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NBS BUILDING SCIENCE SERIES 128

Evaluation of Electrical Connections for Branch Circuit Wiring

U.S. DEPARTMENT OF COMMERCE • NATIONAL BUREAU OF STANDARDS

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NBS BUILDING SCIENCE SERIES 128

Evaluation of Electrical Connections for Branch Circuit Wiring

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PREFACE

This report is one of a group documenting National Bureau of Standards (NBS) research and analysis efforts in developing water conservation test methods, analysis, economics, and strategies for implementation and acceptance. This work is sponsored by the Department of Housing and Urban Development/Office of Policy Development and Research, Division of Energy Building Technology and Standards, under HUD Interagency Agreement H-48-78.

Cover: A receptacle with innovative connections.

ABSTRACT

Performance criteria and test procedures are presented for the evaluation of electrical connections in branch circuit wiring. Investigations and research undertaken to determine needed characteristics of innovative electrical connections are summarized. Design and installation strategies to lessen the chances of electrical connection failures are discussed. Inherent weaknesses are described for design and installation methods of common types of branch circuit wiring connections or terminations, which appear to make them vulnerable to loosening and overheating. There are technology improvements which demonstrate that innovative electrical connections can be developed which may be less costly when installed, and have less chance of becoming hazardous than common conventional connections.

Key words: Contact resistance; electrical codes; fire safety; glowing electrical connections; house wiring; innovative electrical connections; performance testing.

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SI CONVERSION UNITS

In view of the present accepted practice in this country for building technology, common U.S. units of measurement have been used throughout this document. In recognition of the position of the United States as a signatory to the General Conference on Weights and Measures, which gave official status to the metric SI system of units in 1960, assistance is given to the reader interested in making use of the coherent system of SI units by giving conversion factors applicable to U.S. units used in this document.

Length

1 in = 0.0254* meter (m)

Mass

1 pound - mass (lbm) = 0.4535924 kg

Temperature

$t_{\circ C} = 5/9\ (t_{\circ F} - 32)$*

Torque

1 lbf•in = 0.113 newton meter (N·m)

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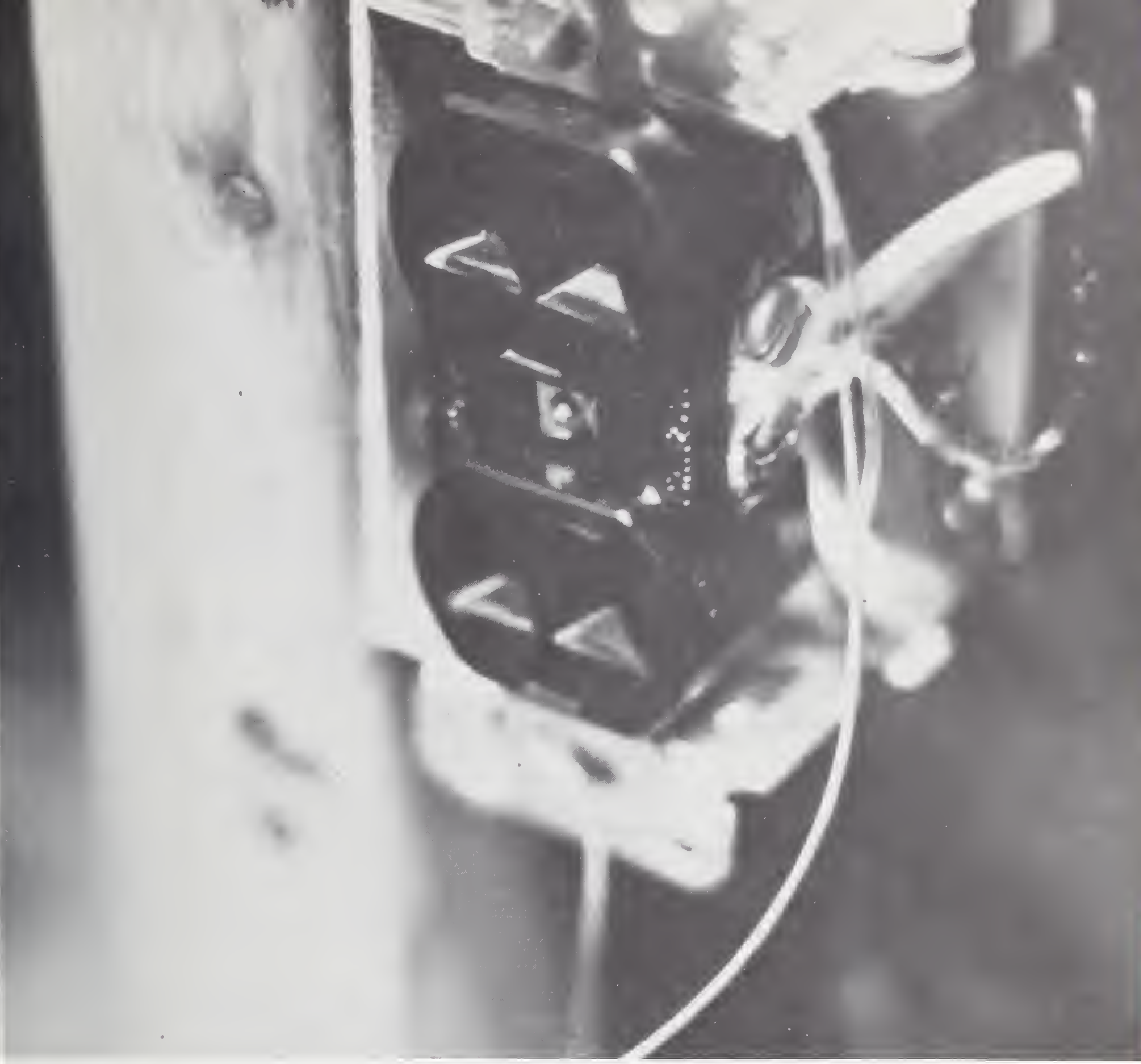
* Exactly

Facing page: Overheating electrical connection.



1. INTRODUCTION

In 1969 the U.S. Department of Housing and Urban Development (HUD) initiated Operation BREAKTHROUGH, having as one of its objectives the encouragement and demonstration of innovations in housing. In the Operation BREAKTHROUGH program several innovations involving electrical connections were proposed. These innovations would eliminate the use of the traditional "box" and in some cases would make connections inaccessible after completion of building construction. Taking cognizance of the potential fire hazard and the lack of durability and other technical information, approvals for innovations involving electrical systems were given sparingly, with conservation stipulations. However, the possibilities of significant economic benefits were recognized. Subsequently, the U.S. Department of Housing and Urban Development sponsored a long-term research project on innovative electrical connections used in residential branch circuit wiring at the National Bureau of Standards. Other publications resulting from this project are as follows:

1. "Analysis of Current Technology on Electrical Connections in Residential Branch Circuit Wiring," NBS BSS 63 [1].

   This report discusses the present methods of evaluating electrical connections, the technical parameters involved, and innovative electrical connection developments.

2. "A Preliminary Approach to Performance Requirements and Criteria for Electrical Connections in Residential Branch Circuit Wiring." NBSIR 75-672 [2].

   This preliminary report presents the framework for a proposed method to evaluate connections on a performance basis and supplements information contained in BSS 63.

3. Exploratory Study of Glowing Electrical Connections NBS BSS 103 [3].

   This report describes and characterizes with quantifiable electrical and thermal measures the extent to which loose electrical connections in residential-type branch circuits have overheated in the laboratory.

4. Experimental Determinations of the Temperatures and Power Losses at the Electrical Connection of Some Duplex Receptacles NBSIR 77-1380 [4].

   The data presented in this report compare the reliability of power loss determinations with the reliability of temperature measurements as a means for determining the quality and adequacy of electrical connections on wiring devices used in branch circuit wiring. This investigation also illustrates the overheating problems associated with copper-wire electrical connections.

The present report, "Evaluation of Electrical Connections for Branch Circuit Wiring" is the fifth and final report of the project. It presents technical information on the evaluation of electrical connections.

Guide Criteria for the evaluation of innovative electrical connections are based on the performance concept. The presentation of, and the rationale for, the performance requirements, criteria, and test methods used to evaluate innovative electrical connections in this project follow, in general, the format developed in the Operation BREAKTHROUGH program [5, 6, 7, 8].

The primary purpose of this report is to present technical information on a substantially comprehensive method for the evaluation of innovative electrical connections in branch circuit wiring by the performance concept. The information may be helpful in the design of electrical connection devices. Information concerning the work of NBS and others specifically relating to aluminum wiring is contained in References [9] and [10].

1.1 SCOPE

This report contains performance requirements and criteria, test methods, and other information intended for the evaluation of permanent electrical connections used in residential branch circuit wiring. Note: The National Electrical Code (NEC) [11] defines "branch circuit" as follows:

> "The circuit conductors between the final overcurrent device protecting the circuit and the outlet(s)."

Branch circuits in housing are generally limited to nominal 120 or 240 volts and rated ampacity (current carrying capacity in amperes) of 15 to 50 amperes. Generally, the wires involved are not larger than #6 AWG or smaller than #14 AWG for copper conductors or #12 AWG for aluminum or copper-clad aluminum conductors. Tap conductors for lighting fixtures (fixture wiring) and other equipment connected to branch circuits may be as small as #18 AWG for copper conductors.

Both wire-to-wire and wire-to-terminal connections such as wire-to-terminal on receptacles, switches, lighting fixtures and permanent appliances, which are made in the field or in a manufactured building or mobile home factory are covered. Connections which are normally made as part of the manufacturing process of electrical equipment are not covered by this report.

Also, devices intended for the connection of portable lamps and portable appliances to electrical systems are not covered. U.L. Standard 498 [12] on attachment plugs and receptacles presents requirements and tests to evaluate this type of connection.

1.2 STANDARDS INVOLVING BRANCH CIRCUIT WIRING ELECTRICAL CONNECTIONS

Many of the principle standards for components of and equipment connected to residential branch circuit wiring are Underwriters Laboratories (UL) Standards and are listed below. Some of these Standards, as indicated below have also been approved as American National Standards.

a.	UL 4		Armored Cable	[13]
b.	UL 20	(ANSI C33.40)	General-Use Snap Switches	[14]
c.	UL 57		Electrical Lighting Fixtures	[15]
d.	UL 67	(ANSI C33.38)	Panel Boards	[16]

e.	UL 486	(ANSI C33.5)	Wire Connectors and Soldering Lugs	[17]
f.	UL 489		Molded-Case Circuit Breaker Enclosures	[18]
g.	UL 496	(ANSI C33.17)	Edison Base Lampholders	[19]
h.	UL 498	(ANSI C33.17)	Attachment Plugs and Receptacles	[12]
i.	UL 512	(ANSI C33.10)	Fuse Holders	[20]
j.	UL 514	(ANSI C33.84)	Outlet Boxes and Fittings	[21]
k.	UL 719		Nonmetallic Sheathed Cable	[22]
l.	UL 869		Service Equipment	[23]
m.	UL 943		Ground-Fault Circuit Interrupters	[24]

Reference [1] contains information on the role of Underwriters Laboratories in testing manufactured electrical products for safety. Also contained in Reference [1] is a brief summary of electrical connection specifications, standards and test promulgated and published by other organizations.

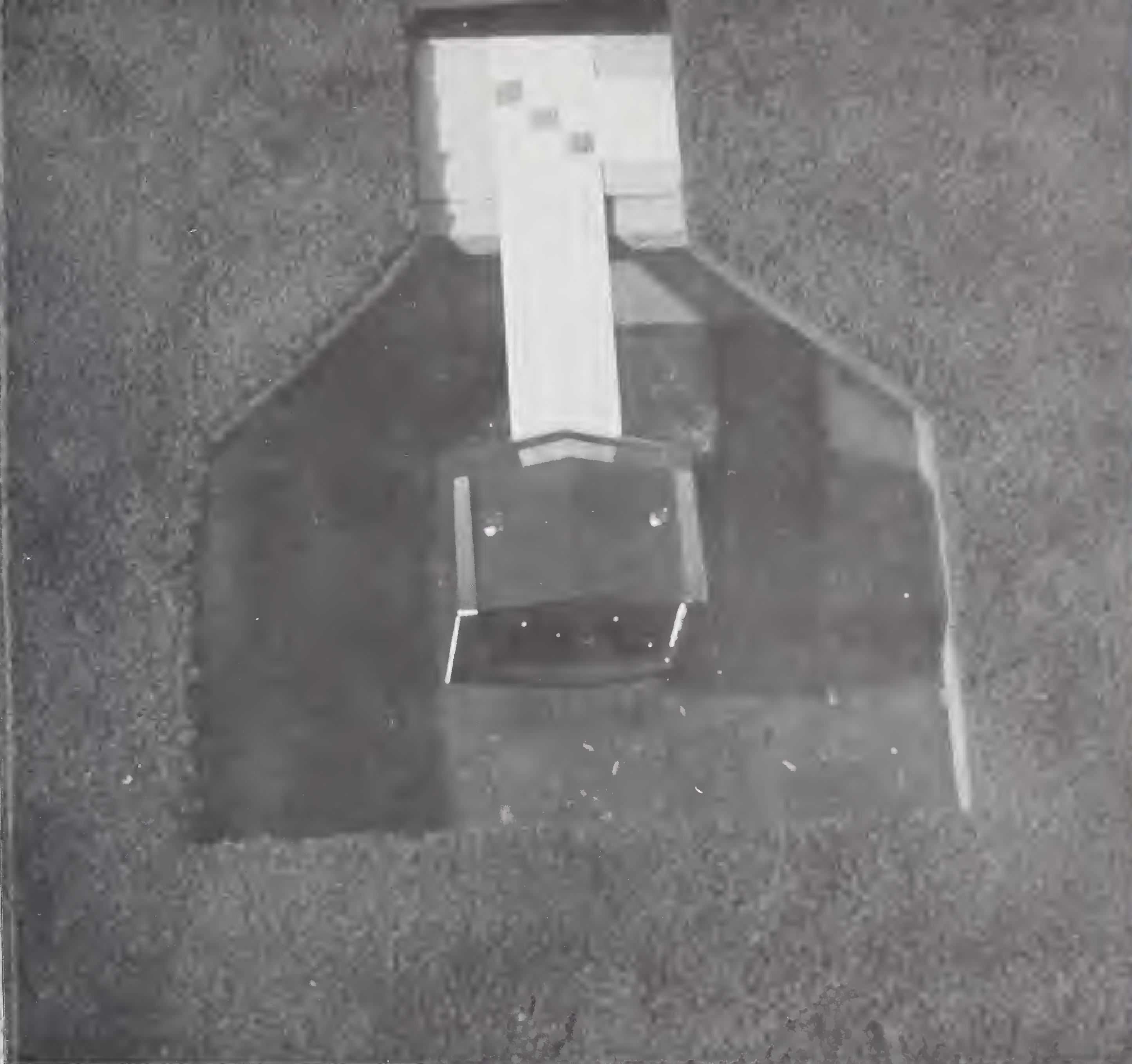
1.3 EVALUATION OF ELECTRICAL INSTALLATIONS IN USA

In the United States, the evaluation and approval of electrical connections as well as other electrical construction in buildings primarily involves three entities which are:

a. Local authorities
b. The National Electrical Code (NEC) [11]
c. Private and public testing laboratories, such as Underwriters' Laboratories, Inc. (UL).

