2.0 DESIGN FOR MAINTAINABILITY

This section contains human factors guidance for designing systems, subsystems, equipment and facilities so that maintenance is easy and cost effective.

2.1 Unitization, modularization, and standardization

Unitization refers to separating equipment into physically and functionally distinct units to allow for easy removal and replacement. This type of equipment separation will permit division of maintenance responsibility, especially troubleshooting, among various maintenance levels. Modularization refers to unitized equipment in which the functional units making up a module are integrated and are removed or inserted as a unit.

2.1.1 Goals of unitization/modularization. Unit design/modularization of equipment should

a. Maximize the efficiency and accuracy of on-line replacement of system components.

b. Facilitate and minimize troubleshooting time at each level of maintenance activity.

c. Allow test, checkout, troubleshooting, and repair procedures to be unit specific and structured to aid in identification of faulty units, then subunits, etc.

d. Reduce down-time.

e. Provide easy access to malfunctioning components.

f. Allow for high degree of standardization.

g. Minimize time and cost of maintenance training.

h. Simplify new equipment design and shorten design time by using previously developed, standard "building blocks."

2.1.2 General principles for unitization/modularization design

2.1.2.1 Division of equipment into modules. Equipment should be divided into as many modules as are electrically and mechanically feasible in keeping with efficient use of space and overall equipment reliability.

2.1.2.2 Uniformity. All modules and component parts should be approximately uniform in basic size and shape for the best packaging, ease of replacement and minimizing spare-parts inventory.

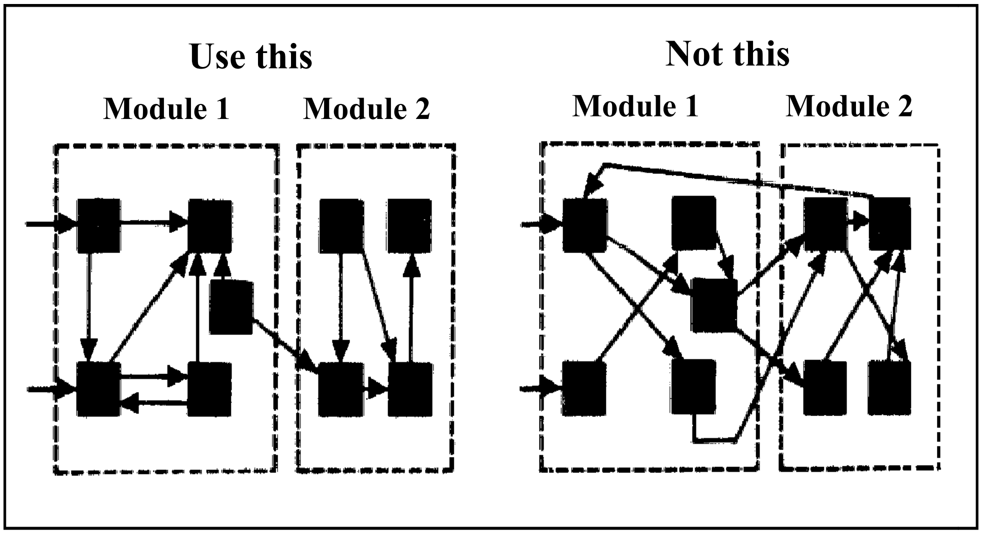
2.1.2.3 Functional commonalty. A module should contain components that contribute to a single, common function rather than providing multiple, divergent functions.

2.1.2.4 Operational testing. Modules and units should be designed to permit operational testing when removed and require little or no calibration after replacement.

2.1.2.4.1 Go-no-go testing. Testing should accept or reject each module or unit on a go-no-go basis.

2.1.2.5 Functional independence of units. The physical separation of equipment into replaceable units should be matched with the functional design of the equipment to maximize the functional independence of units and minimize interaction between units (See Figure 2.1.1).

Figure 2.1.1. A hypothetical equipment design maximizing unit independence. (Ex. 1.1.1)



2.1.2.6 Subassembly or module removal. Where an assembly is made of two or more subassemblies or modules, where feasible, each subassembly should be able to be removed independently without removal of other subassemblies. This is particularly valuable when the various subassemblies have widely varying life expectancies.

2.1.2.7 Easy removal and replacement. All equipment should be designed so that rapid, safe and easy removal and replacement of malfunctioning components can be accomplished by one technician, unless this is structurally or functionally not feasible.

2.1.2.8 Module portability. Where possible, modules and units should be small and light enough for one person to handle or carry. The weight of removable units should not exceed 20.5 kg (45 lb). Units weighing more than 4.5 kg (10 lb) should have handles.

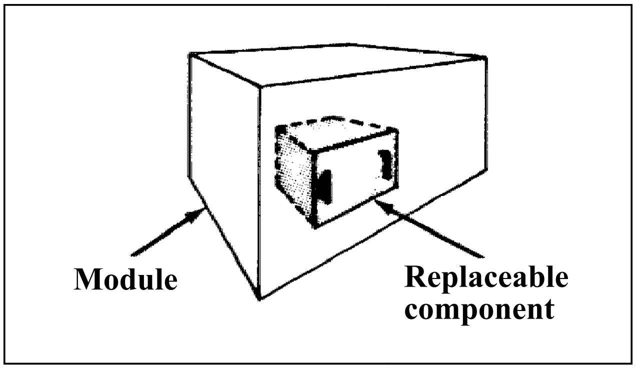
2.1.2.9 Independent testing. Where possible, each module should be capable of being checked independently. If adjustment is required, the module should be able to be adjusted separately from other modules.

2.1.2.10 Controls and linkages. Controls and linkages should be designed so they can be easily disconnected from components to permit easy and safe removal and replacement.

2.1.2.11 Placement of low reliability components within module. Unitizing the module with the low reliability components removable from the exterior of the package should be considered if all components of a module except for one or two are reliable (See Figure 2.1.2).

2.1.2.12 Replaceable multi-lead parts. Replaceable multi-lead parts such as relays and selector switches should be mounted with mechanical connectors such as plugs to avoid the necessity for unsoldering and resoldering when replacement is required.

Figure 2.1.2. Unitization of a module for easy replacement of low reliability components.



2.1.3 Disposable modules

2.1.3.1 Use of disposable modules. Disposable modules should be considered when maintenance is either impractical or costs more than replacement or when other advantages of using disposable modules outweighs their disadvantages as listed below in Table 2.1.1, Advantages and disadvantages of using disposable modules.

Table 2.1.1 Advantages and disadvantages of using disposable modules.

