ELECTRICAL INSTALLATION TECHNOLOGY AND PRACTICE

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LOW-PRICED EDITION

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Editor's Introduction

The new awareness of the imperative need to make the very most of our technical potential makes a foreword to this General Technical Series almost unnecessary, for it aims directly at encouraging young men – and women – to extend their interest, widen their knowledge, and improve their technical skills.

The City and Guilds of London Institute makes special provision for the technician to acquire a qualification appropriate to his Craft. The wide range of examinations now held under its auspices is ample evidence not merely of the need to cater for the technician but also of the growing desire of the Craftsman to improve his knowledge of his Craft. Many of the books in the present series will be related to syllabuses of the City and Guilds of London Institute, but this will not limit their use merely to preparation for the examinations held by that body. The aim is to encourage students to study those technical subjects which are closely related to their daily work and, by so doing, to obtain a better understanding of basic principles. Any study of this kind cannot fail to stimulate interest in the subject and should produce a technician with a clearer understanding of what he is doing and how it should best be done.

But although the series is intended to appeal, in the first instance, to students who are interested in the certificates offered by the City and Guilds of London Institute, that must be regarded as only the immediate aim. Those students who, as a result of their initial endeavours, find that they are capable of going further should aim at obtaining either a National Certificate in an appropriate field of engineering or, alternatively, a General Certificate of Education at a level appropriate to their potential attainment.

All the books in the series will be written by experienced and well qualified teachers who are thoroughly conversant with the problems encountered by young men and women in studying the subjects with which their books deal.

J. R. M.

Preface

This book is primarily intended for students preparing to take the City and Guilds of London Institute's Course B Examination in Electrical Installation Work, but it will also be useful to those following Electrical Installation Craft Practice, Electrical Fitters and Electrical Technicians Courses. Each chapter of the book is followed by a selection of workshop exercises designed to give practical insight into the topics covered in the chapter. It is most important for students to be able to prepare accurate and concise reports of the practical work which they carry out, as their practical knowledge is assessed by means of written examinations. To this end students are advised to maintain a 'log-book' in which they record every practical exercise which they perform. Constructional details of the demonstration boards needed for certain exercises are included in Chapter 14, as this type of apparatus is not generally available from commercial sources.

The authors are indebted to Mr. A. F. J. Riley for his invaluable assistance in preparing the illustrations for this book, and to their colleague, Mr. W. A. Baker, A.M.A.S.E.E., for his help in reading the proofs.

The questions from recent examination papers given in Chapter 15 have been reproduced by kind permission of the following examining bodies:

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Union of Lancashire and Cheshire Institutes (U.L.C.I.).
Welsh Joint Education Committee (W.J.E.C.).

Acknowledgement is also made to the Institution of Electrical Engineers for permission to quote from the Regulations for the 'Electrical Equipment of Buildings' and to Messrs. Enfield Standard Power Cables Limited for permission to reproduce drawings of their catenary supported wiring system.

Finally the authors wish to thank the staff of The English Universities Press Limited for their encouragement and many helpful suggestions in the preparation of this book.

J. O. Paddock
R. A. W. Galvin

Dover, 1964

Introduction

What the Electrical Installation Provides

1. The electricity supply authorities are responsible for providing a supply of electricity to suitable terminals on a consumer's premises; the electrical installation in the premises provides the means of conveying the electricity to the equipment where it is to be used. Like fire, electricity is a good servant but a bad master and so, before anyone can install a safe and efficient electrical system, it is essential for him to be familiar with the nature of electricity and the dangers inherent in its use.

2. The two main hazards involved, wherever electricity is employed, are the danger of shock and the danger of fire. Both types of risk may be reduced to negligible proportions by using suitable materials and correct methods of installation. Because of the vital need to maintain high standards in carrying out installation work various lists of regulations, requirements and codes of practice are published, some are enforceable by law while others, although being merely recommendations are, nevertheless, generally accepted as setting the standards to which every installation should be constructed.

3. The more important sets of regulations concerning electrical installation work are listed below; no electrician can claim to be fully competent if he is not familiar with the contents of these publications.

Electricity Supply Regulations

4. These regulations, issued by the Minister of Fuel and Power, give the supply undertakings mandatory powers to insist on certain minimum standards of installation work before they need provide a supply to a consumer. In general if an installation meets the requirements of the I.E.E. Wiring Regulations then it will also satisfy the requirements of the Electricity Supply Regulations.

