration, or to a lack of time. This must be so for proper safety design. The principle suggests that there must be a minimal integral of acceleration over time that is mandatory for proper operation. This minimal integral (or velocity change that the round undergoes), which exists for every design, can be helpful in determining the degree of drop safety in the design, as well as determining a design for the proper degree of drop safety desired. The minimal velocity V_{m_n} can be found for the nth leaf (Reference 5) depending on characteristics of the leaf as follows:

(1) *If* $\theta_{o_n} > 0$ and $\theta_{o_n} > \theta_{r_n}$, then

$$V_{m_n} \cong \sqrt{\frac{2I_nN_n}{m_na_n}\left[\tan\theta_{o_n} - \tan(\theta_{o_n} - \theta_{r_n})\right]} \qquad (8\text{-}3)$$

(2) If $\theta_{o_n} > 0$ and $\theta_{r_n} \geqq \theta_{o_n}$, then

$$V_{m_n} \cong \sqrt{\frac{2I_nN_n}{m_na_n}\left[\tan\theta_{o_n} + \theta_{r_n} - \theta_{o_n}\right]} \qquad (8\text{-}4)$$

(3) If $\theta_{o_n} \leqq 0$, then

$$V_{m_n} = \sqrt{\frac{2I_nN_n\theta_{r_n}}{m_na_n\cos^2\theta_{o_n}}} \qquad (8\text{-}5)$$

where

$\frac{N_n}{\cos\theta_{o_n}}$ = acceleration required to start moving the nth leaf (obtained by Equation 8-1 with $\theta = 0$)

$$N_n = \frac{b_n - c_n\theta_{o_n} + F_n}{m_na_n}$$

The minimum velocity, V_m, required for operation is, therefore

$$V_m = \sum_{n=1}^{L} V_{m_n}$$

8-2.6.4 (U) Relationship between Minimal Velocity and Drop Safety

A corollary to the existence of a minimal velocity change for arming is that there exists a minimum height from which a unit can be safely dropped. Below this height it is impossible to produce arming, independent of the impact material. This follows from the fact that the impact velocity, V, of a unit dropped from height, h, can be at most $\sqrt{2gh}$; the bounce height can be at most h, so that the maximum velocity change the round can experience is $2\sqrt{2gh}$.

Equations 8-3 through 8-5 are derived from a special acceleration function which can never be met in actual practice; that of instantaneous velocity changes acting on each leaf (infinite accelerations lasting for zero time). If a practical estimate of minimal velocity changes, V_{p_n}, is desired, considerations (Reference 5) lead to the expressions:

$$V_{p_n} = 2V_{m_n}$$

and

$$V_p = V_{m_L} + 2\sum_{n=1}^{L-1} V_{m_n}$$

V_{m_L} = velocity of last leaf

These equations are results for approximately constant accelerations of value $\dfrac{2N_n}{\cos\theta_{o_n}}$ applied to the nth leaf.

The following statements can now be made concerning the possibility of accidental arming from a drop impact of velocity, V

(1) If $2V < V_m$, arming is impossible

(2) If $V < V_m < 2V$, arming can only occur if bouncing of the round occurs but is very unlikely because then, $V < \dfrac{V_p}{2}$ (approximately, since $V_p \cong 2V_m$), and $2V < V_p$

(3) If $V < V_p$ arming is unlikely unless bouncing occurs to make $V + V$ (of bounce) $> V_p$

(4) If $V > V_p$, it is likely that arming will occur when dropped onto some materials.

8-2.6.5 (U) Construction and Design Details

For optimum safety, the designer must provide the following features:

(1) The leaves must be self-resettable. Otherwise, a series of accidental accelerations might eventually trip all the leaves.

(2) The direction of acceleration that is most likely to trip the leaves should be close to the firing direction (axial). Otherwise, accidental accelerations other than base down are more critical.

(3) The acceleration that starts moving each leaf should be about half of the acceleration acting on each leaf. This utilizes a minimum part of the acceleration-time curve and can, therefore, provide maximum safety.

(4) The design should incorporate intrinsic features to prevent misassembly. This is especially important when setback leaves are to be used as a primary safety.

In determining the type of setback-leaf system to use for a particular fuze, the most important consideration is the available space at hand. The cheapest method of construction is to stamp each piece, and if a flat vertical space is available, a system similar to the one shown in Figure 8-1 is preferable to any other. Systems have been proposed in a wide variety of forms and designs, however, because of the space problems encountered (Refs. 22, 23, 24).

In most cases, leaves are staked to shaft that rotate in bearings. Restraining springs are mounted on the shafts, one end attached to the leaf and the other to a nonmoving member of the mechanism.

Once the general shape and type of setback leaf is established, theoretical computation and experiments must be employed to establish the proper parameters. An acceleration-time firing curve is necessary to establish the range of N_n. Centrifuge experiments can provide data on N_n (N_n = centrifuge value $X \cos\theta_{o_n}$), while firing tests will determine whether or not leaves operate properly. Three methods for adjusting parameters are as follows:

(1) Changing N_n by changing the preload of the torque spring.

(2) Changing $I_n/m_n a_n$ by making small changes in the design which do not affect other parameters greatly.

(3) Changing θ_{r_n} by making small changes in design which do not affect other parameters greatly.

It is usually necessary to use one of the above three methods for adjusting parameters of a proposed design. Experience has shown that "first" designs are not perfect, and experimental trial-and-error methods in design are required.

8-2.7 (U) CLOCKWORK

Clock escapements and gear trains are used extensively as acceleration arming mechanisms. Both the watchspring-type (tuned) escapement and the runaway-type (untuned) escapement can be used.

8-2.7.1 (U) Tuned Watchspring Escapements

A tuned escapement is essentially a mass on a spring, and executes simple harmonic motion. This type of device provides greater timing accuracy than most other devices. This is not necessarily an advantage, however, because many fuzing applications do not require precise arming times. A tuned escapement usually includes a means for positive starting. It must include a means to reset to full safe position after any momentary arming force without, in most cases, running the escapement backwards.

Setback force may be used to alter the beat frequency of the clock as well as to provide driving power and, in this way, vary the arming time If the frequency is made proportional to acceleration, the system will integrate to a constant missile velocity before arming. If the frequency is made proportional to the square root of acceleration, the system integrates to a constant distance before arming, assuming that the acceleration is essentially constant.

The operation of a tuned escapement is shown in Figure 8-3. Figure 8-3(A) shows tooth A falling on the locking face of pallet A'. In Fig. 8-3(B), the pallet has reversed its motion and is passing through the equilibrium point in its oscillation where pallet A' is receiving an impulse from tooth A. In Fig. 8-3 (C), the escape wheel tooth C has fallen onto the locking face of pallet tooth B' which is the

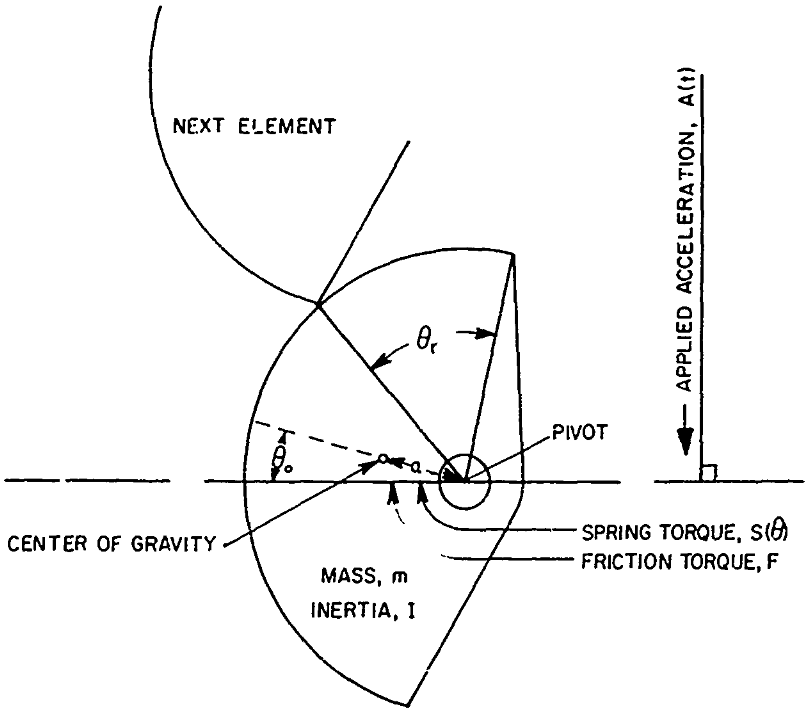
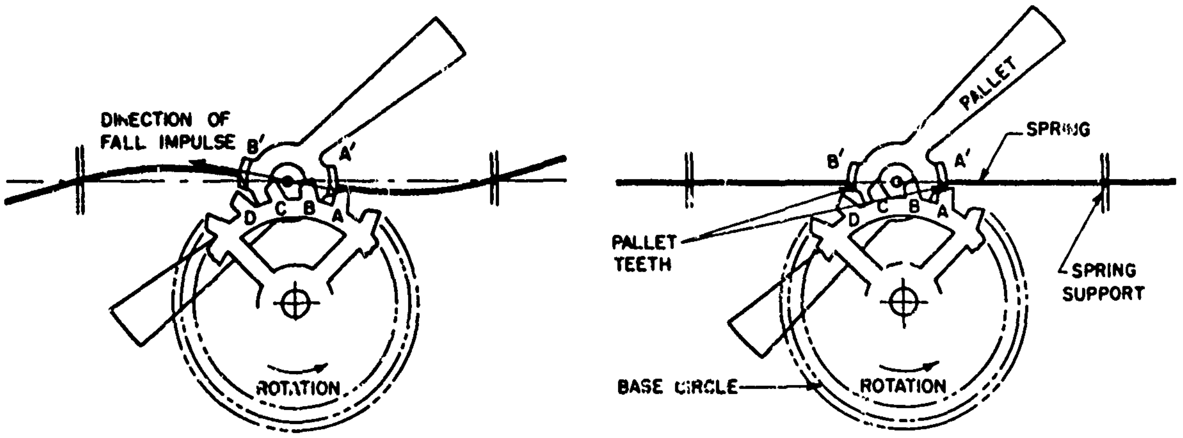
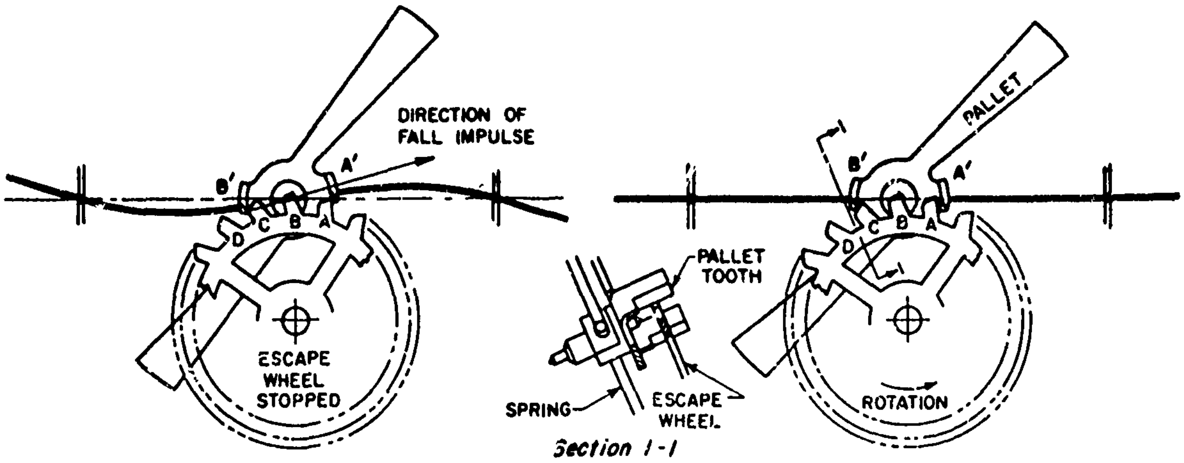


Figure 8-2 (U). Parameters of One Element in a Setback-leaf System



(A) PALLET TOOTH SLIDING ALONG ESCAPE WHEEL TOOTH FACE

(B) PALLET AT EQUILIBRIUM



(C) ESCAPE WHEEL TOOTH FALLING ON PALLET TOOTH

(D) PALLET AT EQUILIBRIUM

Figure 8-3 (U). Operation of Tuned Escapement

opposite part of the cycle from Fig. 8-3(A). If the line of action of the fall impulse passes through the pivot of the pallet, the simple harmonic motion of the pallet will not be altered (neglecting friction). As pallet *B′* slides beneath tooth *C*, the escape wheel stops. In Fig. 8-3(D), the pallet has returned to its equilibrium position and is being driven by the escape wheel as in Fig. 8-3(B). If the energy is added as the pallet passes through its equilibrium position, the frequency of the oscillating mass is least affected.

The tuned escapement is probably more complex than necessary for most arming applications. It can be made to meet unusual arming requirements, however, if necessary. Design data for tuned escapements are given in Reference 1.

8-2.7.2 (U) Untuned Escapements (Ref. 6)

The untuned escapement is simpler and inherently more rugged than the tuned escapement (Ref. 7). It is not as accurate because the beat frequency varies with driving force. This variation can be used to advantage, however, to provide either constant arming velocity or constant arming distance, depending upon how the acceleration force is coupled to the escapement. The untuned escapement also has the advantages of being self starting and reversible.

Untuned escapements are used extensively in rocket fuze arming applications. A timing device measuring a fixed time interval would suffice if the speed of a rocket were constant. Acceleration-time curves for rockets are not the same, however, even for rockets of one type. Figure 8-4 shows the effect of rocket motor temperature at the time of firing upon the acceleration-time curve. Other factors such as air density, velocity of the launcher, and steering activity can also affect the acceleration-time curve significantly. By driving a runaway escapement with a device that derives its power from the acceleration of the rocket, the escapement can be designed to effect arming at a constant distance regardless of acceleration level, as long as acceleration is relatively constant.

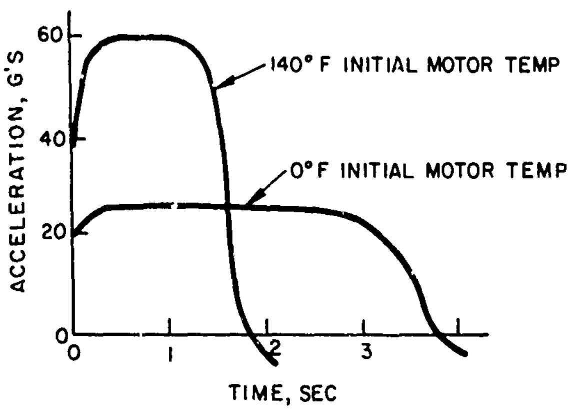


Figure 8-4 (U). Effect of Rocket Motor Temperature on Acceleration-time Relationship

8-2.7.2.1 (U) Operation of Untuned Escapement

An untuned escapement consists essentially of a starwheel and a verge (Figure 8-5).

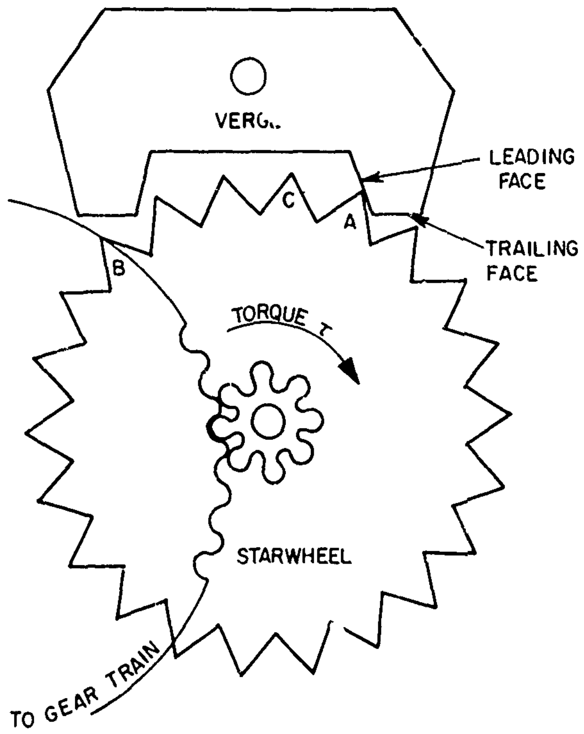


Figure 8-5 (U). Untuned Escapement

Torque is supplied to the starwheel either through a gear train by a force (spring, acceleration, etc.) as shown in Figure 8-5, or directly to the starwheel. The collision of the starwheel with the verge provides substantial delay in the rotation of the starwheel and its geared members.

The actual operation of the untuned escapement is as follows (Figure 8-5):

(1) The torque drives the starwheel so that tooth *A* strikes the leading face of the verge, changing the velocities of starwheel and verge.

(2) After collision, tooth *A* contacts the leading face and slides along until it becomes free of the leading face. This part of the motion is called "leading contact."

(3) Free motion occurs where the verge is not in contact with the starwheel.

(4) Tooth *B* collides with the trailing face of the verge, changing the relative motions of both verge and starwheel.

(5) Tooth *B* slides along the trailing face in "trailing contact."

(6) Free motion again occurs.

(7) Tooth C strikes the leading face of the verge as the cycle repeats again.

Some general characteristics of the operation of untuned escapements are as follows (Refs. 8-11):

(1) Bouncing of starwheel teeth against the verge does not noticeably occur, suggesting an inelastic collision.

(2) With a constant torque on the starwheel, a steady-state periodic motion occurs after about 3 cycles of verge motion. It is then possible to consider the average angular velocity, $\bar{\dot{\theta}}$, of the starwheel, which is a factor needed for calculating time delays.

(3) Experimental evidence (Ref. 11) indicates that the material from which the starwheel and verge are made slightly affects the running rate. Brass and aluminum behave about the same, whereas an escapement made of steel runs about 5% faster, and a clock made from magnesium runs about 5% slower. These results were obtained with equivalent moments of inertia and are different due to material alone.

(4) From a study (Ref. 10) of nearly 300 samples of a particular clock mechanism employing an untuned escapement, it appears that some aging effect occurs. After a mechanism has been run-in several times to remove burrs, a decrease in $\bar{\dot{\theta}}$ of about 2% can be expected when it is stored for a short period of time; for example, a day or so. The study also indicates that the spread in $\bar{\dot{\theta}}$ varies about ± 8% about the mean. The most important reasons for this variation are as follows:

(a) Differences in geometrical dimensions of the verge.

(b) Differences in the center-to-center spacing of the verge and starwheel shafts.

(c) Differences in the friction of the gear train which transmits the torque from the spring to the starwheel.

(5) If acceleration is applied to a rack to produce torque to drive the starwheel, an untuned escapement can be shown to be an approximate integrator to obtain a constant arming distance.

8-2.7.2.2 (U) Analysis of Motion

To determine the average angular velocity of the starwheel, θ, the following assumptions are made:

(1) Collision is inelastic.

(2) Impact time for collision is zero.

(3) Sliding friction between verge and starwheel is zero.

Let ψ = Torque acting on starwheel

I_v = Moment of inertia of the verge

I_w = Moment of inertia of the starwheel (effects of other members of the gear train included)

γ_1 = Ratio of starwheel moment arm to verge moment arm at leading face collision point

γ_2 = Ratio of starwheel moment arm to verge moment arm at trailing face collision point

N = Number of teeth in starwheel

With the three assumptions stated above, any analysis is still necessarily complicated. The equilibrium velocity of the starwheel, $\bar{\dot{\theta}}$, depends upon how much free motion and sliding motion exists. If the assumption that $\gamma_1 = \gamma_2 = \gamma$ is made, however, $\bar{\dot{\theta}}$ lies between the limits

$$\sqrt{\frac{\psi\pi(I_w + \gamma^2 I_v}{2N\gamma^2 I_u I_v}} \geqq \bar{\dot{\theta}} \geqq \sqrt{\frac{\psi\pi I_w}{2N\gamma^2 I_v(I_w + \gamma^2 I_v)}} \tag{8-6}$$

provided that $I_w \geqq \gamma^2 I_v$.

In applying Equation 8-6 an approximation of $\gamma^2 = \gamma_1\,\gamma_2$ can be made.

If $\gamma^2 I_v > I_w$, different formulas apply. The time for sliding motion is radically changed under these conditions because, after collision, the starwheel reverses its direction of motion, against the torque, before moving forward again.

Since the left-hand and right-hand terms in Equation 8-6 represent conditions where no free motion exists and all free motion exists, respectively, their ratio is an approximation of the effects of center-to-center distance between verge and starwheel. The ratio, R, of $\bar{\dot{\theta}}$ when the center-to-center distance is just small enough to jam the mechanism to $\bar{\theta}$ when the center-to-center distance is just large enough so that the starwheel does not contact the verge, is given by

$$R = \frac{I_w + \gamma^2 I_v}{I_w} \tag{8-7}$$

provided that γ does not change radically as the center-to-center distances are changed. Equation 8-7 shows there is no appreciable effect due to changes in center distances if $I_w >> \gamma^2 I_v$.

Generally speaking, a numerical computation using the theory given in References 8 and 9 will yield correct running rates of untuned mechanisms to within 15% to 20%, provided the time for one cycle of the verge is much greater than the impact time for the collision. The latter was assumed zero in the above analysis, an assumption which breaks down in this case. The effects of dynamic friction also introduce error and tend to make the theoretical $\bar{\theta}$ too great.

Most of the breakdowns of assumptions are not important if $I_w >> \gamma^2 I_v$, since the impulsive torque offered by the verge does not appreciably slow the starwheel down. This is equivalent, therefore, to a large ψ when Equation 8-6 is fairly good even when $\gamma^2 I_v > I_w$. With a large ψ, however, dynamic friction greatly affects the error, and theoretical results may differ by as much as 50% from the actual results.

8-2.7.2.3 (U) Design considerations

When designing for a particular application, the limitations of an untuned mechanism must be kept in mind. Generally, time delays up to about 1 minute can be obtained within a reasonably small fuze space. Most applications, however, run 30 sec or less.

The amount of time delay required, rather than the other parameters in Equation 8-6, usually determine the size of the gear train. For example, assume that a delay of 50 msec is desired when bringing a detonator rotor inline from its out-of-line position 90 degrees away. With the size of the parts generally encountered, the inertia of the rotor itself, driven by a suitable spring, will inherently provide about 10 msec. To change the delay by a factor of 5 by just increasing the inertia of the rotor or decreasing the torque of the spring may be impracticable. A factor of 25 is involved for these parameters, and space plus friction problems become magnified. A simple solution would be an untuned escapement attached directly to the rotor without gearing. Experience has shown that such an arrangement can increase time delays by one order of magnitude.

If a delay of as much as one second is desired, the designer may be tempted to increase the inertia of the verge and reduce the torque of the spring. Increasing the inertia of the verge almost always means making it heavier since space is not available to make it larger. Hence the bearing friction of the verge increases to make the action uncertain and erratic, especially if the spring torque is reduced. A better design approach uses a gear train between starwheel and rotor to increase verge speed and, therefore, apparent verge inertia at the rotor.

8-2.7.2.4 (U) Calculations with spring torque and gear reduction

It is usually desirable to determine the speed of the driving gear (the initial member of the gear train) rather than the starwheel. It is the driving gear that receives the delay. With a spring torque, the time delay, T, given to the driving gear is given by

$$T = \frac{2G^{3/2}}{k\sqrt{se}}\left[\sqrt{\theta_o} - \sqrt{\theta_F}\right] \tag{8-8}$$

where

k = constant for any design and is a function of I_v, I_w, N, and γ

G = gear train reduction (ratio of speed of starwheel to speed of driving gear)

s = spring constant

θ_o = initial angular displacement of the spring from the zero torque position

θ_F = final angular displacement ($\theta_o > \theta_F$)

e = ratio of G times the torque delivered to starwheel to the torque delivered by the spring to the driving gear

Equation 8-8 shows the effect of gear ratio G on the time delay. By varying G, delay time,

T, can be altered considerably. Small changes in speed can be accomplished by changing k, usually by varying I_r. Changing the thickness of the verge and still using the same blanking die is common practice. Altering spring constant, s, is another method of producing small changes in the speed. Ratio e is usually a fixed characteristic of the gear train and friction and is a measure of torque transfer efficiency.

If the time of operation between two θ's is obtained experimentally, the constant for the gear train $2G^{3/2}/k\sqrt{se}$ can be evaluated, and the time for rotation through any angle determined.

Similar results can be obtained if the driving gear is a linear rack. If x is the measurement of the compression length of the drive spring, then the time will be proportional to $(\sqrt{x_1} - \sqrt{x_2})$.

8-2.7.2.5 (U) Calculations with acceleration torque

In some applications, firing acceleration is used on either an eccentric initial gear or a rack to produce the driving torque. In the case of an eccentric gear, the average speed of the driving gear, $\bar{\dot{\theta}}_d$, can be obtained by replacing the spring torque with the component of acceleration torque, which can be expressed as

$$Amr\cos\theta$$

where

$r\cos\theta$ = moment arm
m = mass
A = acceleration

In this case, however, a friction term from the acceleration is desirable in addition to the intrinsic frictional loss due to the rubbing of gear teeth involved in parameter e.

As a first estimate, the average speed of the driving gear, $\bar{\dot{\theta}}$, can be expressed as

$$\bar{\dot{\theta}}_d = \frac{k\sqrt{Amr\cos\theta\, e}}{G^{3/2}}$$

The accuracy of this equation is not very great because k changes when the verge and starwheel are operated under acceleration. In many cases, θ increases by as much as 20% with increasing friction torques. The unpredictability of this phenomenon necessitates experimental design to obtain accuracy. It is common, therefore, for an untuned mechanism to be timed at various accelerations in a centrifuge if the driving torque for the mechanism is produced by acceleration.

8-2.8 (U) ACCELERATION-TIME DEVICES (Ref. 12)

Acceleration-time devices are discussed in detail in Reference 1. This section supplements this reference, and is intended primarily to show the application of arming devices as acceleration integrators or pseudo-integrators. The most convenient arming influence for many weapons is the combinations of continuous force, due either to spin or acceleration, for a period of time. For example, the integration of acceleration to measure velocity is sufficient to measure proper launch for many systems. It is applicable to those missiles and projectiles that acquire greater velocity at launching or firing than can be acquired accidentally. The minimum accidental impact velocity is probably that due to a faulty parachute delivery, and is about 150 ft/sec.

The second integral of acceleration, distance, is often used for arming rockets and guided missiles. This is particularly true in the case of low-g rockets with long burning times; the rocket reaches a safe separation distance before burnout.

Often, the arming tolerance, i.e., the percentage difference between minimum and maximum arming distance, is relatively great. Hence, there are several simple mechanisms that can be used to recognize either a minimum velocity or separation distance as a prerequisite to arming. Some of these mechanisms can be classed as true acceleration integrators.

Other mechanisms, can provide a constant arming distance regardless of acceleration level, so long as the acceleration is relatively constant. Mechanisms of this class are distinguished by rate-of-motion proportional to the square root of acceleration, and are often called distance integrators. They are not true acceleration integrators, however, because they integrate the square root of the acceleration.

As shown in Figure 8-6, most small rockets have a relatively constant acceleration. Hence,

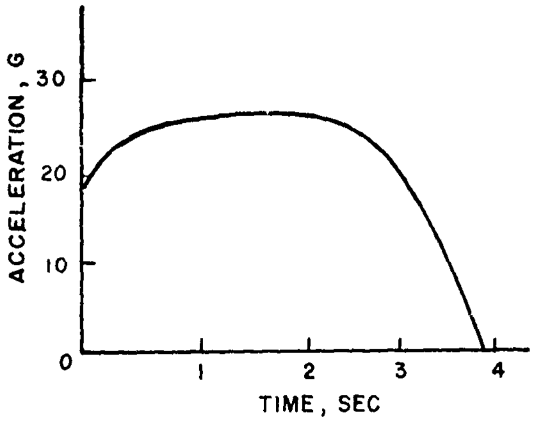


Figure 8-6 (U). Typical Rocket Acceleration

the distance integrators have been used extensively in rocket arming applications.

Another class of mechanisms, typified by sequential arming segments (paragraph 8-2.6), has also been referred to as acceleration integrators. Mechanisms of this class, however, actually provide only a means of insuring a minimum velocity at arming.

Principles of acceleration-time devices are discussed in the following paragraphs. For simplicity, it is assumed that either acceleration is great compared to gravity, or that the missile is launched horizontally so that the effect of gravity can be neglected. It should be remembered that an accelerometer in a free missile can only measure the acceleration that the missile would have obtained, or the distance it would have traveled, in the absence of gravity.

8-2.8.1 (U) Single or Double Integration

If an inertial mass is coupled through a frictionless gear to a flywheel, the torque developed on the flywheel is directly proportional to acceleration. Thus, flywheel acceleration is proportional to missile acceleration, flywheel velocity to missile velocity, and flywheel revolutions to the distance traveled by the missile. The system can theoretically be used for either single or double integration. For single integration, a centrifugal device must be used on the flywheel to recognize a preset velocity. Geartrain friction causes the system to give approximate, rather than exact, integration. Several types of servosystems have been developed that increase integration accuracy by minimizing the effects of friction.

In practice, the system includes other elements to prevent integration below a specified level of acceleration and to restore the system to its initial position in case it does not complete the arming cycle. There are other types of integrating systems, such as the integrating motors and gyro precession systems used in guidance systems. Generally, however, they are not suitable for arming applications.

8-2.8.2 (U) Single Integration

Laminar fluid-flow devices and the eddy current brake are typical systems employing single integration. In single-integration systems, the velocity of the inertial element is proportional to acceleration. The following discussion is based on laminar fluid flow; however, it applies to all systems in which the velocity of the inertial element is proportional to acceleration.

For laminar fluid flow, the resistance to flow varies directly with rate of flow and fluid viscosity. Figure 8-7 illustrates a spring and mass in a fluid-filled body subjected to acceleration, a. The equation of motion for mass m, during setback is then:

$$m\frac{d^2x}{dt^2} + C\eta\frac{dx}{dt} + F = ma$$

where

x = displacement of mass
η = viscosity
C = proportionality constant
F = opposing force of spring and friction

When applied to systems with an acceleration time of the order of 1 sec or longer, the mass acceleration term, $m\frac{d^2x}{dt^2}$, is very small compared to the fluid resistance term, and may be neglected. If the spring restoring force and friction, F, is small compared to ma, it may be neglected and the approximate equation is

$$\frac{dx}{dt} = \frac{m}{C\eta}\cdot a = \frac{m}{C\eta}\frac{dV}{dt}$$

where

V = missile velocity

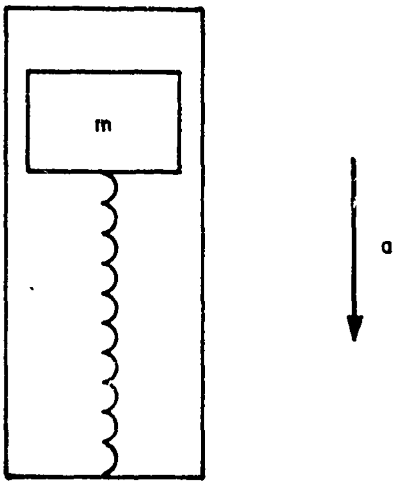


Figure 8-7 (U). Acceleration of a Mass in a Fluid-filled Body

It follows that the displacement of the mass is proportional to the integral of acceleration, or missile velocity. Thus,

$$V = \frac{C\eta}{m} x$$

Actually, the spring can be completely eliminated from the dynamic system by using a separate spring-mass bias that moves faster than integrating mass, m. In rocket applications, the neglected term is usually very small; and therefore the approximations made are valid, and the system can be considered a true acceleration integrator.

When considering laminar flow devices, the designer must bear in mind that the integration constant varies directly with viscosity, and fluid viscosity varies with temperature. The viscosity of the best silicone liquids varies by a factor of about 8 to 1 over the required operating range usually specified by the military. Therefore, the designer must incorporate temperature control into the system, or must compensate for the change in viscosity by choosing materials of different expansion coefficients for the piston and housing.

The use of a gas rather than a liquid reduces the temperature problem. When a gas is used, however, tolerances on piston clearance and flow orifices become more critical.

8-2.8.3 (U) Pseudo-Integrators

Turbulent fluid-flow devices, glass-bead devices and untuned escapements are typical pseudo-integrators. In pseudo-integrating systems, the velocity of the inertial mass is proportional to the square root of acceleration. The following discussion is based on turbulent fluid flow; however, it also applies to glass-bead devices and untuned escapements.

Resistance to turbulent flow varies as the square of the fluid velocity. Thus, for a spring-mass system resisted by turbulent flow through an orifice, the differential equation of motion for mass, m, is

$$m\frac{d^2x}{dt^2} + C\rho\left(\frac{dx}{dt}\right)^2 + F = ma$$

ρ = fluid density

C = constant, which depends on geometry of orifice and piston

x = displacement of mass

F = opposing force of spring and friction

If the mass acceleration term, $m\frac{d^2x}{dt^2}$, and the spring restoring force, F, can be neglected (paragraph 8-2.8.2), the approximation equation is:

$$\frac{dx}{dt} = \sqrt{\frac{m}{C\rho}}\sqrt{a}$$

Since density ρ is relatively constant for liquids, $\sqrt{\frac{m}{C\rho}}$ may be replaced by a single constant, C' thus:

$$\frac{dx}{dt} = C'\sqrt{a} \tag{8-9}$$

Equation 8-9 shows the velocity of the mass varies as the square root of acceleration. Mass displacement, then, is:

$$x = C' \int \sqrt{a}\, dt \tag{8-10}$$

Equation 8-10 is not, in general, a measure of either missile velocity or distance. If the acceleration is a constant ($a = A$), however, mass displacement can be represented as

$$x = C'\sqrt{A}\ t$$

If arming is triggered by a mass displacement of x_a, then arming time, t_a, can be expressed as:

$$t_a = \frac{x_a}{C'\sqrt{A}} = \frac{K}{\sqrt{A}}$$

where

$K = \frac{x_a}{C'}$, which is a constant, depending upon the design of the arming mechanism

Therefore, arming velocity, V_a, and arming distance, S_a, can be expressed by Equations 8-11 and 8-12, respectively.

$$V_a = At_a = K\sqrt{A} \tag{8-11}$$

$$S_A = \tfrac{1}{2}At_a^2 = \tfrac{1}{2}K^2 \tag{8-12}$$

Equation 8-12 indicates that arming distance is a constant independent of acceleration level, provided that acceleration is constant. It is because of the fact that arming distance is independent of acceleration level that this type is sometimes called a distance integrator. If the acceleration is not constant, the arming distance will vary, as indicated in Figure 8-8.