Advantages	Disadvantages
1. Savings in repair time, tools, facilities, and manpower	1. Increased supply burdens because modules must always be on hand
2. Smaller, lighter, denser, simpler, more durable and more reliable design	2. Reduction in failure maintenance data to aid design improvement
3. Fewer types of spares and a one-way supply system, at least for the item	3. Excessive usage through excessive and/or erroneous replacement
4. More concise and less difficult troubleshooting procedures	4. Redesign problems and increased costs because such modules cannot be modified
5. Use of sealing and potting techniques which further increase reliability	5. Degraded performance and/or reliability as a result of production efforts to keep modules economical enough to justify disposal
6. Improved standardization and interchangeability of modules and assemblies	

2.1.3.2 Design and installation criteria for disposable modules. Disposable modules should be designed, manufactured, and installed to meet the following criteria

a. Expensive parts are not thrown away for failure of inexpensive parts.

b. Long-life parts are not discarded for failure of short-life parts.

c. Low-cost and non-critical items are, in general, made disposable.

d. Throw-away modules are encapsulated wherever practical.

e. All encapsulated modules are designed for disposal at failure.

f. Inexpensive modules are disposable wherever practical.

g. The maintenance level of replacable modules is clearly identified.

h. Test procedures to be applied before disposal are clearly specified and provide clear and unequivocal results.

i. The identification plate or marking contains the statement: "Dispose of at Failure."

2.1.3.3 Replacement module. When feasible, replacement module design and configuration should permit verification of operational status prior to installation without the need for disassembly**.**

2.1.4 Standardization. Standard parts, components, circuits, and modules should be used in all equipment that may be removed or replaced during the lifetime of the system. The number of different sizes of parts for equipment should be limited so that the inventory of spares and tools is minimized.

2.1.4.1 Use of standard commercial parts. Where available and subject to removal and replacement, standard commercial parts that meet system requirements should be used in all equipment so that the parts may be quickly exchanged or used in diverse applications. In particular, common hardware parts such as screws, bolts, nuts, and cotter pins should be replaceable by standard commercial parts without alteration.

2.1.4.2 Equipment specification. Where feasible, Equipment specification should require use of only standard and common tools and general-purpose test equipment.

2.1.4.3 Parts numbers. Parts should be identified in drawing by their parts numbers. All parts having the same manufacturers part number should be directly and completely interchangeable with respect to installation and performance.

2.1.4.4 De-energized. Units should be easily de-energized and confirmed for worker safety.

2.2 Unit layout, mounting and configuring,

Layout, mounting, and configuring should be designed to increase equipment and system maintainability. Layout refers to the general arrangement and placement of units and components within a system. Configuring refers to the particular method used to systematically package units or components. Mounting refers to a means of attaching and positioning components.

2.2.1 Goals for layout, mounting and configuring. Effective layout, mounting, and configuring should:

a. Satisfy unitization and modularization objectives.

b. Minimize place-to-place movement of the technician during servicing, check-out, and troubleshooting.

c. Be organized according to maintenance specialties so that maintenance performed by one specialist does not require removal or handling of equipment maintained by another specialist, especially where the equipment is so critical that it requires highly specialized skills.

2.2.2 Layout of units and components.

2.2.2.1 Minimize equipment damages and personnel injury. Equipment components should be located to minimize the possibility of equipment damage and personnel injury. Equipment should be configured with sufficient internal access and clearance space so that personnel injury is minimized due to cramped space and vulnerable components are not damaged during inspection, servicing, removal, and repair. (1.2.3.1.a and Chapter IV-C, Section 2.1, EPRI NP-4350)

2.2.2.1.1 Delicate components. Delicate components should be located where they will not be damaged while equipment is being worked on.

2.2.2.1.2 Contaminants. Components should be positioned so that oil, other fluids, and dirt are not likely to contaminate them.

2.2.2.1.3 High temperature parts. High temperature parts should be labeled, guarded or located such that personnel contact will not occur during operation or maintenance. Heat-producing equipment should be shielded so that technicians are not made uncomfortable.

2.2.2.1.4 High-current switching devices. High-current switching devices should be labeled and enclosed to protect personnel.

2.2.2.1.5 Discharging devices. Discharging devices such as shorting bars should be used to discharge high-voltage circuits and capacitors unless they discharge to 30 volts or less within 2 seconds after power removal.

2.2.2.1.6 Grounding equipment. Equipment and electrically operated tools should be designed so that all external parts and surfaces (except antenna and transmission line terminals) will be at ground potential.

2.2.2.1.7 Replaceable multi-lead parts. Replaceable multi-lead parts such as relays and selector switches should be mounted with mechanical connectors such as plugs to avoid the necessity for unsoldering and resoldering when replacement is required.

2.2.2.1.8 Use of insulation materials. Insulation materials such as rubber gloves, insulating blankets and matting, insulating sleeves, insulating line hose, insulated work platforms, and insulated tools should be used to separate maintenance personnel from potential electric, heat and cold hazards.

2.2.2.1.9 Internal controls. Internal controls should be located away from dangerous voltages or places where they might be accidentally bumped while performing other maintenance activities.

2.2.2.1.10 Additional electrical safety design guidelines. Additional electrical safety design guidelines that should be followed include:

a. Designing equipment to be free of falling or standing water.

b. Where standing water may accumulate, placing electrical equipment and units on elevated pads.

c. Providing storage in or near electrical equipment for safety-related tools (e.g. shorting bars).

d. Locking, ventilating, and placing warning signs on doors to battery rooms as well as prominently displaying instructions for personnel evacuation, first aid (e.g. eye wash station).

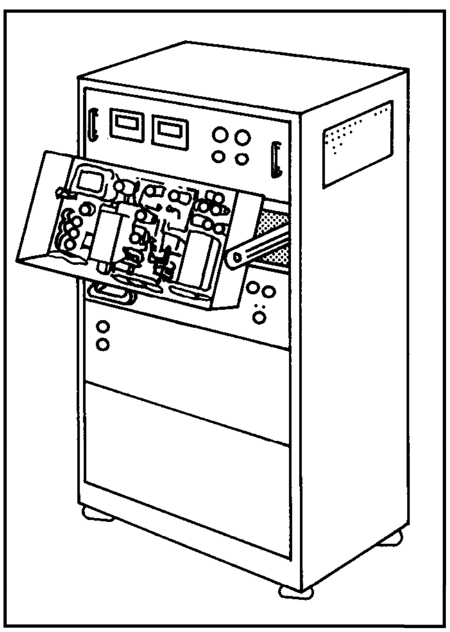
e. Following clear-cut plant equipment identification practices (color coding may be considered to aid in identification) to minimize misidentification errors such as opening a breaker for one circuit and subsequently proceeding to work on a different protected circuit.

2.2.2.1.11 Accidental activation. Components and units should be located so that their removal cannot cause accidental activation (or deactivation) of another unit or subsystem.

2.2.2.2 Check points. Check points, adjustment points, cable end connections, labels, and tools required should be placed in full view and reach of the technician.