Electricity (Factories Act) Special Regulations, 1908 and 1944

5. All electrical equipment installed in factories and workshops must comply with the requirements of the Factories Act. Many of the requirements are similar to those of the I.E.E. wiring regulations but there are certain additional requirements, particularly for conditions where special hazards exist. Anyone engaged in factory installation work should obtain and study the 'Memorandum by the

Senior Electrical Inspector of Factories on the Electricity Regulations' (H.M.S.O.) which gives a lucid explanation of this rather complex subject.

Regulations for the Electrical Equipment of Buildings

6. These regulations, issued by the Institution of Electrical Engineers, provide a comprehensive list of the requirements which experience has shown to be necessary for a safe and efficient installation. Although they are not in themselves mandatory an installation which complies with these regulations will normally also meet the requirements of the various other mandatory regulations. Since the I.E.E. Regulations are so comprehensive they can be said to constitute the 'electricians' bible' and every one concerned with electrical contracting should be thoroughly familiar with them. In view of the importance of these regulations, summaries of their requirements have been included whenever appropriate in this book, nevertheless students are strongly recommended to obtain their own copies of the regulations so that they can compare the full text of any particular regulation with the summaries given.

Contents

CHAPTER 1

Electric Cables and Joints

CONDUCTORS AND INSULATORS

1.1 Conductors

Any material which will allow the free passage of an electric current is known as a conductor. Conducting materials vary in the degree to which they can conduct electricity; good conductors are required for connecting leads in electric circuits so that they may convey the current with a minimum loss of voltage. Materials giving a somewhat higher resistance are sometimes needed for controlling currents, e.g. for the construction of rheostats, motor starters, etc.; similar materials are also required for the construction of heating elements where heat is produced by forcing a current through a relatively high resistance. Some typical materials used as conductors in electric circuits are listed below.

(a) *Silver*. This is the best-known conductor but it is too expensive for general use. The contacts of some switches are plated with silver to lower the contact resistance.

(b) *Copper*. This material is widely used for the manufacture of electric wires, cables and bus bars. Its conductivity is second only to silver and it is reasonably priced. As an electrical conductor it has the following advantages:

(i) Low resistance.
(ii) It is ductile and therefore easily formed into wires.
(iii) It is readily 'tinned' for soldering.

(c) *Aluminium*. This is coming into increasing use as an electrical conductor since, although it is not such a good conductor as copper, its light weight is an advantage in many situations.

(d) *Brass*. Brass is often used for the manufacture of terminals and various parts of electric fittings. Its advantages are:

(i) It is harder than copper.
(ii) It is easily machined.

(iii) It can be readily cast.
(iv) Like copper it is also easily 'tinned' for soldering.

(e) *Nichrome*. This type of resistance wire is used for many purposes of which the following are typical:

(i) Manufacture of fixed and variable resistors.
(ii) Heating elements.

(f) *Eureka* (Constantan or Advance). This is a better quality resistance wire, as its resistance value does not change appreciably with temperature. It is widely used in the construction of electrical instruments.

(g) *Manganin*. Manganin is a high quality resistance wire, which is even more constant in resistance value than Eureka. It is expensive and requires special heat treatment to develop its good properties and it is used mainly for precision resistors as used in laboratories.

(h) *Tungsten*. This material has a very high melting point and so is used in the manufacture of electric lamp filaments.

(i) *Carbon*. Although this is not a metal it is a fairly good conductor and its physical properties make it very suitable for use as 'brushes' in electrical machines. Carbon can be mixed with clay and other materials for the manufacture of carbon composition resistors; these can have very high values of resistance despite their small size and are widely used in radio and electronic equipment.

1.2 Insulators

Any material which does not allow the free passage of an electric current is known as an insulator. Insulators are used to confine electric currents to the conductors in which they are intended to flow, and to prevent leakage of electricity to adjacent conducting materials which are not intended to become 'alive'. Insulation is also needed to prevent 'short circuits' between various parts of an installation. Some typical insulating materials are listed below.

(a) *Rubber*. Widely used for covering wires and cables.
Some advantages:

(i) Good insulator.
(ii) Impervious to water.
(iii) Flexible.

Some disadvantages:

(i) Adversely affected by sunlight.
(ii) Not fireproof.