Reference [1] discusses this evaluation system in detail.

Facing page: Flat conductor cable --under carpet installation.



2. NATIONAL ELECTRICAL CODE CONSTRAINTS

Reference [1] contains background information concerning electrical connection problems in buildings. Included is information concerning fire hazard considerations, electric shock considerations and industrialized housing needs.

It should be noted that the National Fire Protection Association (NFPA) statistics indicate that approximately 165,000 electrically-caused building fires occur annually in the United States, and of these about 60,000 are attributable to motors and other power-consuming appliances

[25]. NFPA statistics list wiring and general equipment as the cause of more than 100,000 building fires annually. Fire hazards are the principal technical concern in the evaluation of electrical connections in branch circuit wiring.

Branch circuit wiring requirements in building codes and standards have been criticized as antiquated. Briefly, the traditional approach in the installation of branch circuit electrical connections and wiring devices is the on-site (1) fastening of outlet, junction or other boxes to building components, (2) fastening of electrical cable to boxes, and (3) making the electrical connections in boxes.

The principal constraints to the development of innovative electrical connections during Operation BREAKTHROUGH were largely removed with the issuance of the 1975 (and 1978) edition of the National Electrical Code [11]. These are the restrictions involving (1) requirements for a "box", and (2) accessibility requirements. Reference [1] discussed these constraints in detail. Removal of these constraints by the NEC is discussed below.

Innovative connection devices which take advantage of both the elimination of the outlet box requirement and the elimination of accessibility requirements in the National Electrical Code have been listed by Underwriters' Laboratories, [11, 26].

2.1 THE BOX

The traditional system of installing electrical boxes at switch, outlet and junction points, the mechanical fastening of electrical cable to boxes and the making of electrical connections in boxes has been required by the National Electrical Code until the 1975 edition [26]. It has been the requirements for "boxes" and not specifically the requirements for electrical connections which appear to have constrained innovation in branch circuit wiring systems. While the previous editions of the NEC permitted some exceptions to "box" requirements, particularly in mobile homes, the exception of the 1975 NEC general requirement for boxes appears to have largely removed this constraint. This exception (exception no. 5 to NEC Section 300-15(b)) states:

> "A device approved for the purpose having brackets that securely fasten the device in walls or ceilings of frame construction for use with nonmetallic-sheathed cable, shall be permitted without a separate box."

It should be noted that innovations involving electrical connections up to the present time all appear to be designed for use with nonmetallic-sheathed cable. The change in Rule 336-3 in the 1975 NEC, whereby the use of nonmetallic-sheathed cable is restricted to buildings three floors or less above grade, impacts on the use of innovative electrical connections.

2.2 ACCESSIBILITY REQUIREMENTS

Section 545.13 of the NEC entitled, "Component Interconnections," has removed the NEC requirement that electrical connections be accessible in manufactured buildings. Interconnection devices are needed to connect the wiring between different components of manufactured buildings. Section 545.13 (which applies only to manufactured buildings) states, "Fittings and connectors which are intended to be concealed at the time of on-site assembly, when tested and approved to applicable standards shall be permitted for on-site interconnection of modules or other building components. Such fittings and connectors shall be equal to the wiring method employed in insulation, temperature rise, fault current withstand and shall be capable of enduring the vibration and minor relative motions occurring in the components of manufactured buildings."

Facing page: Articulated probe test.

3. FRAMEWORK FOR THE EVALUATION OF ELECTRICAL CONNECTIONS

Figure 1 outlines a framework for evaluation of electrical connections on a performance basis. The key to this evaluation is "Performance of 'Essential Physical Elements' when subjected to 'applicable service conditions' shall be in accordance with necessary 'Attributes'." Attributes 4.1, 4.2, etc., are discussed in numbered sections of this report. For instance, Section 4.1A describes the electrical function attribute for the continuous current path element.

ESSENTIAL PHYSICAL ELEMENTS / ATTRIBUTES	A CONTINUOUS CURRENT PATH	B DIELECTRIC	C ENCLOSURE
4.1 Electrical Function			
4.2 Fire Safety			
4.3 Energy Conservation			
4.4 Electrical Safety			
4.5 Burn Safety			
4.6 Mechanical Safety			
4.7 Toxicity Safety			
4.8 Building Environment Non-Interference			
4.9 Accessibility Replaceability			

o Performance of ESSENTIAL PHYSICAL ELEMENTS

When subjected to APPLICABLE SERVICE CONDITIONS (Tests)
Shall be in accordance with Necessary ATTRIBUTES

Figure 1. Performance evaluation of electrical connections.

3.1 ESSENTIAL PHYSICAL ELEMENTS

For the purposes of this report, an electrical connection has three essential physical elements, which are listed and defined below in performance terms:

a. Continuous Current Path Element

The continuous current path element is the electric connection point or area and electric wire and other metal parts in the vicinity of the connection point through which current is intended to flow and which are directly involved in the proper functioning and safety of the connection. In conventional construction this would typically include metal portions of "wire-nuts" in wire-to-wire connections and wire-binding screw terminals on wire-to-terminal connections. Also included is the grounding connection point or area and the wire and metal parts in the vicinity directly involved in the proper functioning and safety of the grounding connection.

In this report "continuous current path elements" are generally referred to in the plural because an electric connection usually involves more than one joint or connection.

b. Dielectric Element

The dielectric element is the insulating material in the vicinity of the electrical connection point or area. Insulating material must completely surround the continuous current path elements. The dielectric element may be air. This is the case where receptacles or switches are rigidly held in place within an outlet box and electrical connections are made by means of wire-binding screws.

c. Enclosure Element

The enclosure element is a rigid metallic or non-metallic material which surrounds an electrical connection (and its dielectric element) and prevents persons, other building components or other objects from coming in contact with the continuous current path elements. In conventional construction, a switch, outlet or junction box is the enclosure. In some cases, the enclosure element may be the same hardware as the dielectric element.

3.2 APPLICABLE SERVICE CONDITIONS

Service conditions of electric connections involving durability (time) environment (ambient temperature, humidity, chemical content of the surrounding atmosphere, etc.) mechanical stresses, (vibration, wire bending, wire disturbance, etc.) and electrical loads (currents, voltage, cyclic patterns, etc.) cannot be accurately predicted. Accelerated tests involving severe, but not unrealistic loads or other physical punishments are used to indicate whether there will be reasonable compliance with applicable attributes. Such tests must be based on engineering judgment and should consider the seriousness of a particular type of failure and the economics involved. The tests presented in this report are intended to provide for safe and reasonable performance of electrical connections while attempting to avoid requirements which may lead to "overdesign".

The criteria and tests presented presume properly installed devices. However, intangible evaluations such as possible improper installation of a device should be considered by those evaluating electrical connections. Will improper installation be likely? If there is improper installation, what would be the consequence? For example, would there be much chance of connecting an ungrounded conductor to a grounding terminal? Judgment, in addition to applicable tests, must be used in determining whether a particular innovative connection device is satisfactory.

3.3 ATTRIBUTES OF ELECTRICAL CONNECTIONS

Test methods to evaluate the performance of electrical connections address the first five attributes shown in Figure 1. These are as follows:

4.1 Electrical Function
4.2 Fire Safety
4.3 Energy Conservation
4.4 Electrical Safety
4.5 Burn Safety

The other four attributes shown in Figure 1, namely, 4.6 Mechanical Safety; 4.7 Toxicity Safety; 4.8 Building Environment Non-Interference; and 4.9 Accessibility and Replaceability will, in general, need to be evaluated by inspection and analysis of the factors involved. Tests or other means of evaluation should be developed to ascertain reasonable compliance with applicable performance requirements, if there are uncertainties as to reasonable compliance.

3.4 THE PERFORMANCE CONCEPT

Standards which are rigid in specifying a product's materials and design can inhibit economic growth and innovation [27]. If standards are to stimulate innovation of new devices, they should stress levels of performance acceptable for the use intended.

The basic premise of the performance concept is that products and devices can be described and their performance measured. In the performance concept, it is assumed that these measurements can be made without considering physical characteristics, design, or method of manufacture. While total achievement of this concept does not appear possible for electrical connections at this time, the thrust of the work of this project has been toward this goal.

The performance standard approach was developed by a hierarchical arrangement of a set of elements as follows:

a. Requirement
b. Criterion

c. Evaluation
d. Commentary

The requirement is a qualitative statement giving the user need for the particular electrical device or connection.

The criterion is usually, but not always, a quantitative statement giving a level of performance deemed necessary to fulfill the user's need.

The evaluation states the performance tests or other information upon which an evaluative judgment of compliance with a criterion will be based.

The commentary presents the rationale for the selection of data in requirements, criterion, and evaluation, and provides clarifying background for the reader.

Facing page: *Vibration test of receptacle with innovative connections.*

4. PERFORMANCE REQUIREMENTS AND PERFORMANCE CRITERIA

In Section 3 a framework for the performance evaluation of electrical connections was presented. This section details the performance concepts used.

For each attribute, the performance requirement(s) of each essential physical element is listed first. This is followed by the listing of performance criteria, which describe the performance requirements in quantifiable or more specific terms. This is followed by a listing of applicable procedures to evaluate the criteria and commentaries which explain and discuss the rationale of each requirement and criterion.

Section 5 contains tests to evaluate electrical function, energy conservation and safety (fire, electrical and burn) attributes. In many cases the same tests are used to evaluate two or more of these attributes.

4.1 ELECTRICAL FUNCTION ATTRIBUTE

4.1-A Continuous Current Path Elements

Requirement 4.1-A
For all currents up through rated current, the continuous current path elements shall provide for adequate flow of current through the connection point or area without excessive voltage drop.

Criterion 4.1-A
Successful performance with Baseline Test I, Connection Resistance, both before and after nondestructive punishment tests (See Section 5.1 and 5.5 through 5.13).

Evaluation 4.1-A
See Baseline Test I - Connection Resistance (Section 5.1 and 5.13).

Commentary 4.1-A
Rule 210-6(d), Voltage Drop, of the National Electrical Code [11] states that the size of conductors for branch circuits should be such that the voltage drop will not exceed 3 percent to the farthest outlet for power, heating or lighting purposes or combination thereof. This rule also states that the maximum total voltage drop for feeders and branch circuits should not exceed 5 percent overall. These requirements are intended to assure adequate voltage for the operation of electrical equipment.

The voltage drop between any two points on a continuous current path element is proportional to the resistance and the current between the two points. This assumes that impedance is essentially all resistance, which previous research has demonstrated to be the case with electric wire, connection devices and other branch circuit wiring devices [3, 4].

The permitted resistance, and therefore, the voltage drop of electrical connections (see Section 5.1) becomes only a small fraction of that permitted in branch circuits. Limits on resistance are governed more by Fire Safety (see Section 4.2) and Energy Conservation Attributes than by Electrical Function Attribute.

4.1-B Dielectric Element

Requirement 4.1-B

The dielectric element shall provide adequate electrical insulation between individual continuous current path elements and between the continuous current path elements and other building components.

Criterion 4.1-B

Successful performance with Baseline Test II - Insulation Resistance and Baseline Test III - Dielectric Withstand both before and after non-destructive punishment tests (see Sections 5.2, 5.3 and 5.5 through 5.12).

Evaluation 4.1-B

See Baseline Test II - Insulation Resistance and Baseline Test III - Dielectric Withstand. (Sections 5.2, 5.3 and 5.13).

Commentary 4.1-B

Application of the above performance criteria are in line with present practice. Tests in the NBS laboratory indicate that the above criteria are readily met by available innovative and conventional connection devices.

4.1-C Enclosure Elements

Requirement 4.1-C

The enclosure element shall be so constructed in combination with the dielectric element and continuous current path elements as to provide adequate protection against contact with the continuous current path elements by persons and other building components.

Criterion 4.1-C

Successful performance on Baseline Test IV - Contactability of Live Parts both before and after nondestructive punishment tests (see Sections 5.4 through 5.13).

Evaluation 4.1-C

See Baseline Test IV - Contactability of Live Parts (Sections 5.4 and 5.13).

Commentary 4.1-C

The specified tests, which are of an assembled connection device, should demonstrate adequate protection against inadvertent contact with the continuous current path elements.

4.2 FIRE SAFETY ATTRIBUTE

4.2-A Continuous Current Path Element

Requirement 4.2-A
For all currents up to 2.67 times the rated current, the continuous current path elements shall be capable of operating without overheating.

Criterion 4.2-A
Successful performance with Baseline Test I - Connection Resistance (see Section 5.1) both before and after non-destructive punishment tests (see Section 5.5 through 5.12). Also successful performance on the Heat Cycling and Vibration Test, when required (see Section 5.18).