2.2.2.3 Slides with tilt action features. Where access may be required to front and back (or top and bottom depending on mounting) slides with tilt action features should be considered (See Figure, 2.2.1, Example of slides with tilt action feature)

Figure 2.2.1. Example of slides with tilt action feature.



2.2.2.4 Mounted on top of supporting surface. Assemblies and components should be mounted on top of a supporting surface, not suspended underneath.

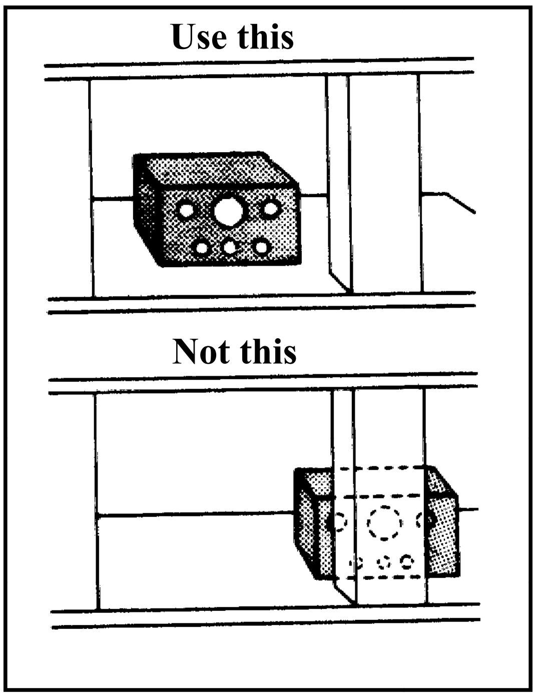
2.2.2.5 Easy access. Units should be located so other equipment does not have to be removed to gain access.

2.2.2.6 Protection from environmental factors. Equipment and systems should be sheltered or separated from environmental threats such as exposure to caustics, acids, moisture, and temperature extremes as appropriate or designed to survive and exist in their intended use environment.

2.2.2.7 Stacking. Parts and units should not be stacked e.g. they should be mounted in an orderly array on a "two-dimensional" surface, rather than stacked on one another. Subassemblies should not have to be removed to access other subassemblies within the equipment. If necessary, place the less frequently accessed unit in the rear or bottom.

2.2.2.8 Frames and structural members. Frames or structural members should not interfere with maintenance activities (See Figure 2.2.2, Proper placement of components).

Figure 2.2.2. Proper placement of components.



2.2.2.9 Components requiring frequent visual inspections. Components that require frequent visual inspection should be installed in positions where they can be easily seen without removing panels, covers, or other units.

2.2.2.10 Working level. Components to be serviced or repaired in position should be at the most favorable working level, i.e., between hip and shoulder height.

2.2.2.11 Similar items. Similar items should utilize a common mounting design and orientation within the unit. This mounting design should only allow interchange of items that are functionally interchangeable. Similar items which are not functionally interchangeable should be made distinguishable by labeling, color coding, marking, etc. (Section 5.9, MIL-STD-1472F)

2.2.2.12 Uses of labels and codes for panels and equipment. Labels and codes should be provided on and within the system panels or equipment as required to: [Letters are keyed to Figure 2.2.3, Labeling and coding for panels or equipment]

a. Outline and identify functional groups of equipment.

b. Identify each item or part by name or common symbol.

c. Identify the value and tolerances of parts such as resistors; this identification should be direct rather than in color code where possible.

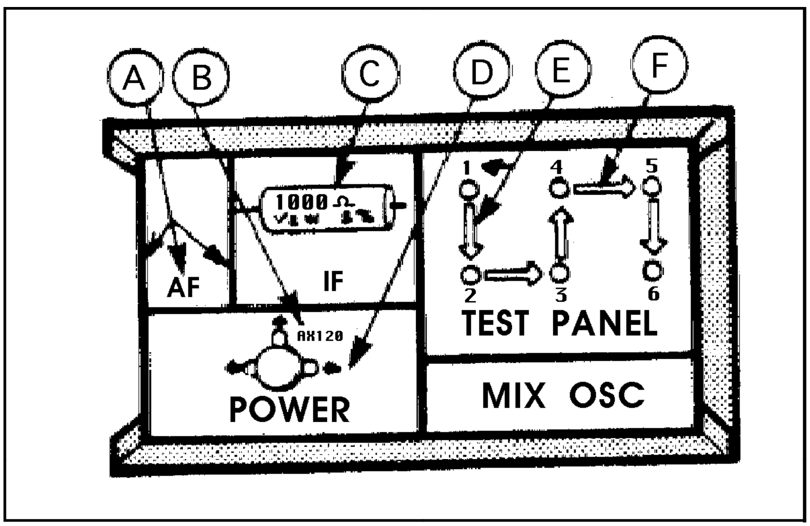
d. Identify each test or service point, and the sequence in which used.

e. Indicate the direction of current or flow to aid systematic elimination of possibilities without continuous cross-reference to schematics.

f. Provide "maintenance highways" to guide the technician through routine process. The following code has proven useful:

- Black for line maintenance
- Green for shop maintenance
- Red for off site maintenance
- Other codes as necessary.

Figure 2.2.3. Labeling and coding for panels or equipment.



2.2.2.12.1 Content of panel and equipment labels. Provisions should be made for the following information and instructions to appear on system panels and equipment when appropriate (see also Section 1.3, Hardware Identification for maintainability, of this document):

a. The weight of units over 20.41 kg (45 lbs).

b. Warning and caution labels as necessary.

c. Instruction plates to outline procedures not made obvious by design and to supply whatever information is necessary for troubleshooting and maintenance.

d. The presentation and/or recording of historical data where practicable, particularly to:

- Display periodic readings at test points to allow development of trends where these are fundamental to maintenance decisions.

- Allow recording of replacement dates or other data necessary to replenishing or preventive maintenance.

2.2.2.12.2 Characteristics of labels and codes. Labels and codes used in system panels and equipment should:

a. Consistently and unambiguously used throughout the system.

b. Of such a nature as to be easily read and interpreted.

c. Durable enough to withstand expected wear and environmental conditions.

d. Coordinated and compatible with:

- Codes and labels on related test and service equipment

- Other coding and labeling within the system

- Related job aids, instructions, handbooks, and manuals.