8-2.8.4 (U) Psuedo-Integrators With Spring Bias

If the peusdo-integrating system described in paragraph 8-2.8.3 has considerable friction, or if a bias spring is used, the approximate equation of motion for the system becomes:

$$\frac{dx}{dt} = C'\sqrt{a-b} \tag{8-13}$$

where

$$b = \frac{F}{m}$$

If part of the friction is proportional to acceleration, the effect is to change the proportionality constant C'.

If acceleration is constant ($a = A$), Equation 8-13 may be integrated, and arming time, t_a, arming velocity, V_a, and arming distance, S_a, can be expressed as

$$t_a = \frac{X_a}{C'\sqrt{A-b}} = \frac{K}{\sqrt{A-b}} \tag{8-14}$$

$$V_a = \frac{KA}{\sqrt{A-b}} \tag{8-15}$$

$$S_a = \frac{K^2}{2}\,\frac{A}{A-b} \tag{8-16}$$

where

$K = \frac{X_a}{C'}$, which is a constant, depending upon the design of the arming mechanism.

If A is large compared to b (Equation 8-16), arming distance is relatively constant.

8-3 (U) ELECTRICAL SAFETY AND ARMING DEVICES

To insure safety most fuzes require that the detonator be physically moved into line for arming. There are certain advantages to using electrical systems rather than mechanical systems to accomplish this. For example:

(1) Electrical components are economical and easily produced by mass production methods.

(2) Electrical systems can be hermetically sealed and will withstand severe impacts.

(3) Extremely short or long delays can be quickly set, and a round may be made inert or destroyed after a specified period.

(4) Command arming of missiles in flight is possible only by using electrical arming.

Electrical devices can be used to accomplish many of the functions of safety and arming. For instance, resistance-capacitance (RC) circuits, fusible-link switches, or the inherent delays of electron tubes can be used to provide delay. Other functions can be accomplished by other types of switches, explosive motors, etc. There are many electrical devices available. Some of the more commonly used ones are discussed in succeeding paragraphs. Power sources to operate these devices are usually internal capacitors, batteries, or generators but may be external for stationary ammunition applications.

8-3.1 (U) SWITCHES

Switches used in safety and arming devices must be small and rugged, must close (or open) in a specified time, and must remain closed (or open) long enough to do their job. Switches may be operated by setback, centrifugal force, impact, or other means.

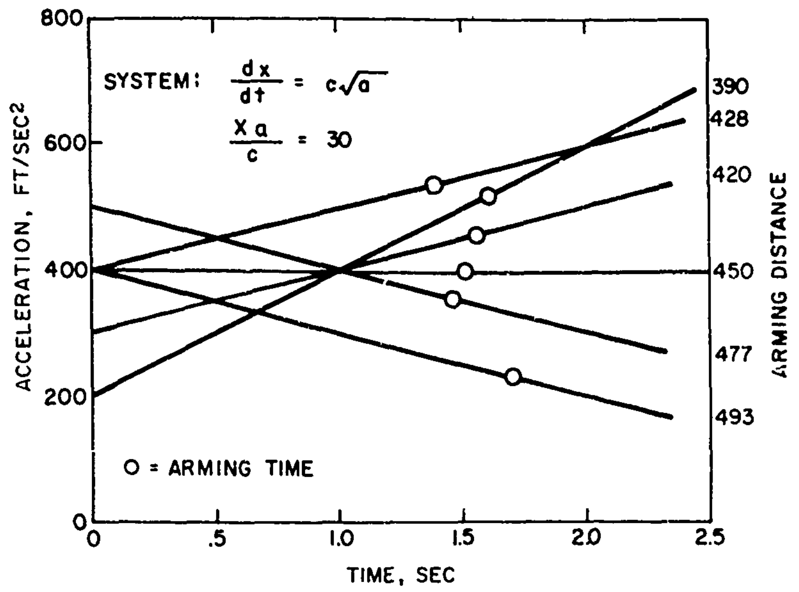


Figure 8-8 (U). Effect of Linearly Varying Acceleration on Arming Distance

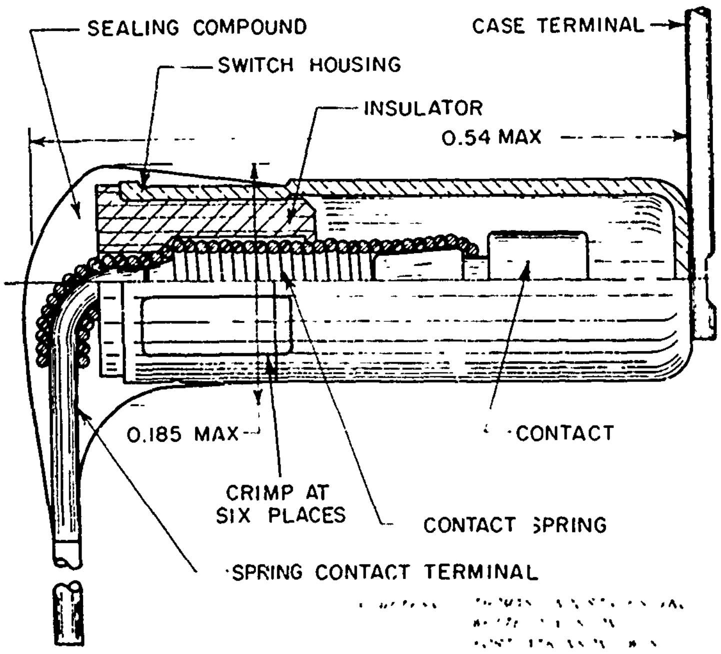


Figure 8-9 (U). Typical Trembler Switch

8-3.1.1 (U) Trembler Switches (Ref. 1)

A typical trembler switch (Figure 8-9) is essentially a weight on a spring. When a missile's velocity changes, inertial forces cause the weight to deflect the spring so that the weight makes contact with the case. The switch shown in Figure 8-9 has a current rating of 100 milliamperes and operates at accelerations of 40 to 100 g.

8-3.1.2 (U) Mercury-Type Centrifugal Switch (Ref. 1)

Figure 8-10 shows a mercury-type centrifugal switch. As the missile spins about its axis, mercury in the right compartment penetrates the porous barrier to open the circuit. The switch has an inherent arming delay that depends on the porosity of the barrier. Mercury-type switches should not be used at temperatures below —40°F.

8-3.1.3 (U) Fusible-Link Thermal Switches (Ref. 13)

Heat generated by thermal batteries may be used to activate simple, reliable time delay mechanisms that permanently close an electrical circuit at some specified temperature. Performance of these devices as delay elements depends upon close control of the rate of heat transfer from the battery to the thermal switch. Their application is generally limited to relatively short time delays (up to a few seconds) in applications where high accuracy is not required. Two switches of this type are shown in Figures 8-11 and 8-12. These switches are used to provide the electrical arming delay and the self-destruction delay in the T1012 hand grenade fuze. Both switches operate over an ambient temperature range of —40° to 125°F.

The arming delay switch, Figure 8-11, closes within 1.0 to 2.4 sec after initiation of the thermal battery. The switch contains a cadmium-lead-zinc alloy disc having a melting point of about 280°F. This metal disc is adjacent to a larger Fiberglas disc, which is perforated with a number of small holes. When the metallic disc melts, the molten metal flows through the holes in the Fiberglas, bridging the gap between the contacts, and closing the switch. Coating the Fiberglas insulator with a wetting agent to improve flow of the molten metal gives more uniform switch closure.

The self-destruction switch shown in Figure 8-12 has an average function line of 4 to 6 sec. Closure times range from 3.5 sec at —125°F to 7.0 sec at —40°F. Its thermally-activated element is a pressed pellet of mercuric iodide, which has insulating characteristics at normal temperatures but becomes a good electrical conductor at its melting point, 500°F. More uniform switch closures are obtained by spring loading one of the switch contacts. This brings the contacting surfaces together sharply when the iodide pellet melts and reduces contact resistance in the closed switch to a few hundredths of an ohm.

Although other thermal-sensitive devices, such as bimetals, may be feasible for thermal switch applications, the fusible link appears to possess the advantages of simplicity, safety and reliability. Its compactness and rugged design make it resistant to damage or malfunction caused by rough handling, shock or vibration. There is also little variation in the temperature at which the switch closes, since this is determined by the melting point of the fusible link. Bimetallic thermal switches must often be individually calibrated and adjusted, and

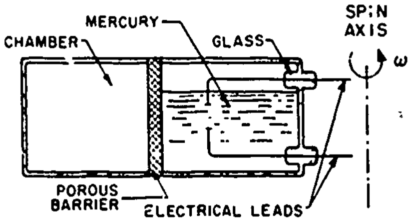
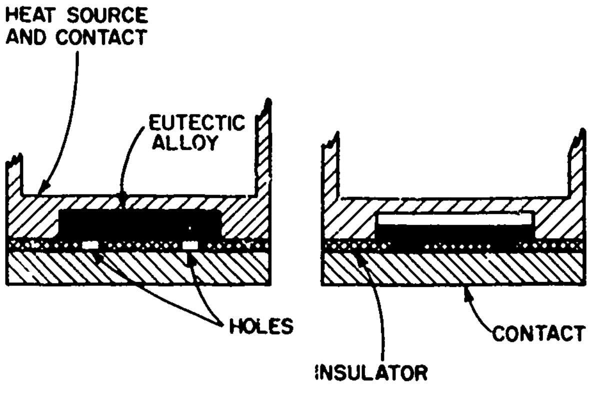


Figure 8-10 (U). Mercury-type Centrifugal Switch



OPEN POSITION

CLOSED POSITION

Figure 8-11 (U). Thermal Delay Arming Switch thereafter may be subject to deformation or premature closure. Cost and size also favor the fusible-link design.

Ambient temperature variation can greatly affect the function time of a thermal switch. Care should be taken to install the switches so that their ambient temperature is kept as nearly constant as possible. The following precautions will aid in reducing the adverse effects of variations in ambient temperature:

(1) Place the thermal switch as close to the heat source as practicable.

(2) Minimize the mass of thermal switch components and of any components interposed between the heat source and the thermal switch.

(3) Use materials with low specific heat wherever possible.

It is also important to closely control the following other factors that influence performance:

(1) The quantity and calorific value of the heat producing material.

(2) Thermal insulation of the assembly.

(3) Manufacturing tolerance of components.

(4) Uniformity of assembly, including assembly pressure on components, intimacy of contact between mating surfaces, etc.

8-3.2 (U) EXPLOSIVE MOTORS (Ref. 1)

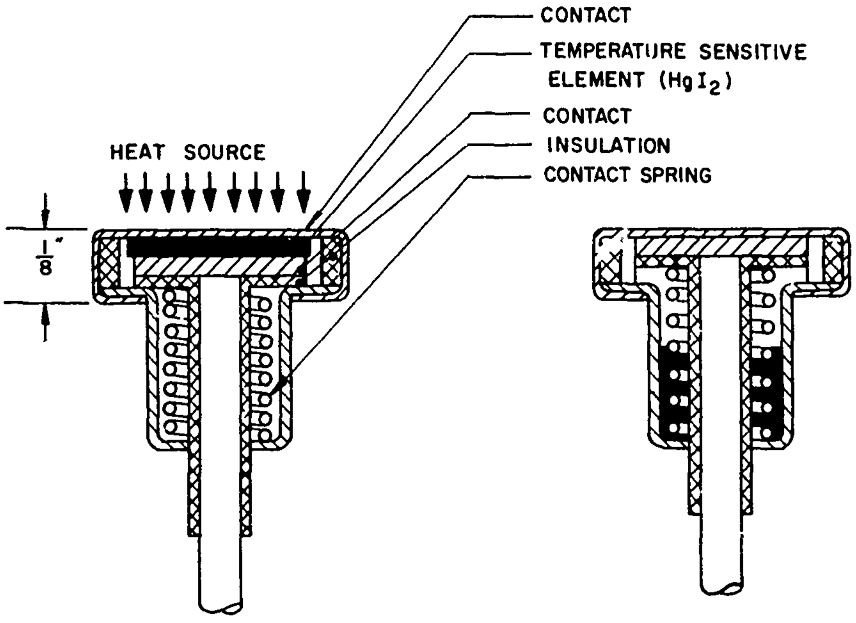
An explosive motor is a small one-shot device used to move, lock, or unlock an S & A mechanism. It can also be used to open or close a switch in an electrical circuit. An explosive switch is a packaged unit containing an explosive motor and the switch which it operates.

The explosive motor is initiated electrically. The size of the explosive charge is such that sufficient gases are created to expand a bellows or deform a case, as desired.

Dimple and bellows-type explosive motors are shown in Figure 8-13. Dimple motors have a travel of about 0.1 in. and deform faster than bellows motors. Bellows motors expand about 1 in. Both types are capable of producing forces up to 10 lb.

8-3.3 (U) ELECTRON TUBES (Ref. 14)

The time lag from th time power is applied to the heater of a diode until electrical conduction through the tube takes place has been considered to delay arming. Delays of 4 to 60



OPEN POSITION CLOSED POSITION

Figure 8-12 (U). Thermal Delay Self-destruction Switch

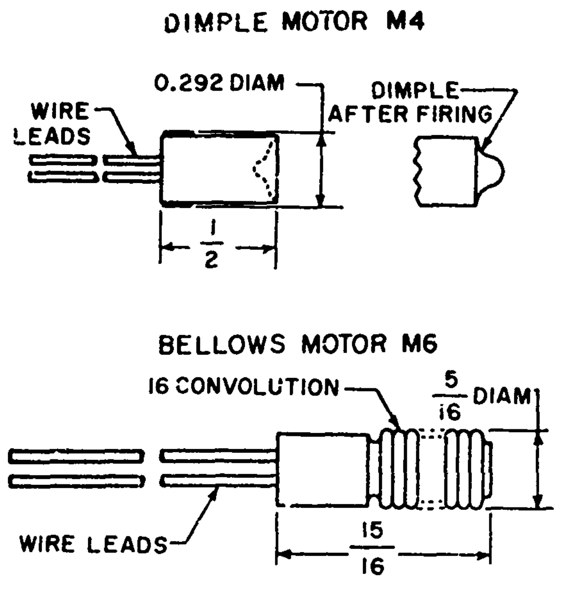


Figure 8-13 (U). Explosive Motors

sec are possible with commercial tubes of the heater-cathode type. Delays of from 0.1 to 1 sec can be obtained with filament type tubes. Delays of this type are affected by high ambient temperatures, but circuits can be adjusted to correct for these variations. Further information on this subject is contained in Reference 14.

8-3.4 (U) ELECTRICAL GENERATORS

Small wind-vane-driven or air turbine-driven generators have been used in some bomb, rocket, and mortar fuzes to provide delay and electrical power for arming. Generators eliminate the temperature and shelf life problems associated with batteries. But because of problems such as damaged propellers or shafts, air-intake clogging, providing adequate sealing, etc., generators are not considered for use in most present-day fuzing applications. Further information on electrical generators is contained in Chapter 7.

8-3.5 (U) RC CIRCUITS (Ref. 15)

RC Circuits provide arming delays in many fuze applications (Refs. 2, 16). The circuits are simple, reasonably accurate, and economical. The desired delay interval may be easily set by varying the value of the resistor, capacitor, or charging potential.

In simple delay systems, a battery is switched on at the start of the delay period to charge a capacitor through a resistor. In other systems, such as the T905 bomb fuze system (Ref. 16), a tank capacitor is charged from the aircraft power supply. The tank capacitor then charges a second capacitor through a resistor to obtain the desired delay.

Six types of RC delay circuits are discussed in this section: the basic RC delay circuit; the tank capacitor RC delay circuit; the triode RC delay circuit; the three-wire RC delay circuit; the cascade RC delay circuit; and the Ruehlmann RC delay circuit. The equations for these circuits are based on the assumption that the capacitors have negligible internal leakage currents. For circuits used over wide temperature ranges, temperature variations of the leakage resistances, along with temperature variations of other circuit elements, limit the lengths of delays realizable in practice.

The simpler types of RC circuits have been used successfully for delays up to a minute under severe conditions. Cascade and three-wire differential circuits extend the delay range several fold. Under restricted conditions, RC delays of a few hours can be obtained.

8-3.5.1 (U) Basic RC Delay Circuits

Figure 8-14 shows a simple RC delay circuit with its power supply. At the beginning of the operation, capacitor C is assumed uncharged. Switch S is closed to initiate charging and is kept closed during the timing operation. When potential V of capacitor C is lower than striking potential V_s of the diode, current through the diode is about 10^{-13} ampere. This current is too low to fire a detonator in load I. When V equals striking potential V_s, the diode fires and permits current through the load.

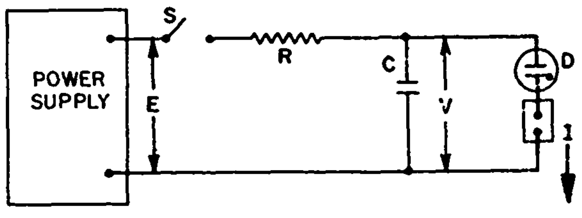


Figure 8-14 (U). Basic RC Delay Circuit

In terms of time, t, measured from switch closure, potential V of capacitor C is given by:

$$V = E\,(1 - e^{-t/RC}) \qquad (8\text{-}17)$$

and,

$$t = RC \ln \frac{E}{E\text{-}V} \qquad (8\text{-}18)$$

Equation 8-18 gives the time, t, required for potential V to rise to diode striking potential, V_s. Using Equations 8-17 and 8-18, any one of the five parameters can be determined when the others are known.

8-3.5.2 (U) Tank Capacitor RC Delay Circuit

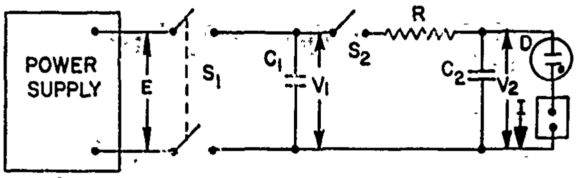


Figure 8-15 (U). Tank Capacitor RC Delay Circuit

In Figure 8-15, tank capacitor C_1 is charged to potential E during the brief interval that switch S_1 is closed. In the T905 bomb fuze (Ref. 16) this interval is about 10 milliseconds. If switch S_2 is permanently closed, delay begins when capacitor C_1 is charged. If switch S_2 is open at charging, delay begins when it is closed. Since charge flows from capacitor C_1 through resistor R to capacitor C_2, potential V_1 decreases while potential V_2 increases. The ratio C_1/C_2 must be considered in determining the charging potential E because, at the end of the desired delay, potential V_2 must reach the value V_s at which diode D strikes to initiate operation of load I.

In terms of time, t, measured from the initiation of the delay, potential V_2 is given by

$$V_2 = \frac{C_1}{C_1 + C_2}\,E\,(1 - e^{-t/T}) \qquad (8\text{-}19)$$

and

$$T = \frac{RC_1C_2}{C_1 + C_2}$$

T is the time constant of the circuit, in this case the time at which V_2 equals approximately 0.42 E. Equation 8-19 can be solved to give the time, t, required for capacitor C_2 to reach some predetermined value $V_2 = V_s$:

$$t = \left(\frac{RC_1C_2}{C_1 + C_2}\right) \ln\left(\frac{E}{E - \dfrac{C_1 + C_2}{C_1}\,V_2}\right)$$

8-3.5.3 (U) Triode RC Delay Circuit

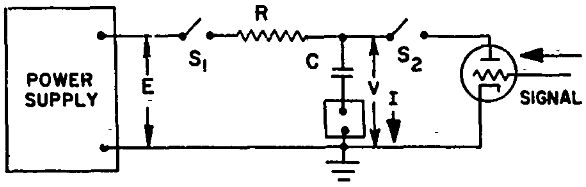


Figure 8-16 (U). Triode RC Delay Circuit

In Figure 8-16, capacitor C is charged through resistor R. Potential V of capacitor C at time t, measured from closure of switch S_1, is given by Equation 8-17, and the time required for capacitor C to attain any potential V is given by Equation 8-18.

When potential V reaches the required plate potential of the triode and switch S_2 is closed, application of a suitable signal to the grid of the triode causes it to conduct. Capacitor C discharges through load I to initiate the desired operation.

This circuit is used in the arming system of some proximity fuzes. Switch S_1 may be omitted if a reserve battery is activated at bomb release. Switch S_2 may be omitted or it may be closed by an auxiliary arming system at the end of its delay. When delays of both arming systems are completed, a signal to the triode grid fires the triode.

This circuit may be used as a two-event arming system. The first event closes switch S_1 or activates the battery source. When capacitor C is charged to the required plate potential of the triode, the second event triggers the triode. Load I is an explosive switch or explosive motor that aligns the explosive train, closes functioning circuits, or performs other operations to complete the arming.

8-3.5.4 (U) Three-Wire RC Delay Circuit

In Figure 8-17, capacitors C_1 and C_2 are charged to different potentials E_1 and E_2 by a brief closure of switch S_1. Potential E_2 may be either higher or lower than potential E_1, but the difference between E_1 and E_2 must be less than striking potentials V_s of diode D. Also, E_1 must be higher than V_s.

Potential V_1 of capacitor C_1 remains at the constant value E_1. When switch S_3 closes, capacitor C_2 discharges through resistor R. At the end of a delay, t, potential V_2 finally drops to such a value that the potential $(V_1 - V_2)$ across diode D reaches its striking potential V_s. The diode then fires and initiates the desired operation of the load.

Potential V_2 of capacitor C_2 is given by

$$V_2 = E_2 e^{-t/RC_2}$$

Diode D striking potential V_s at the end of delay t is given by:

$$V_s = V_1 - V_2 = E_1 - E_2 \left(e^{-t/RC_2} \right)$$

When this equation is solved for delay t

$$t = RC_2 \ln \frac{E_2}{E_1 - V_s}$$

Figures 5-18 and 5-19 show the discharge behavior of this circuit. In Figure 5-18, E_2 is higher than E_1; in Figure 5-19, E_2 is lower than E_1. In either case, diode D strikes when potential V_2 falls to the value of $E_1 - V_s$.

This circuit has less variation in delay with variation in temperature than the circuits mentioned previously, particularly if E_2 is higher than E_1. Both capacitors leak more at higher temperatures, but the potential drops of the two capacitors caused by this leakage tend to compensate each other. When the diode finally fires, the difference in potential between the two capacitors is caused mainly by the decrease in potential V_2 of capacitor C_2 from discharge through resistance R.

S_2 is a safety switch which is open at the beginning of arming to prevent prefiring in case switch S_1 does not close both circuits at the same instant or if there is a break in the circuit which would prevent one capacitor from charging.

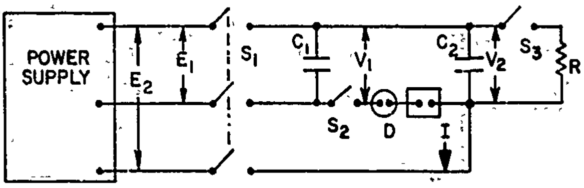


Figure 8-17 (U). Three-wire RC Delay Circuit

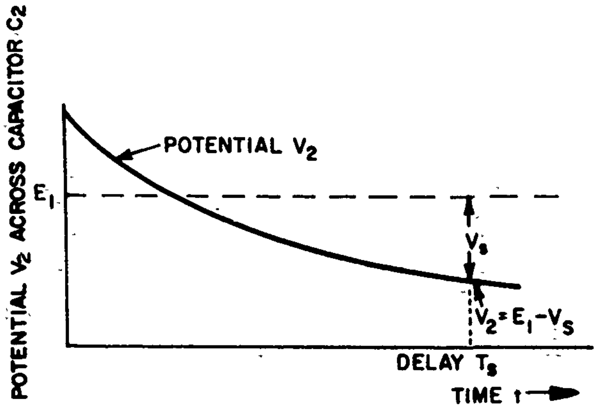


Figure 8-18 (U). Discharge Curve for Capacitor $C_2(E_2 > E_1)$

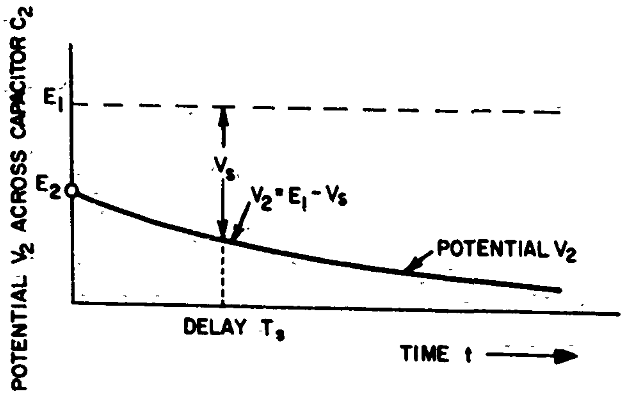


Figure 8-19 (U). Discharge Curve for Capacitor $C_2(E_2 < E_1)$

8-3.5.5 (U) Cascade RC Delay Circuit

Figure 8-20 shows an extension of the basic RC delay circuit (paragraph 8-3.5.1) to lengthen delays several fold, while using components of comparable values. Delay begins when switch S_1 is closed. The switch is kept closed throughout the operation of the system.

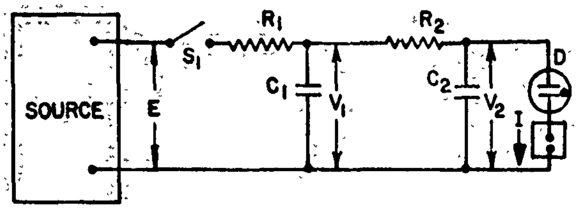


Figure 8-20 (U). Cascade RC Delay Circuit

The solution is simplified if

$R = R_1 = R_2$, and $C = C_1 = C_2$

The value of potential V_2 reached at time t after switch closure is given by

$$V_2 = \frac{2E}{RC\left(\frac{3C}{4R} - 1\right)^{\frac{1}{2}}} \left[e^{-at}\left(e^{bt} - e^{-bt}\right)\right]$$

where

$$a = \frac{3}{2RC}$$

$$b = \frac{1}{RC}\left[\frac{3C}{4R} - 1\right]^{\frac{1}{2}}$$

In Figure 8-21, tank capacitor C_T is added to provide instantaneous charging. Switch S_1 is closed for a period of less than 1 sec to charge capacitor C_T to potential E. Delay starts when switch S_2 is closed. The switch remains closed for the duration of the delay operation. Since the potential of tank capacitor C_T falls as charge leaks to capacitors C_1 and C_2, the delays are longer than those using the circuit of Figure 8-20.

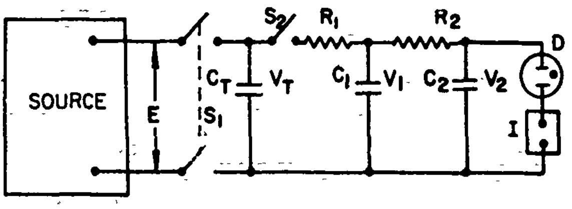


Figure 8-21 (U). Cascade RC Delay Circuit with Instantaneous Charging

8-3.5.6 (U) Ruehlmann RC Delay Circuit

Three tank capacitors give the Ruehlmann circuit advantages over simpler RC circuits. The diode striking potential, on which RC delay accuracy depends, is stabilized immediately before delay begins. Therefore, wide power supply variations can be tolerated.

8-3.5.6.1 (U) Two-Diode Ruehlmann Circuit

Figure 8-22 shows a circuit that gives accurate delays from 10 to 20 sec. This wide range is obtained by varying charging potential E_4. Variation of E_4 in this circuit is permitted by the charging diode T_2.

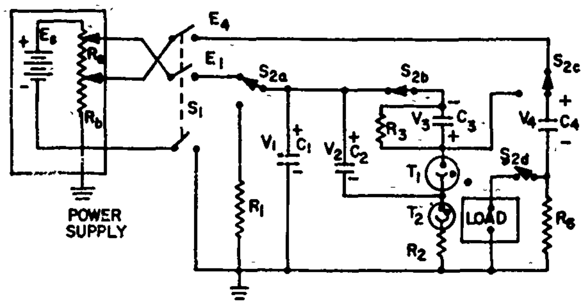


Figure 8-22 (U). Two-diode Ruehlmann Circuit

Resistances R_b and R_a are set for the desired delay. The ratio of E_4 to E_1, on which delay depends, then remains constant even though supply potential E_s may vary.

Capacitors C_1, C_2 and C_4 are charged during a brief closure of switch S_1. Capacitor C_2 is charged through diode T_2 to a potential $(E_1 - V_{2E})$, where V_{2E} is the extinction potential of diode T_2. Capacitor C_2 then discharges through diode T_1, resistor R_3, and capacitor C_3 until potential [illegible] equals $(V_{1s} - \Delta E)$, where V_{1s} is diode T_1 striking potential. If $C_3 << C_2$, ΔE may be of the order of 10 millivolts. The parameters of the diodes, and potentials E_1 and E_4 must be chosen so that the potential across diode T_2 does not again reach the striking potential. The resistance of diode T_2 can be considered infinite after extinction. The relaxation operation is completed in about 0.25 sec.

Delay begins when switch S_2 closes the series circuit shown in Figure 8-23. The initially higher potential $V_1 = E_1$ opposes the sum of potentials V_2 and V_4. Potential $V_4 = E_4 = kE_1$, where k is a function of resistances R_a and R_b.

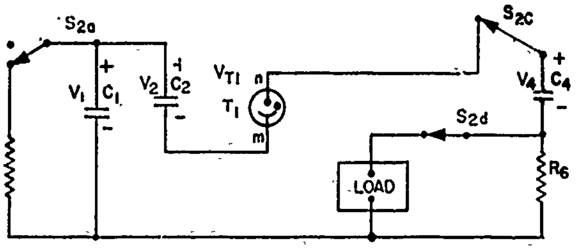


Figure 8-23 (U). Circuit After Closure of Switch S_2

Potential V_1 at time t is $V_1 = E_1 e^{-t/R_1C_1}$. As stated previously, $V_2 = (V_{1s} - \Delta E)$. During the period that potential V_1 is high enough to dominate the series circuit but not high enough to cause diode T_1 to strike, terminal m of the diode is at a higher potential than terminal n, and the sum of potentials in the circuit is

$$V_1 - V_2 - V_4 - V_{T1} = 0 \text{ (current assumed zero)}$$

Finally, potential V_1 drops to the point at which V_{T1} equals zero, and with further decreases of V_1 terminal m of diode T_1 becomes more and more negative. At the potential $V_{T1} = V_{1s}$, the tube fires, and

$$V_1 - V_2 - V_4 + V_{1s} = 0$$

or, on substitution of values

$$E_1 e^{-t/R_1C_1} - (V_{1s} - \Delta E) - kE_1 + V_{1s} = 0 \tag{8-20}$$

Then

$$E_1 e^{-t/R_1C_1} = kE_1 - \Delta E$$

from which

$$e^{-t/R_1C_1} = \left(k - \frac{\Delta E}{E_1}\right)$$

and

$$t = -R_1C_1 \ln \left(k - \frac{\Delta E}{E_1}\right) \tag{8-21}$$

When ΔE is negligible with respect to E_1, Equation 8-21 very nearly equals

$$t = R_1C_1 \ln \left(\frac{1}{k}\right)$$

8-3.5.6.2 (U) Single-diode Ruehlmann circuit

The single-diode circuit shown in Figure 8-24 compares in performance to the two-diode circuit of Figure 8-22, except that a smaller variation range of charging potentials can be tolerated. This circuit is particularly suited to applications in which the leakage resistance R_1 can be adjusted to vary the delay.

Capacitors C_1, C_2, and C_4 are charged during closure of switch S_1. After discharge of capacitor C_2 through T_1, R_3, and C_3, switch S_2 is thrown to initiate the delay by establishing a series circuit similar to that shown in Figure 8-23. Equations developed for the two-diode circuit apply to the single-diode circuit also. When other parameters of the circuit are fixed, R_1 can be found from Equation 8-21 to give the desired delay, t.

8-3.5.7 (U) Accuracy of RC Delays

Delay errors are due primarily to errors in measured value of components and variation of diode striking potential. The delay error is expressed as a fraction of the desired delay time, $\frac{\Delta t}{t}$. To determine the probable fractional error of a particular circuit, $\frac{\Delta t}{t}$ is determined for each parameter separately, and then all are added together. To illustrate the methods of calculating errors, the Ruehlmann circuits are considered in the following paragraphs.

8-3.5.7.1 (U) Calculating errors in component values

The fractional error is computed for each parameter in Equation 8-21. This equation is then partially differentiated with respect to each parameter and, in each case, an equation is obtained of the form $\frac{\Delta t}{t} = M_F \frac{\Delta F}{F}$. The term F represents any one of the parameters. Table 8-1 contains formulas for determining delay errors of Ruehlmann circuits due to errors in component values.

8-3.5.7.2 (U) Calculating error in striking potential

Table 8-1 also contains the formula to determine the delay error due to variation in striking potential. The formula is derived from

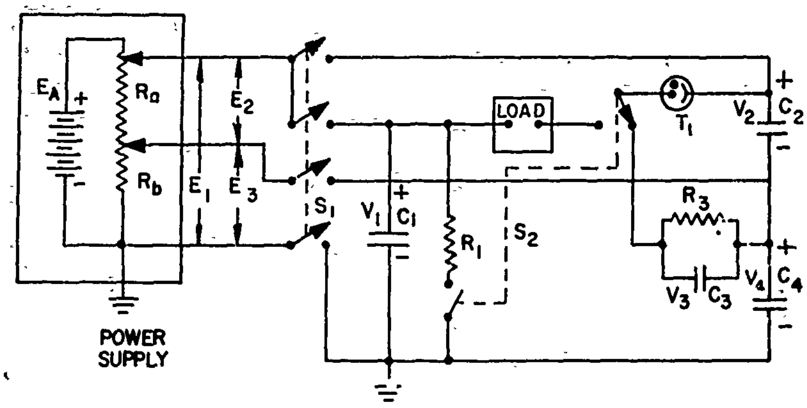


Figure 8-24 (U). Single-diode Ruehlmann Circuit

TABLE 8-1 (U). Fractional Error Relations for the Ruehlmann Circuit

Type of Error	*Parameter, F*	*Multiplying Factor, M_F*	*Error Equation*
Component Errors	R_1	1	$\frac{\Delta t}{t} = 1\frac{\Delta R_1}{R_1}$
	C_1	1	$\frac{\Delta t}{t} = 1\frac{\Delta C_1}{C_1}$
	k	$\frac{1}{\ln k}$	$\frac{\Delta t}{t} = \frac{1}{\ln k}\frac{\Delta k}{k}$
Variation of Striking Potential	V_{1s}	$\frac{-1}{k \ln k}$	$\frac{\Delta t}{t} = \frac{-1}{k \ln k}\frac{\Delta V}{E_1}$

Equation 8-20 by substituting $V_{1s} + \Delta V$ (the actual potential at the time of firing) and $t + \Delta t$ (the actual time of firing) for V_{1s} and t, respective, and solving for $\frac{\Delta t}{t}$.