Evaluation 4.2-A
See Baseline Test I - Connection Resistance (see Section 5.1) and Heat Cycling and Vibration Test (see Section 5.18).

Commentary 4.2-A
High resistance connections may result in high temperatures and consequent overheating of electrical and proximate building components. Glowing electrical connections, which have much higher resistance than "good" connections have been obtained in the laboratory [3].

Research information [3, 4] indicates resistance is a more accurate and sensitive measure of the quality of an electrical connection than temperature. Also, determination of resistance is less dependent on environmental factors and precise test procedures than measurement of temperature. In addition, resistance values can be obtained quicker and in most cases, easier than temperatures.

While temperature is the primary measure of overheating, existing evaluative procedures generally disqualify electrical devices at temperatures considerably below those which could result in fire (such as more than a rise of 30°C above ambient temperature). Application of the 1.5 milliohm resistance requirement should prevent high temperatures from being generated by connections [4]. Application of the requirement (see Baseline Test I - Section 5.1) limiting a connector or connection assembly to an increase of 0.5 milliohm as the result of the various punishment tests is to give an indication that its performance will be satisfactory when it is subjected to expected reasonably severe conditions in service.

Circuits meeting requirements of the National Electrical Code [11] will not be subjected to currents in excess of double their rated current for more than two minutes unless overcurrent protection devices (fuses, circuit breakers) are faulty

[18, 20]. Compliance with the connection resistance requirements listed above will not normally result in temperatures at which ignition may occur if currents are not over 2-2/3 times the rated current. Currents, greater than 2.67 times the rated current, which could result from short-circuits if overcurrent protection devices do not operate properly, may present a potential fire ignition problem at any place in the wiring or other parts of the circuit. The Heat Cycling and Vibration Test will give additional assurance that non-accessible connections will not overheat.

4.2-B Dielectric Element

Requirement 4.2-B

The dielectric element shall be fire resistive and shall prevent arcing between different current carrying elements and between current carrying elements and ground.

Criterion 4.2-B

Successful Performance on Flammability Test, when required (see Section 5.17). Successful performance on Baseline Test III - Dielectric Withstand both before and after nondestructive punishment tests (see Sections 5.3 and 5.5 through 5.13).

Evaluation 4.2-B

See Flammability Test and Baseline Test III - Dielectric Withstand (Sections 5.3 and 5.13).

Commentary 4.2-B

Materials used in wiring devices should be tested for the flammability characteristics in accordance with Section 5.17. During installation of conventional wiring methods, points where the dielectric strength of the insulating material is weakened are often developed (such as by cutting or nicking wire insulation when removing the outer sheath of a cable). Innovative connection devices and their installation procedures should be so designed that the integrity of insulating materials is not easily destroyed.

4.2-C Enclosures Element

Requirement 4.2-C

The enclosure element shall be fire resistive and shall be so constructed in combination with the dielectric and continuous current path elements and/or located to prevent overheating or ignition of other electrical or building components as a result of heat generated by the flow of current (up to 2-2/3 times the rated current) in the continuous current path elements.

Criterion 4.2-C

Successful performance on Baseline Test IV - Contactability of Live Parts both before and after nondestructive punishment tests (see Sections 5.4 through 5.13). Also successful performance on the Heat Cycling and Vibration Test, where required (see Section 5.18), on the Mounting Strength Test, where required (see Section 5.14), and on the Flammability Test, where required (see Section 5.17).

Evaluation 4.2-C
See Baseline Test IV - Contactability of Live Parts (Sections 5.4 and 5.13), Heat Cycling and Vibration Test (Section 5.18), Mounting Strength Test (Section 5.14) and Flammability Test (Section 5.17).

4.3 ENERGY CONSERVATION ATTRIBUTE

4.3-A continuous Current Path Element

Requirement 4.3-A
For all currents up through rated current the continuous current path elements shall operate without excessive loss of energy.

Criterion 4.3-A
Successful performance on Baseline Test I - Connection Resistance both before and after non-destructive punishment tests (see Sections 5.1 and 5.5 through 5.13).

Evaluation 4.3-A
See Baseline Test I - Connection Resistance (Sections 5.1 and 5.13).

Commentary 4.3-A
In the development of innovative connections, an effort should be made to keep energy losses at a reasonable level. Energy losses in connection devices are substantially directly proportional to resistance. The 1.5 milliohm requirement (see Section 5.1) appears to be a practical and reasonable limit for energy conservation purposes.

4.3-B Dielectric Element

Requirement 4.3-B
For all currents up through rated current the dielectric element shall prevent excessive leakage currents.

Criterion 4.3-B
Successful performance on Baseline Test II - Dielectric Withstand and Baseline Test III - Insulation Resistance both before and after nondestructive punishment tests (see Sections 5.2, 5.3, and 5.5 through 5.13).

Evaluation 4.3-B
See Baseline Tests II - Dielectric Withstand and Baseline Test III - Insulation Resistance (Sections 5.2, 5.3 and 5.13).

Commentary 4.3-B
The prevention of excessive leakage currents through dieletric elements will assist energy conservation efforts.

4.3-C Enclosure Element

Conservation of electrical energy is primarily concerned with the continuous current path and the dielectric elements. While faulty installations may waste electrical energy, the potential hazards and not the energy conservation aspects of faulty installations are of paramount importance.

4.4 ELECTRICAL SAFETY ATTRIBUTE

4.4-A Continuous Current Path Elements

Commentary 4.4-A
Protection against electrical hazards is the function of the dielectric and enclosure elements.

4.4-B Dielectric Element

Requirement 4.4-B
The dielectric element shall provide adequate electrical insulation from the continuous current path elements to a person or building component which may inadvertently contact the surface of the enclosure element.

Criterion 4.4-B
Successful performance on Baseline Test II - Insulation Resistance and Baseline Test III - Dielectric Withstand both before and after nondestructive punishment tests (see Sections 5.2, 5.3 and 5.5 through 5.13).

Evaluation 4.4-B
See Baseline Test II - Insulation Resistance (Sections 5.2 and 5.13) and Baseline Test III - Dielectric Withstand (Sections 5.3 and 5.13).

Commentary 4.4-B
See commentary 4.1-B (Electrical Function Attribute, Dielectric Element).

4.4-C Enclosure Element

Requirement 4.4-C
The enclosure element shall be so constructed in combination with the dielectric element and continuous current path

elements to provide adequate physical protection to persons and other building components from contact with the continuous current path elements.

Criterion 4.4-C

Successful performance on Baseline Test IV - Contactability of Live Parts both before and after nondestructive punishment tests (see Sections 5.4 through 5.13).

Successful performance on Mounting Strength Test, where required (Section 5.14) and on the Test on Knockouts, where required (see Section 5.15).

Any exposed parts of the surface of the enclosure element shall have provisions for grounding and, when installed, shall be grounded in accordance with the National Electrical Code [11].

Evaluation 4.4-C

See Baseline Test IV - Contactability of Live Parts (Sections 5.4 and 5.13), Mounting Strength Test (Section 5.14) and Test on Knockouts (Section 5.15).

Adequate provisions for the connection of grounding conductors.

Commentary 4.4-C

In conventional construction, the enclosure element, which is the "box", performs the function described in Requirement 4.4-C, when properly installed with covers in place. It is the intent that the electrical connection device have no live parts which can be readily contacted and when properly installed, all exposed metal parts be effectively grounded.

4.5 BURN SAFETY ATTRIBUTE

4.5-A Continuous Current Path Elements

Commentary 4.5-A

Performance requirements concerning burn safety apply to the enclosure element only.

4.5-B Dielectric Element

Commentary 4.5-B

Performance requirements concerning burn safety apply to the enclosure element only.

4.5-C Enclosure Element

Requirement 4.5-C

The enclosure element shall not attain temperatures sufficient to burn persons or animals who may inadvertently touch the enclosure element.

Criterion 4.5-C

With 135% of rated current in a circuit no surface of the enclosure element shall exceed temperatures specified in Reference [28].

Evaluation 4.5-C

Judgment of the evaluator. If there is any question concerning hazards, evaluation should be in accordance with Reference [28] (NBS technical note 816). This publication presents a criteria and a test procedure for determining burn hazards.

Commentary 4.5-C

It is anticipated that many innovative connections will not have "free space" which is provided in conventional outlet boxes. It is the intent of this requirement that any heat generated by the connection be dissipated in such a way as to not burn persons or animals who may inadvertently touch the enclosure element. Research indicates that there appears to be little chance of the enclosure element becoming a burn hazard for a device which satisfactorily performs in accordance with Baseline Test I - Connection Resistance (see Section 5.1). Because standards for circuit breakers and fuses [18, 20] in this country generally permit 135% of rated current in a circuit for one hour before operation of these devices is required, the surfaces of the enclosure element should not attain excessive temperatures with a sustained current equal to 135% of rated current.

4.6 MECHANICAL SAFETY ATTTRIBUTE

Requirement 4.6

All parts of the electrical connection component, including the continuous current path elements, the dielectric element and the enclosure element, shall present no unreasonable mechanical hazards.

Criterion 4.6

Under applicable service conditions and during installation and maintenance operations, all parts of the electrical connection component shall be so constructed and installed that no unreasonable mechanical hazards exist, such as cutting, pinching, abrasion, tripping or snagging.

Evaluation 4.6

Physical inspection of electrical connection components and evaluation of methods of installing and maintaining electrical connection components shall be conducted to determine mechanical safety.

Commentary 4.6
It is the intent that electrical connection components be examined for mechanical hazards to people which may exist in installation, maintenance or replacement operations or after installation.

4.7 TOXICITY SAFETY ATTRIBUTE

Requirement 4.7
Electrical connection components shall present no unreasonable potential toxic hazards.

Criterion 4.7
Under applicable service conditions all parts of the electrical connection component, including the continuous current path elements, the dielectric element and the enclosure element, shall be so constructed and installed that no unreasonable potential toxic hazards exist.

Evaluation 4.7
Inspection and evaluation is required of electrical connection components and materials, including paints and finishes, used in their construction. In the event of any suspicion of toxic hazards, the opinion of experts in this field should be sought.

Commentary 4.7
Because electrical connection components operate at higher temperatures than most building components, toxicity hazards should be considered in any evaluation. While conventional materials used in electrical construction are not believed to be toxic under normal service conditions the possibility of toxic hazards should not be overlooked, particularly if new materials are introduced.

Under overheating conditions, research has demonstrated that conventional electrical insulating materials, such as polyvinyl chloride (PVC), may give off toxic gases. Such may be the case for insulating materials proximate to glowing electrical connections when there is less than rated current in the circuit [3]. However, potential hazards with such abnormal conditions are present with virtually all electrical insulating materials.

In the event of a fire in a building the amount of toxic gases from conventional electrical insulations in branch circuits is probably only of minor significance compared to the amount of such gases from furnishings, decorations and other burning building components. However, analysis of new electrical materials under overheating conditions should be made for possible toxic hazards. (See Section 5.17 for common dielectric materials in electrical components).

4.8 BUILDING ENVIRONMENT NON-INTERFERENCE ATTRIBUTE

Requirement 4.8

The electrical connection component shall not produce an environment that will interfere with building functions.

Criterion 4.8

Under applicable service conditions, all parts of electrical connection components, including the continuous current path elements, the dielectric element and the enclosure element, shall be so constructed and installed to prevent excessive air and moisture transmission and so that there is no unreasonable interference or unusual interactions with communication, acoustical or other building functions.

Evaluation 4.8

Physical inspections of electrical connection components should be conducted to evaluate the potential for interference with building functions. Applicable tests, such as radio interference tests, should be conducted if interference with any building function is suspected.

Commentary 4.8

For tight well-made connections with low contact resistance, there appears to be little likelihood of interference with building functions. Therefore, specific tests, such as radio interference tests, to ascertain this criterion are not proposed. However, the evaluation of innovative electrical connections should consider the possibilities of such interference.

4.9 ACCESSIBILITY AND REPLACEABILITY ATTRIBUTE

Requirement 4.9

Inaccessible electrical connections shall retain all necessary attributes for the expected life of the building in which they are installed. Otherwise electrical connection components, or parts of electrical connection components which contain the connection point or area of the continuous current path element shall be reasonably accessible and replaceable with readily available hardware.

Criterion 4.9

Inaccessible connections should, in addition to meeting all required tests for accessible connections, successfully perform on the Heat Cycling and Vibration Test (see Section 5.18).

Other electrical connection components or parts of electrical connection components which contain the connection point or area of the continuous current path elements should be accessible without disturbing any building components other than the electrical connection component and should successfully perform the Field Replacement Test (see Section 5.17).