2.2.3 Mounting components.

2.2.3.1. Factors affecting mounting of components. Mounting of components should take the following factors into consideration:

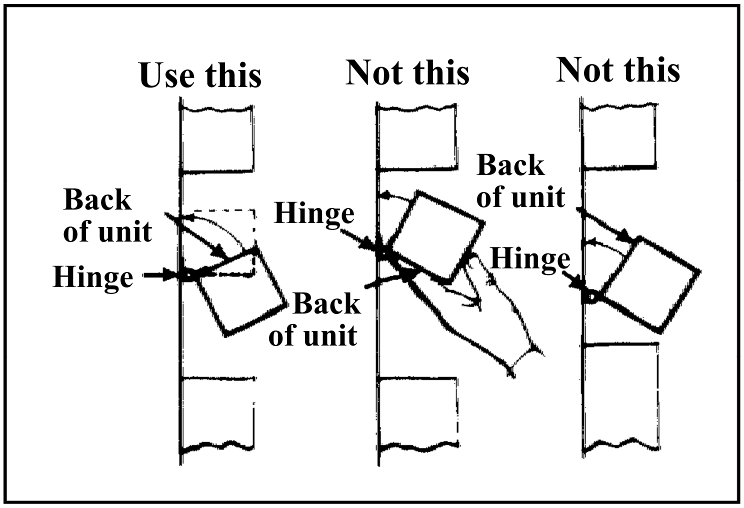
a. How often components will be removed for maintenance or replacement.

b. The accessibility of other components which may be affected.

c. The size and weight of components to be mounted.

d. How much space will be required for access, removal, and replacement of the component or for using test equipment, tools, etc. (e.g. Small, hinge-mounted units, which must have access from the back, should be free to open their full distance and remain open without being held (See Figure 2.2.4, Design of hinged units).

Figure 2.2.4. Design of hinged units.



e. The required preventive maintenance for an installed component.

2.2.3.2 Design of hardware for mounting. Mounting fixtures, e.g., rollers, brackets, slide rails, should be designed so that:

a. Only plugs and structural members are permanently attached to units. All other fixtures should be removable.

b. Built-in fixtures to the chassis are either strong enough to withstand use over the life of the system or are removable.

c. Mounting is compatible with the size and weight of the part to prevent breakage or damage from fatigue, under vibration, handling stress, and other stress causing operating conditions.

d. All mounting hardware should be easily attached and removed by workers.

2.2.3.3 Design to prevent mis-mated or mis-aligned components. Design for mounting of components, modules, and parts should be such as to prevent their being inadvertently reversed, mis-mated, or mis-aligned during installation or replacement.

2.2.3.3.1 Techniques used to preclude mounting errors. Design should make errors physically impossible:

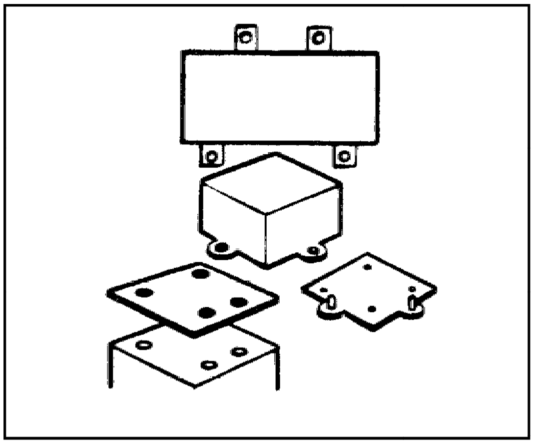
a. Coding, labeling, or keying symmetrical components to indicate the proper orientation for mounting or installation.

b. Providing mounting brackets which are asymmetrical, to prevent incorrect mounting, as below.

c. Providing side alignment brackets which permit mounting in only one position,

d. Providing asymmetrical mounting holes, studs, or alignment pins, as shown in Figure 2.2.5, Error free mounting designs.

Figure 2.2.5. Error-free mounting designs.

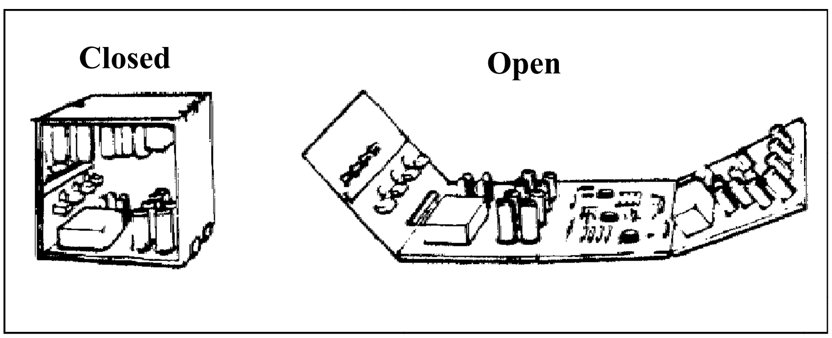


2.2.3.4 Interchangeable components. Components with the same form, function, value, and reliability and other requirements should be completely interchangeable throughout the system or related systems.

2.2.3.5 Similar components with different functional properties. Components of the same or similar form, but of different functional properties, should be readily identifiable, distinguishable, and not physically interchangeable.

2.2.3.6 Fold-out construction. This method of constructing subassemblies should be used whenever feasible. The parts and wiring should be positioned to prevent damage to them when opening and closing this assembly (See Figure 2.2.6, Example of fold-out construction).

Figure 2.2.6. Example of fold-out construction.



2.2.3.7 Braces. Braces or similar items should be provided to hold hinged assemblies in the "out" position while they are being worked on. Rests or stands should be provided to prevent damage to delicate parts. If feasible, the rests or stands should be a part of the basic chassis (See Figure 2.2.7, Bracing of hinged assemblies and Figure 2.2.8, Use of stands for component maintenance).

Figure 2.2.7. Bracing of hinged assemblies.

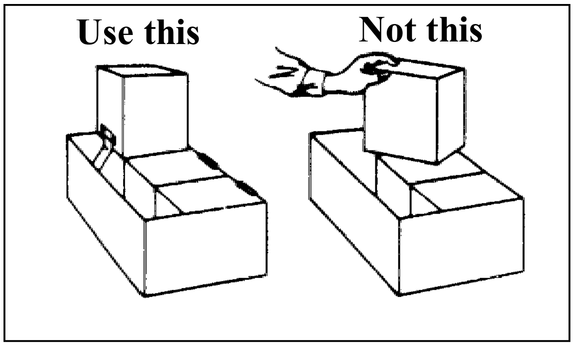
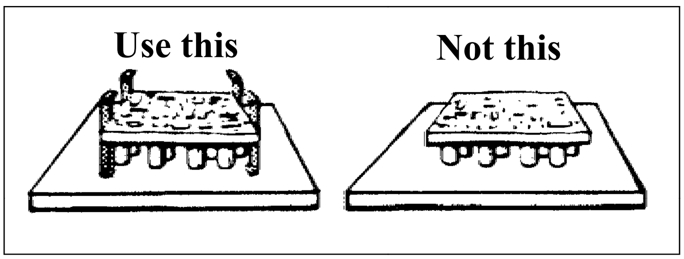


Figure 2.2.8. Use of stands for component maintenance.