8-3.5.8 (U) Application of Delay-Error Theory to Fuze Design

For a circuit using a diode of fixed striking potential, the delay may be adjusted by varying either charging potential E or one or more of the capacitors or resistors. An analysis of the equations governing delay-error theory points out that a much greater delay range can be obtained by varying resistance or capacitance than by varying the charging potential.

The charging potential can be varied by suitable charging gear. Capacitance and resistance values can be changed directly, or controlled remotely by applying radio-frequency pulses from control equipment to explosive transfer switches in the fuze. Resistors required for such a switching system are cheap and take little space.

8-4 (U) MAGNETIC SAFETY AND ARMING DEVICES (Ref. 17)

Although magnetic arming devices have been investigated, none are in use at the time of this writing. A magnetic arming device itself appears simple and inexpensive. However, magnetic and electromagnetic devices small enough to fit in conventional fuzes do not possess sufficient strength to insure positive action under service conditions. They usually require an explosive motor or squib to obtain positive action which many times creates a need for additional RF shielding. Also, schemes such as magnetizing part of a gun barrel or electrically energizing a coil on the barrel or launcher have always been rejected because they involve modifying existing weapons or make weapons more complicated and more subject to failure.

One type of magnetic-delay device that has occasionally been considered is the eddy current brake (Ref. 7). This device is sensitive to acceleration and tends to integrate to a constant velocity rather than distance. It has two advantages over the often used clock-delay mechanisms (paragraph 8-2.7): (1) easier and more positive starting and (2) it is more easily regulated. With respect to clock mechanisms, however, it has the disadvantages of greater size, requires more critical materials for permanent magnets, and is more temperature sensitive. Therefore, the eddy current brake is not generally used.

8-5 (U) FLUID-OPERATED SAFETY AND ARMING DEVICES

Fluid-operated devices provide a simple means of providing arming delays from a fraction of a second to several seconds. They might also be used to program events in complex devices such as guided missiles.

Any mechanism operated by a liquid or a gas is termed a fluid-operated device. These devices are usually simple, easy to design, and inexpensive. Force is readily transmitted in all directions through a fluid, and either force or displacement can be easily amplified.

Devices operating in both the laminar (viscous) flow region and the turbulent (nonviscous) flow region have been investigated for fuze applications. The use of fluid-operated devices has been very limited, however, because their disadvantages quite often outweigh their advantages. For example, they are not capable of providing the required accuracy specified for many applications; fluids leak, creating sealing problems; and in devices where flow is in the laminar region, variation of viscosity with temperature often alters the operating characteristics of the device.

The mechanics of fluid flow are covered in many standard texts. References 1 and 18 describe typical fluid-operated devices. Paragraphs 8-2.8.2 and 8-2.8.3 of this handbook discuss the use of fluid-operated devices as acceleration-time mechanisms.

8-6 (C) ARMING PROGRAMMERS

(U) Although an arming programmer is not considered a true S & A device, it performs essentially the same function and, therefore, is discussed in this chapter. Differences between the two types of devices should be borne in mind, however. For example, an S & A device contains explosive elements, while an arming programmer delivers electrical signals to a device containing the explosives (warhead). Also, an out-of-line element physically interrupts the explosive train in an S & A device; in arming programmers, safety is provided by switches, which must operate in a particular sequence.

Arming programmers provide certain outputs in a desired sequence when they are supplied with a given set of inputs. When programmers are used in missiles, inputs may be command signals from a remote location; signals from built-in timing devices; and signals generated by launching, various degrees of acceleration in flight, changes in altitude, or other environmental conditions. Normally, outputs operate electrical switches in a certain sequence and at specified times to supply power for warhead boosting, primary fuze arming, command dud operation, self destruction, and so on.

8-6.1 (U) TYPES OF ARMING PROGRAMMERS

Arming programmers are generally electromechanical or electronic devices. They may be classified as follows:

(1) *Type 1.* These have gross-motion electromechanical devices such as relays, solenoids, motors, gear trains, and spring-weight combinations. Although they may be one-shot devices, they generally are recycleable, and store

static logic data (logic states) without consuming power in the process. They can be designed to meet the stringent reliability requirements for programmers although, inherently, such mechanisms are vulnerable to vibration caused by launching and flight and to failure caused by foreign particles or corrosive gases that enter during storage, transportation, maintenance, and flight.

(2) *Type 2.* These have magnetic storage devices, a minimum of moving parts, many small components of high inherent reliability, and store logic states without consuming power. They are compact, require small amounts of signal energy, and have relatively simple circuits. Type 2 programmers will operate reliably at temperatures as high as 176°F.

(3) *Type 3.* These are composed entirely of small, space-saving, one-shot components, such as explosive motors, time delay powder trains, and thermal batteries. This type of programmer can also store logic states without consuming energy.

(4) *Type 4.* These have a high number of solid state devices, such as transistors and diodes, but cannot store logic states without using power in the process.

When a missile power supply is not continuous, and when it must complete its mission or destroy itself if power fails, the ability to store logic states without using power in the process is important, and Type 4 programmers cannot be used in such cases.

8-6.2 (C) OPERATION OF ARMING PROGRAMMER

The following steps detail the operation of a typical arming programmer. The programmer, which is of the electromechanical type (Figures 8-25 and 8-26), is for ground-to-air application.

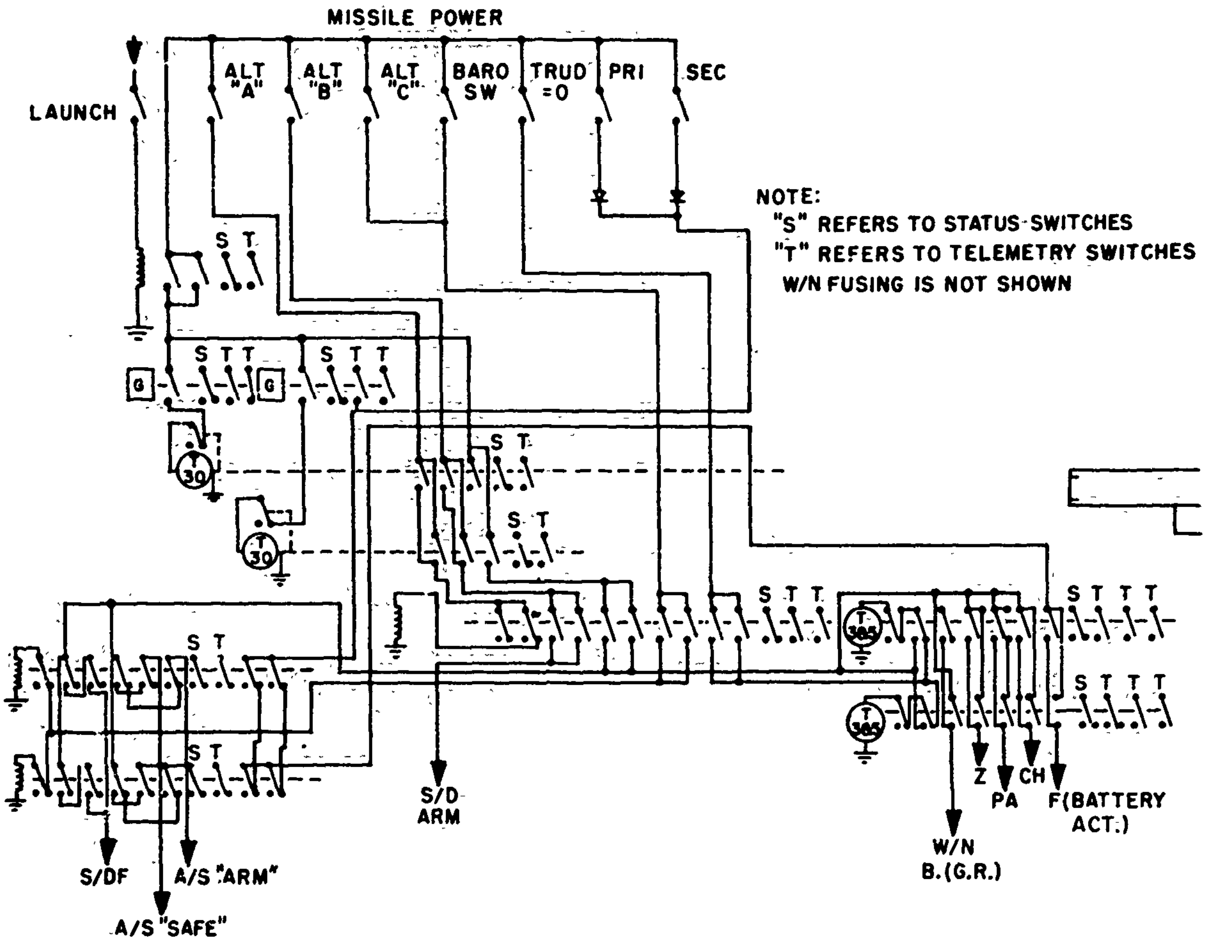


Figure 8-25 (C). Circuit Diagram for an Arming Programmer (U)

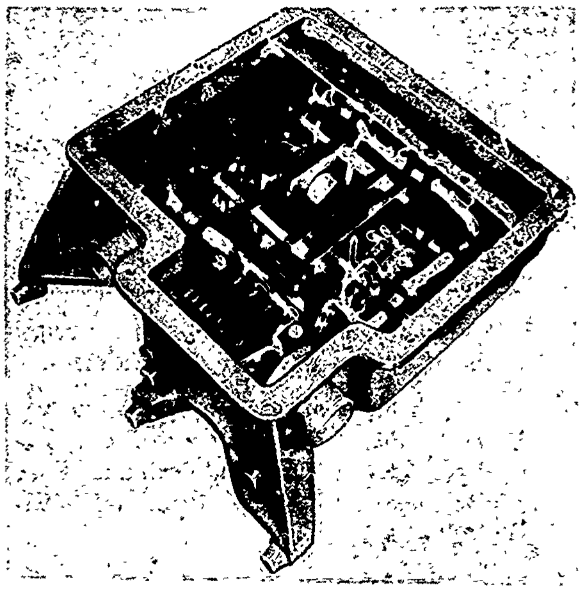


Figure 8-26 (U). Arming Programmer

The missile in which the programmer is used climbs to a predetermined altitude and then dives to intercept the target.

(1) The launch signal energizes the upper solenoid, closing the attached switch contacts to apply voltage to the common terminals of the G switches.

(2) When the launch acceleration exceeds 1.8 g, the g switches close, energizing the timer motors. These motors run only when the acceleration is above 1.8 g, and stop if acceleration drops below this level.

(3) When acceleration has remained above 1.8 g for a total of 30 sec, the T_{30} timer actuates switches, which are connected in parallel for reliability, to deenergize the timer motors, and close the circuit from altitude "A" to the next relay.

(4) The altitude "A" signal energizes the second relay, which causes it to deenergize its associated solenoid. This applies power to the command dud and destruct relay, closes the TRUD $= 0$ (time remaining until dive) and altitude "C" circuits, and energizes the "arm" line of the arm-safe switch in the warhead.

(5) When TRUD $= 0$, timers T_3 and T_5, which are in parallel, are started. These timers immediately actuate contacts to maintain power to their associated motors and to supply power for warhead boosting and primary fuze arming.

(6) After 3 sec, switches are closed to energize the warhead batteries.

(7) After 5 sec, the circuits from the primary and secondary fuze to the warhead fire lines are closed, preparing the warhead for detonation.

(8) If the altitude "B" signal occurs after the altitude "A" signal and before warhead detonation, the self-destruct power supply becomes energized to arm the self-destruct system. Then, if the altitude "C" on the baro-switch signal occurs, the last relays become energized. Switches on these relays disconnect the relay solenoids, transmit a self-destruct firing signal, and energize the "safe" line of the arm-safe switch.

8-6.3 (U) DESIGN CONSIDERATIONS FOR ARMING PROGRAMMERS

Premature functioning of an arming programmer can cause an extremely dangerous condition. Therefore, reliability of an arming programmer is its most important design requirement. The reliability requirement for some missile programmers is 25,000 to 1 against premature detonation, and the probability of proper performance, 100 to 1. Other major design considerations are:

(1) Nature of the inputs and outputs.

(2) Time relationships of inputs and outputs.

(3) The number of times it must function. Although a programmer functions only once in operation, it may have to endure as many as 500 tests simulating various environmental conditions.

(4) Size and weight limitations.

(5) Maintenance and service capabilities of the various echelons.

(6) The number of programmers to be made. Since only a few programmers will be made, as compared to the large numbers of S & A devices made for conventional weapons, emphasis on design for mass production is not usually required.

Reference 19 contains a discussion of the various types of components used in the T3019E3 Arming Programmer, which is an electromechanical programmer. This reference also describes proposed electronic programmers and discusses the types of components that could be used.

(U) REFERENCES

1. *Fuzes, General and Mechanical*, Ordnance Corps Pamphet ORDP 20-210, January 1960.
2. H. B. Smith, *A Summary of Mechanical and Electrical Safety and Arming Devices*, Report No. TR-311, Diamond Ordnance Fuze Laboratories, 1 November 1956. (CONFIDENTIAL)
3. R. Bowles, *Deformation of Materials*, manuscript, Diamond Ordnance Fuze Laboratories.
4. A. Hausner, *Sequential Events Setback Mechanisms*, manuscript, Diamond Ordnance Fuze Laboratories.
5. A. Hausner, *A Safety Analysis of Setback Leaves*, Report No. NBS 16.5-6R, National Bureau of Standards, 24 April 1953.
6. Unless otherwise noted, this section is based on A. Hausner, *Untuned Escapements*, manuscript, Diamond Ordnance Fuze Laboratories.
7. M. Apstein, et al., *Arming Systems for Nike 1, Nike B, and Hawk Missiles*, Report No. TR-214, Diamond Ordnance Fuze Laboratories, 17 August 1955. (SECRET)
8. *A Study of the Dynamics of an Untuned Clock Mechanism*, Department of Physics, VMI, 1 September 1953.
9. *A Study of the Effect of Geometrical Factors Upon the Behavior of an Untuned Clock Mechanism*, Department of Physics, VMI, 30 June 1954.
10. *A Study of Non-Uniformity in Running Rates of a Certain Type of Time Delay Mechanism*, Department of Physics, VMI, 31 August 1954.
11. *The Effect on Unbalanced Verge Torques, Acceleration Friction Torques, and Verge Starwheel Material Upon the Running Rates of a Certain Type of Time Delay Mechanism*, Department of Physics, VMI, January 1955.
12. L. Andrews, *Mechanical Arming Devices*, manuscript, Diamond Ordnance Fuze Laboratories.
13. L. Richmond *Thermal Time Delays Associated with Thermal Batteries*, manuscript, Diamond Ordnance Fuze Laboratories.
14. R. E. Rouse, *Thermal Time Delay Report No. NBS 17-189*, National Bureau of Standards, September 1953.
15. J. G. Moorhead, *RC Circuits*, manuscript, Diamond Ordnance Fuze Laboratories.
16. J. W. Utecht, et al., *Development of T905-E1 and T905E4 Electric Bomb Fuzes*, Report No. TR-159, Diamond Ordnance Fuze Laboratories, 15 April 1955. (CONFIDENTIAL)
17. *Magnetic Arming Device Design Study*, Report No. R-152, Rheem Manufacturing Company, 30 March 1954. (CONFIDENTIAL)
18. *A Study of Fluid Flow and Similar Devices for Use in Fuze Delays*, Summary Report No. R-212, Rheem Manufacturing Company, 30 August 1955. (CONFIDENTIAL)
19. This section based on:

    Safety and Arming Device T-3019E3, Engineering Redesign Evaluation, Hamilton Watch Company, 12 June 1959. (CONFIDENTIAL)

    Design Methods for IM-99A Arming Programmer, Kaman Aircraft Corporation, June 1959. (SECRET)

    Engineering Study Report of the T-3019-3 Arming Programmer, Zenith Radio Corporation, September, 1959. (CONFIDENTIAL)
20. G. Merrill, et al., *Principles of Guided Missile Design Series. Operations Research, Armament, Launching*, D. Van Nostrand, Inc., 1956.
21. J. R. Rosenblatt, *On Prediction of System Performance from Information on Component Performance*, Proceedings of the Western Joint Computer Conference, Los Angeles, California, February 1957.

22. A. Hausner, *A Procedure for Developmental Drop-Testing: Safety and Arming Mechanisms Containing Time-Integration System,* Report No. R-320-61-4, Diamond Ordnance Fuze Laboratories, 15 February 1961.

23. A. Hausner, *An Analysis of Friction in a T293 Type Setback Heat System,* Report No. R-320-60-14, Diamond Ordnance Fuze Laboratories, 10 October 1960.

24. A. Hausner, *Optimizing a Setback Leaf System for Safety,* Report No. R-320-60-22, Diamond Ordnance Fuze Laboratories, 28 December 1960.

CHAPTER 9

(U) COMPONENTS

9-1 (U) INTRODUCTION

Fuze components, like other critical components of a weapons system, must have high reliability in storage and in short-time operation. In many cases, failure of a fuze component is a greater calamity than failure of a component in another system. Early activation can cause personnel hazard. Improper activation results in failure of the weapon after others systems have done their job.

When selecting fuze components, the fuze designer must bear in mind that many components of questionable reliability for long-time applications may be entirely suitable for use in fuzes. Components with a relatively short operating life or with failure rates that rise sharply with cycling might not be usable in some conventional radars or computers. These components, however, might be quite satisfactory for fuzing applications. Even though some fuzes undergo many tests prior to actual use, their total operating life expectancy is normally much less than that of conventional radars or computers, and they are subjected to far less cycling. Similarly, tolerances of some components may prohibit their use in certain types of electronic equipment, but they might be used very well in an on-off fuze application.

The factors working against fuze component reliability vary with the type of fuze with which the components are used. Generally in fuze applications, component reliability in related to the requirements for long inactive shelf life, extreme operational environmental conditions, and the inability to field test certain fuzes or at least parts of them.

9-2 (U) SELECTION OF COMPONENTS

The fuze designer is cautioned to take full cognizance of the importance of utilizing standard components, that is, components that meet all the requirements of an applicable MIL or Federal Specification. The underlying reasons for this are as follows:

(1) Standard components are known to be manufacturable to the specifications for that component.

(2) The performance of most standard components under specific conditions can be predicted.

(3) Standard components are available, and developmental and test times do not constitute a problem.

(4) Standard components have been manufactured in quantity and are probably cheaper than special components.

(5) Standard components do not require engineering development costs.

(6) The logistic problems involved in utilizing special components are tremendous. Stockpiling, cataloging, and distributing require considerable time, effort and cost.

WADC Technical Report 57-1 gives complete information on the publications available for determining suitable standard parts available for various applications. Topics to be consulted are "Military Specifications and Military Standards for Components," "Qualified Products List," and for cases where special parts are required, "Specification Writing."

9-3 (U) ENVIRONMENTAL PROBLEMS

The fuze designer must be well acquainted with the environmental conditions under which the fuze must operate. Any component that is chosen must perform satisfactorily in its expected operating environment; the environment before use is also of importance. Environmental conditions that must be taken into consideration during storage and handling are temperature extremes, corrosive atmospheres, abrasive conditions, barometric pressure, humidity, radiation exposure, shock, vibration and acceleration. Most of the conditions are of obvious elementary consideration. Not so often recognized, however, is the effect of the combination of different conditions. Of particular importance is the relationship between temperature and rate of chemical action. This relationship is an important factor affecting the storage life of equipment.

Methods used to combat deleterious conditions are covered in WADC Technical Report 57-1 under the heading of "Component Application Factors."

9-4 (U) APPLICATION DATA

Much background information and application data for electronic components exist in available literature, and consequently, are excluded from this chapter. Sources of such information are given below. The publications listed give information on electronic components that are widely used in military electronic equipment. These publications are only a few of the many available. However, all commonly used electronic components are covered by at least one of the sources mentioned.

Electronic Components Handbook, series of three volumes, Keith Henney, Craig Walsh, and Harry Mileaf, McGraw-Hill Book Company, 1957-1959.

Prepared for the Air Force. Volume One covers resistors, relays, capacitors, and switches. Volume Two covers power sources and converters, fuses and circuit breakers, electrical indicating instruments, printed wiring boards, solder and fluxes, choppers, blowers, RF transmission lines and wave guides. Volume Three contains information on transformers and inductors, connectors, wire and cable, terminals, tube shields, and hardware. The books present general information and application data. Military specifications pertinent to the components discussed are summarized, and design techniques are included.

RADC Reliability Notebook, RADC TR 58-111, Rome Air Development Center, November 1959.

Prepared for the Air Force. Chapter 8 contains information on electron tubes, tube shields, microwave tools, transistors, semiconductor diodes, crystals, resistors, capacitors, transformers and inductors, connectors, relays and switches, wire, and motors. Included are failure data for the different components under various conditions.

Transistor Application Manual, Arinc Research Corporation, 29 May 1959.

Prepared under joint service contract. Contains information on application of transmitters to military electronic equipment. Part I is concerned with information provided by specifications. Part II presents a summary of applications information including information on product variability.

Techniques for Application of Electron Tubes in Military Equipment, WADC TR 55-1, Electronics Components Laboratory, WADC, 1957.

Part I discusses tube properties, ratings, characteristics essential in circuit operation, and properties detrimental to circuit operation. Part II covers tube properties in relation to circuit design, and includes a checklist for use by the circuit designer. Part III contains numerical data and special design considerations for specific tubes. Part IV presents product distribution curves derived from life tests for certain tube types.

Other information dealing with components essentially unique to fuze design is included in various chapters of this handbook. For example, thermal batteries are covered in Chapter 7, the R-1B klystron in Chapter 3, etc.

9-5 (U) DETONATORS

For published information pertaining to detonators, the reader is referred to the Engineering Design Handbook *Fuzes, General and Mechanical,* ORDP 20-210; and to *Ordnance Explosive Train Designers Handbook,* NOLR 1111.

Additional and more recent information on detonators is included in a new volume of the Engineering Design Handbook, now nearing completion. Tentative title of the new handbook is *Explosive Charge Design.* Exact title and numerical designation will appear on an early list of handbooks published.

CHAPTER 10

(U) MATERIALS

10-1 (U) INTRODUCTION

General characteristics and properties of most materials used in fuzes are covered in standard texts and handbooks. This chapter therefore, presents only information on a few special materials of particular interest to the fuze designer. Emphasis is on potting materials.

The main consideration in selecting a material for a particular application is its intended use. Other considerations are cost, availability, ease of fabrication, tolerances, compatibilty with adjacent materials, and deterioration by the elements or the operational environment. Generally, many materials are available, but none has all of the chemical, physical, and other characteristics desired. The problem is to choose a material with the best combination of characteristics for a particular application.

10-2 (U) POTTING COMPOUNDS FOR ELECTRONIC COMPONENTS

This section presents basic data on the use of various potting materials for electronic components. A detailed evaluation of various potting materials is contained in Reference 1.

Potting compounds are used to seal electronic parts for protection against temperature, pressure, moisture, dirt, corrosion, fungus, vibration shock and arcing between components.

Development of new electronic component parts and circuits, for example miniaturized parts and integrated circuits, results in a continuing demand for potting materials with special properties. Present emphasis is still on potting materials of increased resiliency and flexibility, and decreased dielectric loss.

10-2.1 (U) ADVANTAGES OF POTTING ELECTRONIC COMPONENTS

Low and medium powered electronic components are more reliable and longer lived when encapsulated in the proper compounds. The compound protects the component from moisture, fumes, dirt, external heat, and all adverse environmental factors except internally generated heat. The potting compound gives mechanical support to components; hence, it acts as a ruggedizer. It also prevents unauthorized or unskilled tampering or adjustment of components in the field and provides support for sprayed or painted electrical shielding of the embedded circuit. The potting process is relatively fast and cheap. It can result in a saving in space since components do not require cases, and uncased components can be compacted together. The potting resin itself provides insulation and holds components in fixed position. It may result in a saving in weight over other holding, sealing, and protective measures. Because the potting material gives structural support as well as protection, component cases, chassis, brackets, terminal boards, nuts, screws, washers, and other hardware are usually not required. These items occupy considerable space and are 20% to 30% of the weight of most electronic assemblies. Their elimination generally compensates for the weight of the resin. Resins occupy all free space in a casting, but their specific gravity is low, generally half that of aluminum.

Whether or not space and weight are saved depends on layout. When the layout is good, free space is limited to that required by strength or heat considerations.

10-2.2 (U) DISADVANTAGES OF POTTING ELECTRONIC COMPONENTS

Disadvantages of potting electronic components are: (1) replacing wires and components of a potted assembly is almost impossible, (2) compounds generally do not withstand very high or very low temperature, (3) since the potting material occupies all free space in an assembly, it sometimes adds weight to the assembly, (4) the circuit must be specifically designed for potting, (5) extra time and labor are required to clean the circuit and to protect components prior to embedment, (6) component heat is trapped by the insulating character of the resin, (7) time and special ovens are required to cure the resin after embedment.

Potting compounds also affect the electrical characteristics of a circuit. Distributed capacity increases, circuit "Q" decreases (i.e., power losses increase), and insulation resistance decreases. Initial changes in these factors due to the presence of the compound can be determined and partially compensated for by the designer. Changes caused by aging of the compound and adverse environment are another matter. Stability of the compound during and after exposure to heat, vibration, shock, etc., is therefore important.

In most instances, no potting compound will possess all of the characteristics that the fuze designer desires. For example, one type of compound may have a higher insulation resistance than another in a given environment, but might be inferior in another sense. The designer must compromise, and search for the best, not the ideal, potting compound for the particular application.

10-2.3 (U) TYPES OF POTTING COMPOUNDS

Potting compounds include a catalyst and a resin mixed in correct proportions. They sometimes contain a reactive diluent to facilitate pouring. The mixture is generally poured or foamed in place and allowed to harden. External heat may or may not be used. In the past, natural waxes, tars, and pitch were used to seal electrical compounds. With the discovery of synthetic plastics, new compositions based on polyesters and polystyrene were developed. Now, however, epoxies, polyurethanes, and silicones are available and permit wider use of potted or encapsulated components.

A comparison of various potting compounds is given in Table 10-1. This is a simplified comparison, since it presents properties in ranges to cover a vast number of commercial and laboratory formulations. The table, however, provides a useful guide for preliminary selection.

Three basic resins that have generally proved satisfactory in fuzes are polystyrenes, polyesters and epoxies. Many modifications of these three basic resins have been made, such as the NBS casting resin, which is a modified polystyrene type.

Foamed polyurethane and silicone resins can also be used. Foamed polyethylene, polystyrene and epoxy resins cannot be used, because they can only be foamed in place at temperatures so high as to damage electrical components.

Although vinyls, cellulosics, and phenolics can be foamed in place, the electrical properties of these resins preclude their use as potting materials. Epoxy resins containing amine curing agents should not be used as potting materials in cases where they are in direct contact with explosives; amines may react with the nitro groups of an explosive to cause deterioration of the explosive, or the resin, or both.

Although the silicones have very low water absorption, they nevertheless are very permeable to water vapor. Silicone rubber is a fair heat conductor, a reasonably good electrical insulator and withstand both high and low temperatures.

Silicone resins are sometimes foamed in place. Heat is not required for foaming; a "blowing agent" is used. One manufacturer, when foaming silicone resins, uses a silicone polymer which releases gaseous hydrogen when mixed with an amine catalyst in the compound. Specific amounts of ingredients are mixed together for a certain period of time, poured in place, and allowed to foam. After expansion is complete, samples are cured at given temperatures for specified periods of time.

Catalysts that are added to many potting compounds are selected so as to control the curing process and to modify the properties of the cured compound. The type and amount of catalyst added depends on the compound and its intended use. Peroxide catalysts are used most often.

Commercial polyester resins are solutions of unsaturated polyesters in an unsaturated monomer, such as glycol maleate in styrene. It has been suggested that gamma rays could cure some resins quickly without using heat or catalysts. This process is not considered practical, since the gamma dosage that would probably be required to cure the resin would also be sufficient to damage the electronic components.

TABLE 10-1 (U). Comparison of Properties of Typical Potting Materials (Ref. 2)

Material	*Linear Shrinkage*	*Thermal Expansion*	*Thermal Conductivity*	*Volume Resistivity*	*Dielectric Strength*
Epoxy:					
Unfilled	very low–med.	low–high	low–medium	good–excel.	very good
Filled (rigid)	very low–low	low	high	very good–excel.	very good–excel.
Filled (flexible)	low–high	low–high	medium	good–very good	very good
Syntatic	very low–low	very low	very low–low	very good	good
Polyurethane:					
Foam	very low	low–high	very low	very good	(not avail.)
Cast	very low–high	high	very low	good–very good	good–very good
Polyester:					
Filled (rigid)	med.–very high	low–high	medium	good–very good	very good
Filled (flexible)	med.–very high	high	medium	good	good–very good
Silicone:					
Cast (filled)	low	high	very high	excellent	good
RTV rubber	high	very high	medium	very good	very good
Gel	very low	very high	medium	excellent	excellent

Key to Ranges

LINEAR SHRINKAGE, (in/in): very low 0.002; low 0.0021–0.004; medium 0.0041–0.010; high 0.0101–0.020; very high 0.0201.

THERMAL EXPANSION, (in/in °C) x 10^{-5}: very low 2.0; low 2.1–5.0; high 5.1–10; very high 10.1 (figures referenced against aluminum).

THERMAL CONDUCTIVITY, (cal/sec/sq cm/°C per cm) x 10^{-4}: very low 1.5; low 1.6–4.0; medium 4.1–9.0; high 9.1–20; very high 20.1.

VOLUME RESISTIVITY, (ohm-cm): good 10^{11}–10^{12}; very good 10^{13}–10^{14}; excellent 10^{15}–10^{17}.

DIELECTRIC STRENGTH, (volt/mil): good 225–399; very good 400–500; excellent 500.

Tests, particularly on transistors, have shown this to be true in a number of instances.

Cure doses and cure times for Laminacs, Paraplex, Plasticast, and Selectron potting resins cured by radiation are given in Reference 3. These data are provided for information only. The properties of resins cured by radiation are also contrasted with conventionally cured plastics.

10-2.4 (U) EFFECTS OF TEMPERATURE CHANGES ON POTTING COMPOUNDS

Extreme temperature changes not only physically degrade resinous materials, but change their hardness and impact resistance and their thermal and electrical conductivity. Temperature extremes cause dimensional changes, resulting in stress formations, distortion, cracks, and compression of embedded components. Generally, potting compounds must perform satisfactorily over a temperature range of about −65° to +165°F, which is the operating range normally specified for fuzes.

10-2.5 (U) EFFECTS OF WEATHER ON POTTING COMPOUNDS

Weathering damages resins. Some damage is caused by temperature changes, some by other causes. Sunlight acts as an initiator or catalyst for many chemical reactions that change the color or alter the properties of compounds. For example, transparent compounds may become dark or opaque. Although the change of color is generally unimportant, concomitant physical damage may be harmful. Chemical reactions between potting materials

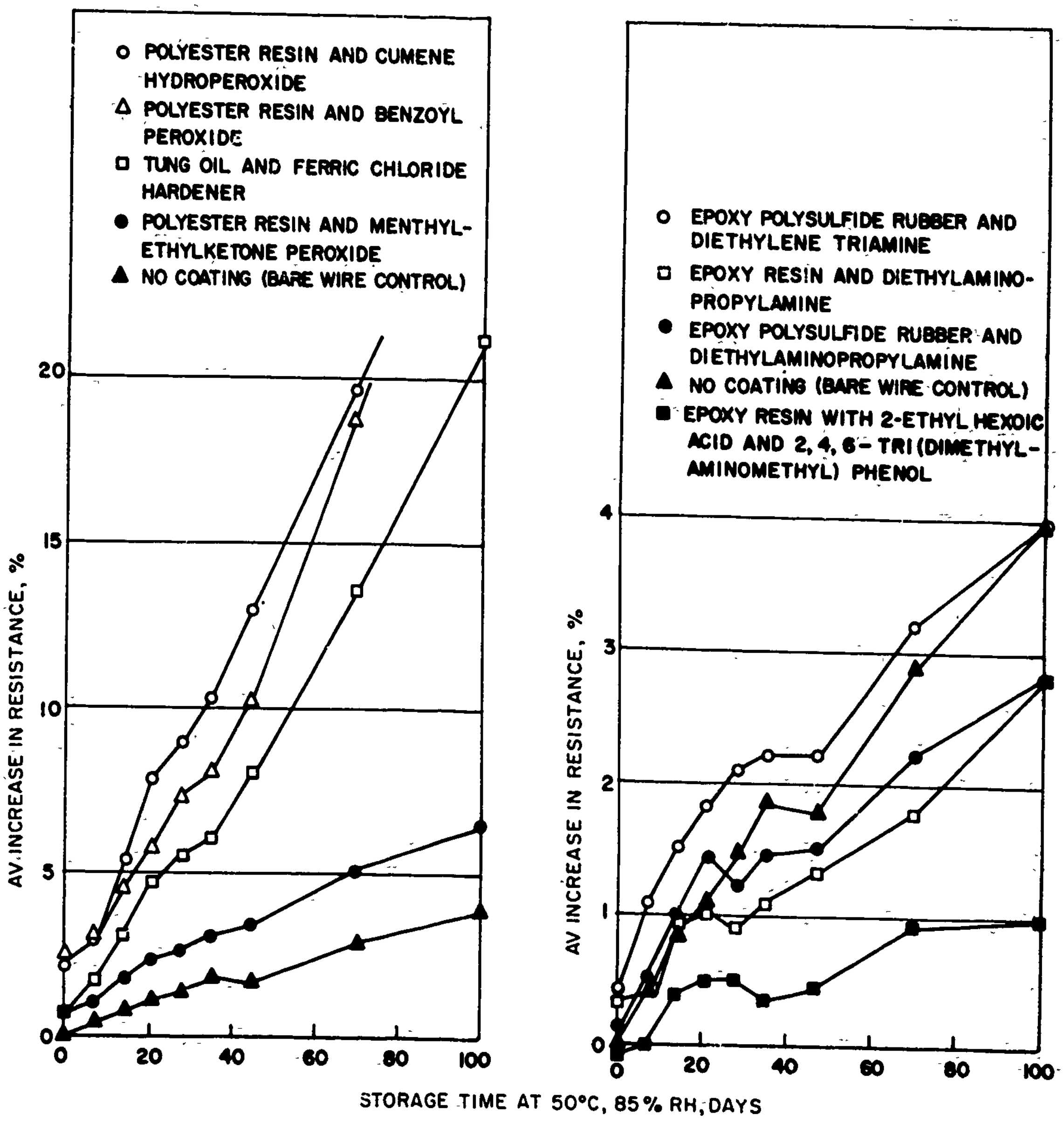


Figure 10-1 (U). Resistance Increase Vs Time for Copper Wire Dip-coated in Embedding Compounds

and atmospheric oxygen, ozone, and other gases cause disintegration. In externally plasticized plastics, rain may leach important modifying agents, the loss of which causes deterioration. For example, the material may become hard or brittle. Of more importance, is the adverse effect on the electrical properties of potting compounds.