(b) *Poly-Vinyl-Chloride* (*P.V.C.*). A modern thermoplastic material which is often used as an alternative to rubber. Some advantages and disadvantages as compared with rubber are:

Advantages:

(i) Resists chemical action and direct sunlight.
(ii) Not so inflammable.

Disadvantages:

(i) Does not afford the same degree of mechanical protection.
(ii) More expensive.

(c) *Paper*. Impregnated paper is often used to insulate the conductors in underground cables; it must be protected from the ingress of moisture.

(d) *Mineral Insulation*. Magnesium oxide is used as insulation in certain types of cables. It is extremely heat resistant but must be protected against ingress of moisture.

(e) *Mica*. Used for insulation where high temperatures are involved, e.g. heating elements. It is also widely used for insulation between the copper segments of the commutators of electrical machines. Its main disadvantage is its brittleness.

(f) *Asbestos*. Used to insulate connecting leads where high temperatures are involved.

(g) *Paxolin*. Used for insulating panels and barriers in switchgear, and other places where a rigid insulating sheet is required.

(h) *Bakelite*. Used for moulded insulating parts of electrical fittings.

CABLES

1.3 The Three Main Parts of a Cable

Cables used in electrical circuits are of many types but all consist of the following main parts:

(*a*) Conductor.
(*b*) Insulation.
(*c*) Mechanical protection.

(a) *Conductors* are usually made of copper, the conducting cores being formed from strands of copper wire so that the cable is more flexible than if solid cores were used. If vulcanized rubber insulation is to be used the copper conductors are tinned to prevent corrosion of the copper by the sulphur which is present in vulcanized rubber.

The size of cables used in domestic installations is normally stated as: No. of strands/Diameter of each strand; e.g. a cable commonly used for lighting circuits is 3/·029; this means that the cable consists of three strands each of ·029 in. diameter. For larger types of cable, the effective cross-sectional area of the core is often quoted as the size.

(b) *Insulation* of cables used in domestic installations is normally of vulcanized rubber (V.R.I.) or poly-vinyl-chloride (P.V.C.). Where mineral insulation (magnesia) is employed the cable has a copper outer sheath, this type of cable being known as Mineral Insulated Copper-sheathed Cable (M.I.C.S.).

(c) *Mechanical Protection* is provided to prevent damage to the cable during installation and throughout its subsequent service. The following types of cables, which are in common use, are discussed in more detail in Chapter 3.

(i) Vulcanized India-rubber Insulated (V.R.I.).
(ii) Flexible Cables and Cords.
(iii) Tough Rubber-sheathed (T.R.S.).
(iv) Lead-sheathed V.R.I.
(v) Poly-Vinyl-Chloride Insulated and Sheathed (P.V.C.).
(vi) Mineral Insulated (M.I.C.S.).
(vii) Paper Insulated Lead-covered (P.I.L.C.).

1.4. Stripping of Cables

The mechanical protection and insulation must be removed from the end of the cable to leave a suitable length of exposed conductor whenever it is required to connect the cable to a terminal or to make a joint.

The following points should be carefully observed when stripping cables:

(*a*) The strands forming the core must not be cut or nicked in any way as this could result in a loss of conducting area, reduction of current carrying capacity and increased resistance. A 'nicked' conductor is always a potential source of trouble as it may easily break completely at a later date.

(*b*) If any cable has an outer protection of cloth, tape or braiding, such as V.R.I. which usually has both, this must be removed to expose at least half an inch of insulation. This is because cloth is not a good insulator and can be a cause of a low insulation resistance.

(*c*) The insulation of the core must not be damaged when removing the outer covering. This particularly applies to multi-core cables such as P.V.C. and T.R.S.

JOINTS

1.5 Mechanical Joints

(a) *Conduit and trunking systems.* When an installation is wired using single core cables enclosed by steel conduit or trunking, it is good practice to avoid joints by using the 'loop-in' system of wiring as explained in Chapter 2. If, however, a joint cannot be avoided this must be made by means of either a mechanical connector or by a soldered joint. The joint must be made in a readily accessible joint box. Fig. 1.1 shows such a joint made using a porcelain shrouded connector, accommodated in a conduit box.

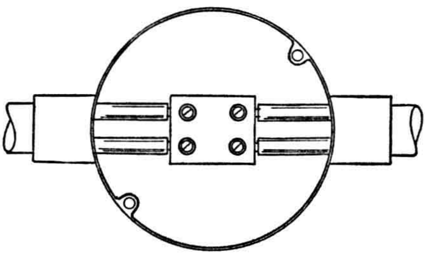

FIG. 1.1 Porcelain Connector used in Conduit Box

(b) *All-insulated systems.* When an installation is wired using T.R.S. or P.V.C. cable, joints are effected using all-insulated joint boxes, which usually possess four fixed terminals as shown in Fig. 1.2.