2.2.3.8 Straps and brackets. Straps and brackets should be used:

a. As necessary for tying down large components.

b. Particularly to support items mounted on the underside of assemblies.

c. Instead of cantilever brackets for mounting parts.

d. As necessary to prevent the mounted item from sliding or jumping out of position. "U" straps should only be used to "tie-down" components, not to support them.

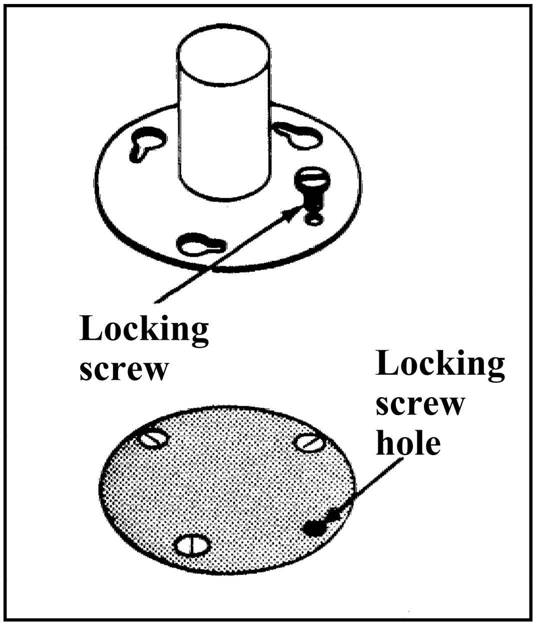
2.2.3.8.1 Features of straps and brackets. Straps and brackets should be:

a. Thick or rounded enough so they have no sharp edges.

b. Shorter than mounted units to provide a clamping action.

c. Twist- or push-to-lock mounting types for small components. Such brackets should be designed so that locking studs are visible when the component is in place, and locking screws or dimples are provided as necessary to ensure security of the mount (See Figure 2.2.9, Twist-to-lock type mounting bracket

Figure 2.2.9. Twist-to-lock type mounting bracket.



2.2.3.9 Shock mounts. Shock mounts should be used, as necessary, to:

a. Eliminate vibration fluctuations in displays, markings, etc.

b. Protect fragile or vibration-sensitive components and instruments.

c. Control sources of high or dangerous noise and vibration.

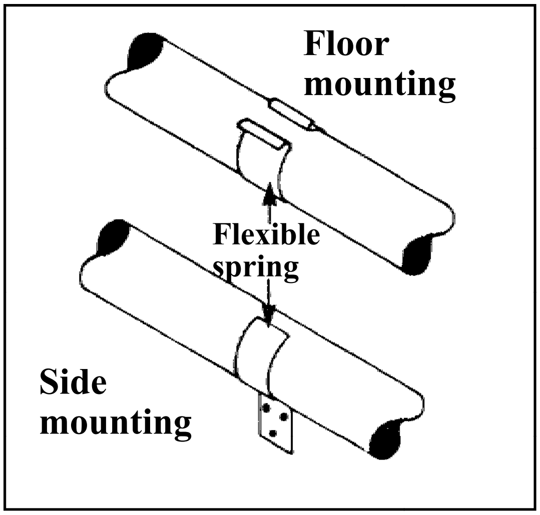
2.2.3.10 Hinged bars. Hinged bars are useful for tying down and -permitting access to a number of small components at one time. Such bars should be padded or provided with springs as necessary to prevent damage to the items secured.

2.2.4.11 Flexible mounting. Where rigid mounting may result in damage to components, a device which permits some flexibility should be used. For example, a frequent cause of thread-stripping of "T" fittings is the rigid mounting of the fittings.

2.2.3.12 Blind mounting. Where blind mounting is required, the inaccessible side should be secured with mounts which will allow exceptionally easy mating and do not require access (such as friction lugs, torque and groove fittings, etc.)

2.2.3.13 Spring clamps. Spring clamps should be used to mount tubing, pipes, or wiring which may require frequent removal and replacement. For overhead mounting, a spring clamp similar to that used for floor mounting should be used, but a hinged locking latch should be provided over the open side of the clamp to prevent accidents (See Figure 2.2.10).

Figure 2.2.10. Use of spring clamp mounts.



2.2.4 Configuring. The configuration of equipment, assemblies, and/or components should be based on logical flow, circuit logic, component relationships (in order of preference), or some combination of the forgoing.

2.2.4.1 Logical flow configuration. Components are placed so that they are arranged as they are functionally used; e.g. in a functionally logical order. In undertaking this method the following guidelines should be followed

a. Circuits, parts, and components should be placed and located in an arrangement parallel to their functional relationships,

b. Methods and subassemblies should be selected so that only single input and output checks are necessary to isolate a fault within an item.

c. The unidirectional signal flow within a given piece of equipment is clearly indicated.

2.2.4.2 Circuit logic configuration. In this method, equipment is arranged as it would in an electrical logic flow (e.g. as the electron flows). In undertaking this method the following guidelines should be followed:

a. All parts of a given circuit, or of logically or generally related groups of parts, should be located in a common area.

b. Each circuit should be placed in a separate module.

c. The circuit should consist of a single terminal board or plug-in type module when possible.

d. Plug-in printed circuit boards should be structurally rigid, easily identified and easy to remove and replace.

2.2.4.3 Component configuration. Similar components have similar or adjoining places in the arrangement. In undertaking this method the following guidelines should be followed:

a. All similar components should be found in one place on the equipment.

b. Relays should be located in a single or small number of relay panels.

c. Resistors, capacitors, etc. should be segregated in a minimum number of locations on subassemblies or terminal boards.

d. Inexpensive components should be placed on separate, plug-in type boards mounted beneath the chassis to facilitate disposal at failure.

e. Multiples of similar parts that are likely to require replacement about the same time should be grouped together.

f. Components should be segregated based on significant variations in the maintenance tasks which are required. For example, items which must be cleaned by different methods (steam, gunk, solvent, etc.) should be packaged so cleaning is possible with minimal masking.

2.3 Labeling, marking, and coding

In addition to the guidelines listed below, labels, legends, placards, signs, markings, and codes should conform to the DOE standards and guidelines provided in NUREG 0700 (Rev 0) or MIL-STD-1472F.

2.3.1 Goals for labeling, marking, and coding. Labeling, marking and coding are used to

a. Identify the purpose or function of specific units, parts, controls, displays, test points, etc.

b. Present critical information for equipment maintenance procedures.

c. Present safety information, (i.e., cautions and warnings which lead to prevention or avoidance of hazards to maintenance personnel or damage to equipment).

2.3.2 Hardware identification. Hardware identification (labels, legends, placards, signs, markings, codes, or combinations of these) should be provided whenever personnel must identify, interpret, follow procedures, or avoid hazards.

2.3.2.1 Identification characteristics. Identification characteristics should be consistent with factors such as

a. Accuracy of identification required.

b. Time available for recognition or other responses.

c. Location and distance at which identification must be read.

d. Level and color of illumination.

e. Criticality of the function identified.

f. Label design and identifying information used within and between systems.