Second-order transitions occur in all polymers. In this type of reaction, heat is not given off, and no volume change occurs, but the thermal expansion coefficient and the specific heat of the compound are different above and below the transition temperature. Below the transition temperature, brittleness may occur; therefore, a polymer should be selected that is not brittle under this condition. Most thermosetting resins satisfy this requirement.

Outdoor weather aging tests conducted at Yuma, Arizona and Churchill, Canada indicate that polyester and epoxy resins are satisfactory after exposure in desert or sub-arctic environments. The electrical properties of epoxy polyester resins were not seriously degraded after exposure for one year in the desert near Yuma. The tests also show that hot melt materials should not be used in the Arctic, since they crack and fall away at low temperatures. Reference 4 contains a detailed discussion and some illustrations of the effects of exposure on various materials.

10-2.6 (U) CORROSIVE EFFECTS OF POTTING RESINS ON BARE COPPER WIRE

The corroding effects of a potting resin on copper wire are particularly important because electronic components are connected by copper wires. Also, many potted components, such as transformers and coils, are composed of fine copper wires.

Corrosion of a copper wire can be measured in terms of the increased resistance of the wire. The resistivity of corrosion products is high compared with the resistivity of pure metals.

Figure 10-1 shows the percentage increase in resistance of coils of bare copper wire (AWG No. 40) when dip coated in various potting compounds, then stored in an environment of 122°F and 85 percent relative humidity for 100 days. The slopes of the curves reflect the corrosiveness of the resin; the steeper the slope, the greater the corrosiveness. Polyester resin cured with cumene hydroperoxide, polyester resin cured with benzoyl peroxide, and tung oil cured with hardener containing ferric chloride are highly corrosive systems. Other resins, for example epoxy resin cured with diethylaminopylamine, actually decrease corrosion of copper wire. Potting compounds producing resistance change-vs-time curves with greater slopes than for bare wires contain a corrosive agent and should be avoided as potting materials.

10-2.7 (U) COMPATIBILITY OF POTTING COMPOUNDS WITH EXPLOSIVES

Some potting formulations may be incompatible with explosives. If the potting resin and explosive are not in close proximity, incompatibility is of little concern. Curing of some resins directly in contact with explosives is the most risky condition. Also, intimate mixtures of precured resins with certain explosives may be dangerous. As pointed out in paragraphs 10-2.3, it is the amine curing agent and not the resin itself that is incompatible with an explosive. Frequently, acid anhydride curing agents can be used near explosives if temperatures are not too high. In any event, the fuze designer should always specify that materials used near explosives must be compatible with the explosives.

Picatinny Arsenal has collected quantitative data on compatibility. Most of these data are contained in References 5 and 6.

10-2.8 (U) MECHANICAL AND ELECTRICAL PROPERTIES OF POTTING COMPOUNDS

A fuze designer generally selects a potting compound first on the basis of its electrical properties and second on the basis of its mechanical properties. The selected potting compound must not only be strong enough to withstand any forces encountered in transportation and handling, but it must also withstand setback, vibration, and other forces and conditions that fuzes are subject to.

Shrinkage of potting compound during cure is an important consideration. Curing time directly affects shrinkage. Compounds are cured by heat or catalysts, or a combination of these. All potting materials undergo a certain reduction in volume during the curing process. This shrinkage is sometimes called the characteristic, or true, shrinkage of the material and differs from material to material. In addition, if external heat is used in the curing process, thermal shrinkage occurs. Shrinkage sets up stress that may cause the potting material to crack during curing or to crush the delicate parts encapsulated within it. These tendencies are increased when the potted assembly is subjected to extreme environments during storage or operational use. Fillers can be added to a potting compound to reduce shrinkage or the effects of shrinkage. This sometimes degrades other properties of the compound, such as electrical behavior, and a compromise must be reached.

Important electrical properties of potting compounds are dielectric constant, dissipation factor, volume resistivity, and dielectric strength (Ref. 8). The dielectric constant of any substance is the ratio of the capacitance of a capacitor filled with the potting compound to the capacity of the same capacitor with the compound replaced by a vacuum. The dissipation factor is the ratio of the energy lost to the energy stored in the material per cycle. Volume resistivity is the direct current resistance in ohms-centimeter. Dielectric strength is the voltage gradient a compound can withstand without rupture.

The dielectric constant and dissipation factor of a given potting compound vary with temperature and frequency. Many compounds have a peak dissipation factor occurring at a particular frequency. The formation of this peak is accompanied by a rapid change in the dielectric constant. These important effects are the result of a relaxation phenomenon occurring in polar materials. The position of the dissipation-factor peak is sensitive to temperature; an increase in temperature raises the frequency at which the peak occurs. Nonpolar potting materials have very low losses without a noticeable peak; the dielectric constant remains essentially unchanged over the frequency range.

Another effect that contributes to dielectric losses is that of ionic and electronic conduction. This effect, if present, is important usually at the lower end of the frequency range, and is distinguished by the fact that the dissipation factor varies inversely with frequency. An increase in temperature of the material increases the loss due to ionic conduction because of the increased mobility of the ions.

The direct-current volume resistivity of many materials is influenced by changes in temperature and humidity.

To select a resin with desirable electrical characteristics, at least the following should be determined:

(1) At what temperature does the part of the dissipation factor that is due to conduction current become a significant part of the whole, and what is the rate of increase of the part due to conduction current? This increase is exponential and depends on the activation energy of the charge carriers. The activation energy is proportional to the slope of the curve of log volume resistivity versus absolute temperature.

(2) Are there one or more dipolar losses and, for a given frequency, at what temperature does the maximum loss occur? These losses are characterized by bell-shaped dissipation factors in the temperature-frequency field (dispersion region). It has been shown that the frequency-temperature relationship is determined by the activation energy for the dipoles in question, and that it is possible to extrapolate the loss factor (delectric constant x dissipation factor) to regions outside the field presented here. Values of dissipation factor below 10×10^{-4} are considered low loss, between 10×10^{-4} and 100×10^{-4} medium loss, and above 100×10^{-4} high loss. The relative terms low, medium, and high are actually delineated by specific applications.

(3) Is the dielectric constant high, and what type of temperature behavior does it exhibit? Most polar resins have postive coefficients of dielectric constant up to some "critical" temperature at which the coefficient becomes negative. Critical temperature is also a function of frequency. This behavior is pronounced at low frequencies and can be offset in low dielectric constant materials by volume expansion.

The following discussion includes data that are useful in making such determinations, and an illustrative example.

Figures 10-2 through 10-5 give the dielectric

TABLE 10-2 (U). Composition of Various Casting Resins

Resin No.	*Resin Type*	*Composition*	
		Component	*Parts by Weight*
1	Modified polystyrene	Styrene	40
		Undisclosed	60
2	Modified polystyrene (NBS Casting Resin)	2,5-dichlorostyrene	33
		Poly-2,5-dichlorostyrene	21.5
		Styrene	21
		Polystyrene	11
		Hydrogenated terphenyl	13
		Divinylbenzene 40% sol'n	0.5
		Cumene hydroperoxide	0.1
3	Modified polyester	Highly unsaturated polyester alkyd	70
		Styrene	30
4	Modified polyester	Highly unsaturated polyester alkyd	50
		Styrene	50
5	Modified polyester	Unsaturated polyester alkyd	50
		Styrene	50
6	Epoxy resin	Epoxy resin	100
		Diethylene triamine	10
7	Modified epoxy	Epoxy resin	100
		Polysulfide rubber	40
		Diethylene triamine	10
8	Modified epoxy	Epoxy resin	100
		Polysulfide rubber	100
		Diethylene triamine	10
9	Epoxidized	Polybutadiene, 6.13% epoxidized	100
		Phthalic anhydride	8

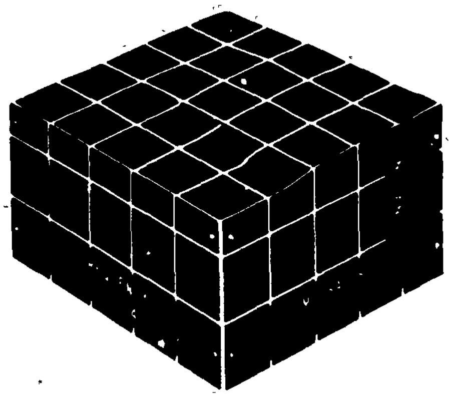
constant, dissipation factor, and volume resistivity of the three main types of potting compounds used in fuzes (modified polystyrenes, polyesters, and epoxies). These figures give data over a wide range of frequencies and temperatures. The figures are photographs of three-dimensional honey-comb type plastic models called "field diagrams" (Ref. 7).

Table 10-2 gives the composition of the compounds. Resins numbered 1 and 2 in the table are modified polystyrene casting resins. Resins 3, 4, and 5 are three commercial modified polyesters. Resin 6 is a commercial epoxy, resins 7 and 8 are epoxy-polysulfide resins, and resin 9 is an experimental epoxidized polybutadiene.

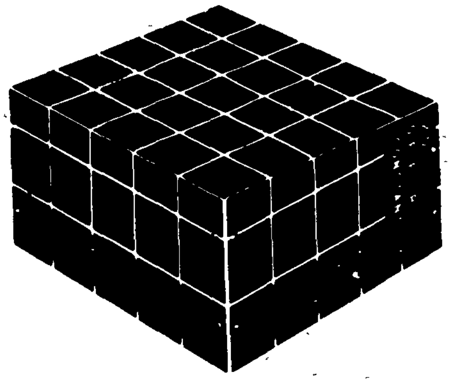
Figure 10-2 through 10-5 are field diagrams of the a-c electrical properties of all the resins listed in Table 10-2; Figure 10-2 shows the dielectric constant as a function of frequency and temperature, while Figure 10-3 gives the dissipation factor as a function of frequency and temperature.

Figures 10-4 and 10-5 give the dielectric constant and dissipation factor of epoxy-polysulfide resins of varied compositions when measured at 1000 cps as a function of temperature. To 100 parts by weight of epoxy resin, polysulfide rubber was added in amounts increasing from zero to 100 parts by weight. Two of the resultant resins are numbered 7 and 8 in Table 10-2. Field diagrams of this particular type, wherein the ingredients of the resin were varied, are included only for the epoxy-polysulfide resins.

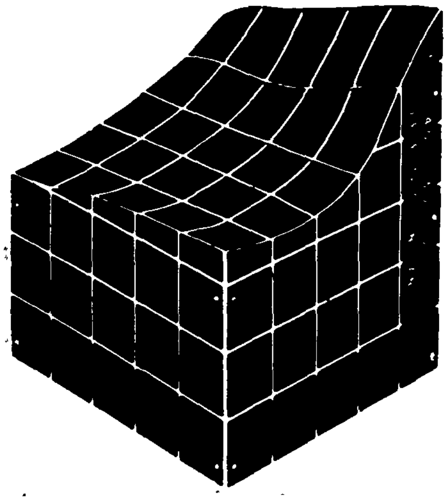
Figures 10-6 through 10-8 show volume resistivity as a function of temperature for all except one of the resins listed in Table 10-2. Resin No. 7 of Table 10-2 contains 100 parts



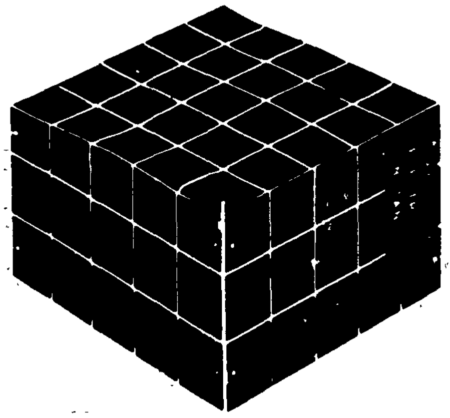
MODIFIED STYRENE RESIN-40 PARTS STYRENE, 60 PARTS UNDISCLOSED



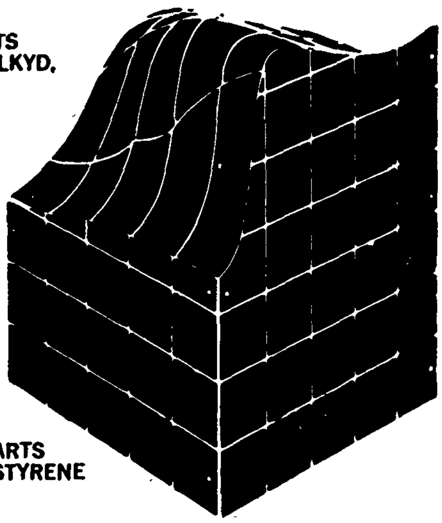
MODIFIED STYRENE RESIN-NBS CASTING RESIN



MODIFIED POLYESTER ALKYD-70 PARTS HIGHLY UNSATURATED POLYESTER ALKYD, 30 PARTS STYRENE

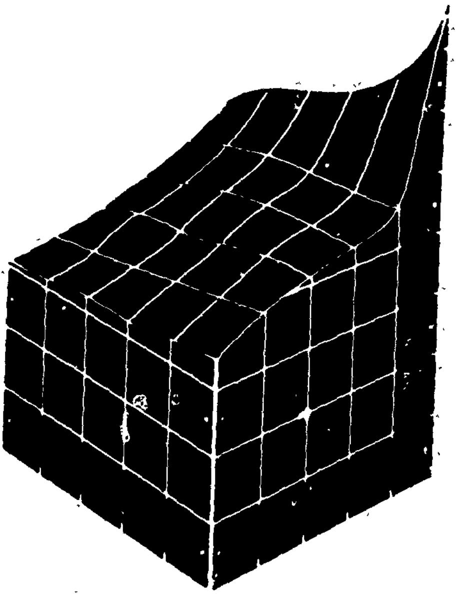


MODIFIED POLYESTER ALKYD-50 PARTS HIGHLY UNSATURATED POLYESTER ALKYD, 50 PARTS STYRENE

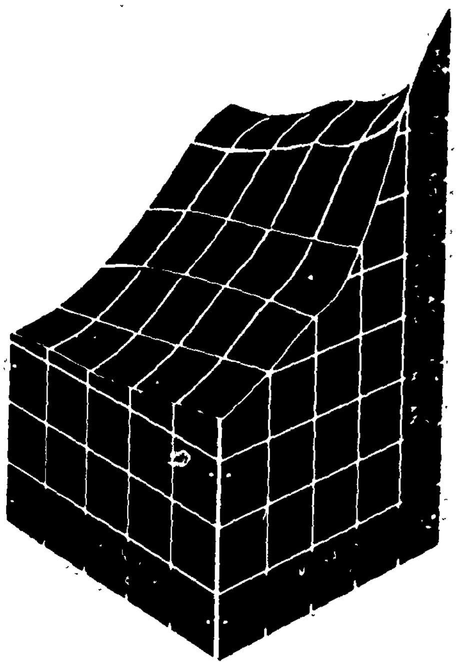


MODIFIED POLYESTER ALKYD-50 PARTS UNSATURATED ALKYD, 50 PARTS STYRENE

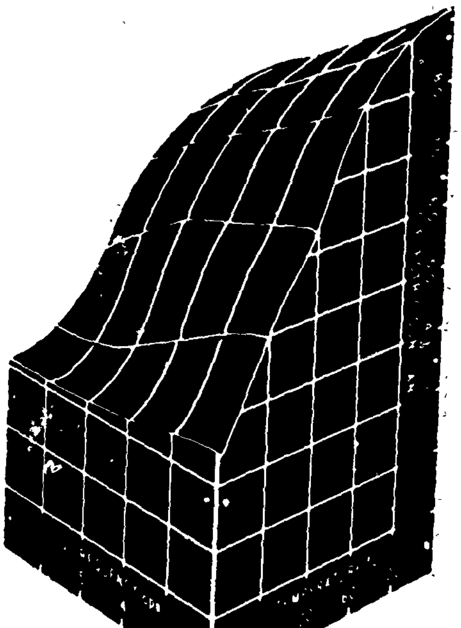
Figure 10-2 (U). Dielectric Constant of Resins as a Function of Frequency and Temperature



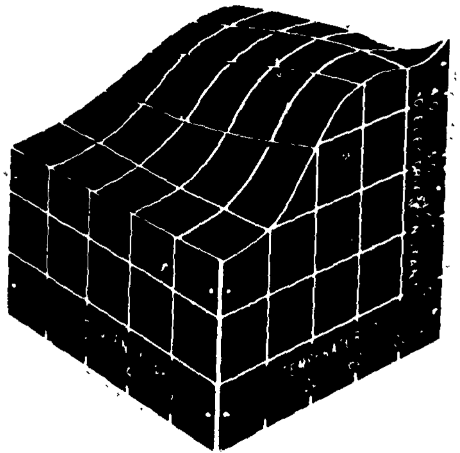
EPOXY RESIN CURED WITH DIETHYL-AMINETRIAMINE



MODIFIED EPOXY RESIN-100 PARTS EPOXY, 40 PARTS POLYSULFIDE RUBBER

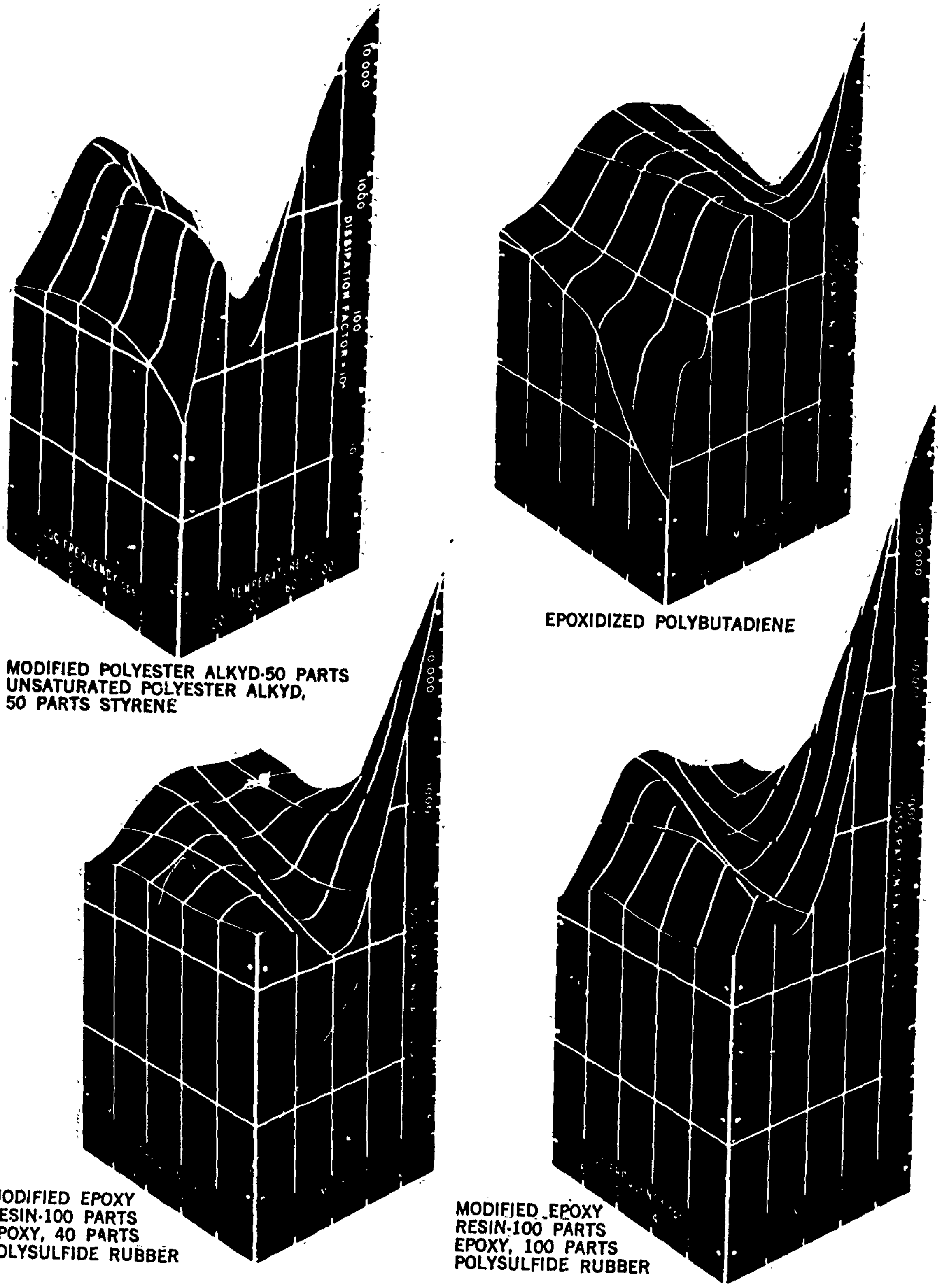


MODIFIED EPOXY RESIN-100 PARTS EPOXY, 100 PARTS POLYSULFIDE



EPOXIDIZED POLYBUTADIENE RESIN

Figure 10-2 (U). Dielectric Constant of Resins as a Function of Frequency and Temperature (continued)



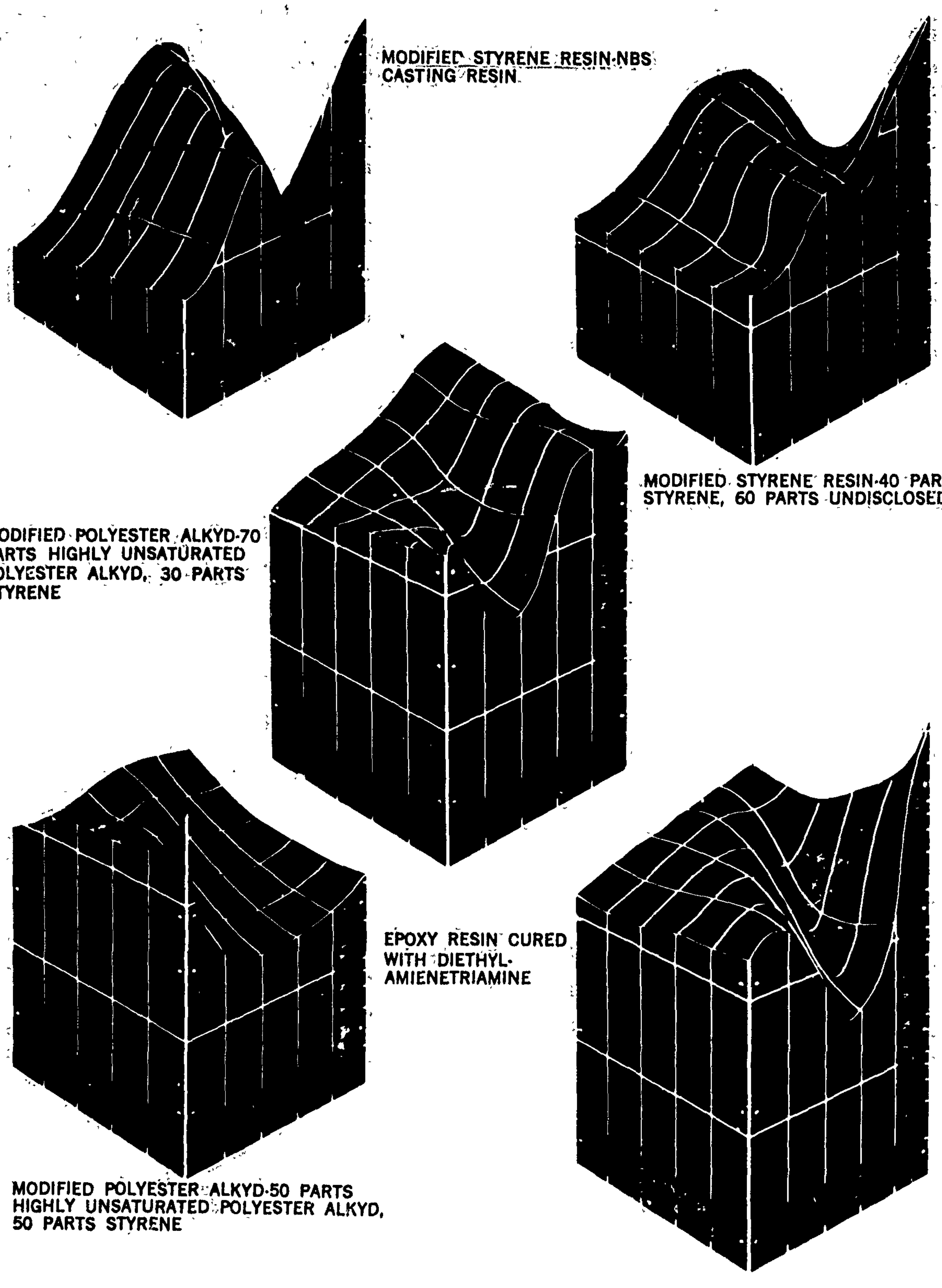
MODIFIED POLYESTER ALKYD-50 PARTS UNSATURATED POLYESTER ALKYD, 50 PARTS STYRENE

EPOXIDIZED POLYBUTADIENE

MODIFIED EPOXY RESIN-100 PARTS EPOXY, 40 PARTS POLYSULFIDE RUBBER

MODIFIED EPOXY RESIN-100 PARTS EPOXY, 100 PARTS POLYSULFIDE RUBBER

Figure 10-3 (U). Dissipation Factor of Resins as a Function of Frequency and Temperature



MODIFIED STYRENE RESIN-NBS CASTING RESIN

MODIFIED STYRENE RESIN-40 PARTS STYRENE, 60 PARTS UNDISCLOSED

MODIFIED POLYESTER ALKYD-70 PARTS HIGHLY UNSATURATED POLYESTER ALKYD, 30 PARTS STYRENE

EPOXY RESIN CURED WITH DIETHYL-AMIENETRIAMINE

MODIFIED POLYESTER ALKYD-50 PARTS HIGHLY UNSATURATED POLYESTER ALKYD, 50 PARTS STYRENE

Figure 10-3 (U). Dissipation Factor of Resins as a Function of Frequency and Temperature (continued) of epoxy resin and 40 parts of polysulfide rubber, whereas the data presented in Figure 10-8 are for a resin containing 100 parts of epoxy resin and 60 parts of polysulfide rubber (curve 7A).

To illustrate the use of the foregoing data in selection of a suitable potting resin, an anlysis of the field diagrams of resin No. 2 of Table 10-2 follows. Although resin No. 2 is not available commercially, its low-loss properties are not equalled by those of any presently available casting resin. The pertinent field diagrams are shown in Figures 10-2 and 10-3. Volume resistivity information can be found in Figure 10-6.

Figure 10-2 shows the dielectric constant of the resin to be low, about 2.6, over the entire temperature-frequency field. The dielectric constant has a slight negative temperature coefficient because volume expansion of the resin decreases the dipoles per unit volume at a faster rate than the rate at which rising temperature increases the freedom of alignment. Figure 10-3 shows a dissipation-factor field that is typical of dipolar processes. The single dissipation-factor peak occurs at 10^2 cps and 208°F and shifts to higher temperatures as the frequency is increased. The rapid increase in dissipation factor above 284°F could have been predicted from the curve of volume resistivity versus temperature in Figure 10-6. Figure 10-6 shows that this resin has a very high volume resistivity, greater than 10^{16} ohm-cm, at 212°F, and a high activation energy. This resin typifies the electrical behavior of low-loss casting resins.

Generally, all resins of a given type display common electrical properties. Modified polystyrene resins exhibit low or medium losses. Their volume resistivity is usually high, but can

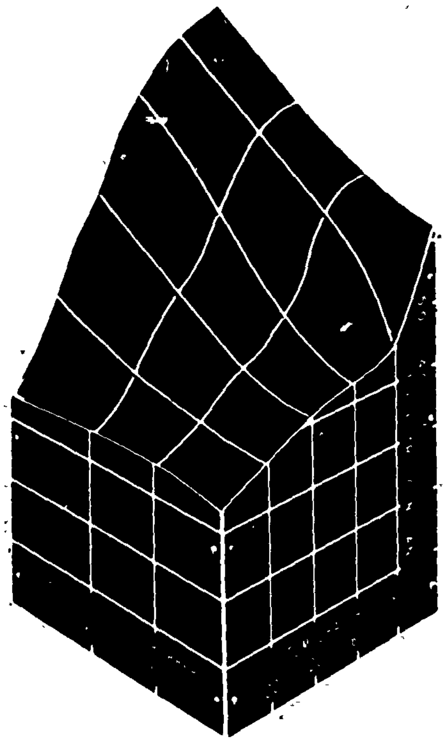


Figure 10-4 (U). Dielectric Constant of Epoxy-polysulfide Resins at 1000 Cps as a Function of Temperature and Resin Composition

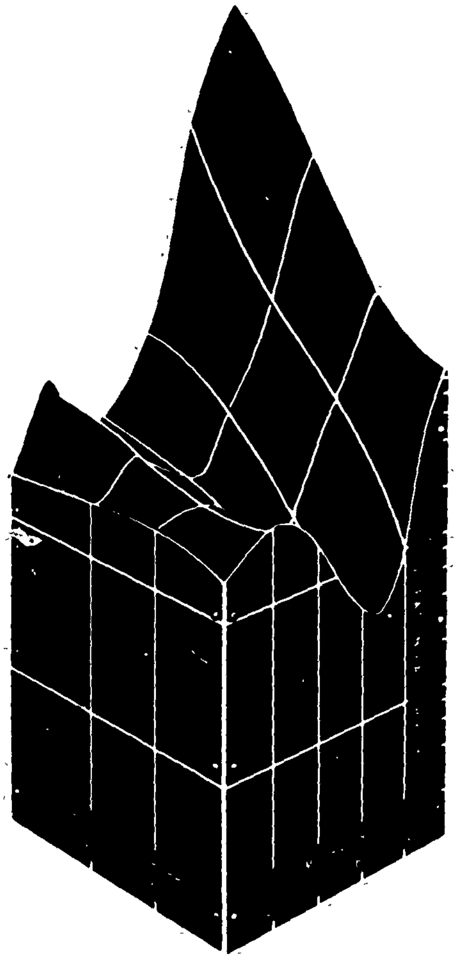


Figure 10-5 (U). Dissipation Factor of Epoxy-polysulfide Resins at 1000 Cps as a Function of Temperature and Resin Composition

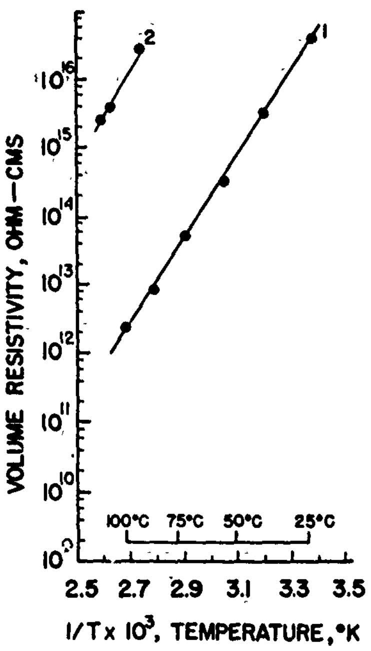


Figure 10-6 (U). Volume Resistivity Vs Temperature for Modified Polyester Resins 1 and 2 of Table 10-2

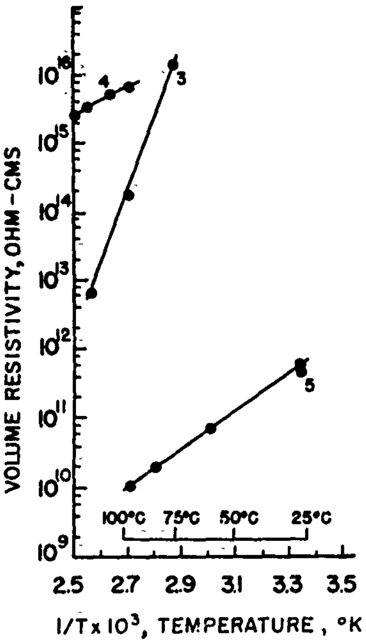


Figure 10-7 (U). Volume Resistivity Vs Temperature for Modified Polyester Resins 3, 4, and 5 of Table 10-2

be greatly reduced by impurities or incomplete cure. The dielectric constant is low and has a small temperature coefficient. These resins are superior in applications where a low dissipation factor and high volume resistivity are required.

Modified polyester-type resins usually have medium-to-high losses. Factors which influence this behavior are the degree of initial unsaturation and the final unsaturation after curing. Resin No. 3, which has high initial unsaturation and some unsaturation after curing, and resin No. 4, which has high initial unsaturation and low unsaturation after curing, show how the degree of unsaturation affects the electrical properties. Resin No. 4 has better a-c electrical properties. Resin No. 5, which has some initial unsaturation and little unsaturation after curing, is flexible at room temperature, and has comparatively poor electrical properties.