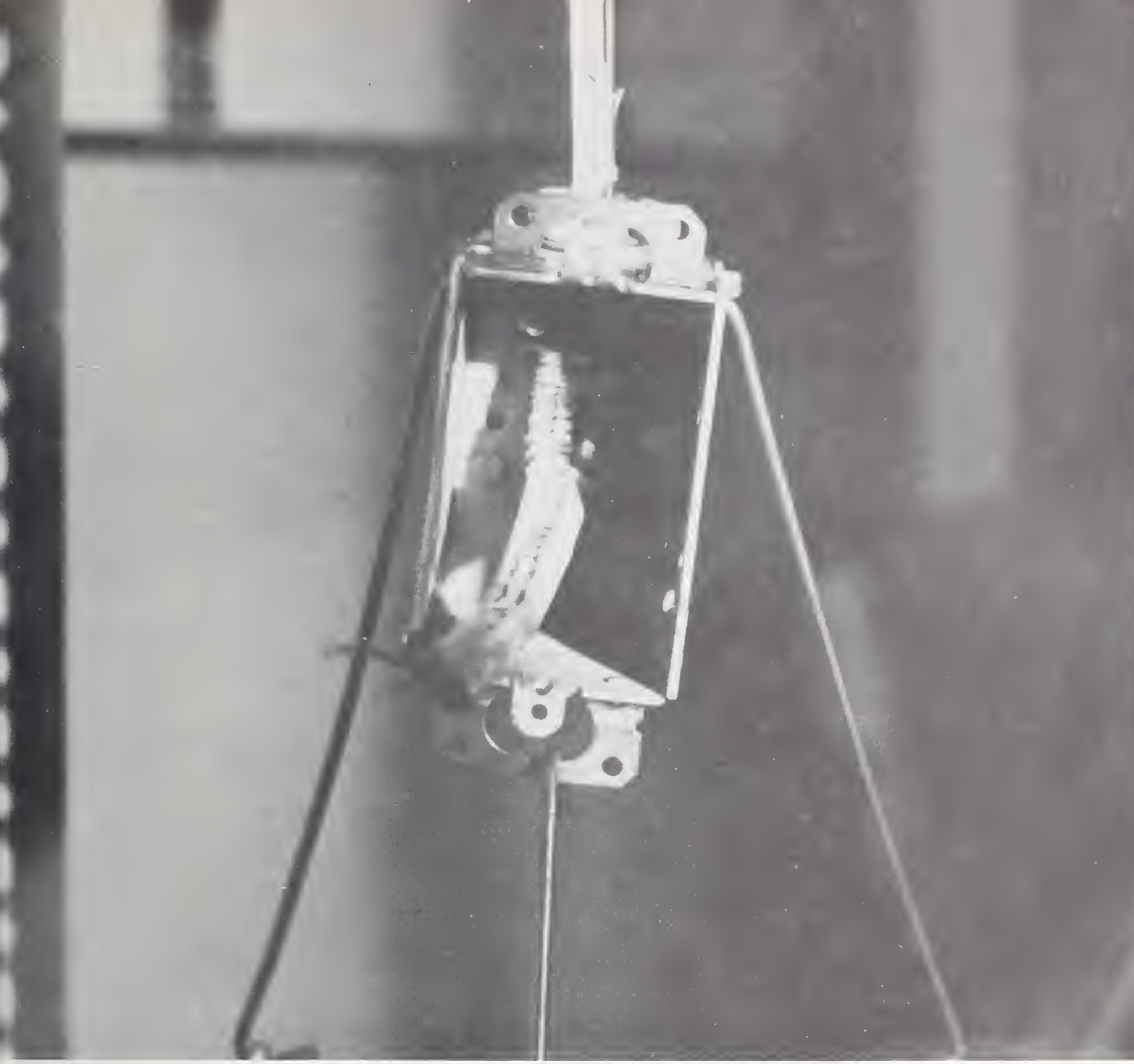
Evaluation 4.9

Inspection to determine accessibility and replaceability aspects of electrical connection components in accordance with Criterion 4.9 should be conducted. For inaccessible electrical connections satisfactory performance on all tests listed in this report including the Heat Cycling with Vibration Test (see Section 5.18) is recommended.

Commentary 4.9

The primary requirement involving electrical connections is for connections to be installed and remain tight. It appears, based on numerous tests, that tight connections will not overheat or cause other problems. Inaccessible electrical connections, of course, are of special concern because of the difficulty of retightening or repairing the connection if it becomes loose or damaged in service. The added test "Heat Cycling with Vibration" is recommended to give added assurance that inaccessible connections will remain tight and undamaged in service. The effects of building vibrations on electrical connections have not been determined. The heat cycling part of this test represents conditions considerably beyond those which could be approached in normal service with connections designed and installed in accordance with the National Electrical Code. However, laboratory tests have shown that available connecting devices are able to perform satisfactorily on this test.

Facing page: Cable pull-out test.



5. PERFORMANCE TESTS

This section of the report contains a series of performance tests on which the evaluation of electrical connections may be based. Figure 2 is a tabular outline of the methodology to be used in making these tests. These tests address most of the performance criteria specified in Section 4 of this report. These performance criteria statements refer to the various tests which are intended to demonstrate satisfactory performance for the attribute being considered. However, as indicated in the commentary for the various tests, subjective judgment on the part of those evaluating innovative connection designs or devices

A. 1.	Make complete or partial installation of connection devices (see sec.5).		
2.	Perform applicable non-destructive punishment tests before completing installation.	---	Applies only to connections subject to mechanical strain during installation (5.5 and 5.6)
3.	Evaluate -- visual inspection.		
4.	Complete partial installation.		
5.	Determine initial performance	---	Continuous Current Path Elements Baseline Test I - Contact Resistance (5.1) Dielectric Element Baseline Test II - Insulation Resistance; and Baseline Test III - Dilectric Withstand (5.2 and 5.3) Enclosure Element Baseline Test IV - Contactability of Live Parts (5.4)
6.	Evaluate measured quantities.		
7.	Perform non-destructive punishment tests.	---	Quantified Mechanical, Electrical, and Environmental Abuses (5.5-5.12)
8.	Evaluate -- visual inspection.		
9.	Determine final performance	---	Repeat Baseline Tests I-IV (5.13)
10.	Evaluate -- measured quantities.		
B. 1.	Make other installations or specimens as required (see sections 5.14-5.18).		
2.	Determine performance quantities	---	Destructive Tests; Tests not dependent on Baseline Measurements to evaluate performance (5.14-5.18)
3.	Evaluation -- visual inspection and measured quantities.		
C.	Subjective Judgments	---	Example: Is installer likely to connect ungrounded conductor to grounding terminal?

Figure 2. Methodology Outline -- Performance evaluation of electrical connections.

is needed to fully evaluate some aspects. It is recommended that these tests be conducted at an ambient temperature of 23°C (± 3°C) and with a relative humidity of 50% (± 10%).

NBS investigations indicate that the principal characteristics of satisfactory electrical connections are:

1. Sufficiently low contact resistance,

2. Sufficiently high insulation resistance of nonmetallic-material in devices where connections or terminals are made,

3. Sufficiently high dielectric strength of insulation material, and

4. Devices which guard persons or building components from contacting the continuous current path elements. Requirements and tests of Section 5.1 through 5.4 address these four principal characteristics; these four tests have been referred to as "Baseline Tests."

Section 5.5 through 5.12 contain "non-destructive punishment tests" which are intended to simulate "abuses" to which electrical connections may be subjected to in service. These laboratory tests address the results of what may commonly be expected to happen to connections in field service. These tests represent conditions somewhat in excess of what may occur in service, but are not so severe as to be unrealistic to the extent that they cause unnecessary requirements or unnecessarily high costs for the building electrical systems.

Section 5.13 contains a repeat of the Baseline Tests after the non-destructive punishment tests have been made. It is the intent that satisfactory performance on the Baseline Tests will demonstrate that connections will satisfactorily perform after expected or reasonable "abuses" in service (other evidence being visual inspections covering loosening or damaging of connections or devices, etc.).

Sections 5.14 through 5.17 contain tests which may be needed to demonstrate characteristics of some connection or device designs for which repeat of all Baseline Tests may not be appropriate. Section 5.17 contains a flammability test which is similar to flammability tests now performed on electrical devices. It is a destructive test; after such tests, a connecting device should not be expected to perform satisfactorily.

Section 5.18, "Heat Cycling and Vibration Test" is intended for use only if a connection is intended for use in non-accessible locations. Beginning in 1975 the National Electrical Code permitted the installation of non-accessible connections under certain conditions (see Section 2.2 of this report), particularly in manufactured buildings.

The Heat Cycling and Vibration Test is costly to perform, because of both the time involved and the equipment which is needed. Heat Cycling, which puts severe "electrical stresses" on a connection is being recommended at this time for non-accessible connections because of the long life required of such connections. Vibration characteristics in buildings and their effect on the loosening of electrical connections is not well understood. Vibration is generally considered to be an added problem for manufactured building components during transportation from factory or assembly site to the field installation site. Because of the long life required of electrical connections in non-accessible locations acceptable performance on a vibration test is recommended for such connections.

Many of the tests reported herein are similar to tests which are commonly performed on electrical equipment. Where satisfactory performance on such tests is readily achieved by electrical equipment, basic changes have not been made to the procedures or requirements of such tests.

The tests described below are generally performed after connections or terminals have been assembled in accordance with the manufacturer's instructions. However, where the connections are stressed during the installation procedure (such as in the case of conventional devices installed in outlet boxes), the Cable or Wire Disturbance test should be performed prior to full assembly (see Sections 5.1 and 5.5).

Also, the Conductor Pull Test, when required, (see Section 5.6) is to be made at the point in the installation procedure which is immediately after the electrical connections have been made. This is before the device is fully assembled, and particularly before strain relief mechanisms have been tightened or secured.

When tightening of wire-binding screws or bolts is up to the installer (in field), such screws or bolts are to be tightened to 6 lbf•in with appropriate torque screwdrivers or other devices for these tests. Such screws or bolts should only be tightened to a higher torque when the design is such that the device will not work or cannot be assembled without such screws being tightened to a higher torque.

It is the intent that all applicable baseline tests and non-destructive punishment tests (Sections 5.1 through 5.13) be performed on the same device specimens. It is suggested that at least ten device specimens be subjected to and perform successfully on these tests.

The performance tests which are described below in Sections 5.1 through 5.18 should be performed in the following order:

(1) Cable or Wire Disturbance Tests and Conductor Pull Tests when it is necessary to perform them prior to completing assembly of the connection or terminal device (see Sections 5.5 and 5.6).

(2) The four baseline tests (see Sections 5.1 through 5.4). These baseline tests may be performed in any order.

(3) The non-destructive punishment tests (See Sections 5.5 through 5.12), which were not made prior to the Baseline Tests (See Sections 5.5 and 5.6). The Temperature Test (Section 5.7) and Fault Current Test (Section 5.8) should be made before the other non-destructive punishment tests. After these tests, the other non-destructive punishment tests may be made in any order.

(4) Repeat of the baseline tests (See Section 5.13). These tests may be made in any order. Evaluators of electrical connections may wish to make these baseline tests after some or all of the non-destructive punishment tests to determine which non-destructive punishment test caused a device to fail. However, the basic requirement is that devices successfully perform on the baseline tests after all applicable non-destructive punishment tests have been made.

The remaining tests (See Sections 5.14 through 5.18) involve different device specimens and, therefore, may be made at any time.

It is the intent that the evaluation of innovative electrical connections be based on the tests specified in this report without the use of reference documents. Some of these tests are similar to tests developed by other organizations, such as Underwriters' Laboratories and the American Society of Testing Materials.

5.1 BASELINE TEST #1 - CONNECTION RESISTANCE

A. Test Objective
To determine that electrical connections are of sufficiently low resistance.

B. Test Procedure
This test is made after connections have been made and devices have been completely assembled unless the cable or wires must be bent (as is the case with devices in conventional boxes) to complete the installation after electrical connections are made. If such bending is required prior to complete assembly, the Cable Disturbance Test (Test Procedure (b) - Section 5.5) is to be performed before this test (Baseline Test I).

It is recommended that low voltage be used in making Connection Resistance Tests for safety (and energy conservation) purposes. It is recommended that currents be obtained by controlling supply voltage rather than by controlling resistances in series with connections.

Instruments capable of measuring voltage drops of less than 100 millivolts in units of tenths of a millivolt and less than 1000 millivolts (one volt) in units of millivolts, should be used. Instruments capable of measuring currents of less than 10 amperes in units of hundredth of an ampere and currents over 10 amperes in units of tenths of an ampere should be used. The accuracy of such instruments should be ± 1%.

Connect the ammeter in the circuit. The ammeter should be connected so that the current it measures is the same as the current which is flowing through all connections or terminals to devices being tested.

Connect the voltmeter leads to the wiring as closely as is practical across the connection or devices to which the wiring is connected. If substantial lengths of wire (connected to the device) are used, the resistance of the wire must be determined so that it can be subtracted from resistances determined from these measurements.

For wire-to-wire connections the voltage drop is measured from wire-to-wire. For a two piece device (such as connections intended to electrically join manufactured building components) each piece of which is connected to a wire and then the two separate pieces of the devices connected together, the measurement should through three connections plus the continuous current path through the two-piece device.

For feed-through devices with wire-to-terminal connections, such as most receptacles, (where the wire is broken for connection to the device) the voltage drop measurement is from wire-to-wire. The measurement is through two connections and the continuous current path within the device. (See Commentary for innovative connections to switch terminals).

For "dead-end" devices with wire-to-terminal connections, the voltage drop measurement is from the wire to an accessible part of the continuous current path within the device. Generally, this should be at a point where current will flow from the terminal connection through all or substantially all of the continuous current path within the device.

For feed-through devices where the wire is not broken for connection to the device, (i.e., the device is attached to an uncut wire), the measurement is to be made in the same manner as described above for "dead-end" devices.

All devices shall be assembled in their intended manner so that current will flow through normally ungrounded ("hot") connections and grounded (neutral) connections.

Rated current (±5%) shall be applied to the circuit and voltage drop measurements shall be made across connections which are normally ungrounded ("hot") and normally grounded (neutral) at the locations described above for the various types of devices. Record the current and voltage drop measurements.

With a different test set-up (different wiring to the device), rated current (±5%) shall be applied across connections or terminals in grounding conductors. This should be done without disconnecting any wires to the device being tested or otherwise disturbing connections to the device being tested.

Rated current (±5%) shall be applied so that it will flow through any grounding connections or terminals. During this test the current may, or may not, at the option of those making the test, also flow through connections within the device which are intended to be in the ungrounded ("hot") part of the circuit. Voltage drop measurements and current measurements are to be made and recorded. Then apply one-half rated current (±5%) and measure voltage drops across the same connections. Record these current and voltage drop measurements.

C. Test Requirements

(1) No resistances determined from tests described above under "Test Procedure" shall exceed 1.5 milliohms (See commentary regarding tests with innovative connections to switches). Resistances are to be determined by the following formula:

$$\text{Resistance} = \frac{\text{Measured voltage drop}}{\text{Measured current}}$$

(2) Resistance for each connection when measured at one-half rated current, shall not differ more than ±3% from the value measured at rated current.