2.3.2.2 Multi-unit facilities. Where mistakes might occur, identifiers used in multi-unit facilities should be sufficiently distinctive to prevent confusing one unit with another.

2.3.2.3 Administrative control of hardware identification.

All labeling, marking, coding additions and modifications should be governed by administrative procedures.

2.3.2.3.1 Examination of labels and other identifiers. Periodic facility-wide surveillance checks should be made to ensure that all equipment and facilities are properly identified, and that informal labels added by operators and maintenance technicians are systematically replaced with accurate, easily read, high-contrast, permanent labels and tags.

2.3.2.3.2 Inspection of labels and identifiers by maintainers. Maintenance procedures should include a step to check for the availability of identification tags and labels as part of the system restoration process.

2.3.2.3.3 Identifier replacement subsequent to maintenance tasks. Quality control inspection procedures should include measures to ensure that identification tags and labels are replaced when necessary subsequent to maintenance tasks.

2.3.2.4 Equipment name plate. Equipment (except detailed assemblies and parts) should be identified with a securely attached, permanent, non-fading, oil-, gasoline-, and corrosion-resistant name plate. The name plate should be permanently and legibly marked with the following information:

a. Contract order.

b. Item name (noun first).

c. Specification number.

d. Manufacturer's part no. (or Government Standard Part No.).

e. Serial no. (when available).

f. Stock no. (when available).

g. Manufacturer's name and address. Manufacturers' logos should be eliminated or removed if they interfere with identifying or interpreting equipment functions.

2.3.2.5 Other equipment descriptive information. Equipment labeling should also include pertinent information about its function, capacity, capabilities, limits, ranges, frequency, and current requirements. Weight, rpm, horsepower, and other basic information should be included.

2.3.2.6 Electrical assembly connections. Electrical assembly connections should be marked according to MIL-STD-195, or comparable industry standards.

2.3.2.7 Insulated wire. Insulated wire should be color- or number-coded per MIL-STD-681, or comparable industry standards.

2.3.2.8 Color coding. For color coding using surface colors, no more than nine easily distinguishable colors should be used for color-normal and color-deficient observers. Recommended surface colors are listed.

Color	Spec. No.	Color	Spec. No.
Red	1110	Gray	1625
Orange	1210	Buff	1745
Yellow	1310	White	1755
Blue	10B 7/6	Black	1770
Purple	2715		

*From Fed. Spec. li-C-595 except for blue, which is from Munsell (1942).

2.3.2.9 Instruction plates. Instruction plates should describe or illustrate, the following as necessary

a. Basic operating instructions.

b. Calibration data and adjustment instruction.

c. Simple wiring or fluid flow diagrams.

d. Warning and safety precautions.

e. Test point locations.

f. Transistor and other pertinent electronic equipment.

g. Valve settings.

h. Type of fuels, oils, or greases applicable.

i. Other similar data for routine preventive maintenance.

2.3.2.9.1 Visibility. Permanent instruction plates should be attached in an easily visible and suitable location.

2.3.2.10 Permanent pocket. Where required, a permanent pocket or similar device should be attached to equipment for containing various maintenance aids such as signal flow diagrams, diagnostic procedures, pictorial presentations, calibration and maintenance records.

2.3.2.11 Parts and reference designations. MIL-STD-16 should be used in the formation and application of alpha-numeric parts and reference designations. The unit numbering method should be used for all new equipment.

2.3.2.11.1 Location of parts and reference designations. Parts and reference designations should be located as follows

a. Designation markings on equipment should be placed on or immediately adjacent to the part to which it pertains in a consistent manner.

b. Small electrical parts (e.g., resistors, capacitors, terminals) affixed to mounting boards should be identified by marking on the boards.

c. Multiple terminals should be identified by labels on the component or adjacent chassis.

d. Parts which protrude from an electronic chassis should be labeled on the wiring side.

e. Terminals of transformers, relays, capacitors, and all socket-mounted items, except standard vacuum tubes, should be marked adjacent to each terminal.

f. Receptacles for plugs, modules and units, and similar parts that are accessible from the top side should have both bottom and top side identification.

g. Markings should be placed so that they are visible without removing parts.

h. Markings should be oriented so that they can be read with the unit in the normal, installed position.

2.3.2.11.2 Marking and identifying parts. Parts should be marked or identified as follows:

a. Parts should be identified by designations which refer to parts descriptions on a drawing or schematic.

b. Wires, sockets, plugs, receptacles, and similar parts should carry designations from wiring diagrams prepared in accordance with the schematic diagrams.

c. Replaceable mechanical parts should have standard designations.

d. Semi-fixed electrical items (e.g., fuses, ferrule clip-mounted resistors) should carry the electrical rating in addition to the standard designation.

e. Critical polarity and impedance ratings should be shown on items having these ratings.

f. If an assembly is complex, a concise wiring diagram should be affixed to the unit.

g. Markings should be accurate and sufficient to identify the referenced part.

h. Markings should be permanent enough to last the life of the equipment.

i. Stacked parts and modules should be marked so that they can be individually recognized.

j. Individually enclosed or shielded parts should be identified on the outside of the enclosure.

l. Fixed and removable parts of a plug-in assembly should be marked identically.

m. Individual sections of dual parts should be clearly identified.

2.3.2.12 Labels. Labels are lettered indications of the name, identifying number, and function of equipment which should be affixed on or near the relevant equipment. It is usually better to over-label than under-label, especially in cases where equipment has operation and instruction manuals.

2.3.2.12.1 Label color combinations. Color combinations of printing and background should be provided which will maximize legibility. Best color combinations for labels, in descending order, are:

- Blue on white
- Black on yellow
- Green on white
- Black on white
- Green on red
- Red on yellow.

See 2.3.2.8 for recommended surface color specifications.

2.3.2.12.2 Color coding. If color coding of labels is necessary, colors should be selected on the basis of recognizable differences. The following colors are particularly suitable for surface coding because they are easily recognizable by both normal and color deficient persons.

Color	FED-STD-595 Spec. No.
Black	1770
White	1755
Yellow	1310
Blue	1OB 7/6

2.3.2.12.3 Label Design. Label design should conform to good label practices as outlined in MIL-STD-1472F section 5.5, Design of label characters should conform to the following:

a. Characters should be black where the ambient illumination is above 10 lux (0.9 ft.-c), black characters should be provided against a light background.

b. Style of characters should be a san serif font, and large enough to provide at least 20 minutes of visual arc from the normal reading position.

c. Should be in all capitals, except where lower case or punctuation marks are indigenous to the item being identified.