Epoxy resins modified with polysulfide rubber are medium-to-high-loss resins. Electrical properties of this type of resins are related to the rigidity of the cured resin. Figures 10-4 and 10-5 show electrical properties of the modified

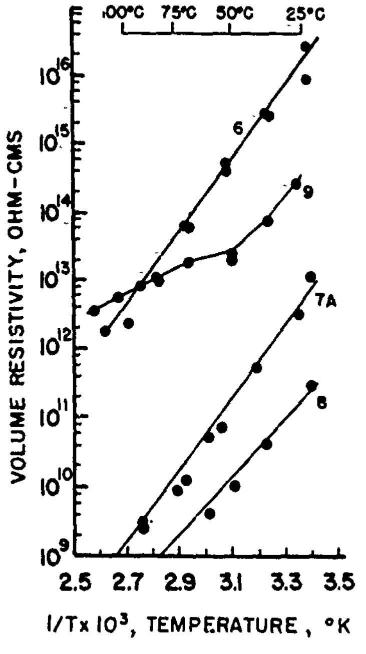


Figure 10-8 (U). Volume Resistivity Vs Temperature for Modified Polyester Resins 6, 7, 8, and 9 of Table 10-2

epoxy resins at 1000 cps as a function of temperature and parts of polysulfide rubber. The dissipation-factor peak, the critical temperature, and the temperature at which the conduction current becomes a significant part of the dissipation factor, all shift to lower temperatures with increased parts of polysulfide rubber and increased flexibility. Other measurements indicate that the curing agent used will have a similar effect on the electrical properties if the resulting resins have varying degrees of rigidity.

The epoxidized polybutadiene (resin No. 9) has good electrical properties when compared to resins of similar flexibility. Resin No. 5 and resin No. 8 both have about the same degree of flexibility as the epoxidized polybutadiene resin at room temperature but the dissipation factor of the latter resin is lower over most of the temperature-frequency field. This superiority of the epoxidized polybutadiene resin is due primarily to the low slope of its curve of volume resistivity versus temperature shown in Figure 10-8; that is, to its low activation energy.

Factors other than electrical properties, such as curing properties and mechanical properties of the cured resin, are important in the final selection of a resin for a particular application. Also, for each application, the required electrical and mechanical properties are different. For this reason, the resin selected usually represents a compromise.

10-2.9 (U) SELECTING POTTING COMPOUNDS

Selecting a suitable potting compound is very important, since an unsuitable one may defeat the purpose of potting.

The ideal potting compound does not exist. If it did it would

(1) Hermetically seal the unit from its environment with a minimum of stress at the boundaries and a minimum of strain in the resin itself.

(2) Support the unit and cushion it from shock. This requires some resiliency at all operating temperatures.

(3) Provide good electrical insulation at all frequencies, and low absorption especially at high frequencies.

(4) Protect the unit from extreme temperature changes, yet dissipate the internal heat generated.

(5) Be transparent so that embedded components can be seen.

(6) Have good adhesion to all potted surfaces including sides of the container.

(7) Have a curing or baking temperature not higher than 150°F. Have low internal temperatures due to controlled, slow exothermal reaction.

(8) Not shrink during curing.

(9) Not become brittle at temperatures as low as —65°F, melt at high temperatures, or lose any of the above desirable qualities at any operating temperature.

(10) Resist deterioration by the weather and chemical agents.

(11) Be compatible with the embedded components and adjacent materials.

Since no known material has all of these qualities, some compromise must be made whenever a material is chosen for use. Aside from electrical characteristics, important parameters of a potting compound are pour temperature, cure temperature and shrinkage during curing, exothermal heat, operating environment, resistance to deterioration, thermal conductivity, and heat resistance.

10-2.10 (U) FABRICATING THE CIRCUIT

Usually, circuit components that are combined to perform a function, such as a sine wave generator, a pulse generator, or an audio amplifier, should be potted together. This simplifies testing and replacement. Where interconnecting wiring is needed, solid bare or solid enamel covered wire is preferable. If insulated wire is used, the insulating materials must be inert to the chemical and thermal reactions of the potting compound. Vinyl insulation reacts with some compounds, and prevents "through-curing" of the resin. When electrical connections are made with conventional lead-tin solder, assurance must be obtained that the heat of casting and curing does not melt the solder. Also, if a potted assembly is to be exposed to temperatures above the melting point of the solder used, external pins on the assembly should be sealed with high temperature solder to insure that the leads remain firmly connected to the pins. If solid pins are used, and connections to these pins are made within the potted area, conventional solder is suitable, since the cured resin will restrict solder flow.

The shape of the mold for the functional unit depends on space limitations, component arrangement, and other factors. Preference in component placement is given to vaccum tubes. To hold tubes and to protect them from being crushed when the potting compound contracts as it cools, silicone rubber jackets and a "star-shaped" mesh support are used. All components should be kept as far from the surface as possible to retain the strength of the resin.

Additional information on constructing potted assemblies is contained in Chapter 11.

10-2.11 (U) RECOVERY OF POTTED COMPONENTS

Potted assemblies are normally discarded when any one component becomes defective. It is generally uneconomical to attempt to repair defective components or to salvage good components. Occasionally, however, it might be desirable to salvage an extremely valuable com ponent or to recover a defective component to determine the cause of failure.

Methods of depotting components are dedescribed in References 9 and 10. Again it is emphasized that the recovery of potted components is not economically feasible, except under very special circumstances.

10-3 (U) SEALANTS AND SEALING MATERIALS

Fuzes are sealed to keep out moisture, fungus, vapors, dust, and dirt. Keeping moisture out is the most difficult problem. Moisture in a fuze causes corrosion of metal parts, deteroration of the explosive if exposed, and electrical malfunction. Atmospheric corrosion is an oxidation process that causes progressive deteroration and weakening of all parts. Deterioration of an explosive is caused by chemical or electrochemical changes in the explosive composition, and may result in erratic sensitivity. In extreme cases, deterioration may result in nonfunctioning or spontaneous functioning.

10-3.1 (U) CONSIDERATIONS IN SELECTING A SEALANT OR SEALING MATERIAL

A sealant is a viscous liquid which can be cured to a solid; a sealing material is a solid, e.g., a gasket. Before selecting a sealant or sealing material, careful consideration must be given to the design of the joint in order to make it suitable for a specific sealant or sealing material. The following factors must be carefully weighed when selecting a sealant or sealing material.

(1) Physical properties of the sealant or sealing material, such as tensile strength, compression set, elongation, and hardness.

(2) Chemical compatibility. The seal must be chemically compatible with the metals, fuels, lubricants, explosives, acids, or nuclear materials to which it may be exposed.

(3) Storage characteristics. The seal must withstand exposure to a wide range of environments over a long period of time in storage.

No sealant or sealing material has all the qualities required. The problem, then, is to choose the best combination of characteristics. Choice is usually based primarily on the overall physical and chemical properties of the sealant or sealing materials and secondarily on its aging properties. Other things to be considered before a final decision is made are availability of materials, cost, ease of application, toxicity, useful bath life, and service life.

10-3.2 (U) SEALANTS

A sealant is a liquid or paste which is applied to a joint to prevent or reduce the penetration of gases, liquids, and/or dust. Two types of joints on which sealants are often used in fuze construction are the butt or crimped joint, and the threaded joint. A sealant used on threads must not act as a cement for the threaded joint, but must be easily broken to permit inspection or repair of enclosed components. A sealant for a butt or crimped joint has greater latitude because this type of joint is usualy a permanent one and cementing is desired.

A polysulfide rubber and two forms of neoprene are suitable thread sealants. Polyesters, styrenated alkyds, styrenated isobutylene, phenolics, vinyls, and epoxy resins are possible sealants for crimped or butt-type surfaces. No sealant has yet been found that will produce a seal as tight as that made by an unbroken metal surface or even a well-soldered joint.

10-3.3 (U) SEALING MATERIALS

Plastic, natural rubber, and synthetic rubber gasket-seals are commonly used in fuzes. A particular seal is selected primarily on its ability to seal a fuze, or a fuze assembly, against such contaminants as moisture, dirt, gases. However, other characteristics of the sealing material, such as high and low temperature resistance, aging characteristics, elongation, tensile strength and compatibility with adjacent materials, must also be considered. Characteristics of various sealing materials are discussed in Reference 11. This reference also discusses considerations involved in designing the joint that is to be sealed.

10-3.4 (U) CERAMIC-TO-METAL SEALS

The use of ceramic covers, or windows, in slotted-waveguide antennas is common practice in guided missile fuzing applications. Both glass seals and metalized seals have been used to bind the window to the waveguide.

Choosing a ceramic to use with a given metal, and the type of seal needed to bond the two, are major considerations. Primarily, the coefficient of expansion of the ceramic and the metal should be similar. Often, the ceramic-to-metal bond should also:

(1) Withstand temperatures to about 1600°F.

(2) Withstand shock, vibration, and bending stresses.

(3) Be adaptable to production.

(4) Withstand erosion due to rain and dust.

(5) Hermetically seal the component against moisture and changes in atmospheric pressure.

Bonding considerations differ, depending upon the particular fuze application. Powdered glass ceramic-to-metal seals are fairly easy to apply, require no special equipment and withstand temperatures up to 1110°F. Various metalized ceramic-to-metal bonds are described in References 12 and 13. Some require special equipment and involve as many as four firings. Metalized seals are stronger than glass seals and withstand temperatures up to 1380°F.

Several glasses have been developed which closely match the coefficient of expansion of a given ceramic or metal and will adhere to both metals and ceramics to form a bond between the two. The problem is that glasses used for sealing are low-temperature glasses and soften when subjected to high temperatures. Also, the wide softening range of glasses requires that they be fired into place at much higher temperatures than they will withstand in operation.

The technique for using powdered glass in ceramic-to-metal seals involves mixing a 200-mesh powdered glass with water to form a thin paste. The paste is brushed onto the parts to be sealed, allowed to dry, and then fired in an oxidizing atmosphere. Only one firing operation is required. Firing temperature depends on the glass used. A disadvantage of the method is that the required oxidizing atmosphere tends to oxidize metals used.

10-3.5 (U) POLYETHYLENE-TO-METAL SEALS

Many radio proximity fuzes must have an electrically transparent enclosure to permit the transmitting and receiving of signals. This enclosure frequently consists of an injection-molded polyethylene nose fastened to a metal base. The fuze shown in Figure 10-9 is typical. The area of contact between the polyethylene and the metal base presents a greater sealing problem than a metal-to-metal seal. Conventional seals formed by O-rings and seals formed of polyethylene injection-molded directly onto the cold aluminum base leak when subjected to relatively low air pressures, or more significantly, to high humidity.

Leakage, in such cases, can be more than ten times that of a well-designed metal-to-metal O-ring seal. In addition, because polyethylene cold-flows under pressure, these seals deteriorate with time.

Injection molding the nose to a fused-floc coating on the metal base is one effective sealing method used. Floc may be powdered polyethylene in air suspension, deposited on a hot metal surface to which it becomes fused. In addition to sealing out water vapor, it is believed

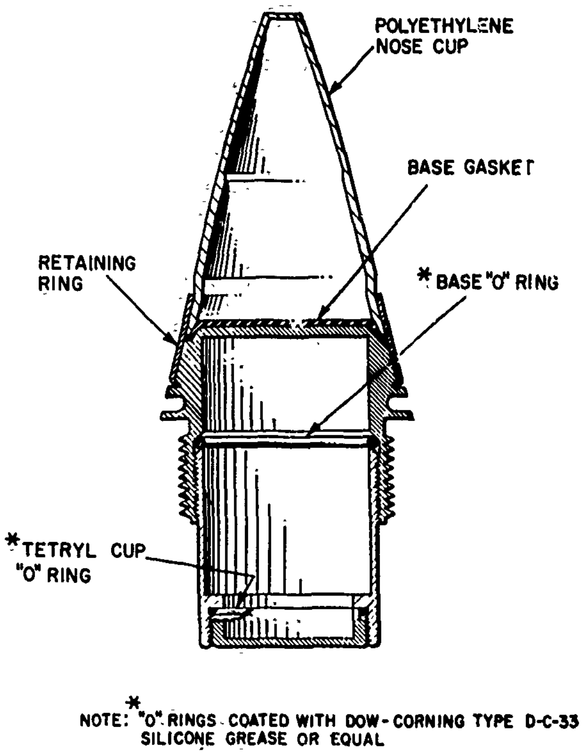


Figure 10-9 (U). Provision for Prevention of Entry of Moisture Into Fuze

that the bond between the polyethylene and the metal eliminates cold flow of the plastic. Pretreatment of bases, floc-coating techniques, and preheating temperatures for the best possible bond depend on the kind of polyethylene used, the metal used as a base, and on the mechanical designs of both the nose and base. Reference 14 contains further information on this subject. More recently, the contact surface of the polyethylene has been oxidized in chromic acid to render it bondable; the use of a plastic or rubber sealant then establishes a bond to both the polyethylene and the metal surfaces.

10-4 (U) SOLDERS AND FLUXES

10-4.1 (U) SOLDERS (Refs. 15, 16)

Solders are fusible metals or metal alloys which, when melted, are used to join metallic surfaces. The joining occurs through intermetallic solution. For example, the action of molten solder on a metal such as copper involves first the dissolution of a small amount of the copper by the solder at a temperature below the melting point of the copper, and then the formation of an alloy with the copper. Thus, a well-formed solder connection is a continuous metal bond.

The two general classes of solder are soft solders and hard solders. In assembling components, soldering operations must be performed at temperatures well below the melting point of the metals to be joined. Therefore, soft solders, which are low-melting solders (below 650°F), are used for this purpose. Only soft solders are discussed in this section.

Soft solders possess a number of very desirable properties. Some of these are as follows:

(1) They can be used to join metals at relatively low temperatures.

(2) They can withstand considerable bending without fracture.

(3) They can usually be applied by simple means and can be used with metals having relatively low melting points.

Probably the primary disadvantage of soft solders is their low strength as compared to the strength of the metals usually joined.

The most commonly used soft solders are lead-tin alloys. Lead and tin together form a fusible alloy, and this alloy composition melts at a lower temperature than does either component alone. However, there exists only one composition of lead and tin that has a sharp and identical melting and solidification point. Such a composition is known as a eutectic mixture. The phase diagram given in Figure 10-10 shows that the eutectic mixture of lead and tin occurs at a composition of 61.9% tin and 38.1% lead, and melts at a temperature of 360°F (Point C). A solder of these characteristics is known as a eutectic solder.

Point A of Figure 8-10 is the melting point of pure lead (620°F) and point B is the melting point of pure tin (450°F). When increasing amounts of pure lead are mixed with pure tin, the temperature of complete melting will follow the line BC. When these mixtures are then cooled, and their solidification points measured, only the eutectic mixture will solidify at a true melting point (360°F). Most of the other mixtures will begin to solidify (become plastic) at some definite temperature higher than 360°F;

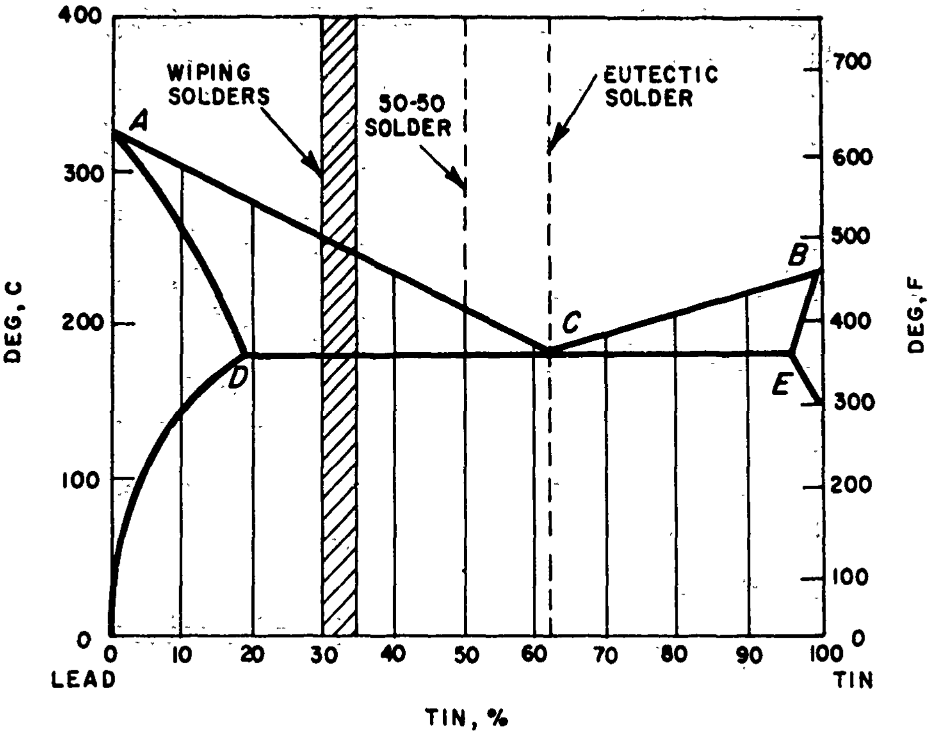


Figure 10-10 (U). Phase Diagram for the Lead-tin Alloy System

that is, they will begin to solidify along ACB, which is called the liquidus, and they will complete solidification at 360°F along DCE, the solidus. However, as shown in Figure 10-10, mixtures containing less than 20% or more than 97% tin will not have their solidus at 360°F but rather at some higher temperature, that is along AD or BE. By studying the phase diagram, the lead-tin composition best suited for a particular application can be chosen.

The composition of lead-tin solders commonly used in electrical application varies from 40% tin/60% lead to the eutectic 62% tin/38% lead. Actually, the best alloy to use in electrical applications is the eutectic mixture because it acts like a single metal, and crystallizing-out of one of the components does not occur. Thus, formation of "cold-joints" is less apt to occur than when noneutectic solders are used, and the joint formed should have maximum strength. In fact, Figure 10-11, which presents the relationship between the composition of lead-tin solders and the resistance of the joint

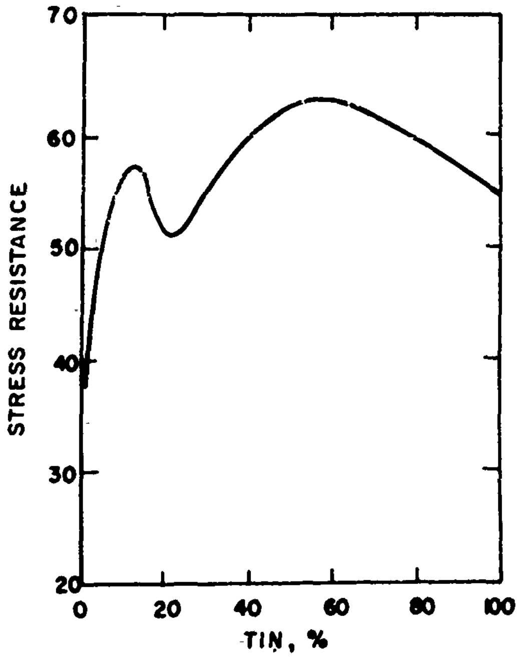


Figure 10-11 (U). Change In Joining Quality of Tin-lead Solders with Increase in Tin Content

TABLE 10-3 (U). Low-melting soft solders used in electrical equipment subjected to temperatures less than 360°F

% Sn	% Pb	% Bi	% Cd	Liquidus, °F	Solidus, °F	Use
30	70			361	496	Wiping solders
35	65			361	477	
40	60			361	460	General purpose, radio, TV
45	55			361	441	
50	50			361	421	
60	40			361	370	Electronics, printed circuits
62	38			361 eutectic	361	
16	32	52		205 eutectic	205	Low temperature
25	25	50		266	205	
37.5	50	12.5		374	205	
50	25	25		338	205	
51	31		18	288 eutectic	288	Low temperature

to mechanical stresses, shows that the maximum strength of the joint is obtained near the composition of the eutectic soldering alloy.

As shown in Table 10-3, lead-tin alloys containing less than 60% tin are often used, sometimes to take advantage of the plastic stage, which gives the opportunity to mold, or "wipe," the joints and sometimes for reasons of economy only, since tin is the more expensive metal.

Table 10-3 also shows that some commercial lead-tin solders contain a third element and form a eutectic of lower melting point than the lead-tin eutectic. For example, a mixture of 32% lead, 16% tin, and 52% bismuth forms a eutectic melting at 205°F. A mixture of 31% lead, 51% tin, and 18% cadmium forms a eutectic melting at 288°F.

The low melting-ranges of the lead-tin alloys can be a disadvantage. As the upper temperature requirements for military applications rise, the need for solders of increasingly higher melting points also rises. In addition, even a eutectic lead-tin solder joint loses much of its physical strength when heated to 250°F, regardless of the fact that its actual melting point is 360°F. Apparently, an embrittlement of the joint occurs.

There are several two-component alloys which melt at temperatures higher than 360°F. Among these are lead-silver alloys which contain 2.25% to 2.5% silver (Table 10-4). The lead-silver eutectic contains 2.5% silver and melts and resolidifies at 581°F. Quantities of silver higher than 2.5% raises the liquidus so sharply that the mixtures quickly become hard solders. The commercial form of the lead-silver eutectic is actually multi-component; it contains not only 2.5% silver but also 0.50% antimony, 0.08% copper and 0.25% bismuth. Its melting range is 580° to 585°F.

For the soldering of silver-plated or silver-fired ceramics, silver-saturated lead-tin solders are used to avoid solution of the silver plating. The concentration of the silver must be adjusted to provide saturation at the working temperature of the alloy. Such printed circuit solders are available commercially.

Other high-melting two-component alloys include: (1) the 95% cadmium / 5% silver alloy, which has a solidus of 640°F and a liquidus of 740°F; (2) the 82.5% cadmium / 17.5% zinc alloy, which is a eutectic melting at 508°F and is useful for soldering zinc; and (3) the 75% lead / 25% indium alloy, which has a solidus of 441°F and liquidus of 504°F (Table 10-4).

For soldering to aluminum, solders containing 30% to 75% tin and the remainder zinc have been developed, but it is generally recommended that aluminum and its alloy be welded.

TABLE 10-4 (U). High-melting soft solders used in electrical equipment subjected to temperatures above 360°F

% Sn	% Pb	% Sb	% Ag	% In	% Cd	% Zn	Liquidus, °F	Solidus, °F
0.25	97.5	$<.4$	2.5				581 eutectic	581
1.0	97.5	$<.4$	1.5				588 eutectic	588
			5.0		95.0		740	640
					82.5	17.5	508 eutectic	508
					50	50	619	508
	75			25			504	441

10-4.2 (U) FLUXES (Ref. 18)

The primary requirements for an ideal soldering flux for electrical applications are:

(1) It must be capable of removing oxide films on the surfaces of metals to be joined.

(2) It must prevent reoxidation of the metallic surfaces during the soldering operation.

(3) It must be displaceable by molten solder, and preferably should reduce the surface tension of the solder.

(4) It must not give rise to corrosive and/or hygyroscopic residues whether inside or outside the soldered joint.

Soldering fluxes may be divided into two general classes: (1) inorganic fluxes, which form highly corrosive and hygroscopic residues, and (2) organic fluxes, which are less corrosive than inorganic fluxes. Inorganic fluxes are not suitable for electrical applications and, therefore, are not discussed in this section.

The most widely used organic fluxes are rosins and rosin dimers. Rosin is the generic term for abietic acid and its isomers. Rosin dimers are the anhydrides of rosin. While rosin contains one acid group (carboxyl group), rosin dimers contain no acid groups.

Neither rosins nor rosin dimers are hygroscopic. They are dissolved in alcohol to form a liquid, or mixed with petrolatum to form a paste. After the soldering operation, the joint is covered with the rosin flux, which is an excellent insulator. A cubic inch of rosin has a volume restivity of 3.3×10^{15} ohms.

Rosins exhibit poor spreading and wetting characteristics and fluxing activity of a low order; however, they are often satisfactory where only mild fluxing action is needed, as in the case of copper, for instance. Rosins are practically noncorrosive at low temperatures and only mildly corrosive at soldering temperatures. Rosin dimers are noncorrosive both at low and at soldering temperatures, and their wetting qualities are somewhat superior to those of rosins.

Ways of increasing the fluxing activity of rosins and rosin dimers, while maintaining their noncorrosivity, have been investigated. The most common approach is to add 1% or 2% of a hydrochloride of an organic base to an alcohol solution of the rosin. Although these so-called "activated" fluxes are often called noncorrosive, most of them leave corrosive residues, and should not be used in electrical applications. In cases where commercial fluxes meet military specifications for corrosion, the activating agents are usually considered proprietary information by the manufacturer.

10-4.3 (U) CONDUCTIVE ADHESIVES

Conductive adhesives can sometimes be used in applications where heat generated during the soldering process might damage temperature-sensitive components. Typical applications include bonding barium titanate elements together or to ferrite rods, making electrical connections to battery terminals, and repairing printed circuits.

A low-viscosity conductive adhesive has been developed having a volume resistivity of approximately 0.5 ohm-cm and bond strengths greater than 4000 psi. Details of this adhesive, and of similar adhesives, are contained in Reference 19.

(U) REFERENCES

1. *Evaluation of Plastic Encapsulating Materials,* Report FRL-TR-4, Plastics and Packaging Laboratory, Picatinny Arsenal, August 1960.
2. E. A. Schatz "A Survey of Encapsulating Systems," Product Engineering, McGraw-Hill Publishing Company, 19 September 1960.
3. T. D. Callinan, *Curing Resins Suitable for Embedding Electronic Components by Irradiation,* Army-Navy-Air Force sponsored Symposium on Casting Resins, Diamond Ordnance Fuze Laboratories, 24-25 January 1956.
4. E. G. Linden, *The Effects of Outdoor Weather Aging on Encapsulating Materials,* Army-Navy-Air Force sponsored Symposium on Casting Resins, Diamond Ordnance Fuze Laboratories, 24-25 January 1956.
5. M. St. Cyr, *Compatibility of Explosives with Polymers,* Technical Report 2595, Picatinny Arsenal, March 1959.
6. O. R. Abolafia, Technical Report 1838, Picatinny Arsenal.
7. "Field Diagrams Ease Comparing Casting Resins," Chemical and Engineering News *32,* 4942 (1954).
8. R. Tucker, et al., *Dielectric Properties of Several Casting Resins,* DOFL Technical Review, Vol. I, No. 1, 91-103, Diamond Ordnance Fuze Laboratories, October 1957.
9. L. Lane and R. Rudy, *Depotting of Epoxy-Resin-Encapsulated Components,* Report No. R53-57-33, Diamond Ordnance Fuze Laboratories, 20 August 1957.
10. Report No. 58-M2-1, Picatinny Arsenal, 1 April 1958.
11. *Gasket Materials,* MIL-HDBK-212, Department of Defense, 26 September 1958.
12. L. Shoot, *Literature Survey of Ceramic-to-Metal Seals,* Report No. R53-56-18, Diamond Ordnance Fuze Laboratories, 6 August 1956.
13. L. Shoot, *Sealing Ceramic Windows to Waveguide Antennas,* Report No. R53-57-2, Diamond Ordnance Fuze Laboratories, 15 January 1957.
14. *Humidity Permeability of Fuze Seals,* Report No. R22-56-8, Diamond Ordnance Fuze Laboratories, 21 November 1956.
15. M. Schwartz, *Solders and Soldering Techniques,* Report No. R53-57-43, Diamond Ordnance Fuze Laboratories, 18 November 1957.
16. R. Mels and W. Roeser, *Solders and Soldering,* NBS Circular 492, National Bureau of Standards, 28 April 1950.
17. *Solder, Its Fundamentals and Usage,* Kester Solder Company, 1954.
18. M. Schwartz, *Soldering Fluxes,* Report No. R53-57-44, Diamond Ordnance Fuze Laboratories, 20 November 1957.
19. T. Kilduff and A. Benderly, *Conductive Adhesives for Electronic Applications,* Report No. TR-650, Diamond Ordnance Fuze Laboratories, 31 October 1958.

CHAPTER 11

(U) CONSTRUCTION TECHNIQUES

Broadly speaking, there are two interdependent aspects that must be considered when designing an electrical fuze. These are (Ref. 1):

(1) Electronic design, using proven circuits and properly chosen components so that the fuze can perform its specified function.

(2) Mechanical design, which supports the components in their proper relationship to each other.

Both mechanical and electrical design must take into account the environments to which the fuze will be exposed. The planning necessary for proper shock and vibration isolation, heat transfer, packaging, etc., must be instituted during the early phases of a fuze development program and must continue to grow, and change if necessary, along with the electronic planning.

11-1 (U) MECHANICAL CONSIDERATIONS

11-1.1 (U) STRUCTURAL

The environments to which a fuze will be exposed are generally more severe than those for many other types of electronic equipment, both military and commercial. Fuzes for artillery and antiaircraft projectiles are exposed to accelerations of the order of 10,000 to 50,000 g; guided missile fuzes must withstand severe vibrations caused by the propulsion system.

The permissible volume and weight of the fuze, and its location in the associated missile, are generally specified at the start of a program. However, since a fuze program is only one part of an overall systems program, these specifications may change as the program progresses. Constant liaison between the fuze designer and other members of the system team is, therefore, imperative.

The anticipated fuze environments during operational use and during storage, handling and transportation are also specified. These environments, particularly any unusual ones, must be kept in mind from the start of a fuze program.

When designing housings, packages, and other mechanical parts of a fuze, it is not sufficient to consider only the mechanical requirements for strength, volume and weight. In many instances, their effect on the electrical performance of the fuze must be considered. The dimensions of some parts, and the tolerances on the dimensions, may have a direct relation to electrical performance. On other parts, the degree of stiffness or positional variation under conditions of shock or vibration may affect the electrical performance of a fuze.

Although the mechanical designer has the problem of designing a fuze of specified weight and volume that will withstand the rigors of shock, vibration, rough handling, etc., the electronics designer, by judicious circuit design, can help to simplify this problem. For example, using miniaturized circuits can greatly reduce a weight or volume problem. Or, when the electronic designer uses circuits that are not greatly affected by shock or vibration, the mechanical designer need only concern himself with designing the circuit package to withstand these environments. Obviously, close cooperation between the mechanical and electronic designers is imperative.

Many mechanical design problems can be eliminated by following a logical design approach. A suggested approach is as follows (Ref. 2):

(1) Determine the mechanical requirements in shape, dimension, rigidity, material, and finish imposed by the electrical functions of the fuze, and the tolerances within which the requirements may vary.

(2) Determine the mechanical requirements in shape, dimension, strength, material, and finish, etc., imposed by operational use, transportation, handling and storage.

(3) Make a preliminary design and check critical elements for stress, resonant frequency, static and dynamic balance, etc. Refer the design to the electronic designer for a check on its electrical functions.

(4) Examine these designs with respect to ability of the shop to manufacture and to obtain the required tolerances.

(5) Check the preliminary designs by observing the performance of a preliminary fuze model subjected to tests pertinent to the verification of the design.

(6) Revise the design as indicated by the model tests and repeat the tests if necessary.

(7) Prepare the manufacturing information, incorporating all of the information and tolerances which must be observed in the manufacture and inspection of the fuze.

11-1.2 (U) SHOCK AND VIBRATION ISOLATION

11-1.2.1 (U) General Considerations

Because of the nature of employment of a fuze, it is often subjected to severe shock and vibration. These occur not only during operational use of a fuze, but also during rough handing and rugged transportation.

Shock occurs when a force is applied suddenly. Its effect is a transient vibration of the structure at its natural frequency. Brittle material is fractured, ductile material flows. A secondary shock effect is that large accelerations are transmitted to all components and equipment attached to the structure.

Vibration is a continuing, periodic motion induced by an oscillating force. When the frequency of a disturbing force is much less or much more than the natural frequency of a mass system, forces tend to oppose each other. When the frequency of the disturbing force approaches the natural frequency of the system, and damping forces are small, very large oscillations are built up. When the frequency of the disturbing force and the natural frequency of the system are the same, a condition of resonance exists. This is the most dangerous condition. In such cases, very small forces can cause considerable damage.

Fuzes generally employ rigid mounting; i.e., parts and assemblies are mounted in such a manner that relative motion of the parts and assemblies is not possible. Shock mounts and vibration isolators are not used in fuze construction primarily because of their low natural resonant frequency and because additional space is required to allow for the excursion of the part or assembly that they support.

Mechanical considerations alone do not dictate the need for adequate shock and vibration protection. Since proximity fuzes are, in general, very sensitive devices, the problem of microphonics is very important. While special ruggedized tubes have been developed for fuze applications, care must be taken to insure that spurious fuzing signals are not generated by mechanical vibration.

Fuzes for conventional weapons, such as rockets, mortar projectiles, etc., are generally of catacomb construction. Ideally, all parts should be made as a block so that the completed fuze is literally "as solid as a rock."

Figure 11-1 shows the basic construction of a typical mortar fuze. The top part, which is made of plastic, contains a four-tube electronic system with the RF oscillator in the nose of the fuze. The remaining electronic components, consisting of a two-stage amplifier and a thyratron firing circuit, are mounted immediately below the oscillator tube. A plastic catacomb, which houses many of the electronic components, is shown in the lower right part of Figure 11-1. The catacomb also serves as a mounting block around which the components are wired (Figure 11-2). In other applications, printed end plates have been used on one or both sides of the catacomb (Figure 11-3) and sometimes, only printed end plates, without a catacomb (Figure 11-4).