D. Commentary

This is the basic performance test to determine the quality and safety of electrical connections. Investigations by the National Bureau of Standards [3] [4] indicate that the primary characteristic of a good electrical connection is low resistance

Temperature is the usual characteristic on which the performance of electrical devices under load is based. The characteristic "resistance" is a more sensitive measurement than the characteristic temperature [4]. Also resistance measurements can be made almost immediately after energizing a circuit; a considerable time (usually one hour or more) is required for temperatures to reach or to approach equilibrium. In addition, the resistance of a connection is only affected by environmental factors in a minor way, whereas temperatures depend not only on heat generation but also on heat dissipation parameters. Resistance determinations from voltage drop and current measurements are also easier and quicker and therefore less costly than temperature measurements. Reference [4] details research on these measurement techniques.

The 1.5 milliohm requirement for connections, which as explained under "Test Procedure" may contain up to three connections, has been established by tests at NBS as a reasonable requirement for good electrical connections. Electrical connections which become loose may have resistances of 100 milliohms or more with rated load in the circuits and in such cases may glow [3].

A number of tests at NBS indicates that a wire-to-wire measurement across a switch where the current is flowing through the switching element will often result in resistance being higher than 1.5 milliohms. It is not the intent of these criteria and test procedures to evaluate the quality (resistance) of the switching mechanisms. Therefore, it may be necessary to solidly bridge the switching mechanism with a short piece of wire or other conductor in order to determine that the wire-to-terminal connections to the switch are in conformance with these criteria.

The purpose of testing connections with both rated and one-half of rated current (See "(2)" under "Test Requirement") is to determine that substantially the same resistance values are obtained with different currents. Tests at NBS [3] have indicated that if substantially the same resistance cannot be derived from voltage drop measurements at different currents, the connection is loose or otherwise faulty [3].

5.2 BASELINE TEST II - INSULATION RESISTANCE

A. Objective
To determine that the insulation resistance of connecting or wiring devices is adequate.

B. Test Procedure
An instrument capable of measuring insulation resistance to within 3% should be used to determine insulation resistance between:

(a) "Live parts" of opposite polarity.
(b) "Live parts" and dead metal parts which are exposed to contact by persons or which may be grounded in service, and
(c) "Live parts" and any surface which is exposed to contact by persons or which may be in contact with ground in service.

C. Test Requirement
All measurements should indicate an insulation resistance of at least 100 megohms.

D. Commentary
A resistance of 100 megohms is generally required for branch circuit wiring devices. Insulation resistance measurements should not be considered the equivalent of dielectric withstand voltage or electric breakdown tests. Clean, dry insulation may have a high insulation resistance, and yet possess a mechanical fault that would cause failure in a dielectric withstand test.

5.3 BASELINE TEST III - DIELECTRIC WITHSTAND

A. Objective
To determine whether wiring or connecting devices will withstand substantially high voltages.

B. Test Procedure

Using suitable apparatus (See Commentary) gradually apply (approximately 500 volts per second) 1000 volts plus two times rated voltages (±5%) between the following elements, and maintain this voltage for one minute (use 60 Hz power):

(a) Current carrying paths of opposite polarity.

(b) Current carrying paths and grounding conductors.

(c) Current carrying paths and dead metal. The device is to be wrapped in aluminum foil and the foil used as one electrode for this test.

C. Test Requirement

No dielectric materials should break down (See Commentary).

D. Commentary

Requiring withstand voltages of the magnitude stated in the test procedure is usual practice for wiring devices in branch circuit wiring. A number of tests on both conventional and innovative devices indicated no problems in meeting this requirement. Most devices would withstand much higher voltages before breaking down. Whether withstand voltages of the magnitude required are necessary from a performance viewpoint was not evaluated.

The high voltage test set-up should have means to determine if voltage breakdown in the specimen has occurred. The high voltage equipment should be of such design and kilovolt-ampere rating that serious distortion of the sinusodial wave form does not take place. The crest factor (ratio of crest voltage to effective test voltage) should not differ by more than ±5% from that of the sinusoidal wave.

5.4 BASELINE TEST IV - CONTACTABILITY OF LIVE PARTS

A. Objective

To determine that the assembled connecting or wiring device does not present an unreasonable shock hazard.

B. Test Procedure

An articulated probe, as described in Figure 3, should be used at all holes, slots, or other indentations in assembled connecting or wiring devices where there may be access to live parts. An ohmmeter connected to the tip of the articulated probe and to another part of each conducting path, as shown in Figure 3, should be used to determine if contact is made with potentially live parts.

C. Test Requirement

No indication by the ohmmeter that contact can be made with any potentially live parts.

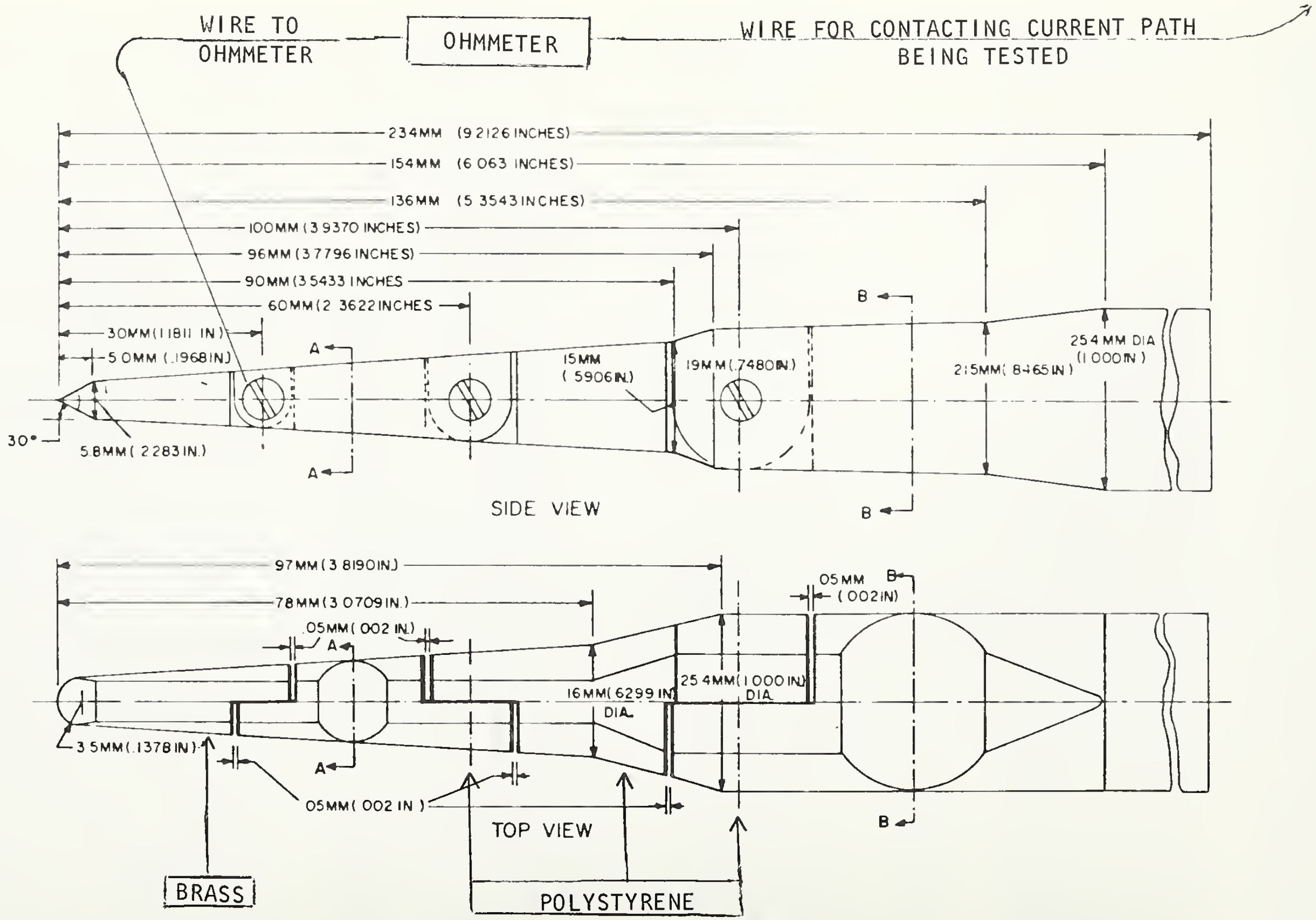


Figure 3. Articulated probe.

Note: The probe as shown is designed for use in determining the contactability of live parts of the electrical equipment. For use with innovative connections, the probe will not ordinarily protrude into the device beyond the first section (brass section). If it does protrude beyond this section, it may be necessary to make alterations so that the wire to the ohmmeter will not interfere with the use of the probe.

D. Commentary

The articulated probe was developed by Underwriters' Laboratories in an effort to produce a working tool for the purpose of gaining experience in judging the accessibility of live parts and parts which may cause physical injury.

The probe design is based on the sampling of adults' and children's fingers in respect to penetration through openings. The probe is constructed of high impact polystyrene.

The probe as modified by NBS eliminates the uncertainty of determining by visual means whether the probe tip was in contact with a potentially live part. The significant change was that the probe tip was made of brass rather than of polystyrene. The brass tip was machined to the same dimensions as the polystyrene tip shown in Figure 3. With the brass tip in contact with a current carrying part, an ohmmeter was used to determine whether or not the probe would contact a live part, such as through the small openings in duplex receptables and other devices. No live parts were contacted on any innovative and conventional specimens tested at NBS using this test method.

In the process of using the probe, it was determined that the probe tips would touch the live blade of an attachment plug when the blade was partially inserted into a duplex receptacle. Ten, two pole, three wire grounding receptacles of different manufacturers were tested to determine if live blades could be contacted. The results were positive in all cases. The articulated probe demonstrates the possibility of receiving a shock in this manner. This is outside of the scope of the evaluations being made under these tests.

5.5 CABLE OR WIRE DISTURBANCE TEST

A. Test Objective

To determine whether cable or wire disturbance (bending the cable or wire in the vicinity of the connection) will loosen or otherwise destroy the integrity of the connection.

B. Test Procedure

(a) For connections or devices which require that the wires or cable be bent after electrical connections are made to complete the assembly, assemble devices or make connections in the manner prescribed by the manufacturer. Any wire-binding screws should be torqued to 6 lbf•in in making this test except under conditions described in Section 5 above.

Grasp the cable two inches from the point at which the cable is firmly held by the device and gradually bend it 90° in four different equally spaced directions or in any of these four directions the cable can be bent. The four directions should be such that they are substantially perpendicular to sides of the device, if this can be determined or is practicable. If individual insulated wires are used in the intended wiring method the bending should be done separately on each individual wire (in the four directions).

(b) This procedure should be used for devices for which bending of wires or cables is required after making electrical connections, but before the installation is complete. For such devices the installation should proceed to the point where the wires are to be bent. At this point bending of wires as described in (a) above should be performed. Any wire-binding screws should be torqued to 6 lbf• in in this test.

C. Test Requirement
No wires should loosen or wire-binding screws turn and no damage to any parts or components should occur; also, there should be subsequent satisfactory performance on baseline tests (Section 5.13).

D. Commentary
This test, while very simple, may be the most severe test for most conventional connections. Even if loosening of connections is not observed, the connection Resistance Test (Baseline Test I) in some cases may reveal loose or poor connections. The test is intended to simulate the "stuffing" of wires into boxes after electrical connections are made. This inherent weakness of conventional connections is discussed in Section 6 of this report. A standardized procedure for this test, which would be applicable to various innovations, is difficult to specify when based on "stuffing" of outlet boxes. Therefore, a rather simple test procedure is specified with the understanding that the evaluation must consider specific designs in determining all aspects as to exactly how this test is to be made.

5.6 CONDUCTOR PULL TEST

A. Objective
To determine whether the connection can withstand a substantial conductor pull force.

B. Test Procedure
This test is necessary only if a separate operation is necessary to obtain strain relief for the electrical connection. When required, the test should be made immediately after electrical connections have been made. This is before the device has been completely assembled and particularly before strain relief mechanisms have been tightened.

A device rated 15A shall be installed with single copper conductor No. 14 AWG (Type TW) connected to each terminal. A device rated 20A shall be installed with a single copper conductor No. 12 AWG (Type TW) connected to each terminal. Each conductor shall be subjected to pull of 20 pounds applied for a period of 1 minute.

C. Test Requirement
The conductors should not be displaced from the connections; also there should be subsequent satisfactory performance on baseline tests (Section 5.13)

D. Commentary
The Cable Pull Test should provide adequate assurance that the connection is capable of withstanding sufficient stress from conductor pull forces when a separate operation is required (such as tightening cable clamps on conventional devices with boxes) to obtain strain relief on the connection.

5.7 HIGH TEMPERATURE TEST

A. Objective
To determine whether an elevated temperature will have an undue effect on the life, performance and safety of devices with electrical connections.

B. Test Procedure
Innovative devices shall be assembled (when possible) to type NM cable of the largest AWG size intended to be used. Devices not intended for connection to type NM cable should be connected to the appropriate cable or other types of wiring with which they are intended to be used. Each device shall be placed in an air-circulating oven for a period of 300 hours at a temperature of 90°C (194°F).

C. Test Requirement
The devices shall subsequently (at room temperature) comply with the Cable Pull Test (Section 5.9) and with requirements of baseline tests (Section 5.13).

D. Commentary
This is primarily a test of the thermoplastic insulating materials used in wiring devices. If materials other than those currently used (See Section 5.17) in wiring devices are part of an innovative device, additional tests of such materials should be considered.

This test is similar to tests made on electrical devices by Underwriters' Laboratories. The purpose is to provide a sufficiently severe accelerated test to determine satisfactory performance for the subjecting of devices to environmental stresses.

A series of limited long-term tests were made at the National Bureau of Standards on duplex receptacles with both innovative and conventional means of connecting wires. The tests briefly described below were "Hot/Cold Cycle", "Heat Aging at High Humidity" and "Normal Environment Tests."