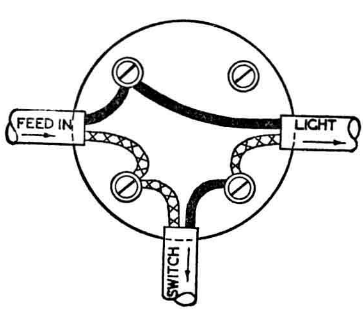

FIG. 1.2 All-insulated Joint Box

(c) *Lead-sheathed wiring systems.* The joint boxes used in connection with lead-sheathed wiring systems are made of metal and are fitted with arrangements for bonding the lead sheaths in order to maintain the earth continuity of the installation. The joints between the conductors are made either using porcelain shrouded connectors or scruits as shown in Fig. 1.3.

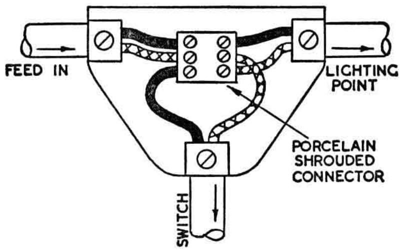

FIG. 1.3 Metal Joint Box

1.6 Soldered Joints

(a) A correctly made soldered joint possesses a low resistance which gives good electrical continuity and has a fair degree of mechanical strength. In a soundly made joint the two parts to be joined are linked by a thin film of solder which has penetrated into the surface of each metal.

Solder is an alloy of tin and lead which melts at a comparatively low temperature. For most electrical joints the grade of solder known as 'Tinmans' solder is most suitable. This is an alloy containing approximately 60% tin and 40% lead with a small amount of antimony added; it melts at about 200° C.

(b) Flux is required to assist the molten solder to flow over the surface of the metal. The flux helps to prevent the surface absorbing oxygen from the air, and also can remove any oxides which may already be present on the surface. Suitable fluxes for electrical work are:

(i) Pure amber resin.
(ii) 'Activated' resin as used in cored solders.
(iii) Solder paste such as Fluxite.

Acid fluxes, such as 'killed spirits', should not be used as they tend to cause corrosion if the part concerned is not thoroughly washed after soldering, and this is seldom practical with electrical work. The amount of flux used should be just sufficient to encourage the solder to flow readily; excessive fluxing only results in a messy job, without improving the soldered joint. If a large quantity of flux is needed before the solder will run and tin properly, this points to the fact that the parts have not been sufficiently cleaned before starting to solder them.

(c) The secret of successful soldering lies in the cleaning of the parts to be soldered. All traces of oil or grease must be removed and the metal thoroughly cleaned using emery paper if necessary. Copper and brass are easy metals to solder, iron is more difficult and, correspondingly, more care must be taken in preparation. Wherever possible the parts should be 'tinned', that is covered with a thin layer of solder before the main soldering job is begun. Aluminium can only be soldered by using special techniques which it is beyond the scope of this book to discuss.

(d) The part to be soldered must be heated until solder will flow freely over its surface. Insufficient heating may result in a layer of solder over the metal which is not actually alloyed into the surface of the metal. This solder can be easily peeled off and it *does not* make a good electrical connection. Joints with this type of defect are called 'dry joints'. On the other hand excessive heating can cause damage to the insulation of a cable due to heat conducted along the wires. Methods of soldering vary mainly in the way in which heat is applied to the job. The principal methods used by electricians are:

(i) Soldering iron; this tool has a copper bit which may be heated by blowlamp, gas, electrically or by any other convenient method.
(ii) Metal pot; an iron pot or ladle containing solder is heated and the molten solder is subsequently poured over the job.
(iii) Blowlamp; the part to be soldered may be directly heated using a blowlamp.

Examples of the use of these methods will be found in exercises Nos. 1.9 and 1.10. While one method only has been described for each job it must be emphasized that any of the jobs could be carried out using any of the methods. The particular method used in any circumstance depends on the nature of the job; for example joints between wires are best made using a soldering iron or metal pot, since direct application of a blowlamp may cause excessive burning of the adjacent insulation; whereas when soldering a lug, direct