The components of the fuze shown in Figure 11-1 are held rigidly in place by molding the entire electronics assembly with injected polyethylene. Fiber glass packing, however, is placed completely around the oscillator tube, which appears contradictory to the practice of mounting all components as rigidly as possible. This packing is often necessary for fuzes that are required to operate during heavy rain. Raindrops impact the nose of a high speed projectile much like buckshot. Fuzes fired for recovery in heavy rain have shown fairly deep pockmarks over their external plastic portions. These repeated impacts produce the same effect as serious vibration, resulting in severe microphonics. The Fiberglas packing provides high-frequency damping and, thus reduces the

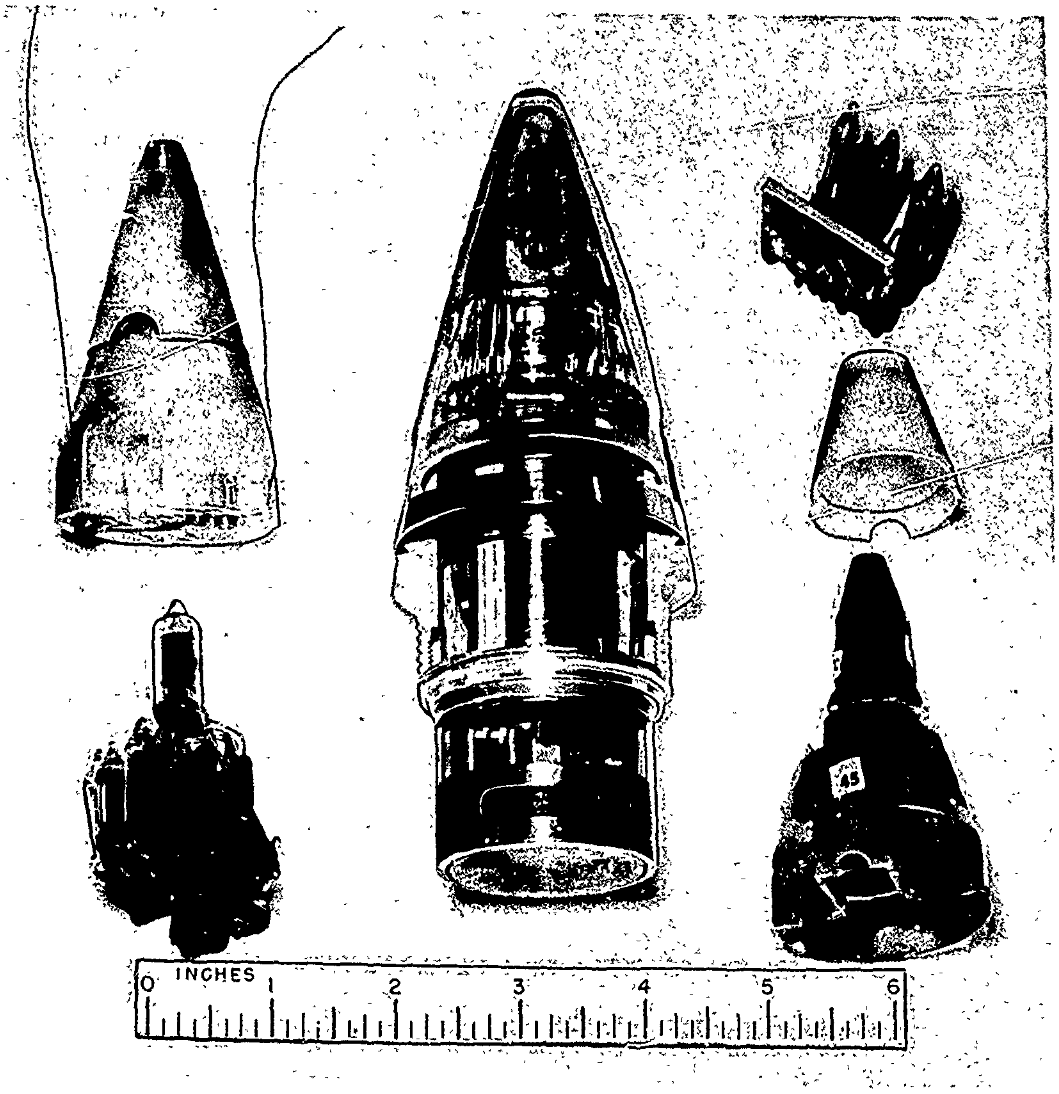


Figure 11-1 (U). Construction of Typical Mortar Fuze

microphonic noise output of the oscillator. In applications of this type, it is necessary to compromise between the required rigidity to withstand the shock at firing and the desired cushioning to eliminate raindrop impact effects.

The method of mounting a fuze to its associated missile is very important. For a given vibratory force, acceleration is inversely proportional to mass. Thus, no matter how the fuze is mounted, it must be made a rigid part of the missile.

11-1.2.2 (U) Considerations for Guided Missile Fuzes (Ref. 3)

Two approaches to the design of a guided missile fuze to resist vibration are:

(1) Isolate the fuze from vibration.

(2) Stiffen the fuze so that it has a very high natural frequency.

Isolation from all vibration is highly desirable but, as in the case of fuzes for bombs, rockets, and mortars, it is impractical because of space limitations and because of the wide frequency

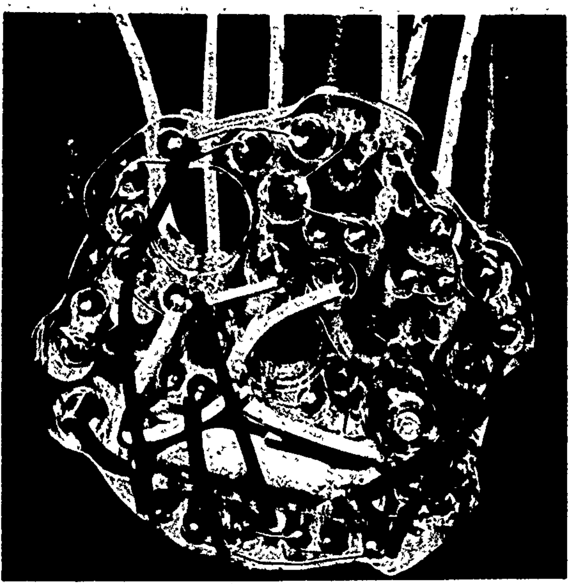


Figure 11-2 (U). Catacomb Amplifier

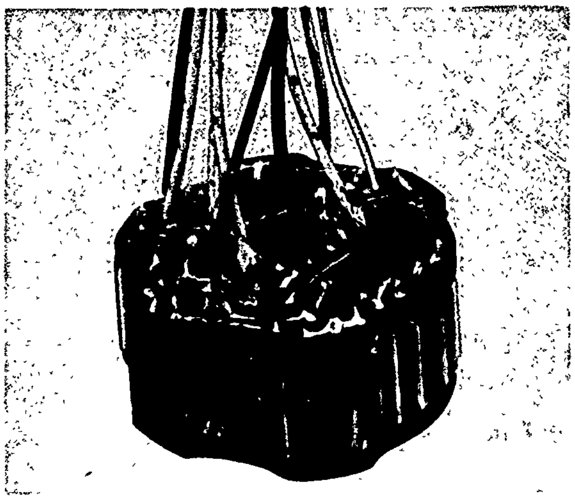


Figure 11-3 (U). Catacomb Amplifier with Printed End Plates

range of the vibrations to which the fuze is subjected. Major frequencies encountered are generally in the range of 10 to 2000 cps in flight. Lower frequencies (down to 1.5 cps) are encountered in transportation and handling, and frequencies in the range of 10,000 cps are produced by rocket engine noise.

A simple, practical approach is to design the support structure with a natural frequency so high that transmissibility does not exceed 1.5. As most guided missiles seldom have vibration forces over 10 g at the fuze mounting, this transmits 15 g to the fuze components. Properly mounted fuze components are well able to withstand this and operate satisfactorily.

The equation for transmissibility, T, is

$$T = \frac{1}{1 - \left(\frac{F}{f_n}\right)^2}$$

where

F = disturbing frequency

f_n = natural frequency of vibration

For the transmissibility to be less than 1.5, the natural frequency must be nearly double the disturbing frequency. For most fuze structures the natural frequency should be greater than 2000 cps.

Damping may also be used to minimize effects of vibration. Silicone oils and hollow glass beads have been investigated as damping materials for fuze packages (Ref. 4). The effect of damping, however, is appreciable only with excessive motion (Figure 11-5). Damping is not needed in a system with a transmissibility of less than 1.5 because the system has only a negligible relative motion.

Lightweight castings of a material such as aluminum or magnesium alloy are generally

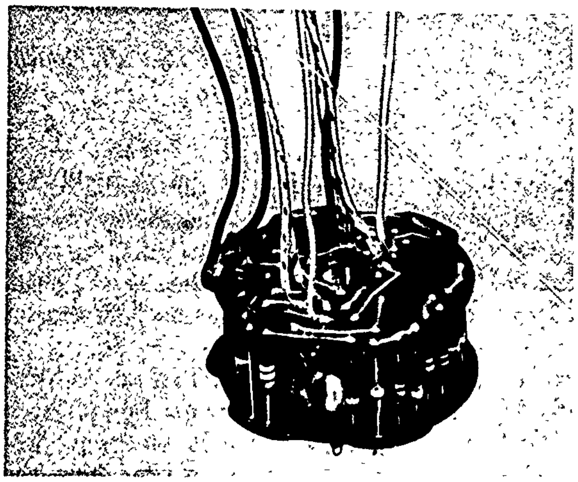


Figure 11-4 (U). Amplifier with Printed End Plates Only

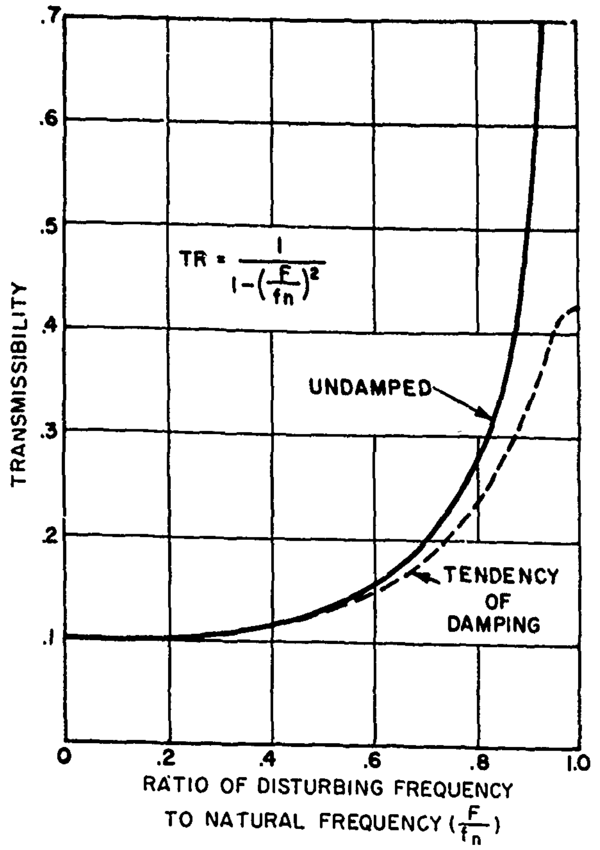


Figure 11-5 (U). Transmissibility of Undamped Single Degree of Freedom System

used to construct a fuze structure having a high natural frequency. Castings are generally preferred over sheet metal structures because they provide a more rigid structure and are usually more economical. Components are inserted into cavities (Figure 11-6) and are secured in place with an adhesive or with screws. Passive circuit components such as coils and capacitors, which do not emit appreciable heat, are grouped in modules and rigidly potted in epoxy resin.

Transmission of vibration within the block is limited to preclude undesirable excitation of the enclosed components. The response vibration of all units within the block is very nearly the same, and the response vibration of the entire package is practically insensitive to small changes of components inside the block. This type of package may be treated as a simple structure having a definite mode of vibration, at least for low frequencies (Ref. 5).

Surprisingly, the weight and space required for several block-type designs is sometime no more than that required by conventional package designs. An additional advantage of the block-type design is that the block can add strength to the missile body. In fact, its exterior wall can also serve as the missile body. The strength and mass of the block can be made greater; consequently its resonant frequency is high, and the amplitude of vibration low. Vibration energy is distributed throughout the block and not concentrated in any one place. The block might also be built in the form of a ring, and located at a vibrational node of

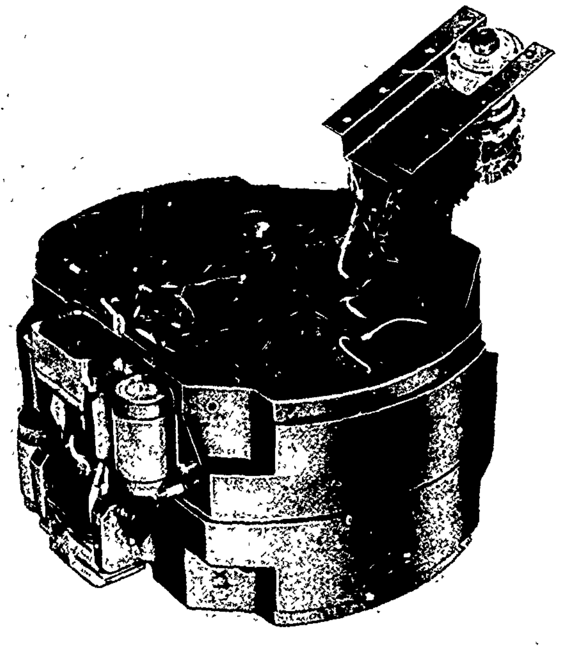


Figure 11-6 (U). Electronics Assembly for Typical Guided Missile Fuze

the missile shell. Of equal interest is the fact that the blocks also enhance heat transfer from the components.

The main support structure must be designed first. If it is inadequate with respect to shock and vibration, the fuze system will probably be inadequate. The support should be built and vibration tested with solid masses simulating the electronic components. This permits the natural frequency of the structure to be found without the obscuring effect of resonances in components and terminal boards. If the natural frequency is low, the structure should be corrected before components are added.

As soon as possible after the design of the fuze structure, mockups of the proposed terminal boards and electronic components should be made so that layouts and arrangements can be studied with respect to shock and vibration. It must be emphasized that when designing electronic assemblies to have high natural frequencies, each component must have a correspondingly high natural frequency. Individual components are subject to resonance and possible damage at their own natural frequencies, regardless of the remainder of the system. When considering the shock and vibration design of a fuze, the following should be kept in mind:

(1) Springs or other compliances and large masses resiliently supported complicate the vibrational response of the fuze. They should be kept to a minimum, and avoided altogether if possible. When resiliently-mounted large masses cannot be avoided, stops must be used to limit their motion. These stops require very sophisticated nonlinear design to prevent the generation of damaging shocks.

(2) Heavy items such as transformers and chokes should be bolted directly to the structure as close as possible to the points where the fuze is attached to the missile. The lines of force from the center of gravity of heavy items should lie within the metal of the fuze structure. Use of cantilever beams and unsupported spans should be avoided.

(3) Thin panels should not be used as it is hard to avoid resonances in them. When thin panels are unavoidable, their span should be as short as possible. Generally, section modulus and light weight are more important than high tensile strength. Aluminum and magnesium are preferable to steel unless high temperature is a problem.

(4) Components should be arranged in a nonlinear, unsymmetrical manner to break up the formation of nodes.

(5) Fillet radii should be kept as large as possible to avoid creating stress concentrations.

(6) If possible, block-type construction should be used.

11-2 (U) ENCAPSULATION

Embedding compounds for electronic components, the advantages and disadvantages of their use, criteria for selecting a suitable embedding compound, and recovery of embedded components are covered in Chapter 8. Encapsulation as a construction technique, and methods of encapsulating, are covered below.

The trend toward standard circuits, miniaturization, and modular construction has made knowledge of encapsulation increasingly important to the fuze designer. Encapsulation is performed before final testing in constructing a packaged electronic assembly. By encapsulating, components are surrounded by a solid resinous material that holds them in fixed positions, and protects them from moisture, fungus, shock, vibration, and external heat. The last sometimes causes a heat dissipation problem.

11-2.1 (U) ENCAPSULATING METHODS

The basic encapsulating methods are potting, dipping, coating, and casting. Potting involves melting the embedding compound and pouring it into a pot or mold. The pot is normally left in place and the resin used is comparatively soft. Dipping and coating are generally confined to single components such as coils, resistors, or capacitors. Casting usually involves the use of resins which require the chemical process of polymerization to set. The resulting compound is hard and the mold is stripped from it. Molds may be made of metals or rigid plastics.

Of the four methods, casting is the most complicated. Typical procedures in a casting operation follow.

(1) The unit to be embedded is assembled, tested, cleaned, and given special preparation

required to ensure protection from corrosion, heat, contraction of the compound during cooling, or other special conditions.

(2) A suitable mold is made. Here good design is important. Proper dimensions, minimum thickness, correct tapering, rounding of sharp corners, and many other factors must be considered and the necessary compromises made.

(3) The inside of the mold is coated with a mold release preparation, the selection of which depends on the type of resin used.

(4) The assembly is positioned in the mold and the mold and contents are preheated in an oven to drive off any absorbed moisture.

(5) Immediately after removal from the oven, the prepared resin is poured into the mold, either under atmospheric conditions or under a vacuum, depending on the degree of penetration desired. Coils, transformers, and capacitors are usually embedded while in a vacuum.

(6) The filled mold is then cured. In some cases this process requires a heated oven, although many embedments are cured at room temperature.

(7) The mold is removed, the casting inspected, and the assembly retested.

Two different approaches are possible in the embedment of electronic assemblies. One is to embed the entire circuit in one large casting. The disadvantage of this is if one component fails, the entire circuit is useless and must be discarded. The repair of embedded circuits is difficult because dissolving the resin is time consuming and may be injurious to elements of the circuit. Drilling and other machining processes to gain access to defective components are expensive, time consuming, and practical only where clear resins have been used.

The second approach is to make several smaller castings, embedding components such as tubes having high failure rates separately. This reduces the possibility of having to throw away large castings containing many usable components when one component fails.

11-2.2 (U) DESIGN CONSIDERATIONS

When designing an assembly for embedment, tests must be made to determine the effects of the resin on the electrical characteristics of the circuit. Typical dielectric constants of resins are from 2.5 to 4.0. Anticipated changes in the circuit after embedment may be considered in advance. In some castings a small hole is provided to allow for screwdriver adjustments. The hole is then filled after final adjustments have been made.

Compatibility of the resin with embedded components is always a consideration. An improperly chosen resin may react with materials of a fuze component thereby damaging it. Contraction of the resin on cooling or dimensional changes of components due to temperature changes may result in damaging pressures or movement of components. These effects are not always predictable.

Special precautions are required when small electron tubes are embedded in polyesters. These resins contract during polymerization and may crush the envelopes. Possible solutions are to place nylon or silicone-rubber jackets around the tubes, or to apply a spongy tube-coating compound to the tube surface before embedment.

All plastics absorb and transmit moisture to some degree. This changes their dielectric properties and heat dissipation factors. Moisture also has a deteriorating effect on many circuit components. Varying the compound ingredients, increasing the embedding compound thickness, and coating the completed castings are several ways to minimize this problem.

A serious problem is moisture seepage into the embedment around metal leads. If flexing of wires at entrance points, due to vibration or handling, is not severe, solid, bare, single-conductor leads are best. Leads must be located so that the plastic, on shrinking will make a seal around them. When stranded wire is required, the separate strands should be spread out within the embedment for a short distance. Care must be taken to insure that the spread strands do not extend beyond the embedment or the lead will be weakened. Spreading permits the plastic to shrink around each separate strand, making a better seal. To offset the moisture problem, casting resins with good adhesion to metals are required. It is also essential

TABLE 11-1 (U). Thermal Conductivity of Some Potting Compounds

Type of Compound	*Kilowatts/in²/°C*
100% bitumin	0.008
Bitumin, 45% silica	0.015
Bitumin, 55% silica	0.016

that coefficients of expansion of metal wires and the plastic be close.

Another serious problem is heat dissipation. Resins suitable for embedding electronic circuits must have low electrical conductivity. Unfortunately, materials with low electrical conductivity have low heat conductivity as well. Heat is transferred from embedded components by conduction through both the plastic and the metallic wiring. Since the plastic is a poor conductor, failure of the electronic part, fracture of the plastic, or melting of solder connections is possible when heat concentration is 0.5 watt or more per cubic inch. Table 11-1 gives thermal conductivity of three potting compounds.

Thermal conductivities of polyester resins are about ten times that of air, and only 0.001 times that of aluminum. However, heated bodies exposed to air are cooled mainly by convection and very little by conduction. Only components with very low heat dissipation can be used in many castings. Spot temperature caused by power concentrations of 0.5 watt per cubic inch, which can destroy the component, the casting, and the solder joints, must be avoided. In a few cases it is possible to run components at higher temperatures in castings than in air. The reason for this is that the casting excludes the oxygen of the air and prevents oxidation. The most effective way to remove heat from an embedded component is to use a metal mass to conduct it to a surface radiator or heat sink.

"Satisfactory performance" at —50°C is claimed for many resins. Most manufacturers, however, mean by this that a block of resin exposed at —50°C will not crack. This does not take into consideration the problems involved when irregular shapes are embedded in the plastic. Sharp corners of embedded components will cause cracking in some plastics at temperatures which these plastics in block form would withstand. Similar problems are encountered at high temperatures because of different coefficients of expansion. Since resins soften and flow at high temperatures, the problem is less serious.

Many resins shrink appreciably during polymerization. By controlling the process, and by using fillers, this can be reduced in most cases.

11-3 (U) SEALING

Sealants and sealing materials are covered in Chapter 8. Some techniques developed to seal fuzes are covered here. Fuzes are sealed mainly to keep out moisture, since this is the most common deteriorating agent. However, sealing also protects a sealed fuze from fungus, harmful vapors, dust, and dirt. Since a fuze is used only once or, at most, a few times if it is to be tested, its operational life is measured in minutes. Thus, deterioration takes place almost entirely in storage rather than in use. Long storage periods and demands for higher reliability make fuze sealing more important than ever. Sealing can sometimes be a major problem and should be considered in the early design stages of a fuze or subassembly.

A waterproof seal protects against entry of large amounts of water and is moderately moisture resistant. It also seals out sand, dust, fungus, water vapor, and salt spray. O-rings and lapped disk seals are common waterproof seals.

The ideal seal is the true hermetic seal which protects against all infiltration. It does not deteriorate in any environment (including a nuclear one) and therefore gives permanent protection. The nearest approach to this is a glass, ceramic, or metal seal. Ceramics, soldered glass bushings, and fused metal joints are usually moisture proof. Generally, true hermetic seals cannot be made of organic materials, because such materials have low resistance to deterioration.

11-3.1 (U) COMPONENT SEALING VERSUS UNIT SEALING

Hermetic sealing can be accomplished by sealing the overall package, or by sealing individual components. When individual components only are sealed, care is required in the

TABLE 11-2 (U): Relative Merits of Hermetic Sealing Techniques

Technique	*Mechanical Rigidity*	*Temp Resist*		*Heat Transfer*	*Effective Dielectric Constant**	*Losses at High Freq*	*Humidity Protect*	*Ease of Service*
		High	*Low*					
Resin embedment	E	P	P to F	P	2.5 to 4.0	P to G	E	P
Foam embedment	G	P	F	P	1.03 to 1.2	G	G	P
Ceramic embedment	E	E	E	F	10	F to G	E	F
Plastic coating	P to F	P	F	P to F	1.0	G to E	F to G	F to G
Silicone film	P to F	G	G	P to F	1.0	G to E	P	G
Silicone fluid filling	P	G	F to G	F to G	2.5 to 3.5	G to E	E	F
Gas filling	P	E	E	F	1.0	E	G to E	F to G

E = Excellent
G = Good
F = Fair
P = Poor

* Circuit stray capacitances are increased by approximately this factor.

final assembly to protect plugs, sockets, and interconnecting wiring from moisture and fungus. Sealed components are generally heavier and more expensive than those used in an overall sealed package.

Overall sealing is simpler and cheaper because only one large seal is required. Its disadvantage is that any servicing requires breaking the seal and then resealing after servicing. When the seal is broken, any gases or liquids used in the assembly are lost and moisture enters. The moisture must be removed and gases or liquids replaced before resealing.

11-3.2 (U) FILLERS FOR HERMETICALLY SEALED UNITS

A hermetic seal must, of course, be absolute and permanent. Any break in the seal of a unit containing free space allows breathing, which may permit moisture vapor to condense in the free space. If the free space is small, breathing may be prevented by filling it with a casting resin, if the unit is not thereby damaged or its function impaired. Sometimes liquids are used, instead of resins, to help transfer heat to the outside in conventional electronic equipment. In fuze design, however, liquids are generally not used. In many fuze applications, the weight of a liquid alone prohibits its use. When solids or liquids cannot be used, an inert gas can be used. Table 11-2 compares a number of hermetic sealing techniques.

Factors to be considered when using casting resins are covered in paragraph 11-2. Considerations involved in the use of gases are discussed in the following paragraphs.

Filling spaces in hermetically sealed devices with embedding compounds or fluids is often impossible. However, such devices can usually be filled with a dry, inert gass at atmospheric pressure. Advantages of this are:

(1) No electrical losses are added to the circuit.

(2) Gas filling does not increase circuit capacitance.

(3) The gas does not affect operating temperatures.

(4) Gas filling permits inclusion of moving parts.

(5) Arcing of relays, switches, and other current interrupting devices is reduced.

(6) The gas prevents oxidation of lubricants in moving assemblies.

(7) The gas prevents oxidation of switch contacts and similar devices.

(8) Gas convection cooling, which is better than resin conduction, is provided.

Some of the disadvantages of filling electronic packages with gas are:

(1) Gas filling does not provide additional mechanical support to contained elements against vibration and shock that embedding resins do.

(2) Gas filling necessitates using a container strong enough to withstand the internal pressure when in outer space or high-altitude operation. The structural and form rigidity requirements are usually more stringent. The container must usually withstand 15 psi.

(3) Gas filling requires a controlled atmosphere or drying facility for both fuze and gas when servicing. This makes field maintenance of the equipment more difficult.

Typical gases used for filling are helium, argon, and nitrogen. Hydrogen possesses many desirable characteristics but is flammable. Dry air instead of inert gas is sometimes used to fill packages, but is less desirable. When dry air is used, a chemical desiccant, packaged so that it can be removed, must usually be included in the space.

11-3.3 (U) SEALING AND MAINTENANCE

Hermetic sealing of equipment considerably reduces the need for maintenance but does not eliminate it. Discretion is required in deciding whether or not to seal a unit. A hermetically sealed unit cannot normally be repaired in the field. It may have to be replaced, and the defective unit returned to a repair depot or to the manufacturer's plant. It is desirable to limit sealing to components extremely sensitive to moisture or to relatively small assemblies that may easily be replaced and shipped. When little or no maintenance is anticipated and high reliability is required, units should normally be sealed.

11-4 (U) HEAT TRANSFER

The increased capacity and variety of electronic equipment, combined with the growing trend to pack it in smaller and smaller space, makes it necessary to transfer internally generated heat from the package. A missile fuze designer may also find that he must locate electronic equipment near other sources of heat such as the missile skin or rocket motors. This adds to the problem.

The internal temperature of equipment may approach a value where low melting point materials become soft and flow. Embedding resins, seals, protective finishes, solders, and explosives are particularly sensitive to heat. Most thermoplastics have heat distortion temperatures below 95°C.

Differential expansion of materials can distort structures, rupture seals, and bind moving parts. "Aging" is also much faster at high temperatures.

It is generally good practice to select components so that they can operate in temperatures as high as may be encountered. It is also desirable to keep temperatures down.

11-4.1 (U) METHODS OF HEAT TRANSFER

Heat is transferred by conduction, convection, and radiation. Each method is discussed briefly below.

11-4.1.1 (U) Conduction

Heat transferred by conduction goes from one part of a body to another part of the same body, or from one body to another one in physical contact with it, without displacement of the particles in contact. To obtain maximum heat transfer by conduction:

(1) Use the highest conductivity material possible. Generally, the thermal conductivity of a metal is proportional to its electrical conductivity.

(2) Keep conducting paths short.

(3) Use tight bonds between materials forming the conducting path. Soldering, welding and brazing are good metal-to-metal contacts. If pressure joints are used, they must be tight fits. Figure 11-7 shows how increasing contact pressure increases heat conductivity.

11-4.1.2 (U) Convection

Convection is the transfer of heat from one place to another within a fluid or gas by the mixing of one portion of the fluid or gas with another. This method of heat transfer is not used in fuzes, primarily because of weight and size restrictions on the fuze.

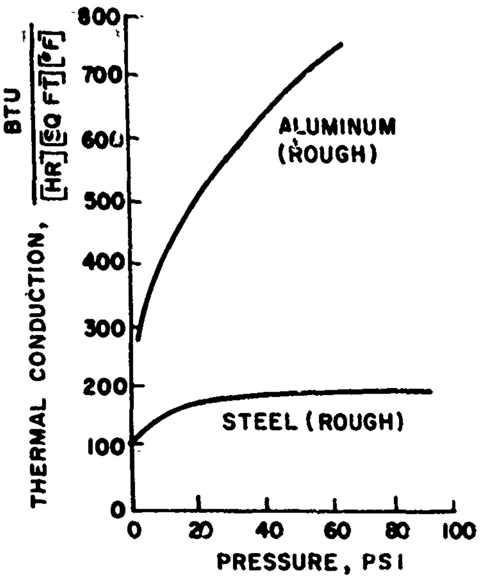


Figure 11-7 (U). Thermal Conduction of Aluminum-to-aluminum and Steel-to-steel Joints as a Function of Contact Pressure

11-4.1.3 (U) Radiation

All bodies give off heat in the form of radiant energy. This energy is propagated in all directions as wave motion. Radiation falling on a body is either absorbed or reflected by it. Energy in the form of radiant heat is continually being interchanged by all bodies. A hot body radiates more energy than it absorbs, a cold body absorbs more than it radiates. This goes on all the time, even after equilibrium has been established. The amount of heat radiated by a body depends on its color, its temperature, and the character and area of its radiating surface. Generally, polished surfaces make poor radiators, while rough surfaces make good one. The color of the radiating surfaces is also important. A "black-body" is a perfect radiator. Increasing the area of a radiating surface increases the amount of heat radiated.

The rate that a body absorbs heat is in direct relation to its radiating ability. Good absorbers are good radiators. Rough, black surfaces are the best absorbers and radiators.

The amount of radiant heat reflected from a surface also depends on the character of the surface and its color. Polished surfaces are good reflectors. Rough black surfaces are poor reflectors. Surfaces that are good radiators or absorbers are poor reflectors.

To increase heat transfer by radiation the following methods are recommended:

(1) Select materials that have high emissivity and absorbency. Discretion must be used, however, not all surfaces should be blackened. For example, vacuum tubes should not be painted black. In this case the surface that can be painted is not the primary radiator. In general, painting the glass hinders the escape of radiation from the interior elements.

(2) Increase the temperature differential between the radiating and absorbing bodies. The greater the temperature difference, the greater the radiant heat dissipation.

(3) Locate heat-sensitive parts so that they cannot "see" the heat radiators. Place parts that radiate large amounts of heat near good absorbers.

11-4.2 (U) TECHNIQUES FOR HEAT TRANSFER

Heat dissipation from electronic equipment is divided into two phases. The first phase, internal cooling, is the transfer of heat within components or embedments to a local sink of limited capacity. The second phase is the transfer of heat from the local sink to a large one of relatively unlimited capacity.

11-4.2.1 (U) Cooling of Components

Various ways have been devised to remove heat from each of the primary heat producing electronic components. These components are, in order of importance, tubes, iron core inductors, and resistors. Some techniques that are illustrative of those that may be used follow.

11-4.2.2 (U) Electron Tubes

The electron tube is by far the greatest heat producer in electronic equipment. Tube shields are sometimes used to conduct heat from tubes. However, the standard miniature tube shield is not fully satisfactory from a heat transfer standpoint. The shield is a heat barrier. The blanket of air enclosed between the shield and the tube envelope is too thin for formation of free convection currents, making heat transfer from the tube to the shield possible only by gaseous conduction and radiation. For this and other reasons tube shields should either be in accordance with MIL-S-9372, which provides good conduction by a special design, or be the blackened standard shield, with a commercially available insert to improve conduction.

Thicker shields produce relatively lower temperatures because of the larger heat conducting path. There is a point, however, where increasing thickness results in diminishing. An increase from 1/32 to 1/16 in. decreases the tube-to-shield temperature difference by 10%, whereas an increase from 1/32 to 3/16 in. decreases the difference by only 20%.

Tubes should always be mounted so that conduction flow is unimpeded, and provision for cooling by convection and radiation should be made. To insure cooling by radiation, tubes should be located so that radiation to a cooler surface is possible.

11-4.2.3 (U) Iron-Core Inductors

Cooling of iron-core transformers and chokes can be improved by conduction from the core. Thermal resistance of the core is usually low, and hot spot can be reduced by cooling the external surface of the core. The core should be thermally bonded over a wide area to a heat-conducting support or chassis connected to a sink. Eddy current losses from a lamination short circuit at the thermal bond must be prevented, however.

Increased cooling, together with size and weight reduction, can be obtained by inserting metal heat conductors into the laminations and windings. In one case the temperature rise was reduced by 20°C and weight reduced from 18 to 8 lb by this technique.

11-4.2.4 (U) Resistors

Most resistors are rated with natural cooling in still air. Greater power can be dissipated from a resistor when adequate cooling is present. The dissipation rating of a given resistor, therefore, depends on its environment.

11-4.2.5 (U) Cooling of Assemblies

Two concepts govern thermal design of assemblies. The first is that heat-emitting components are located so that they transmit minimum heat to their neighbors; the second, a heat-removal path, thermally matched and connected to a sink, must be provided. Metal-block chassis are especially effective as heat-transfer mediums.

Unless special heat-transfer paths are designed into an embedded assembly and heat sinks are provided, heat is transferred from embedded components by conduction through the metal wiring and conduction through the plastic. Since plastics and embedding resins are poor conductors, extreme care is required in designing embedded assemblies. Embedding materials must be selected which can stand the required operating temperatures.

Heat-generating components must be located as close as possible to the coolest surface available. This provides the shortest thermal path from the source to the sink, together with the minimum heat gradients. To obtain maximum heat transfer, heat-producing parts cooled by radiation and conduction must be mounted with their major axes parallel to cooled surfaces. When natural convection is used, heat-producing parts are mounted with their longer axes vertical.

When heat-producing parts cooled only by convection and radiation are mounted in closely spaced groups, overheating is inevitable. Much can be accomplished by judicious arrangement of components, and by conducting heat away from hot spots to local sinks, and from them to larger surfaces, where it can be transferred to the air or some other cooling medium.