(a) Hot/Cold Cycle Test
This test consisted of cycling 30 specimens (conventional receptacles with both brass and steel wire-binding screws

and receptacles with innovative connections) from an oven to a freezer. Screws were torqued to 16 lbf•in. The cycling started with the specimens being placed in the oven for 90 minutes at 60°C (140°F). In the next step they were placed in the freezer for 90 minutes at -26°C (-15°F).

Cycling at these time intervals allowed three complete cycles per day. For the last, or freezer half of the third cycle each day, the specimens remained in the freezer overnight, a period of 16-1/2 hours. On Friday evenings they remained in the freezer for 64-1/2 hours until they were removed Monday morning to commence cycling again. Voltage drop measurements with currents at 5, 10 and 20 amperes were made periodically. All the readings were made after the specimens were removed from the oven and were allowed to cool to room temperature on the lab bench for two hours. This experiment was terminated after 107 days.

(b) Heat Aging at High Humidity Test
Another set of 30 similar specimens was used for this test. All the specimens were placed in a humidity cabinet at 38°C (100°F) and 95% relative humidity.

Voltage drop measurements were taken periodically with currents at 5, 10 and 20 amperes. These experiments were terminated after 389 days.

(c) Normal Environment Test
A third set of 30 similar specimens was kept in a laboratory where the environment was approximately constant with temperature at 24°C (75°F) and 40% relative humidity. Voltage drop measurements (same as in "a" and "b" above) on these devices were terminated after 394 days.

These experiments showed that the resistances of all specimens were, for all intents and purposes, the same at the beginning, during and at the end of the experiment. Expected environmental stresses do not appear to have nearly as much effect in destroying the integrity of connections as expected mechanical stresses do.

5.8 FAULT CURRENT TEST

A. Objective
To determine whether the connecting or wiring device will withstand a substantially high fault current.

B. Test Procedure
The assembled test specimen is to be installed with cotton around the connection, or if the connection is not exposed, at places most vulnerable to arcing or sparking. The circuit should be so designed that

at least 1000 amperes are applied for at least one-tenth of a second before overcurrent protection operates. Power should be applied between: (a) ungrounded and grounded (neutral) conductors and, (b) between ungrounded and grounding conductors.

C. Test Requirement

(a) The cotton should not scorch or ignite.

(b) There should be no damage to the device.

(c) Subsequent successful performance on baseline tests (Section 5.13).

D. Commentary

The purpose of this test is to give an indication that the device and connections to the device will not present a fire hazard under short-circuit conditions and can be subjected to a short circuit of reasonable time and magnitude without being damaged.

5.9 CABLE PULLOUT TEST

A. Objective

To determine that a wiring device will withstand a substantial pull on the cable without damage.

B. Test Procedure

(a) Install the test specimen in its normal position and by its attachment means. Using a pencil, mark the cable at a clamp or other reference point on the device and cable interface so that cable slippage, if any, can be observed.

(b) Strain relief clamp screws, if any, should be torqued to 10 lbf.in.

(c) Gradually, over a period of one minute, apply a 60-lb pull to the free end of the cable.

(d) Sustain the 60 lb pull for five minutes.

(e) Gradually, over a period of one minute remove the pull.

(f) Inspect the device for physical damage.

C. Test Requirement

(a) No physical damage upon inspection.

(b) No slipping of the cable in excess of 1/8"

(c) Successful performance on baseline tests (Section 5.13)

D. Commentary
This test is made to give an indication of the mechanical strength and rigidity of the connection device. Possibly, the 60 lb pull requirement is more severe than necessary. Some acceptable conventional devices, as noted below will not pass this test. U.L. has generally required innovative devices to sustain a 60 lb pull. The 60 lb pull was endured successfully by all innovative devices and connectors tested in our laboratory. Voltage drops and temperatures taken before loading were essentially the same after loading. In some tests power was applied to devices and connectors while they were subjected to a continuous 60 lb cable pull for a period of thirty minutes. There was essentially no change in voltage drops or temperatures during these tests.

Additional loadings were applied to an innovative duplex receptacle. When the load reached about 185 lbs, the cable sheath ruptured. Although the device enclosure cracked, the device was still functional after the test.

It is interesting to note that some conventional, nonmetallic-sheathed cable connectors would not hold more than a 30-lb pull. However, other connectors of the same type and manufacture held 90 lbs without slipping. In all cases when failure occurred with less than 60 lbs, each cable clamp was screwed down as tight as possible; there was no additional slack existing in the clamp for further tightening. Also, it should be noted that some nonmetallic outlet boxes use neither cable clamps nor cable connectors. Such outlet boxes have been observed in mobile homes.

5.10 IMPACT TEST

A. Objective
To determine that innovative devices will withstand a reasonably severe impact blow.

B. Test Procedure
This test should be made on the enclosure of the device in which electrical connections are made. This test should not be made to the face of receptacles, switches or other wiring devices. Depending on the geometry of the device, alterations in the method of making this test may be necessary.

With the assembled device on a steel plate, (1/2 inch thick), drop a five pound lead weight with a reasonably flat surface seven inches onto the device. The impact forces should be only those of a freely-falling object.

C. Test Requirement
The device should not be damaged and should subsequently perform satisfactorily on baseline tests (Section 5.13).

D. Commentary

Tests at NBS indicate that most electrical connector device enclosures can pass this test. Judgement should be used in applying and evaluating this test so as not to require unrealistic performance.

5.11 COMPRESSION TEST

A. Objective

To determine whether the assembled device in which electrical connections are made will withstand a substantial compressive force.

B. Test Procedure

This test should be made on the enclosure of the device in which electrical connections are made. The test should not be made to the face of receptacles, switches or other wiring devices. Depending on the geometry of the device, alternatives in the method of applying the force may be necessary.

Over a period of one minute apply 150 lbs evenly over the largest surface area of the device by placing the device between a lead sheet and a steel plate. Sustain the load for one minute and remove the load over a period of one minute.

C. Test Requirement

The device should not be damaged and should subsequently perform satisfactorily with baseline tests (Section 5.13).

D. Commentary

Judgement should be used in applying and evaluating this test so as to not require unrealistic performance.

5.12 ASSEMBLY SECURITY TEST

A. Objective

To determine that attachment plugs inserted into receptacle devices will not unduly affect the connection of electrical wires or cables to the device.

B. Test Procedure

This test is only intended for receptacle wiring devices. The test of the security of the assembly shall be a force of 100 pounds applied by means of a rigid steel push-out tool (as shown in Figure 4) inserted into the slots of the receptacles for a period of five minutes.

C. Test Requirement

There shall be no mechanical breakage of the device or separation of the face and rear portions, and there shall be subsequent satisfactory performance of the device with baseline tests (Section 5.13).

D. Commentary

Other tests are performed to evaluate the adequacy of receptacles and attachment plugs and the temporary connection between these devices.

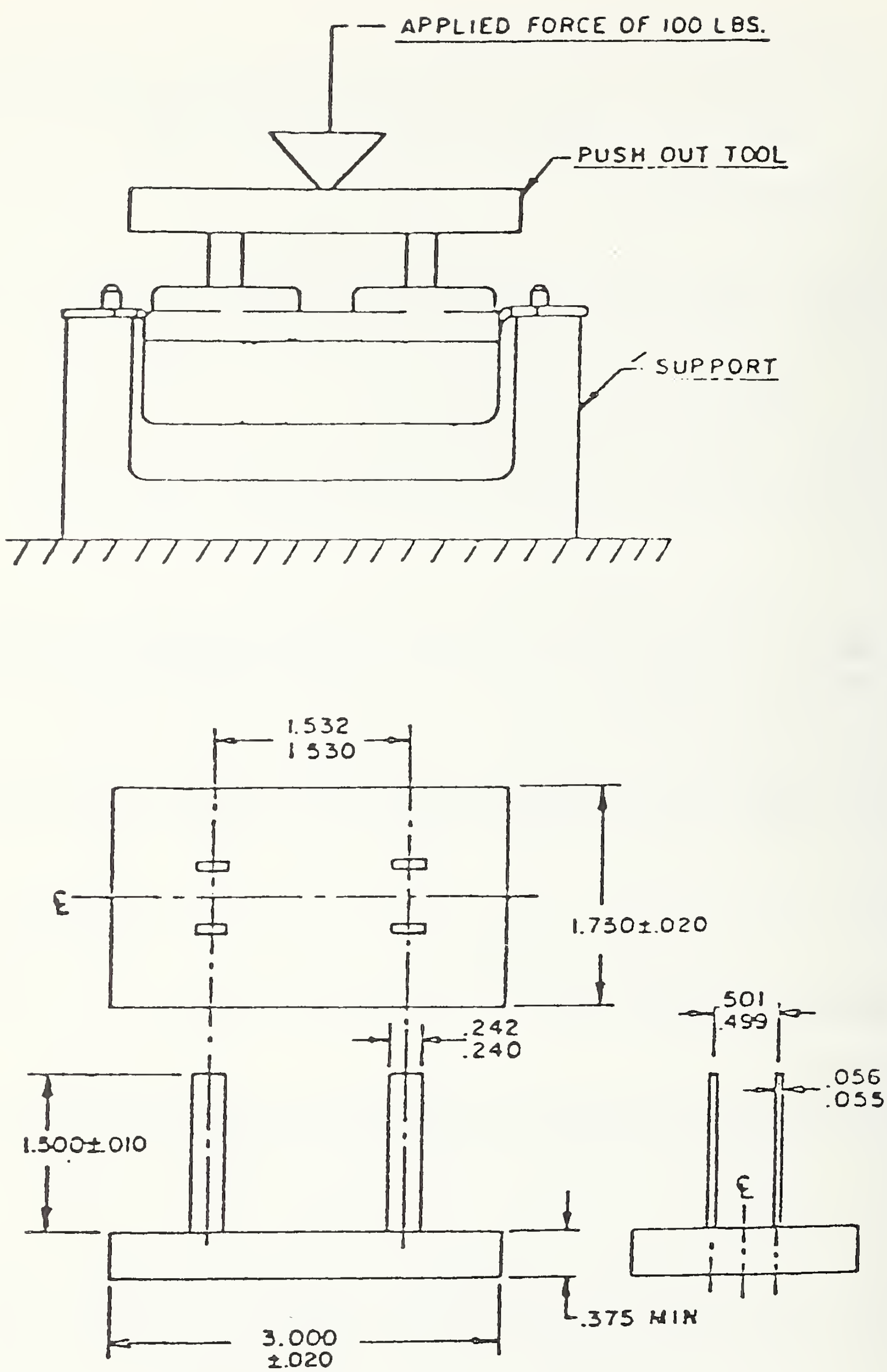


Figure 4. Rigid steel push-out tool for use in testing receptacle wiring devices.

Permanent connections of wire or cable to receptacles should not be loosened or otherwise damaged after completion of tests designed to evaluate the adequacy of the function of the receptacle.

5.13 REPEAT OF BASELINE TESTS

A. Objective
To determine that non-destructive punishment tests (Tests 5.5 through 5.12) have not destroyed the integrity of connections or the devices to which connections are made.

B. Test Procedure
Repeat Baseline Tests I, II, III and IV as described in Section 5.1, 5.2, 5.3, and 5.4 after all applicable non-destructive punishment tests have been made (Sections 5.5 through 5.12).

C. Test Requirement

(1) On Baseline Test I, all values of resistance should be not more than 0.5 milliohm greater than the original resistance value of each connection (each wire-to-wire or wire-to-terminal measurement). "Test Requirement (2)" should be within the limits specified in Section 5.1.

(2) The "Test Requirement" specified in Section 5.2 should be met.

(3) The "Test Requirement" specified in Section 5.3 should be met.

(4) The "Test Requirement" specified in Section 5.4 should be met.

D. Commentary
Tests 5.5 through 5.12 are described as nondestructive punishment tests. These are tests intended to determine whether connections will remain "tight" and retain their "Baseline" characteristics specified in Section 5.1 through 5.4 after being subjected to certain prescribed levels of abuse.

5.14 MOUNTING STRENGTH TEST

A. Objective
To determine that the supports to which an innovative device is intended to be fastened are adequate.

B. Test Procedure
This test need not be performed where a device is intended to be fastened only to structural building members except as noted in the "Commentary".

A device intended to be supported from paneling or other non-structural building components shall be installed in accordance with the manufacturers instruction in a wall (such as paneling) of the least thickness for which the device is designed. The wall shall be reinforced with a support (typical of a stud) 6 inches from one edge of the opening for the device. A force of 50 pounds shall be applied for a period of 5 minutes in a direction normal to the face of the paneling along the center line of the device tending to push it into the opening. The same force shall be applied in a direction tending to pull the receptacle out of the opening, and also to the NM cable in a downward direction from the point where the cables exit.

C. Test Requirement
The device shall remain in position without damage or permanent displacement of more than 1/8 inch from the plane of the face of the wall.

D. Commentary
It should be determined that adequate sizes and numbers of nails, screws, or other fastening means are incorporated in the design. Where non-conventional fastening means (such as glue) are intended to be used, the above test should be performed (with necessary modifications) even when fastening to structural building members is intended.

5.15 TEST ON KNOCKOUTS

A. Objective
To determine that knockouts will not be vulnerable to unintended removal.

B. Test Procedure
This test applies only to devices with knockouts. Knockouts shall be subjected to a force of 10 pounds for 1 minute. The force is to be applied at right angles to the plane of the knockout by means of a mandrel with a 1/4 inch diameter flat end. The force shall be applied at a point most likely to displace the knockout.

C. Test Requirement
The knockouts shall remain intact. However, knockouts shall be easily removed with appropriate tools without breakage of the insulating body of the enclosure and shall leave no sharp edges.

D. Commentary
If knockouts are too easily removable, the function or safety of the device may be impaired.

5.16 FIELD REPLACEMENT TEST

A. Objective
To determine that a device employing innovative connections will be readily replaceable in the field without damaging the building structure or finish.