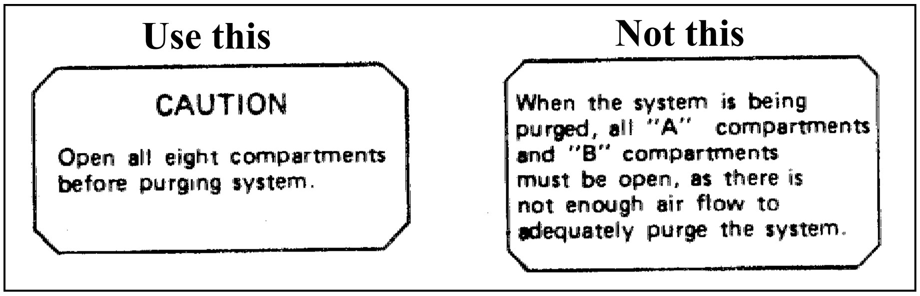
d. Letter width should be 3/5 to 4/5 of the height except for single stroke characters (e.g. I or 1) which should be between 1/10 and 1/5 of the height.

2.3.2.12.4 Label composition. Label composition should conform to the following

a. Labels should be brief yet explanatory. Brief, familiar words should be used.

b. Abbreviations should be used only when known to all personnel. Key action words should be used instead of abbreviations when possible (See Figure 2.3.1, Label composition).

Figure 2.3.1. Label Composition.



c. Labels containing a number of steps to be performed sequentially should itemize the steps rather than present them in paragraph form (See Figure 2.3.2, Label containing usable sequence of steps).

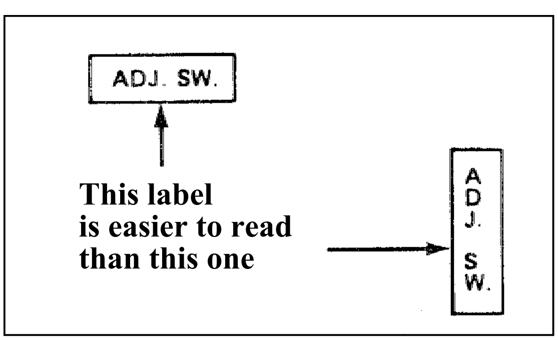
Figure 2.3.2. Label containing usable sequence of step.

Use this	Not this
ASSEMBLING INJECTOR TAPPING TOOL	**ASSEMBLING INJECTOR TAPPING TOOL**
1. Replace defective part. 2. Install nut and washer on hand-tap shank. 3. Install rollpin on nut. 4. Check tapping tool for proper operation.	First, replace the defective part from supply. Install nut and washer on hand-tap shank. Next, place the rollpin in the nut. Upon completion, check the tapping tool for proper operation.

d. Codes and labels on equipment should be consistent with instruction manuals and equipment parts catalogs.

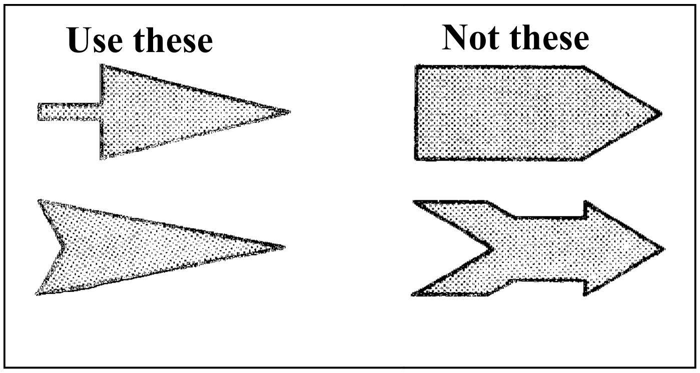
e. Labels should read horizontally rather than vertically (See Figure 2.3.3, Use of horizontal rather than vertical labeling).

Figure 2.3.3. Use of Horizontal rather than Vertical Labeling.



f. Arrows used in labels should be clearly recognizable and easily identifiable when read from a distance. It is easier to interpret the direction of arrows with sharp angles and clean lines from a distance than arrows which use wide angles and broader overall width-to-length ratios (See Figure 2.3.4, Use of arrows with narrow width-to-length ratios).

Figure 2.3.4. Use of arrows with narrow width-to-length ratios.



g. Wording of labels should be chosen based on the operator's familiarity with them when possible. Common technical terms, if familiar to the maintenance technician, may be used as necessary. Abstract symbols (e.g., squares and Greek letters) should be used only if they are understood by all intended readers.

2.3.2.12.5 Label orientation. Labels should be oriented horizontally so that they may be read quickly from left to right. Vertical orientation should be used only when labels are not critical for personal safety or performance. When vertical labeling is used, (for example, for vertical meters, pipes, and conduits), the characters are be oriented vertically and read from top to bottom.

2.3.2.12.6 Location. Labels should be placed on or very near the items they identify to eliminate confusion with other items and labels.

a. If there is a possibility of confusion, label brackets, association tie lines, or some other method to make the association more apparent should be used.

b. Labels should be located so as not to obscure any other information needed by the operator.

c. Controls and other panel elements should not obscure labels.

d. Labels will not be placed where a control adjustment or position will obscure it.

2.3.2.12.7 Location to avoid being obscured by grease, filings, dirt or moisture. Labels should be located so they will not be obscured by grease, filings, dirt, or moisture. Where a label may be particularly susceptible to being covered by material falling from above, it may be mounted vertically (See Figure 2.2.5, Label positioning).

2.3.2.12.8 Other considerations for label location. Other determinants of label location are as follows:

a. Labels used on similar pieces of equipment should be placed in relatively a similar position.

b. Labels should not be hidden from view, crowd each other, or obscure other useful information.

c. Parts that look similar but are not physically interchangeable and cannot be physically, keyed should be labeled. Labels should be located on several sides of the part, if possible, with precautions about interchangebility or use-distinctive markings that correspond with markings or the assembly in which the part will be placed.

d. Labels or other markings should be provided to indicate control positions. A rider may be attached to the shaft of a valve to indicate position. Labels may also include calibration data, where applicable (See Figure 2.3.6, Component labeling to preclude operator error and Figure 2.3.7 Label indicating control positions).

e. Labels should be placed consistently in the same place in relation to the instrumentation on a panel. Labels normally should be placed above the controls and displays they describe. If a panel is above eye level, labels may be located below if the visibility is enhanced (See Figure 2.3.8, Relating labels to controls and displays).

Figure 2.3.5. Label positioning

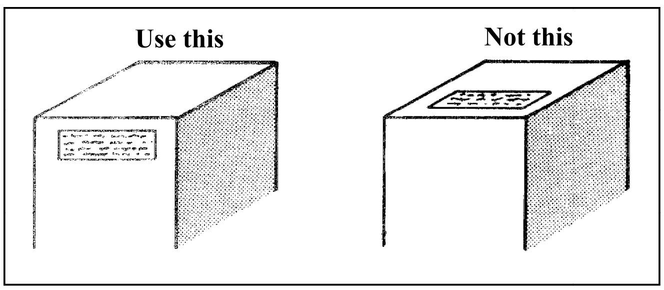


Figure 2.3.6. Component labeling to preclude operating error.