(U) REFERENCES

1. *RADC Reliability Notebook,* Report No. RADC-TR-58-111 (Astia AD-148868), Rome Air Development Center, Griffiss Air Force Base, Rome, New York.
2. *Design Factors for Aircraft Electronic Equipment,* WADC Technical Report No. 56-148, Wright Air Development Center, Wright-Patterson Air Force Base, December 1956.
3. R. W. Warren, *Design of Guided Missile Fuze Structure for Vibration,* Report No. R40-56-1, Diamond Ordnance Fuze Laboratories, January 1956.
4. J. E. Vineski and R. W. Warren, *The Effect of Added Mechanical Damping on Fuze Electronic Assemblies,* Report No. R40-56-7, Diamond Ordnance Fuze Laboratories, April 1956.
5. I. Pollin, *A Study of the Problem of the Mechanical Design of Guided Missile Fuzes,* Report No. R40-55-32, Diamond Ordnance Fuze Laboratories, November 1955.

CHAPTER 12

(U) INDUSTRIAL ENGINEERING

12-1 (U) INTRODUCTION

Industrial engineering is that activity of engineering which translates the item developed during R & D to an item which can be manufactured and procured in production quantities economically and reliably. In research and development (R & D) a basic functional fuze design evolves which meets operational requirements and which is capable of being fabricated. The industrial engineering effort assures that this basic design can be manufactured in the needed quantities, at the required production rates, and with the minimum expenditures of manpower and natural resources, while still maintaining the specified reliability.

12-2 (U) FUNCTIONS OF AN INDUSTRIAL ENGINEERING PROGRAM

A modest industrial engineering program may involve only the preparation of a technical data package (paragraph 12-2.4). At the other extreme, the most extensive type of program involves: (1) a detailed study of the R & D item during the R & D phase; (2) product and process engineering to reduce costs, improve manufacturing methods, etc.; (3) testing the product-engineered item; and (4) preparation of a technical data package. Between these two extremes are programs tailored to specific fuze projects. Regardless of the extent of industrial engineering, a technical data package must always be prepared.

12-2.1 (U) STUDY AND FAMILIARIZATION PHASE DURING R & D

During the R & D phase, industrial engineering makes recommendations on product engineering to the R & D project group, collects evincive data, and helps establish or firms up applicable military characteristics. Evaluation tests are made and the validity of test data established to substantiate the fact that the item meets the user's requirements. Also, R & D documents such as specifications, drawings, and notes on development type materials are reviewed for completeness, accuracy, conformance with ordnance specifications, etc.

12-2.2 (U) PRODUCT AND PROCESS ENGINEERING

Product engineering is the engineering effort applied to the item itself to improve producibility and to conserve critical material, manpower, time, and money. Process engineering has the same objectives, but involves improving the processes used to manufacture the item.

Among the things to be considered when an R & D item is examined for product and process engineering are:

(1) Alternate manufacturing processes.

(2) Substitution of less critical or less costly materials.

(3) Relaxation of noncritical tolerances.

(4) Redesign to permit more economical production techniques, including minimizing the number of required parts or use of standard parts.

(5) Consideration of human engineering factors.

(6) Development of new or special processes, inspection and testing techniques, or equipment.

(7) Automation of production operations where appropriate.

The amount of product and/or process engineering to be applied must be judged by comparing the gains with the cost of the work. The gains are (1) reduction in cost of fuze, (2) improvement in reliability, and (3) savings of critical material.

Figure 12-1 shows an example of product improvement as a result of product engineering. The mounting plate supports two safety and arming mechanisms and contains a low-pass filter network for each mechanism. The product-engineering mounting plate is essentially a repackage of the R & D design, with some components changed to suit the new package. The product-engineered design has less than half

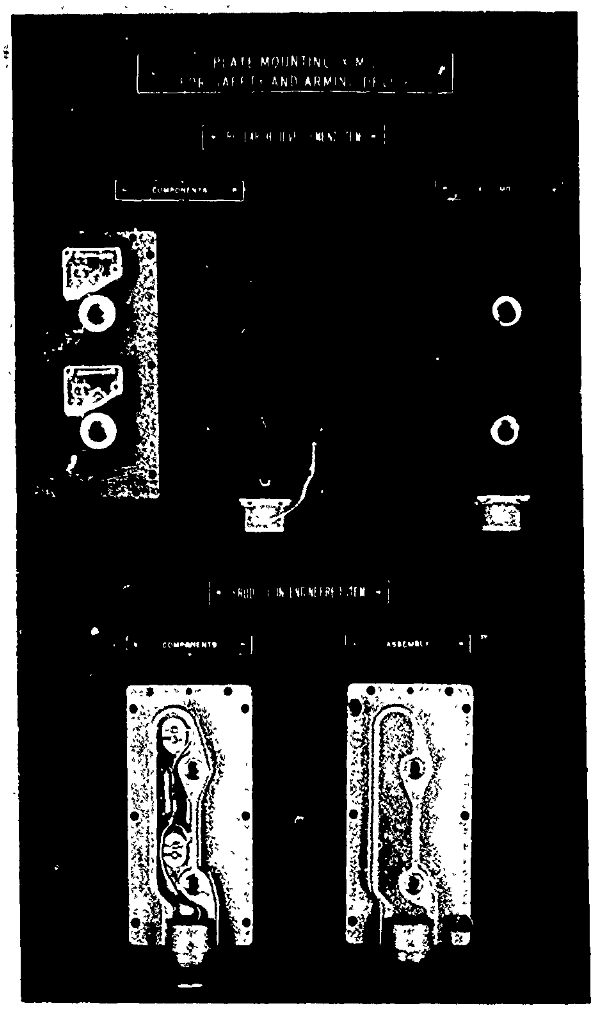


Figure 12-1 (U). Product-engineered Mounting Plate Used in a Certain Missile

the number of parts in the R & D design, and even in small quantities can be produced at 25% of the cost of the R & D design.

12-2.3 (U) MODELING AND TESTING OF PRODUCT-ENGINEERED FUZE

Modeling and testing the product-engineeerd items assures that the user's requirements have not been compromised. The degree of modeling and testing depends on the extent of product engineering. Extensive product-engineering changes made to the R & D model might require additional field testing, which is very undesirable, particularly in the case of guided missile fuzes. Thus, one can see the importance of considering the producibility of a fuze from the very beginning of a development program.

12-2.4 (U) TECHNICAL DATA PACKAGE

A technical data package is a compilation of technical information required for procurement or manufacturing of an item, including the criteria for acceptance by the Government. Any industrial engineering program requires that a technical data package be compiled for transfer to the procuring agency. This package insures that the item purchased is, in fact and performance, the item that the user intended to obtain. It must be self-contained and sufficiently comprehensive so that the fuze can be procured or manufactured with a minimum of engineering support.

12-2.4.1 (U) Types of Technical Data Packages (Ref. 1)

There are three types of technical data packages. Each type is briefly described in the following paragraphs.

12-2.4.1.1 (U) Final Technical Data Package

This is a technical data package that is complete in all respects. Its contents conform to the provisions of ORDM 4-4 (and applicable supplements), and its adequacy has been proved through its use in actual production. A final technical data package is fully adequate for use in competitive procurement. No technical data package can be considered as final prior to classification of the item as adopted type.

12-2.4.1.2 (U) Interim Technical Data Package

The interim package, like the final package, is complete in all respects and its contents conform to the provisions of ORDM 4-4 and applicable supplements. It differs from the final package in that its adequacy has not been proved in actual production. The interim package may be used for competitive procurement when the gains of such use outweigh the risks incurred. No technical data package can be considered as interim unless the design is suitable for classification as limited production type, and in no event prior to the successful completion of engineering tests.

12-2.4.1.3 (U) Preliminary Technical Data Package

The preliminary technical data package consists of a preliminary purchase description, item drawings, Security Item Check List (DD Form 254), inspection equipment list, inspection equipment, drawings and specifications, engineering parts list, and bill of materials. Although it is desirable that the contents of the package conform to the provisions of ORDM 4-4, for the sake of expediency they may not do so. This package is used when it is necessary to initiate procurement prior to completion of engineering tests. Since design parameters are not necessarily fixed at this time, the package may have to be modified by engineering orders. The prelimnary technical data package is generally considered inadequate for use in competitive procurement, but may be used for controlled procurement where the control is vested in the responsible development mission activity.

12-2.4.2 (U) Development of a Technical Data Package (Ref. 2)

To avoid the loss of valuable data, the designer must always be aware that his design must be definable through the technical data package. Once he has solved a technical problem, even in the very early phases of development, he must insure that all future manufacturers will be able to profit by his solution. Whenever design factors are defined, some sort of preliminary document should be prepared that can ultimately be included in the technical data package. This document should consist of enough drawings, preliminary specifications, descriptive notes, and tests to insure that whatever was tested and approved can be made again. Sometimes the designer does this naturally. He generally does it, however, to assure himself of the soundness of the development, and may overlook the need to guide others in the necessary perpetuation of the final item in production. Unless the designer considers both of these points, much confusion and loss of design effort may occur during the production phase of a program.

In addition to a qualitative study of user requirements, the fuze designer must also make a quantitative evaluation of the design. The effect of variation of any of the specified parameters must be known. The designer readily recognizes certain design problems. Unless absolutely necessary, he should avoid methods such as screening components, selective assembly, setting very tight tolerances on parameters, etc., to solve the problems. These methods are usually very expensive, and frequently result in production problems.

The above discussion illustrates not only the need for recording important data from the start of the development program for the item but also the need for conducting the program in a manner that will yield the required data. Such data can sometimes be obtained later, but always at a considerable cost and lack of flexibility. Item development and technical data package development are parallel rather than series programs.

12-2.4.3 (U) Contents of a Technical Data Package (Ref. 2)

The following paragraphs discuss the various types of information a technical data package must contain. The discussion is based on the final technical data package, the most comprehensive of the three types of packages (paragraph 12-2.4.1).

12-2.4.3.1 (U) Item Requirements

All requirements needed to insure that the production item will meet the specified military characteristics must be given. To be useful, these requirements must possess the following characteristics:

Definition—The requirement must be specific and complete to insure only one interpretation

Measurability—The requirement must be amenable to verification by inspection as a basis for acceptance or rejection of the product. Inspection uses three basic tools:

(1) Measurement of dimensional or physical properties.

(2) Functional testing.

(3) Visual inspection.

Practicability—The requirement must be capable of being achieved. Such ability should be clearly demonstrated by data obtained from development and production engineered items. Requirements that are only ultimate wishes will result in high prices and may make it impossible to procure the item at the time it is needed.

Thus, they have no place in the technical data package.

Efficiency—First, of the vast number of parameters that define an item, a relatively small number of the parameters must be selected to establish the acceptance criteria for the item. It is practically impossible to inspect everything and, therefore, it is necessary to use the available effort in the most effective manner. For example, incoming inspection tests might require testing only a few resistors from each lot to establish the quality of the lot. On the other hand, it is generally advisable to test all magnetrons and klystrons because of their comparatively high cost and because of the limited number needed.

Second, nondestructive requirements are preferable to destructive ones, and those requiring simple tests are preferable to those needing complex testing or test equipment. Finally, the time for testing and evaluation should be as short as feasible to enable prompt corrective action and to avoid large, high-risk inventories.

12-2.4.3.2 (U) Inspection Criteria

For each requirement, there must be a means of establishing that the requirement has been met. The inspection criteria must be specific and, above all, repeatable. They must be amenable to determination by the inspection tools listed in paragraph 12-2.4.3.3. In addition, the frequency and extent of inspection must be determined from the importance of the parameter and the likelihood of variation in manufacture. Inspection should be kept to the minimum required to obtain assurance that a suitable product is obtained. The measurements, tests, and other criteria used for this inspection, however, must be specific enough to insure that any inspector or manufacturer applying them makes the same fundamental measurements and obtains the same results. The inspection information should specify variables such as position, measuring points, and environmental conditions existing when the requirement was evaluated in design.

12-2.4.3.3 (U) Inspection Equipment

The basic design of inspection equipment and gages must be documented for both procurement and inspection methods. In general, such designs should be specifically documented only to the extent that they fundamentally affect the test. For example, the holding fixture, the basic radius measurement point, and the rpm are generally adequate for most centrifuge tests. A voltmeter may be entirely defined by its range, input impedance, sensitivity and scale accuracy. The ultimate aim is to avoid the need for highly specialized test equipment beyond the absolute minimum required to properly perform the required tests.

Because these equipments and gages must be established for each design, it is necessary to be able to correlate and calibrate them against each other and against standards. There must be means of insuring that the test equipment is functioning properly at the time of inspection. The basic correlation standard must be identified and perpetuated, and must literally "stand up in court." Again, the primary requirement for equipment is to insure that it will perform the inspection function exactly as required every time it is used.

When it is necessary to design special equipment for certain tests, adequate drawings and specifications must be prepared in order to establish the fundamental portions of the equipment and necessary test standards. Beyond these fundamentals, it is better to leave the remaining portions to each manufacturer in order to best fit his facilities, although a complete design may be shown for information.

12-2.4.3.4 (U) Instructions

All pertinent data for performing tests, operating test equipment, calibrating and correlating procedures, repairing equipment, handling procedures, determining responsibilities, etc., must be included. These instructions must specifically cover such points as formation of lots, selection of sampling plans, initial product qualification procedures, engineering samples, contractor records, and inspection responsibilities. These areas are controlled to a large degree by procurement policies of the Army. Within the field of these policies, however, it is necessary to define the particular applications necessary for the particular ordnance item to be procured.

12-2.4.3.5 (U) Acceptance Limits

It is of paramount importance that a specific definition be established for acceptance of each parameter inspected. The limits directly affect the reliability, cost, and manufacturability of the item. To keep costs down and to enhance producibility, limits should be as broad as practical, consistent with satisfactory function of the item. The following should be considered:

(1) Evaluation of limits in terms of importance for determining acceptability of function.

(2) Evaluation of process variation by actual measurements and tests.

(3) Actual test or engineering results showing variation of performance with variation of the parameter.

(4) Evaluation of cost of maintaining limits versus reliability increase obtained. To establish a valid comparison, these costs should reflect all costs of failure such as round costs, logistics, and firing costs.

Limits should then be chosen that result in the least cost per effective round delivered on the target area. When only extremely tight limits can be used to achieve effectiveness, the item might border on nonprocurability, and additional design and development may have to be undertaken to enable normally achievable limits to be used.

12-2.4.3.6 (U) Processing Procedures

A final manufacturing process report is normally prepared after substantial pilot line production has been completed. Processing information is required for two purposes:

(1) To define and describe any special or critical processes required to produce satisfactory items.

(2) To assure realistic bidding (when applicable) by furnishing enough information for realistic evaluation of the extent of production capacities.

The primary purpose of the manufacturing process report is to provide the detailed description of specialized techniques. Shop records, sketches, photographs, etc., are generally all that are needed for this purpose.

12-2.4.3.7 (U) Security Requirements

The question of security must be evaluated in great detail. Since some manufacturing plants are not generally set up to handle classified information, special procedures must be established to perform classified operations. This is expensive and disruptive. Therefore, no security requirements should be placed in the package without a thorough study to determine their necessity. Policies are available for the various types of ordnance, and must be used to insure that security is adequate but not excessive.

12-3 (U) INDUSTRIAL ENGINEERING METHODS (Ref. 3)

There are numerous industrial engineering methods that have been used or could be used in fuze programs. Some of these methods, and obvious advantages and disadvantages, are discussed in the following paragraphs.

12-3.1 (U) MINIMUM PROGRAM (NO PRODUCT OR PROCESS ENGINEERING)

Only the preparation of a technical data package is required for this type of program. No product or process engineering studies are performed prior to production. Any such studies would be performed after production begins.

Disadvantages of this method:

(1) Inability to establish or maintain production control.

(2) Imbalance in the productive capacity of the various segments of the production line with attendant excessive capital investment.

(3) Overdesign of product and processes leading again to excessive costs for capital investment as well as for manufacture.

(4) Excessive costs and delays in initiating production and in maintaining production because of inadequacies of the production tooling equipment and processes.

(5) Possible compromise on quality in order to meet the schedules involved.

(6) Hesitancy to change the process or product once production has been established, to avoid interfering with production schedules.

The primary advantage of this method is that it allows immediate production of an item in at least limited quantities. Such quantities could be obtainable, for example, by screening out the good from the bad. However, there is considerable danger that long delays may be encountered in providing quality materiel in the quantities needed.

12-3.2 (U) ENGINEERING EVALUATION

An engineering evaluation requires a so-called desk or paper engineering study of the research and development prototype fuze after final research and development engineering tests. Additional studies, if any, would be conducted after initiation of production. Some advantage is gained over the first method with respect to overdesign of product and process. However, only limited and superficial changes will be made in the design or processes to avoid any engineering tests. Moreover, there is the danger that some of these changes may yield an unsatisfactory product.

12-3.3 (U) PILOT LOT MANUFACTURING

Pilot lot manufacturing is carried out to evaluate the technical data package, and to prove the producibility of the design.

Advantages of this type of program are:

(1) Production procedures are developed on pilot lines.

(2) Guides for costs and rates of production are determined.

(3) Items are provided for field testing.

12-3.4 (U) COMPREHENSIVE STUDY AFTER R & D ENGINEERING TESTS

This method calls for a comprehensive study to be initiated after successful preliminary research and development engineering tests. The study includes a desk or paper engineering study plus the manufacture and test of sample items and, finally, the production of limited production quantities to proye out the proposed product design and processes. This method may require the longest time for accomplishment. but it provides proved designs and product and processes that are suitable for economical quantity production. It is important to note that considerable time can be saved for a complex system containing many components if the individual components are product-engineered one at a time as they are developed, without waiting for the entire system to be developed.

12-3.5 (U) COMPREHENSIVE STUDY CONCURRENT WITH R & D PHASE

This method is similar to the one discussed in paragraph 12-3.4 and is the most extensive. It calls for a comprehensive industrial engineering study to be conducted along with functional design to cut lead time to production to a minimum. Advantages of this method are similar to those of the method discussed in paragraph 12-3.4, with the added advantage of minimum time to production. The major disadvantage is that preliminary designs, many of which might be discarded along the way, must nevertheless be continuously evaluated. This results in a greater expenditure of money and manpower for the production engineering.

12-3.6 (U) COMPARISON OF INDUSTRIAL ENGINEERING METHODS

A comparison of the industrial engineering methods discussed in this section is given in Table 12-1. Each method is rated with respect to all other methods, with the numeral 1 indicating best choice and the numeral 5 indicating worst choice. No one method appears applicable to all programs. At present, a systematic or scientific means does not exist for selecting the most effective method for a particular program. The selection must generally be based on engineering and executive judgment.

12-4 (U) PHASING OF R & D AND INDUSTRIAL ENGINEERING

Functional design and industrial engineering may appear to be two separate functions. Actually, however, they are considered as two interdependent functions that run parallel to one another through at least a major part of the program. At the beginning, emphasis must necessarily be on designing a fuze that will meet the specified military characteristics. As the

TABLE 12-1 (U). Comparison of Industrial Engineering Methods

Method	*Least Mfg. Cost*	*Least Capital Investment*	*Greatest Probability of Successful Prod.*	*Least Time to Initiate Prod.*	*Highest Quality or Efficiency*	*Least Utilization of Critical Material*	*Least Cost of Prod. Eng.*
Minimum program (No product or process eng.)	5	5	5	1 or 2*	5	5	1
Engineering paper study	4	4	4	3*	4	3	2
Pilot lot Mfr.	3	3	3	4	3	4	3
Comprehensive study after R & D eng. tests	1 or 2	1 or 2	1 or 2	5	1 or 2	1 or 2	4
Comprehensive production study concurrent with R & D phase	1 or 2	1 or 2	1 or 2	1 or 2	1 or 2	1 or 2	5

* Production rate will be limited

functional design features become more firm, however, the procurement and producibility aspects must be given more and more consideration, until the item is finally released for quantity production. The degree of effort exerted on functional design and on manufacturability at various stages of development will, of course, depend on the particular project. The industrial engineer must be considered as a part of a team, contributing in his specialty to the overall development of the item. He can contribute on an informal or consultant basis even in the very early stages of development. Also, the production engineer brings an entirely new perspective to the problem which can, in some cases, lead to final successful acceptance of a new item. He is there to assure that the item will be acceptable from a procurement and production standpoint only.

Figure 12-2 shows one way in which industrial engineering is phased into an overall development program. The phasing diagram is based on the method described in paragraph 12-3.4, and shows the various stages established between research and development and mass production for a typical item. The mission responsibilities encompass both the National Development and National Industrial Engineering Mission Agencies. The illustration indicates guide lines to determine the category of an item when control responsibility for the item is transferred from the National Development to the National Industrial Engineering Mission.

When a project has been established for the development of an item, the responsibility is retained by the National Development Mission and is carried through a period known as status E, which encompasses various phases: research, feasibility study, engineering design, component development, system demonstration, and engineering tests.

When the development of an item has proceeded to such a point as to indicate with a reasonable degree of certainty that the design, as established, is basically sound and can be developed into a satisfactory item by refinements in design (normally upon success in preliminary engineering tests), the status of the item is considered such that a production-engineering study can be initiated. This stage is designated as D status, and at this time the Industrial Engineering Agency technically and formally evaluates design producibility.

Note that development continues concurrently with production engineering to a point where the final engineering tests have proved to be successful (C status). Any changes made by the agencies between D and C periods are fully coordinated to assure that the product-engineered design includes the latest features of the

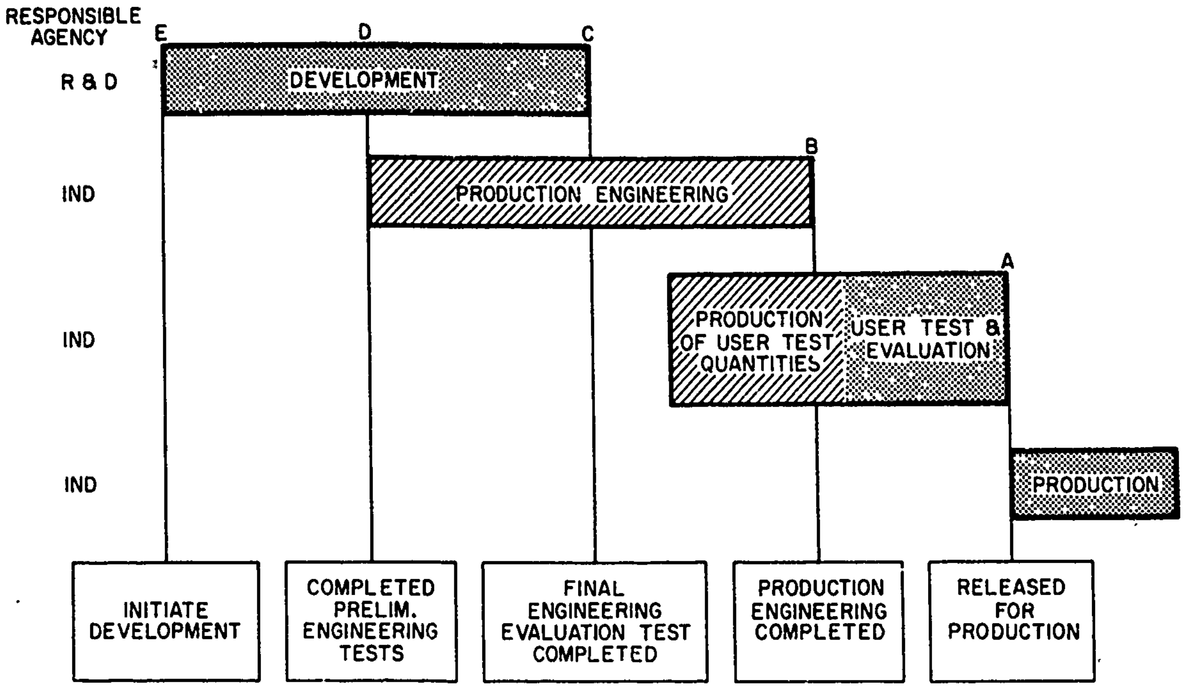


Figure 12-2 (U). Phasing Diagram from Research and Development to Mass Production

research and development item. Any changes developed by the Industrial Engineering Agency during this period are similarly coordinated with the research and development agency.

Product engineering is continued after the final engineering tests to a point where sufficient hardware has been produced and engineering tests conducted to prove out the anticipated producibility of the product-engineered version item. At the same time, this assures that the quality of the research and development design has not been compromised in terms of the established military characteristics, safety, etc.

Transfer of responsibility for the item from research and development to industrial, including the preparation of user test qualities, occurs at the C status point. The Industrial Engineering Agency will, upon completion of product engineering, furnish the using service with the quantities of items required for user testing. User test items will be of the product-engineered design. Furnishing a product-engineered item allows the user to test an item that is exactly the same as will be subsequently furnished in production.

When product engineering is completed and the user test quantities have been delivered, the design may be released for production, depending upon the need to meet urgent deadlines. At this point, known as status B, a complete technical data package is made available pending acceptance of the item by user and type classification as a standard item. The technical data package is then transferred to the National Procurement Agency.

In situations where the need for a particular item is critical and time schedules are very tight, there is a modification of the above scheme. This arises quite often with items for special weapons. The modification is known as interim procurement, and involves delivering acceptable items to the user while the final technical data package is being prepared and while product and process engineering is being conducted. Actual production is initiated with an accepted risk.

The unit item cost is found to be high when procured on this basis. The high cost, however, is outweighed by such factors as earlier availability of the item and earlier discontinuance of other items that become obsolete because of the new replacement item.

(U) REFERENCES

1. *Ordnance Corps Engineering and Drafting Manual,* ORDM 4-4 (OSWAC), Ordnance Corps, February 1960.
2. G. R. Keehn, *Basic Requirements of a Procurement Package,* Report No. M63.0-58-2, Diamond Ordnance Fuze Laboratories, February 1958.
3. *Engineering for Production,* Picatinny Arsenal.

CHAPTER 13

(U) TESTING

13-1 (U) INTRODUCTION

This chapter discusses basic philosophy and considerations involved in fuze testing. The various types of tests that must be performed and typical test facilities are also described. Additional information on testing can be found in Reference 1.

13-1.1 (U) TEST PROGRAM

The program to develop any fuze must include provisions for testing all along the line. Careful analysis must be given to the following:

(1) The point in development at which a test should be performed.

(2) The order in which the tests should be performed.

(3) The procedure to be used to accomplish the required tests.

The analysis given to each of these points can have a significant effect on the cost, reliability, safety, and producibility of a fuze.

The designer must take cognizance of the test problems involved during the development of the design. He must provide access to mechanisms, electrical test points, etc., to facilitate testing.

The ultimate aim of any test program is to determine whether a fuze satisfies its requirements. However, if a test indicates that the requirements cannot be met but at the same time isolates the problem, the test will still have made a valuable contribution to the development program.

Since fuze tests often destroy the fuze and the available number of fuzes for test is limited, it is necessary to apply special methods of analysis to the test data. There is a definite trend toward standardization of fuze tests and the designer should give attention to this area. There are many established procedures that can serve in the absence of a standard.

13-1.2 (U) VALIDITY OF TEST PROGRAM

The fuze designer must recognize that testing fuze components, or the complete fuze, in a simulated environment is only a step in the right direction. The operational use of the fuze will introduce factors which are difficult to foresee. In laboratory tests, the personnel involved in the handling of the device are influenced in their handling procedures by a more intimate knowledge of the device than those who will be handling it as part of the final weapon system. The assembly techniques for those who fabricate the test item are usually different from those used in production models.

Fuzes must often be tested before associated units of the weapon system have been produced. This makes it impossible to test the fuze in exactly the same surroundings as in the final system. Added to this is the problem of fuze compatibility with parts of the system that are not available at the time the fuze is tested.

Unfortunately, the fuze designer cannot wait until the rest of the system is completed; he must, therefore, exert every effort to use all the information at his disposal to develop a testing program that will, as realistically as possible, provide conditions equivalent to those in which the fuze must eventually operate.

13-2 (U) TYPES OF TESTS

Fuzes are given various types of tests to determine whether they will operate as intended. Tests are given to complete fuzes and to individual fuze components or combinations of components. Where applicable, standardized tests are suggested. Programming of development-type performance tests should always be included in the initial planning for a fuze development project. Development tests are used to evaluate the designer's latest efforts. They seek an answer to the behavior of a component, a combination of components, or the complete unit. Acceptance tests apply only to the final design. They are often called ordnance approval tests or ordnance evaluation tests. They are used to confirm the acceptability of the design. Acceptance tests are not within the scope of this handbook.

13-2.1 (U) DEVELOPMENTAL TESTS

Developmental tests often begin before the start of assembly. It may be necessary to test a component for its performance in an area not covered by specifications or the performance data record.

Developmental tests will continue through the completion of assemblies and the complete unit. Each test should be aimed at proving the ability of the item under test to perform. It is desirable to test the item under the environmental conditions to which it will be exposed. This includes safety tests that duplicate conditions to be encountered during storage, handling, and proof testing.

13-2.2 (U) TESTS GOVERNED BY MILITARY STANDARDS (Ref. 1)

Various Military Standards have been established and approved by the Departments of the Army, Navy, and Air Force for testing fuzes and fuze components. These standards give complete information on a type of test which will meet some specific test requirement. The specifications cover purpose and description of the test, test equipment, procedures, and safety precautions. Some MIL-STDS contain drawings showing the construction of the test equipment or list the source of such drawings.

Table 13-1 lists MIL-STDS applicable to fuze tests. Each MIL-STD test serves a definite purpose. The selection of tests for a specific application requires engineering judgment. In no case should tests be applied indiscriminately without due consideration as to necessity and costs involved. In Table 13-1, the tests are grouped together for convenience, but not with the intent that each test should apply to every development and production program. On the other hand, these tests are standards, and once a particular test has been prescribed by the procuring agency, it is mandatory that it be performed precisely as specified without exception or deviation.

The standard temperature and humidity test (MIL-STD-304, MIL-STD-354) involves exposing bare fuzes to two complete 14-day cycles. During these periods, fuzes are heated to 160°F and then cooled to −65°F nine times. A relative humidity of 95% at the high temperatures is used to accelerate the damage. All fuze elements must be present during the test and all must be safe and operative following the tests. Static and operational tests under field conditions are used to determine whether the fuze withstood the test.

Figure 13-1 shows average heating and cooling characteristics of fuzes subjected to the temperature and humidity test cycle.

The vacuum-steam-pressure test (MIL-STD-305, MIL-STD-355) simulates tropical climates. It is especially important for fuzes that contain electrical components. The test has been found to be the equivalent of approximately eight months storage in the Pacific. Each sample fuze is exposed to 1000 consecutive, 15-minute cycles in a vacuum-steam-pressure chamber. Figure 13-2 shows a typical installation. Considerable equipment is required to control the cycles automatically and to record results.

In the waterproofness test (MIL-STD-314), fuzes are immersed in water to determine their ability to withstand water penetration. After soaking for one hour in water containing a

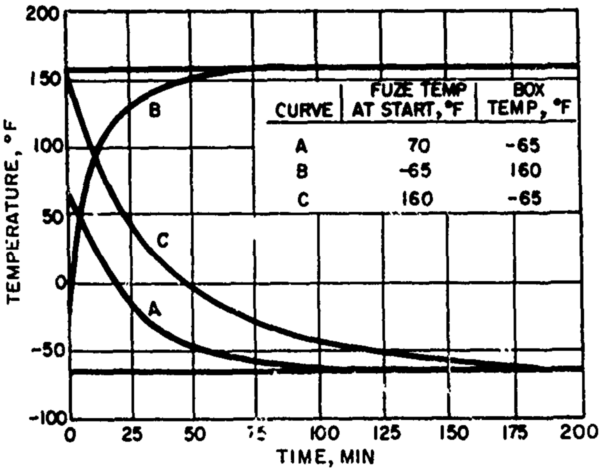


Figure 13-1 (U). Average Heating and Cooling Characteristics of Fuzes Subjected to the Temperature and Humidity Test Cycle

fluorescent dye, they are examined under ultraviolet light for evidence of moisture.

In addition to these more common tests, the fuze may be subjected to other environmental conditions that it may encounter. For example, it may be exposed to the cold and low absolute humidity of the polar regions, or to low pressure, cold air streams at high altitude. Procedures are available to test effects of sand and dust, fungus, solar radiation, rain, and low pressure. These may be found in "Environmental Testing, General Specification for, Specification MIL-E-5272B, 5 June 1957, Custodian: USAF.

13-2.3 (U) ACCELERATED STORAGE TESTS

One area of test consideration which is particularly applicable to fuze design is that of storage. The design must provide for proper operation after a storage period of up to 20 years. MIL-STDS provide for accelerated storage tests. The designer, however, must recognize that the MIL-STDS may not, as individual tests, provide a cycling of conditions that will be revelant to the storage envisioned for the fuze undergoing design. Beside the normal environmental problems of extremes of temperature, pressure, and humidity, the designer may have to consider exposure to magnetic fields, inductive fields, etc.

In some instances the designer will plan on overcoming storage problems by packaging. But unless he has conclusive evidence that his proposed packaging will be fully effective, he will have to arrange for testing of the packaged unit.