B. Test Procedure

A self-contained device to be replaced in the field with a conventional outlet box and receptacle or other wiring device shall be installed on a typical wall panel of the minimum thickness intended, as indicated by the manufacturers installation, in accordance with the specified minimum length of slack in the appropriate cable or type of wiring. The device shall then be removed from the wall and disassembled from the cable. A conventional outlet box and duplex receptable or other wiring shall be installed.

C. Test Requirement

The conventional outlet box shall be installed using its wall support tabs as intended, or "old work" brackets. At least four inches of free wire length shall be available in the box for the connection to the receptacle suitable for mobile homes and recreational vehicles; and at least 6 inches of free-wire length for the connection to the receptacle suitable for rewiring in other buildings.

D. Commentary

This test is applicable only to innovative devices not requiring outlet boxes and is not required for devices with innovative connections which are not required to be accessible.

5.17 FLAMMABILITY TEST

A. Objective

To determine that nonmetallic or insulating materials of innovative wiring devices are reasonably non-flammable.

B. Test Procedure

Only devices with insulating materials other than those specified in the commentary need to be subjected to this test. Ten specimens of each component shall be tested; five in the as-received state and five after 7 days conditioning in an air oven at 90°C (194°F).

Each specimen is to be supported by a clamp on its upper 1/4 inch so that its major axis is vertical. A Bunsen or Tirrill burner having a 4-inch-long tube with a 3/8 inch bore shall be adjusted to produce a 3/4 inch high blue flame while in a vertical position. With the burner tube tilted 20 degrees from the vertical, the tip of the test flame is to be applied to the center of the lower end of the specimen for 10 seconds and then withdrawn at least 6 inches. When the flaming stops, the test flame is to be reapplied for 10 additional seconds and again withdrawn. (Note: Burning insulating materials may emit gasses or vapors hazardous to personnel conducting the tests.)

C. Test Requirement

A specimen shall not continue to burn for more than 30 seconds after each withdrawal of the test flame.

A specimen shall not burn with flaming or glowing combustion up to the holding clamp.

A specimen shall not continue to burn with a glowing ember for more than 60 seconds after the second withdrawal of the test flame.

D. Commentary

Insulating materials listed below have generally been accepted as having characteristics suitable for use in wiring devices.

Material (Generic Name):

Molded Epoxy[a,b]
Molded Phenolic[b]
Molded Melamine [b,c]
Molded Melamine-Phenolic [b,]
Urea Formaldehyde[b]
Molded Alkyd[b]
Molded Diallyl Phthalate[b]
Molded Polyester[a,b]

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[a] includes heat - and pressure-molded types only, not those intended for casting or pouring.

[b] Includes materials having filler systems of fibrous (other than synthetic organic) types but excludes fiber reinforcement systems using resins which are applied in a liquid form.

[c] Compounds having a specific gravity of 1.55 or greater (including those having cellulosic filler material) are acceptable at temperatures not greater than 150°C (302°F).

5.18 HEAT CYCLING AND VIBRATION TEST

A. Objective

To determine whether the combination of severe overcurrent and vibration will result in electrical connections overheating.

B. Test Procedure

This test is required only for electrical connections which are intended for use in non-accessible locations, and/or which may be subject to transportation vibration as defined by the National Electrical Code (Section 545-13).

A total of 20 samples divided into two groups shall be assembled with nonmetallic-sheathed cable having copper conductors: Group I shall be assembled to two conductor No. 14 AWG cable with ground and Group II shall be assembled to two conductor No. 12 AWG cable with ground. Currents as tabulated below shall be passed through the conductor connections to terminals in the devices in a cycle of 1-1/2 hours on and 1/2 hour off.

Group	NM Cable Size	Rating (Amperes)	Test Current Amperes
I*	No. 14-2	15	40
II	No. 12-2	20	53

*Omit for 20 ampere devices.

Thermocouples and suitable indicating means shall be used to record temperature rise. At the end of approximately 125 cycles, six samples from each group (total of 12) shall be removed from the circuits and subjected to a vibration conditioning. Eleven samples shall be installed onto plates by means of the device mounting brackets and the 12th sample installed on a sheet of panelboard of the minimum thickness for which the device mounting means is designed, supported on 20-inch centers. All the samples are to be subjected to a simple harmonic motion of amplitude of 0.03 inch with the frequency varied uniformly between 10 cps and 44 cps in a 1 minute span. The motion shall be applied for 2 hours in each of three mutually perpendicular directions for a total of 6 hours of testing.

After vibration the samples shall be reinserted into the heat cycling operation for an additional 375 cycles making a total of 500 cycles.

Temperature measurements shall be made commencing with the 25th cycle and approximately every 25 cycles thereafter for a total of five measurements (approximately 125 cycles). Measurements shall then be taken approximately every 40 cycles for a total of three measurements (approximately 125 cycles) and, finally, approximately every 80 cycles for a total of three measurements (approximately 250 cycles). This will yield eleven (11) measurements total over approximately 500 cycles.

C. Test Requirement

The temperature rise over ambient tempeature of each of the eleven (11) measurements shall not vary from the average of eleven (11) measurements by more than 10°C (18°F). A temperature rise of more than 100°C (212°F) measured at any time during the test shall not be acceptable.

D. Commentary

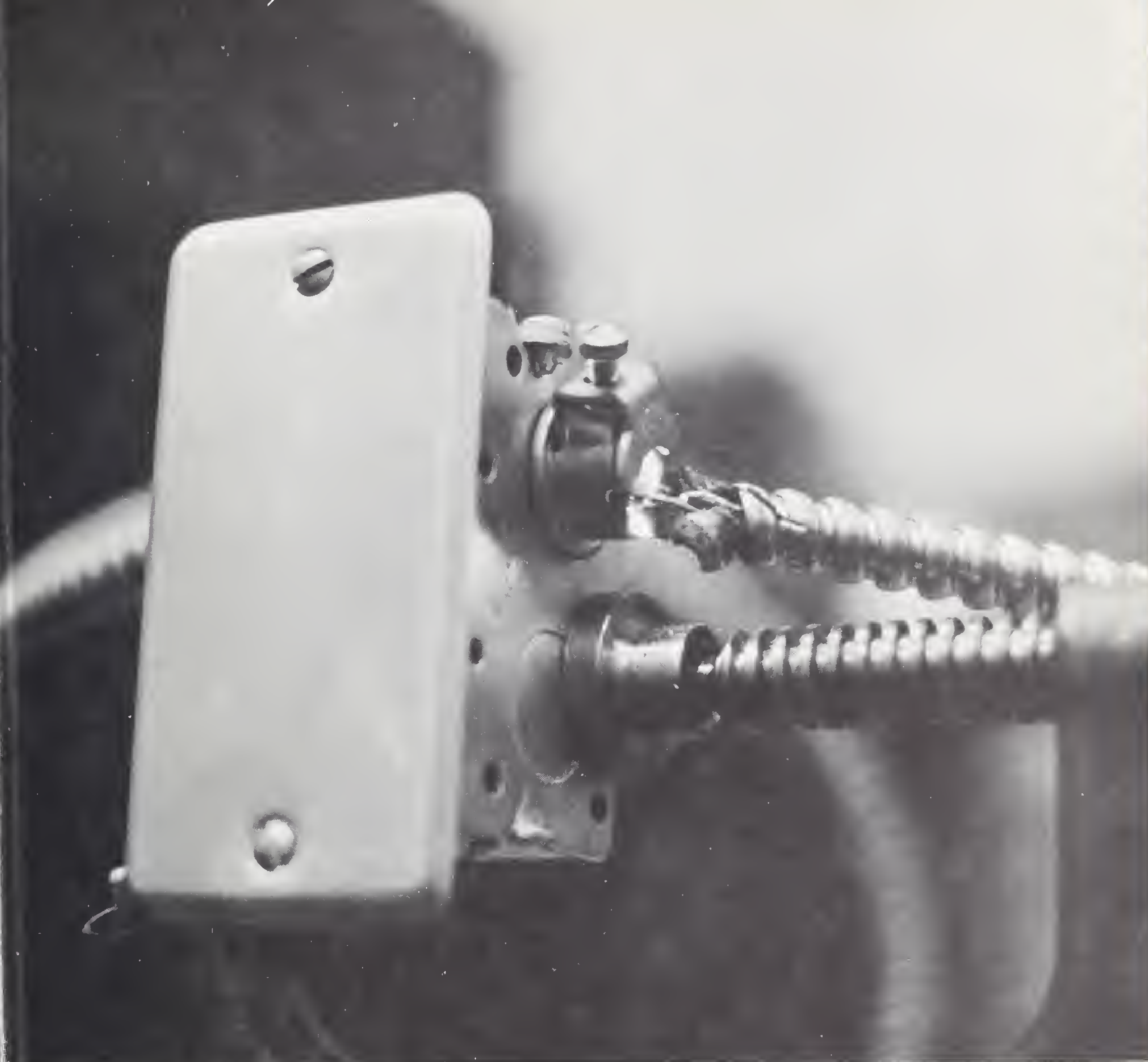
Tests at NBS indicate that electrical connections are probably more susceptible to loosening and consequently overheating because of mechanical stresses than because of electrical stresses. A series of tests at NBS [4] indicates that electrical connections which are tight are not likely to loosen in service unless subjected to mechanical stresses (See Section 6). The extent and the effect of vibration in housing or other buildings has not been evaluated. Vibration tests at NBS indicate that both innovative connections and properly tightened wire binding-screw connections are capable of meeting the requirements of this test. At this time there does not appear to be sufficient justification to require, on a general basis, that electrical connections pass tests with severe (2.67 of rated) overcurrent and vibration. Such tests are time consuming and costly.

However, it must be recognized that non-accessible electrical connections must be designed for the life of a building. When such connections are not located where they may be readily inspected, tightened, repaired, or replaced, more severe requirements to assure long-life performance are recommended. Also, the National Electrical Code (beginning with the 1975 edition) permits the use of non-accessible connections in manufactured buildings (See Section 2.2 of this report). This type of construction is subjected to vibration during handling of building components. At this time the test involving vibration and heat cycling is recommended for such non-accessible connections.

The vibration test specified is basically in accordance with Mil-Std-202E Method 201A [29]. This test is simple harmonic in nature; most vibration encountered in field service is not. However, vibrations of this type have proven satisfactory for determining critical frequencies, modes of vibration and other information necessary for taking steps to prevent effects of undue vibration [29]. At NBS specimens with innovative connections endured the vibration test.

While voltage drop measurements are used to determine performance in other tests, temperature measurements are specified in this test. Since severe overcurrent (2.67 of rated current) is used in the test, temperature differences will be more readily detectable than in tests made with rated currents.

Facing page : Damaged grounding path connection with neutral conductor fault.



6. VULNERABILITY OF CONVENTIONAL CONNECTIONS TO FAILURE

The principal practical problem with electrical connections is making reasonably certain that they are tight and remain tight. Loose connections may develop a relatively high contact resistance which may result in overheating at the connection interface. The result may be a glowing electrical connection and this may occur with either copper or aluminum wire. Overheated electrical connections were not obtained in the laboratory as long as connections remained tight [3].

How electrical connections become loose under field conditions is not well understood. Some postulated mechanisms leading to loose connections are:

(1) Vibration
(2) Creep of the wire or conductor material
(3) Thermal expansion and contraction at the connection interface
(4) Installation procedures.

The effect of these mechanisms in inducing connections to become loose needs to be investigated. However, observations of investigations performed at NBS indicate that "mechanical stresses" rather than "electrical stresses" are more likely to lead to loose and consequently overheating connections. Tight connections have sometimes gone many months with "on" and "off" cycling at high currents (2.67 of rated currents) without substantial increase in resistance at the connection interface. It should be noted that compared with rated current, 2.67 of rated current will result in about seven times the power being dissipated at the connection interface. On the other hand, mechanical stresses may immediately loosen connections and result in high resistance at the connection interface and in almost immediate overheating even below rated current [3].

The usual manner in which conventional electrical connections are made to wiring devices installed in outlet boxes indicate that a possible fundamental shortcoming has persisted for a long time.

Usual practice is to: (1) mechanically fasten outlet boxes to the building structure, (2) mechanically clamp electrical cable to outlet boxes where the cable comes through knockouts and into the box (the NEC requires a minimum of 6 inches of the individual wires in the box) (3) strip the insulation off the end of each individual wire, bend the end of the wire and connect each wire to the appropriate terminal (ungrounded, grounded, grounding) on the wiring device (switch, receptacle, etc.), (4) tighten wire-binding screw terminals, (5) arrange the wires so that they will go into the box and "stuff" the wiring device (i.e., receptacle, etc.) into the box and fasten it to the box.

The "stuffing" of wires and wiring devices into outlet boxes results in mechanical stresses at connections to the terminals on the wiring device (See Figure 5). It appears that when wire-binding screws are used, there is about a 50% chance that the wires will exert a clockwise force on the screws, thus tending to tighten the connections, and about a 50% chance that the wire will exert a counter-clockwise force on the screws, thus tending to loosen the connections.