13-2.4 (U) S & A SYSTEM TESTS (Ref. 2)

Development of safety and arming devices requires an extensive series of tests in the laboratory and field. There are two types of laboratests: (1) design tests that are performed on a

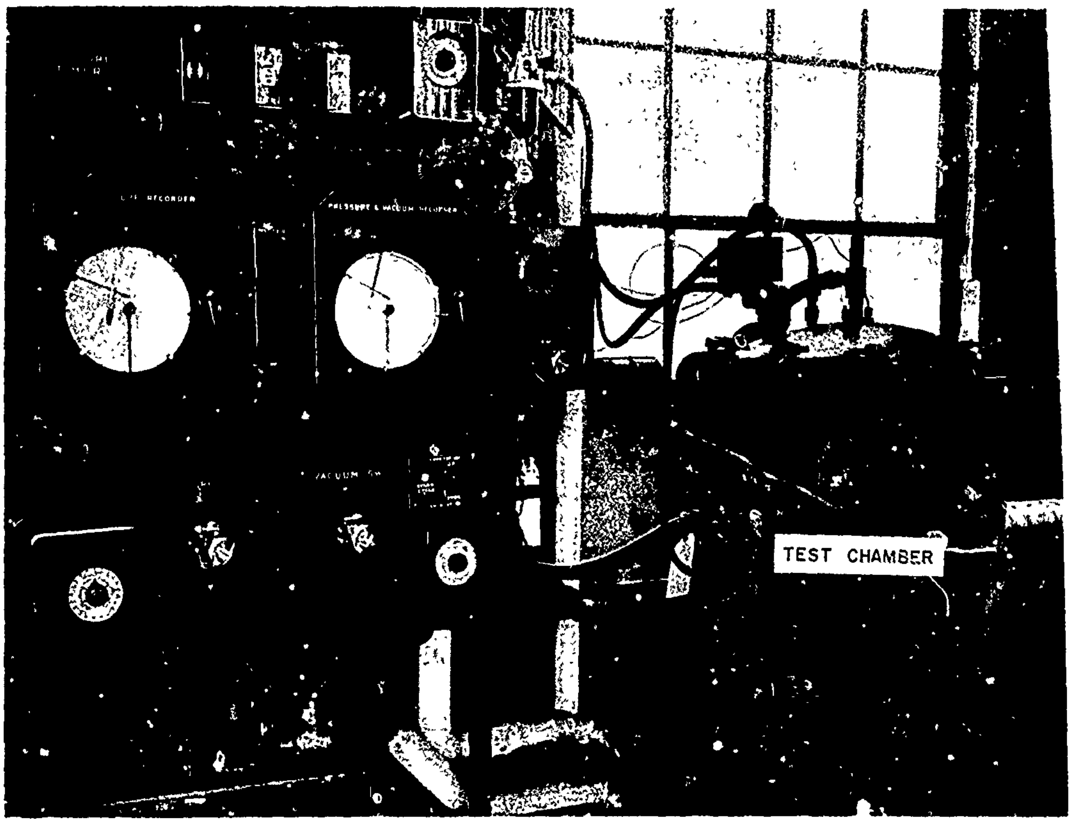


Figure 13-2 (U). Typical Installation in a Vacuum-steam-pressure Chamber

TABLE 13-1 (U). MIL-STD Tests for Fuzes

	DEVELOPMENT SERIES
MIL-STD-300	Jolt Test for Use in Development of Fuzes
MIL-STD-301	Jumble Test for Use in Development of Fuzes
MIL-STD-302	Forty- (40) Foot Drop Test for Use in Development of Fuzes
MIL-STD-303	Transportation-Vibration Test for Use in Development of Fuzes
MIL-STD-304	Temperature and Humidity Test for Use in Development of Fuzes
MIL-STD-305	Vacuum-Steam-Pressure Test for Use in Development of Fuzes
MIL-STD-306	Salt Spray (Fog) Test for Use in Development of Fuzes
MIL-STD-307	Jettison (Aircraft Safe Drop) Test for Use in the Development of Fuzes
MIL-STD-308	Jettison (Simulated Aircraft Safe Firing from Ground Launcher) Test for Use in the Development of Rocket Type Fuzes
MIL-STD-309	Jettison (Simulated Aircraft Safe Drop from Ground Launcher) Test for Use in the Development of Fuzes
MIL-STD-310	Jettison Aircraft Safe Firing Test for Use in the Development of Rocket-Type Fuzes
MIL-STD-311	Accidental Release (Low Altitude Hard Surface) Safety Test for Use in the Development of Fuzes
MIL-STD-312	Muzzle Impact Safety Test for Use in Development of Projectile Fuzes
MIL-STD-313	Impact Safe Distance Test for Use in Development of Fuzes
MIL-STD-314	Waterproofness Test for Use in Development of Fuzes
MIL-STD-315	Static Detonator Safety Test for Use in Development of Fuzes
	PRODUCTION SERIES
MIL-STD-350	Jolt Test for Use in Production of Fuzes
MIL-STD-351	Jumble Test for Use in Production of Fuzes
MIL-STD-352	Forty- (40) Foot Drop Test for Use in Production of Fuzes
MIL-STD-353	Transportation-Vibration Test for Use in Production of Fuzes
MIL-STD-354	Temperature and Humidity Test for Use in Production of Fuzes
MIL-STD-355	Vacuum-Steam-Pressure Test for Use in Production of Fuzes
MIL-STD-356	Salt Spray (Fog) Test for Use in Production of Fuzes
MIL-STD-358	Five-Foot Drop Test for Use in Production Fuzes

limited number of units for preliminary engineering evaluation; and (2) Group I and II evaluation tests. The objective of the design tests is that of the immediate requirement of the designer. The Group I and Group II tests have specific objectives.

13-2.4.1 (U) Group I Tests

Group I tests are performed to determine the safety and reliability of the design. Passing the Group I tests permits the S & A unit to be used in flight tests with high explosive warheads under controlled conditions that will assure safe operation.

13-2.4.2 (U) Group II Tests

Group II tests are more rigorous than Group I tests. They yield results which permit an evaluation of the design for safety and operational reliability under field service conditions.

13-2.4.3 (U) Field Tests

In the field, S & A units are tested in their associated missile with, or without, the associated fuze system. Performance is monitored by telemetering and spot-change action. Safety is usually measured in terms of arming time and/or distance from the launcher.

Frequently it is desirable in the early stages of development to incorporate a telemetering system into the basic design of an S & A device. This avoids having to improvise systems when telemetry data is needed. Such a system can be bypassed in the operational device.

13-3 (U) TEST PROGRAMMING FOR ECONOMY (Ref. 3)

When a series of non-destructive tests is required, even though the order of performance of the tests will have no technical significance the order may be of real significance from an economic standpoint. Often the difference in cost warrants effort to select the least-cost sequence. This is particularly true when repetitive testing is planned. It may be applicable to testing a large number of components when many items are to be tested during development.

The method of selecting the manner in which the least-cost sequence will be determined depends on the testing program, the information available to the designer on test costs and reject rates, and the possibility of integrating the testing program with another. For testing a large number of components or fuzes, there are at least three significant approaches that offer considerable possibilities for cost saving.

13-3.1 (U) Reject Approach

The reject approach requires an analysis of reject rates. The tests are then arranged in such an order that those producing the greatest number of rejects are performed first. This has the advantage of removing the requirement for test of a maximum number of items at the earliest possible stage, thus reducing the overall number of tests required.

13-3.2 (U) Cost-per-Test-Approach

The cost-per-test approach requires an analysis of the cost required to make each test. The tests are then arranged in an order of increasing costs. This has an advantage of eliminating the high-cost test on an item that will be rejected on the basis of a low-cost test performed at a later stage of the testing program.

13-3.3 (U) Least-Cost Sequence Method

If the series of tests is such that the test having the highest reject rate has the lowest cost-per-test, and the other tests have a similar inverse relationship of reject rate and cost, both the reject approach and cost-per-test approach will result in the determination of the same least-cost sequence. In actual situations, however, the relationship between cost and reject rate will often produce contradictory sequences. By consideration of both the reject rate and the cost-per-test, it is possible to determine mathematically the least-cost sequence.

The total cost C_T is the sum of the costs accrued at each test position throughout the program. The cost of operating each test position is the per-item cost of test times the number of items tested. For the first test position this is

$$Cost_1 = NC_1$$

where

N = number of items entering test
C_1 = per-item cost of test number one

The cost of operating the second test position is

$$Cost_2 = N(1 - R_1)C_2$$

where

R_1 = reject rate of test position 1
C_2 = per-item cost of test number two

The factor $(1 - R_1)$ is included in this equation since the number of items entering test position 2 is the number, N, entering test position 1 reduced by the amount of rejects from test position 1. Thus, if 100 items enter test position 1, and $R_1 = 0.02$, then 98 items will enter test position 2, since two of the items were rejected in position 1. In general, then,

$$Cost_n = N(1 - R_1)(1 - R_2)(1 - R_3)\ldots(1 - R_{n-1})C_n$$

is the cost of operating the *nth* test position.

If an accept rate is defined as

$$A_n = 1 - R_n$$

then the expression can be written as

$$Cost_n = N(A_1 \cdot A_2 \cdot A_3 \ldots A_{n-1})C_n$$

The total cost of operating the whole test program is then

$$\begin{aligned} Cost_T &= Cost_1 + Cost_2 + Cost_3 \ldots Cost_n \\ &= NC_1 + NA_1C_2 + NA_1A_2C_3 \\ &\quad + NA_1A_2A_3C_4 + \ldots + N(A_1A_2A_3 \\ &\quad \ldots A_{n-1})C_n \\ &= N\,[C_1 + A_1C_2 + A_1A_2C_3 + A_1A_2A_3C_4 \\ &\quad + \ldots + (A_1A_2A_3 \ldots A_{n-1})C_n] \end{aligned}$$

where

$Cost_T$ = total cost of operating entire test program
N = number of items entering test program
C_n = per-item cost of the nth test
$A_n = (1 - R_n)$ = accept rate of the nth test
R_n = reject rate of the nth test

Define C_T as the per-item cost of the whole program.

Then

$$C_T = \frac{Cost_T}{N}$$

And

$$C_T = C_1 + A_1C_2 + A_1A_2C_3 + A_1A_2A_3C_4 + \ldots + (A_1A_2A_3 \ldots A_{n-1})C_n$$

Implicit in this treatment is the assumption that the values of the individual A's and C's for each test are independent of the position of the test in the sequence.

The least-cost sequence, then, is that sequence of tests *a, b, c, d* . . . which will minimize C_T. Therefore, the procedure is to calculate C_T with test "a" in position number 1, test "b" in position number 2, test "c" in position number 3, etc. This process is to be continued with all combinations of tests and positions. Finally, the procedure is to select that combination yielding the lowest value of C_T. This sequence, by definition, is the least-cost sequence.

For a small number of tests (n), 2 or 3 for example, this procedure is feasible for manual computation since only two or six calculations are necessary. For larger values of n, a computer is advisable, since the total number of possible sequences is factorial n.

13-4 (U) TEST FACILITIES

A major consideration in any fuze testing program is where, when, and how the tests will be conducted. The fuze designer must determine what he wants tested, how he wants it tested, and what measurements or records he needs. After he has determined this, he will have to look into the availability of facilities capable of carrying out his program. Generally, this will require a direct contact with the personnel who operate the facility. Pertinent matters to be decided are: the availability of open time for the tests to be conducted; the adequacy of the measurement and recording system; the security requirements; set up time required; the determination as to who will conduct the test and the indoctrination requirement; and the cost for the use of the facility or performance of the test. Other pertinent matters are: means of shipment and handling of the device to be tested; storage arrangement; and any special requirements for power, mounting, etc.

Special test facilities provide a means of applying simulated conditions or environments in a determinable or measurable degree. Although simulated tests give an indication of field performance, they do not provide a guarantee of reliable operational use. Advantages of simulated tests are: close control and measurement of conditions or forces involved; safety; confinement of test item for ease of inspection after test; and, in many cases, saving of the test item in a usable condition for future use.

Various special test facilities suitable for fuze testing have been developed. The following paragraphs describe typical testing facilities available to fuze designers.

13-4.1 (U) AIR GUN TEST FACILITIES (Ref. 4)

Air guns provide a means of testing components and assemblies at high acceleration forces. Items of various size and weight can be tested. An air gun at Sandia Corp. can test objects up to 24.5 in. in diameter, and is capable of exerting an acceleration of 3000 g on a 50-lb test item. One air gun at the DOFL test area has a 32-ft barrel. Muzzle velocities up to 500 fps are obtained.

Another DOFL air gun was specifically designed for testing fuzes and fuze components. In this air gun, low-pressure air gradually brings a projectile up to high speed along the length of a 96-ft, 4-in. ID tube. The projectile is then stopped suddenly in a catcher box to produce high acceleration forces. A 125-psi, 70-cu ft tank supplies the air needed for projectile acceleration. The air gun catcher box provides space for inserting various materials to stop the projectile. The density and hardness of the material will determine the deceleration forces applied. Provision is also made at the catcher box to measure impact velocity. Both break wire and photoelectric means are used for measurement.

Although this air gun is designed to use low pressure air, the 1-in. wall thickness of the tube provides sufficient strength for great latitude in working pressures, and makes the use of explosive gases as a propelling medium a realistic possibility.

A smaller air gun is also located at DOFL. This air gun operates in much the same manner as the larger one. It is capable of accelerating a 1-1/8-lb steel projectile to a speed of 400 fps, or a light plastic projectile to a speed of 750 fps. The tube of this gun is 22 ft in length and is 1/2 in. in inside diameter.

13-4.2 (U) CENTRIFUGE TEST FACILITIES (Ref. 4)

There are many centrifuge test facilities in operation throughout the country. DOFL centrifuges, designated H1, H2, L1, and L2, provide a wide range of capability. The H1 provides the greatest acceleration force, while the L1 has the most weight-carrying capacity. The H2 and L2 are of intermediate range.

The H1 was designed to produce ultra-high acceleration forces. It is capable of producing an accelerating force of 60,000 g on a specimen weighing up to 1 lb. Full speed of 11,000 rpm can be attained in 30 sec. The centrifuge arm rotates in a chamber capable of helium filling and evacuation.

The L1 is capable of testing heavy components under the influence of acceleration forces of relatively low magnitudes. The centrifuge can produce an acceleration of 100 g on components weighing up to 100 lb.

The fuze or its parts can be mounted in various positions on the arm of the centrifuges. Many valuable devices have been used with these centrifuges. Some of these devices are: optical systems to observe the part during the test; slip rings to take off signals for data recording; data storage systems that can be carried on the rotating arm; telemetering systems. The acceleration pattern may be programmed for the part. By proper fixture design, the effects of axial accelerations (propulsion), lateral acceleration (steering), and rolling accelerations can be simulated and measured.

13-4.3 (U) ROCKET SLED TEST FACILITIES (Ref. 5)

Rocket sleds provide a means of testing fuze function at very high target-to-fuze closing speed. Hypersonic closure is possible. Monorail sleds have achieved near hypersonic velocity and,

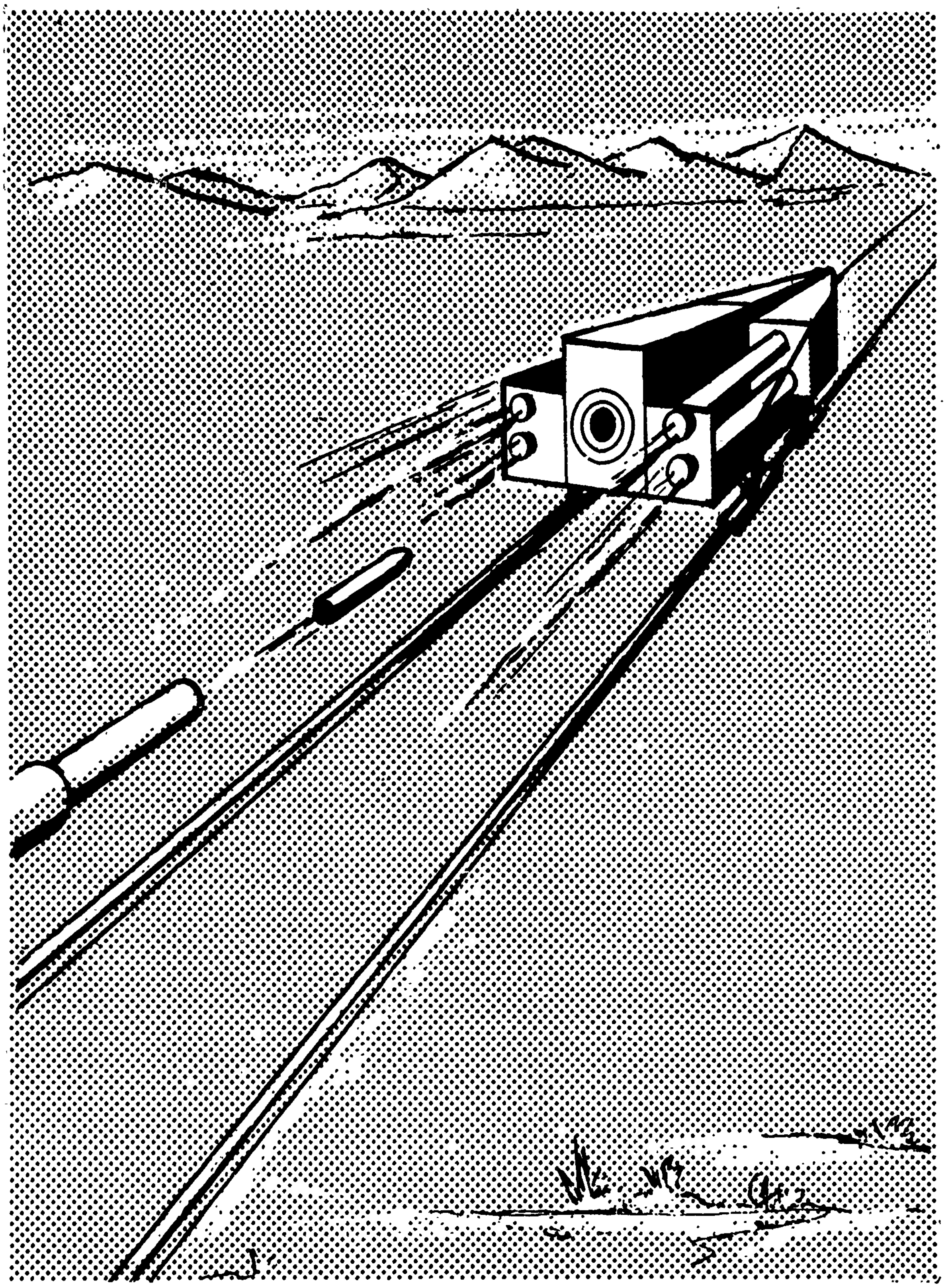


Figure 13-3 (U). Recovery of Projectile in Catcher's Mitt Rocket Sled

by the use of two such sleds fired on opposite rails from opposite ends of a dual rail track, closure speeds well above hypersonic can be achieved.

Speed of rocket sleds can be so closely controlled that live projectiles travelling at practically muzzle velocity can be softly caught in flight without damage to the projectiles (Figure 13-3). This permits a complete examination of a recovered projectile.

Rocket sleds can be used for package testing when large quantities of small components are to be tested for such characteristics as fuze-arming time and operability of components under high acceleration.

Fuze function can be tested and evaluated. Recovery may be made of the test item, or impact may be arranged under controlled conditions, and the results assessed.

Effect of rain may be determined by use of a simulated rainfall over a desired portion of a run.

Items that can be tested by rocket sled vary from minute size to full size airframes or missiles weighing many thousands of pounds.

Track lengths run from a few hundred feet to seven miles. The ballistic track at the Aberdeen Proving Ground is of particular interest to fuze designers. This 2448-ft track is protected by a canopy running the full length of the track. Use of aircraft rockets in multiples or in stages makes it possible to achieve high supersonic speed. Telemetering and other types of electronic instrumentation are available. Photographic coverage includes Fastax and other types of camera equipment.

13-4.4 (U) PARACHUTE RECOVERY TEST FACILITIES (Ref. 6)

Particularly valuable for the determination of the burst height of guided missile fuzes is an aircraft "bomb type" test vehicle. This vehicle, containing the item undergoing test, may be dropped from an aircraft and recovered without damage by means of a parachute deployed subsequent to the functioning of the test item.

Vehicles used for this purpose may be of the modified bomb type or may be specially designed vehicles of supersonic capability.

Burst height measurement may be obtained by using burst charges and cine-theodolites, by telemetering, and by vehicle-borne instrumentation and recording equipment.

If the size of the test item permits, multiple units may be tested on the same drop.

Parachute recovery test facilities are also available for testing rockets, mortar projectiles, and other projectiles. These tests permit studying the performance of arming mechanisms and the effects of firing forces on fuze components. Figure 13-4 shows a mortar projectile equipped for parachute recovery of the fuze. An explosive delay train ejects the parachute and fuze at the desired time. A rubber pad protects the fuze from the ejection shock.

13-4.5 (U) RAIN TEST FACILITIES

Rain and clouds can cause premature fuze function or the reduction of the sensitivity of the fuze to its target signal. Rain test facilities can aid investigations in this area.

Rain is generally simulated in test chambers by water flowing through controllable spray nozzles. A typical rain chamber is equipped with water spray nozzles capable of simulating rainfall at the rate of one to four inches per hour. The rainfall is dispersed uniformly over the test area and is in the form of droplets having a minimum diameter of approximately 1.5 mm. Variable speed blowers and refrigeration equipment drive the rain and cool the test space, respectively. A well lighted interior and large window equipped with a wiper permit visual observation.

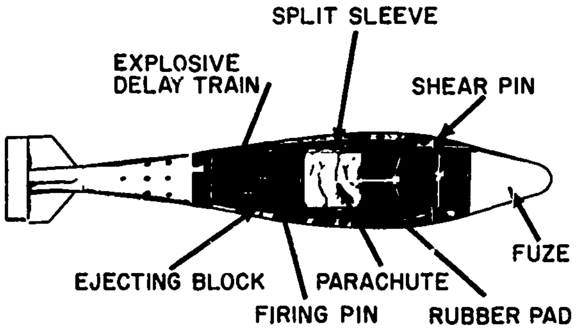


Figure 13-4 (U). Paracovery Mortar Projectile

13-4.6 (U) NUCLEAR ENVIRONMENT TEST FACILITIES

Nuclear radiation environment is simulated by a nuclear reactor and associated chambers in which the fuze or component is irradiated.

Gamma facilities are also used to simulate nuclear radiation environment. In these facilities, the specimen under test is placed in a chamber or cell with a radioactive source of gamma radiation. The radioactive source can be fission products, spent fuel elements from nuclear reactors, or a radioactive element, usually cobalt-60.

13-4.7 (U) EXPLOSIVE ATMOSPHERE TEST FACILITIES

Tests in explosive atmospheres are conducted in explosion chambers by simulating the various parameters involved in an explosive atmosphere. The most important of these parameters are air/fuel ratio, temperature, altitude and humidity.

Explosion chambers range in size from several cubic feet to approximately 50 cu ft. Explosion chambers at Wright Air Development Division can provide an altitude range of 0 to 60,000 ft and temperature control, by use of a heater, to 200°F (93°C).

13-4.8 (U) FLYOVER TEST FACILITIES (Ref. 7)

Flyover test facilities are used to obtain information on the dynamic operation of a guided missile fuzing system. The setup for a flyover test, such as has been conducted at the Aberdeen Proving Ground, is shown in Figure 13-5. The target aircraft is flown over a stationary fuze. Suitable instrumentation provides data in such a way that the intercept may be reconstituted at a later date.

The system used at the Aberdeen Proving Ground provides for the same target-fuze relative trajectory as would be expected in an actual encounter. Target positions relative to the fuze can be determined within ± 1%. Each fuze function is recorded so that the fuze time sequence is accurately determined. Both electronic and photographic records are made for the complete and accurate time history.

13-4.9 (U) ROCKET TARGET RANGE FACILITIES (Ref. 8)

Rocket target ranges are designed primarily for tests of air-to-air rocket and guided-missile

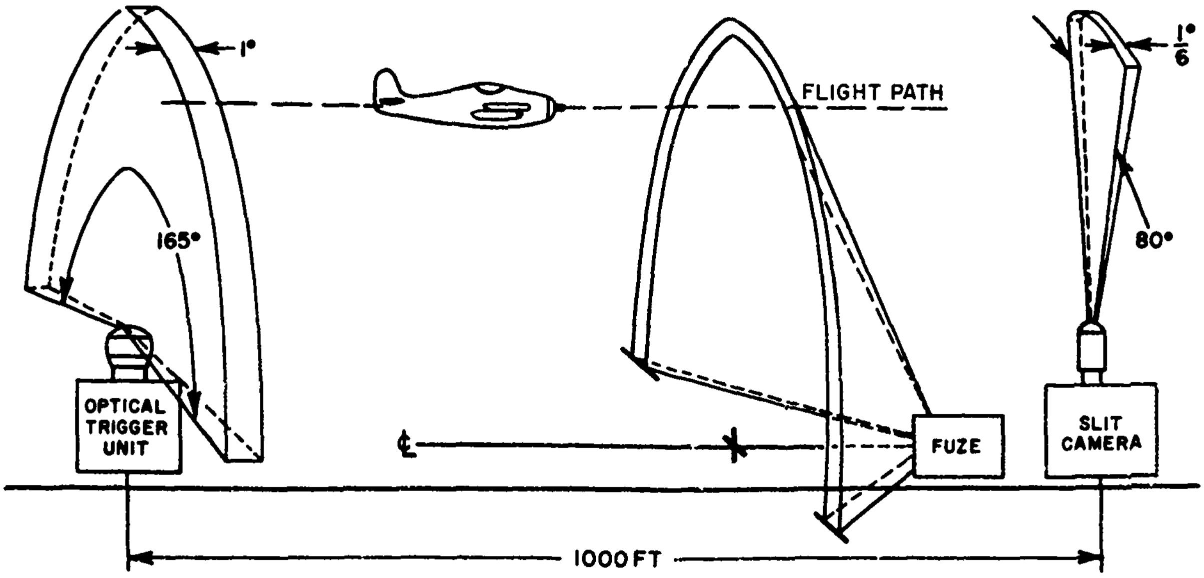


Figure 13-5 (U). Flyover Test Principle

fuze sensitivity and pattern, and for obtaining accurate trajectory information. At the U. S. Naval Ordnance Test Station, at China Lake, California, and at DOFL facilities, it is possible to simulate rocket and missile launchings from aircraft against aircraft targets.

Principal components of the facility at China Lake are two 300-ft wooden towers standing 700 ft apart, and a 150-ft rocket launching tower with a variable-angle track launcher.

The two wooden target towers are capable of supporting a target of up to 20,000 lb 150 ft above the ground. Hemp hawsers are used rather than steel cables to ensure that there are very few reflections unrelated to tactical conditions. Targets available range from a 10-ft diameter metal sphere, to various full size aircraft and mockups of aircraft. Full electronic instrumentation including telemetering is available, as is photographic coverage.

At the DOFL test area, captive rocket tests are possible. In this test, the rocket is suspended and restrained by ropes while it is fired, which permits investigation of fuze noise generated by flame ionization, afterburning, and rocket vibration. The ropes are attached to steel loops, welded to the rocket head, or welded to a ring clamped to the rocket motor. They provide a relatively resilient restraint and permit normal rocket vibration to develop more freely than would be the case if the rocket were held in a rigid firing stand. Voltage fluctuations produced in the fuze circuits by rocket vibration, and the response of accelerometers used to measure the vibrations, are recorded by radio or wire telemetry.

13.4.10 (U) GUN TARGET RANGE FACILITIES

Gun target range test facilities can be used for accurate sensitivity and pattern measurements of gun-fired projectiles equipped with fuzes. They are also valuable in determining the effect of a prematuring round in a salvo upon the other fuzes in the salvo. The effect of various environments, such as heavy smoke between gun and target, can be also investigated. The gun target range at U. S. NOTS, China Lake, California, is particularly well suited for determination of the effect of varying target aspects on fuze performance. On this range, two wooden towers are used for suspending targets between them. They are 640 ft apart, and can suspend a target as large as a 50,000 lb B-29 bomber 250 ft above the ground. Although the normal range is 3200 yd, a mobile gun road extends the firing limits of the range to 10,000 yd. Complete electronic instrumentation and photographic coverage are available.

13-4.11 (U) VERTICAL-FIRING RANGE TEST FACILITIES (Ref. 9)

Vertical recovery firing tests are particularly valuable because they provide a composite of conditions unattainable by any other test procedure. The magnitude and duration of the setback acceleration and of the barrel vibration, etc., are essentially the same as those which proximity fuzes undergo in service use.

For this test the fuzes are mounted in inert-loaded projectiles. The gun elevation is set at nearly vertical so that the spinning projectile will maintain its nose-up position throughout the entire flight and will land base-down, thus protecting the fuze from impact with the earth.

The impact force on hitting the earth may, or may not, be as great or greater than the force produced on firing. The impact force is a function of ground hardness. The soft soils at the test facilities at Stump Neck, Newton Neck, and Edgewood Arsenal generally produce a lower impact force than that produced at firing. The dry sands at the Naval Ordnance Test Station can produce impact forces appreciably above those produced at firing.

Various systems have been devised for the "soft" recovery of projectiles and/or fuzes. Both parachutes and whirling-wire drag devices have been used successfully.

Instrumentation recording provides: (1) the time at which the fuze signal is first received, when it becomes fully modulated, when it ultimately disappears, and any intermittence or change in strength of the signal; (2) the frequency of the fuze radiation and any drift in this frequency; and (3) time of fuze function.

13-4.12 (U) DROP TOWER TEST FACILITIES

There are many drop tower test facilities throughout the United States. Essentially they are towers from which a test item is allowed to free-drop to the ground to test for safety. Most drop test facilities provide for extensive instrumentation and photographic coverage.

(U) REFERENCES

1. *Fuzes, General and Mechanical,* Ordnance Engineering Design Handbook, Ammunition Series, ORDP 20-210, Ordnance Corps Pamphlet, January 1960.

2. H. B. Smith, Jr., *A Summary of Mechanical and Electronic Safety and Arming Devices,* Report No. TR 311, Diamond Ordnance Fuze Laboratories, 1 November 1956. (CONFIDENTIAL)

3. H. Walter Price, *Reliability Engineering Notes,* DOFL, Reliability Branch, "Least-Cost Testing Sequence" as published in The Journal of Industrial Engineering, July-August 1959.

4. *Air Gun Building,* U. S. Department of Commerce, National Bureau of Standards.

5. *Rocket Sled Design Handbooks,* ISTRACON Report No. 60-1, ARDC, January 1960.

6. *USAF Parachute Handbook,* WADC Report No. TR 55-265, Parachute Branch, Equipment Laboratory, WADD, December 1956.

7. G. Cohen and A. Diem *Flyover Instrumentation,* Report No. TR-175, Diamond Ordnance Fuze Laboratories, May 1955. (SECRET)

8. *Randsburg Wash Test Activities,* Report No. NOTS 1433, U. S. Naval Ordnance Test station, China Lake, California, March 1956.

9. C. R. Larkin and V. A. Brown, *A Survey of VT Fuze Field Tests,* NAVORD Report No. 3715 U. S. Naval Ordnance Laboratory, White Oak, Maryland, May 1954. (SECRET)

U. S. GOVERNMENT PRINTING OFFICE : 1963 C -706 -693

ENGINEERING DESIGN HANDBOOK SERIES

The Engineering Design Handbook Series is intended to provide a compilation of principles and fundamental data to supplement experience in assisting engineers in the evolution of new designs which will meet tactical and technical needs while also embodying satisfactory producibility and maintainability.

Listed below are the Handbooks which have been published or submitted for publication. Handbooks with publication dates prior to 1 August 1962 were published as 20-series Ordnance Corps pamphlets. AMC Circular 310-38, 19 July 1963, redesignated those publications as 706-series AMC pamphlets (i.e., ORDP 20-138 was redesignated AMCP 706-138). All new, reprinted, or revised handbooks are being published as 706-series AMC pamphlets.

General and Miscellaneous Subjects

Number	Title
106	Elements of Armament Engineering, Part One, Sources of Energy
107	Elements of Armament Engineering, Part Two, Ballistics
108	Elements of Armament Engineering, Part Three, Weapon Systems and Components
110	Experimental Statistics, Section 1, Basic Concepts and Analysis of Measurement Data
111	Experimental Statistics, Section 2, Analysis of Enumerative and Classificatory Data
112	Experimental Statistics, Section 3, Planning and Analysis of Comparative Experiments
113	Experimental Statistics, Section 4, Special Topics
114	Experimental Statistics, Section 5, Tables
134	Maintenance Engineering Guide for Ordnance Design
135	Inventions, Patents, and Related Matters
136	Servomechanisms, Section 1, Theory
137	Servomechanisms, Section 2, Measurement and Signal Converters
138	Servomechanisms, Section 3, Amplification
139	Servomechanisms, Section 4, Power Elements and System Design
170(C)	Armor and Its Application to Vehicles (U)
270	Propellant Actuated Devices
290(C)	Warheads--General (U)
331	Compensating Elements (Fire Control Series)
355	The Automotive Assembly (Automotive Series)

Ammunition and Explosives Series

175	Solid Propellants, Part One
176(C)	Solid Propellants, Part Two (U)
177	Properties of Explosives of Military Interest, Section 1
178(C)	Properties of Explosives of Military Interest, Section 2 (U)
210	Fuzes, General and Mechanical
211(C)	Fuzes, Proximity, Electrical, Part One (U)
212(S)	Fuzes, Proximity, Electrical, Part Two (U)
213(S)	Fuzes, Proximity, Electrical, Part Three (U)
214 (S)	Fuzes, Proximity, Electrical, Part Four (U)
215(C)	Fuzes, Proximity, Electrical, Part Five (U)
244	Section 1, Artillery Ammunition--General, with Table of Contents, Glossary and Index for Series
245(C)	Section 2, Design for Terminal Effects (U)
246	Section 3, Design for Control of Flight Characteristics
247(C)	Section 4, Design for Projection (U)
248	Section 5, Inspection Aspects of Artillery Ammunition Design
249(C)	Section 6, Manufacture of Metallic Components of Artillery Ammunition (U)

Ballistic Missile Series

Number	Title
281(S-RD)	Weapon System Effectiveness (U)
282	Propulsion and Propellants
284(C)	Trajectories (U)
286	Structures

Ballistics Series

140	Trajectories, Differential Effects, and Data for Projectiles
160(S)	Elements of Terminal Ballistics, Part One, Introduction, Kill Mechanisms, and Vulnerability (U)
161(S)	Elements of Terminal Ballistics, Part Two, Collection and Analysis of Data Concerning Targets (U)
162(S-RD)	Elements of Terminal Ballistics, Part Three, Application to Missile and Space Targets (U)

Carriages and Mounts Series

341	Cradles
342	Recoil Systems
343	Top Carriages
344	Bottom Carriages
345	Equilibrators
346	Elevating Mechanisms
347	Traversing Mechanisms

Materials Handbooks

301	Aluminum and Aluminum Alloys
302	Copper and Copper Alloys
303	Magnesium and Magnesium Alloys
305	Titanium and Titanium Alloys
306	Adhesives
307	Gasket Materials (Nonmetallic)
308	Glass
309	Plastics
310	Rubber and Rubber-Like Materials
311	Corrosion and Corrosion Protection of Metals

Surface-to-Air Missile Series

291	Part One, System Integration
292	Part Two, Weapon Control
293	Part Three, Computers
294(S)	Part Four, Missile Armament (U)
295(S)	Part Five, Countermeasures (U)
296	Part Six, Structures and Power Sources
297(S)	Part Seven, Sample Problem (U)

END 5-68