Post-installation torque tests which simulated installations of receptacles were made by another NBS laboratory [9]. A general description of these tests is given below:

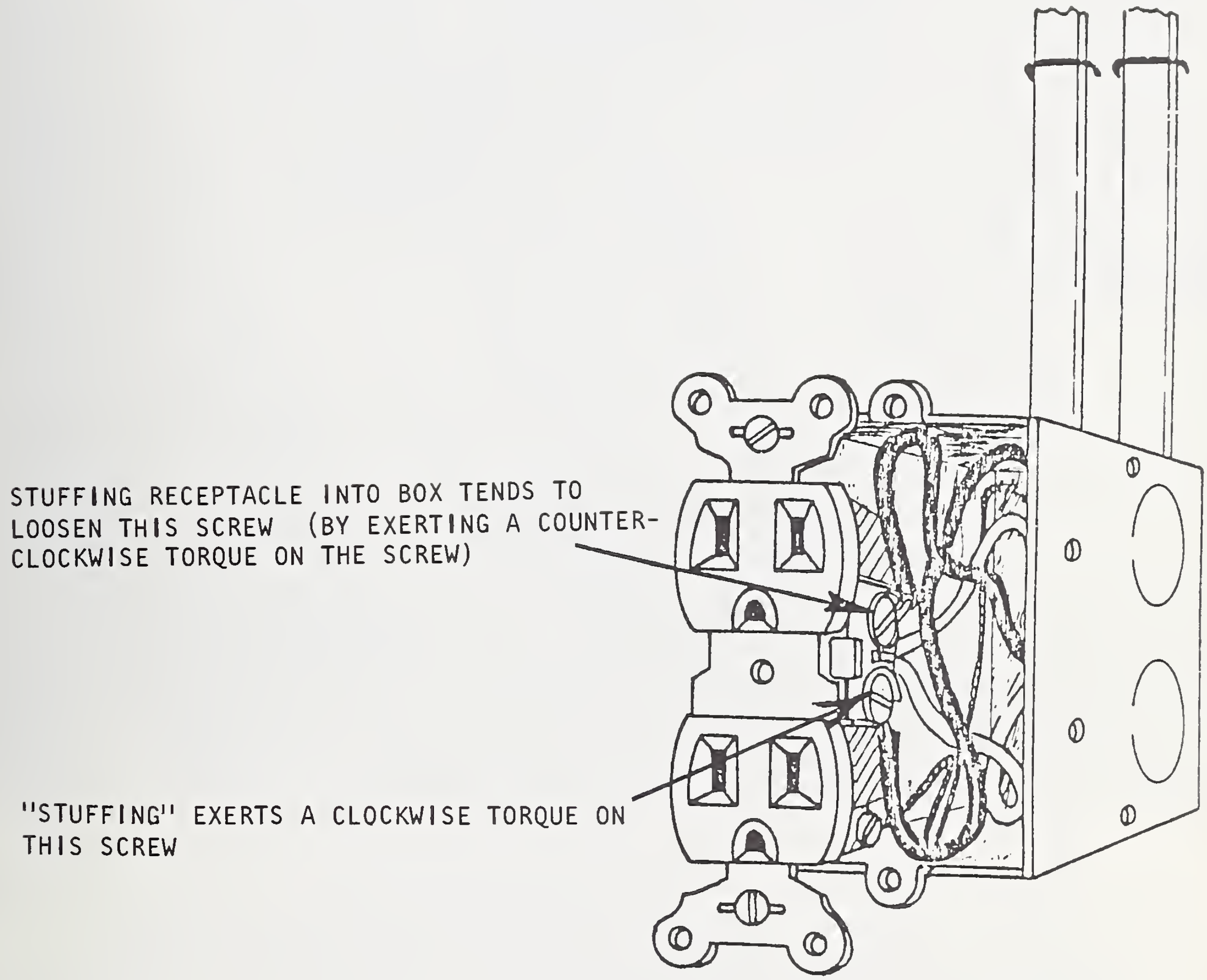


Figure 5. Stresses on conventional connections.

"It has been suggested that one possible cause of receptacle failures in the field might be due to screws that are loosened when the receptacle is pushed into the wall box. To explore this factor, a series of post-installation torque tests have been made on two types of old receptacles and six types of CO/ALR receptacles. In these tests, a standard metal wall box with removable sides was rigidly attached to a test stand and two lengths of #10, 2-wire aluminum cable were installed and clamped in the box in a conventional manner. The wires were then stripped and connected to the test receptacle. In an attempt to simulate actual installation practices, the screw connections were made in a hurried fashion, and no attempt was made to form perfect wire loops. All screws were then tightened to a known torque and the receptacle was then pushed into the box and secured by its mounting screws. At this point, the sides were removed from the box and residual torque on each screw was measured and recorded. For each receptacle type, this procedure was repeated three times each at initial torque levels of 6, 10, and 14 inch pounds (lbf•in). For each test trial, new wire loops were made, and a new receptacle was used."

A summary of the results of the tests on old style (non-CO/ALR) receptacles is [9]:

"On both old style receptacles tested, the measured post-installation screw torques were highly variable, particularly at the 6 and 10 inch pound test levels. At the 6 inch pound test level one of the 24 test connections was totally loose, and 11 connections had residual torques of less than 3 inch pounds. At the 14 inch pound test level the average residual torque on both non-CO/ALR receptacle types was 10 inch pounds." (Post torque data on CO/ALR receptacles was substantially better.)

In any event there is a belief that conventional connections to wire-binding screws are vulnerable to loosening during the "stuffing" operation if the screws have not been tightened sufficiently. The "stuffing" of wires and wiring devices into boxes also puts stresses on back-wired "push-in" connections. Referring to the data presented above, it appears that there may be a rather high probability of the "stuffing" operation resulting in the loosening of many screws. In other words connections which are sufficiently tight when made, may be stressed and loosened before the installation has been completed. There is reason to believe that this fundamental weakness in the way we ordinarily make branch circuit electrical connections is the principal reason there are so many reported cases of overheated and failed connections. Since aluminum wire (for a given ampacity) must be larger, and consequently stronger, than copper wire, it appears that there is a better probability of de-torquing aluminum wire. This may, at least in part, account for past problems with branch circuit aluminum wire, particularly when #10 aluminum wire is used.

Facing page: Electrical connection of modules of industrialized housing.

7. RECOMMENDED PERFORMANCE CHARACTERISTICS FOR INNOVATIVE CONNECTIONS

The purpose of this section is to present to innovators the primary performance characteristics needed for electrical connections to prevent loosening, high contact resistance and overheating. Generally, in order to perform satisfactorily on the tests listed in Section 5 of this report, designs of devices should incorporate the performance characteristics listed below.

7.1 STRESS RELIEF

A connection device should be designed such that the connection itself is not stressed by the bending or moving of wires. The consequences of such stressing is discussed in Section 6. Innovative designs should be such that the stress exerted by moving or bending wires or cables is applied at some point other than at connections.

7.2 ASSURED PRESSURE

A connection is more likely to remain tight if slight movement between a wire and a terminal or other wire will not result in substantial loosening of the connection. Assured pressure, which in most cases would probably be provided by "spring" characteristics of materials, is recommended in the design of innovative connections.

Conventional wire-binding screw terminals do not have "assured pressure". If a screw which is tight is turned even slightly, there is considerable loss of torque and a loose or potentially loose connection. "Stuffing" of wire and devices into outlet boxes as described in Section 6 of this report could cause such loosening at connections. Properly designed lock washers would appear to be one means of providing "assured pressure" when wire-binding screws are used.

7.3 INSTALLATION PROCEDURES

To complete the installation of conventional wiring devices, stresses are put on electrical connections after the connections have been made when the wires are bent and wires and wiring devices are stuffed into boxes (See Section 6 of this report). Designs of innovative connection devices should be such that stresses are not exerted on connections by the bending of wires or cables.

7.4 MATERIALS

Investigations of glowing electrical connections indicated that certain combinations of materials at the interface of connections were more likely than others to result in high resistance and overheating (glowing) connections, if the connections become loose. Results of these investigations are documented in Reference [3] of this report. A significant finding was that of the two principal materials (steel and brass) used at connecting interfaces on wiring devices, steel (such as steel wiring-binding screws) was much more likely to result in high resistances and high temperature if the connections became loose. This was true with both copper and aluminum wire. Innovators should consider the effects of various materials when connections become loose.

Facing Page: Results of improper electrical connection.

8. SUMMARY

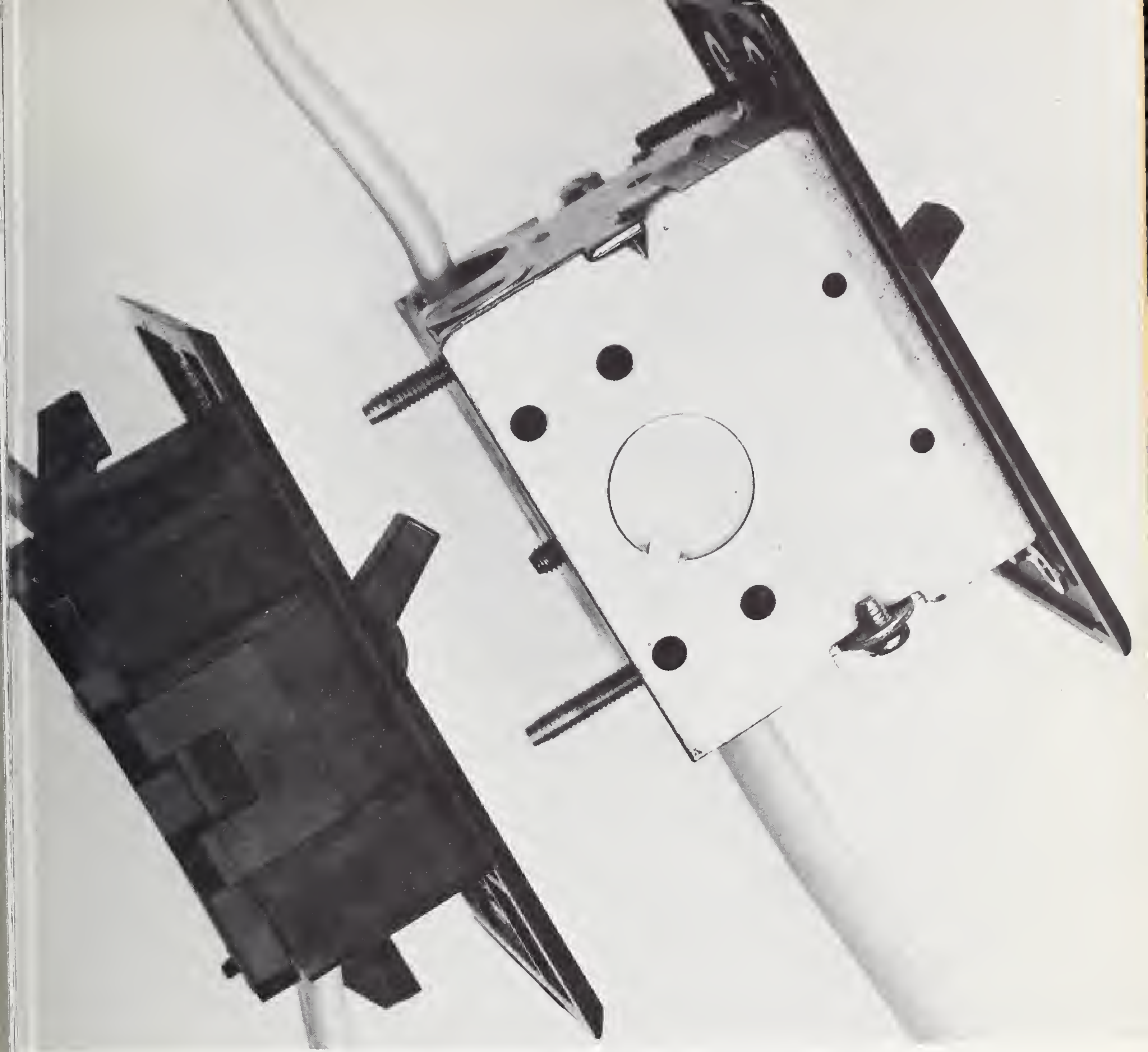
Since the Operation BREAKTHROUGH program of the late 1960's and early 1970's, considerable progress has been made in removing prescriptive requirements in codes and standards which apply to electrical connections. The National Electrical Code [11] is now written in such a way that electrical connections may be evaluated on a performance basis (See Section 2).

This report contains detailed performance criteria and a series of performance tests to be used in the evaluation of innovative electrical connections for branch circuit wiring. These tests must be supplemented with subjective judgment to fully evaluate all applicable parameters.

The primary hazard with electrical connections is loosening which may result in high contact resistance at the connection interface and which in turn may lead to overheating. The key to satisfactory electrical connections is that they be made tight and remain tight.

While there may be a number of reasons for connections being loose or becoming loose in service, the design and installation procedures of common conventional electrical connections appear to make such connections vulnerable to loosening and resulting failure (see Section 6). Innovative connections tested and evaluated by NBS have characteristics incorporated into their designs which appear to make them less vulnerable to failure. These design characteristics are discussed in Section 7.

Facing page: Contrast in size between switches with conventional and innovative connections.



9. CONCLUSIONS AND RECOMMENDATIONS

9.1 INNOVATIVE ELECTRICAL CONNECTIONS

Innovative electrical connection devices or systems which will not only lead to cost savings but will also lead to less hazardous electrical installations appear to be possible with current technology if mass-produced. Some such connection hardware of this type is currently available.

9.2 CONVENTIONAL ELECTRICAL CONNECTIONS

Conventional electrical connection devices for branch circuit wiring have inherent weaknesses which appear to make them vulnerable to loosening, which may result in overheating. The hardware, systems and installation practices of all existing connections now in common use should be reevaluated in accordance with the performance criteria test methods and information presented in this report.

From the results of the study, it appears that a basic change in the present practices used in making branch circuit electrical connections is needed. A study should be made to determine if many currently approved electrical connection systems are potentially too vulnerable to overheating for them to continue to be approved for installation in this country. A major result of this work, therefore, is the conclusion that conventional branch circuit electrical connection systems may involve inherent weaknesses where the potential risk of hazard is high. It also appears that cost savings are possible with simplified installation techniques; thus there is much need for innovative systems.

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

Performance criteria and test procedures are presented for the evaluation of electrical connections in branch circuit wiring. Investigations and research undertaken to determine needed characteristics of innovative electrical connections are summarized. Design and installation strategies to lessen the chances of electrical connection failures are discussed. Inherent weaknesses are described for design and installation methods of common types of branch circuit wiring connections or terminations, which appear to make them vulnerable to loosening and overheating. There are technology improvements which demonstrate that innovative electrical connections can be developed which may be less costly when installed, and have less chance of becoming hazardous, than common conventional connections.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Contact resistance; electrical codes; fire safety; glowing electrical connections; house wiring; innovative electrical connections; performance testing.

13. AVAILABILITY

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