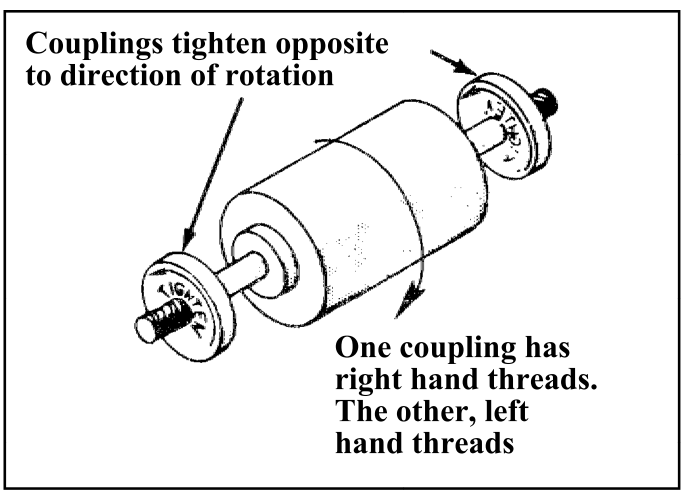


Figure 2.3.7. Label indicating control positions.

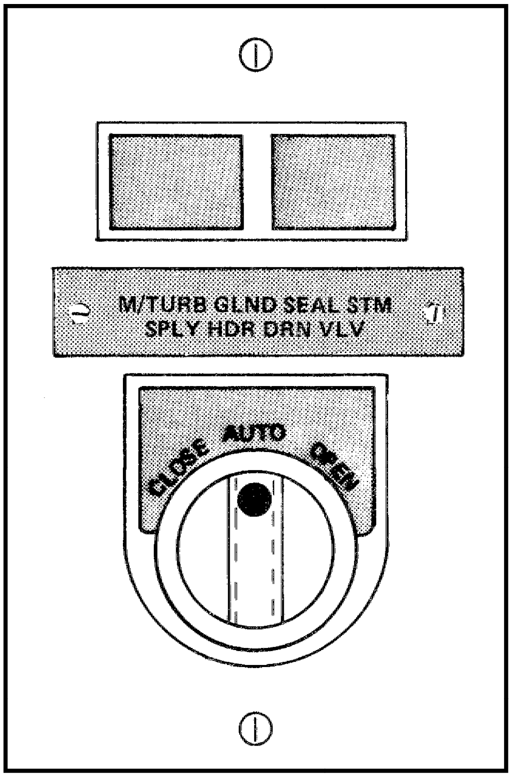
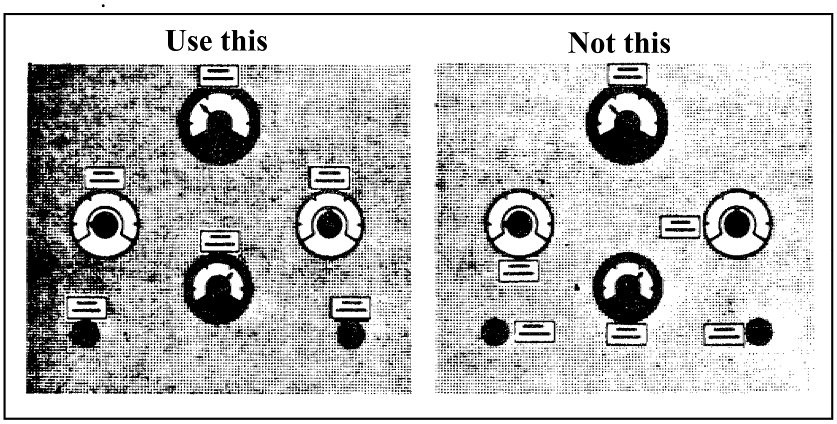


Figure 2.3.8. Relating labels to controls and displays (Ex. 1.3.11)



f. Functionally grouped controls and displays should be identified by labels located above the functional groups which they identify. If a functional group is demarcated by a line, the label should be centered at the top of the group either in a break in the line, or just below the line. When colored pads are used, the label should be centered at the top within the pad area.

2.3.2.13 Mounting of labels. Labels should be affixed securely in place in a manner to prevent their loss, damage, slippage, or accidental removal; however, the means used to mount the labels should permit their removal when necessary without damaging the surface they were attached to. Tamperproof adhesives such as double-backed foam tape which fractures when the label is removed may be used to hinder unauthorized repositioning of the labels. Labels on equipment should be attached to a structural member that is not removed during equipment servicing or routine maintenance.

2.3.2.14 Tags

2.3.2.14.1 Tag orientation. A tag is a labeling device attached to equipment for special considerations. Tags are often used to indicate some special equipment state, such as inoperability. To prevent personnel from picking them up and reorienting them, tags should be hung so that the information is displayed horizontally. Labeling both sides of a tag may also be used to decrease the need for user manipulation.

2.3.2.14.2 Tag mounting. Tags should be attached securely to equipment components by means of durable stranded stainless steel cable, clamps or chains. Plastic ties are not recommended since the plastic may become brittle and break

2.3.2.14.3 Attaching Temporary tags. In attaching temporary tags to components, care should be taken to ensure that the tag will not damage the components, interfere with operational features, or obscure necessary information such as other labels or controls or displays, unless the intent of the tag is to indicate inoperability.

2.3.2.15 Warning labels and placards

2.3.2.15.1 Warning labels and placards indicating necessary use of technical manual. Warning labels should be installed whenever a maintenance technician must consult a technical manual before working on the equipment.

2.3.2.15.2 Use of warning labels and placards. The following are examples of specific applications in which warning labels and placards should be used:

a. WARNING PLACARDS-Warning placards should be mounted adjacent to any equipment which presents a hazard to personnel (e.g., from high voltage, heat, toxic vapors, explosion, ionizing radiation).

b. CENTER OF GRAVITY AND HEIGHT-Where applicable, the center of gravity and the weight of equipment should be marked.

c. WEIGHT CAPACITY-The weight capacity should be indicated on stands, hoists, lifts, jacks, and similar weight-bearing equipment to prevent overloading.

d. IDENTIFICATION OF PROTECTIVE ITEMS - Operation and maintenance areas requiring special clothing, tools, or equipment (e.g., insulated shoes, gloves, suits, respirators) should be specifically and conspicuously identified.

e. "NO-STEP" MARKINGS-These markings should be provided, when necessary, to prevent injury to personnel or damage to equipment.

f. ELECTRICAL LABELS-All receptacles should be marked with their voltage, phase, and frequency characteristics as appropriate.

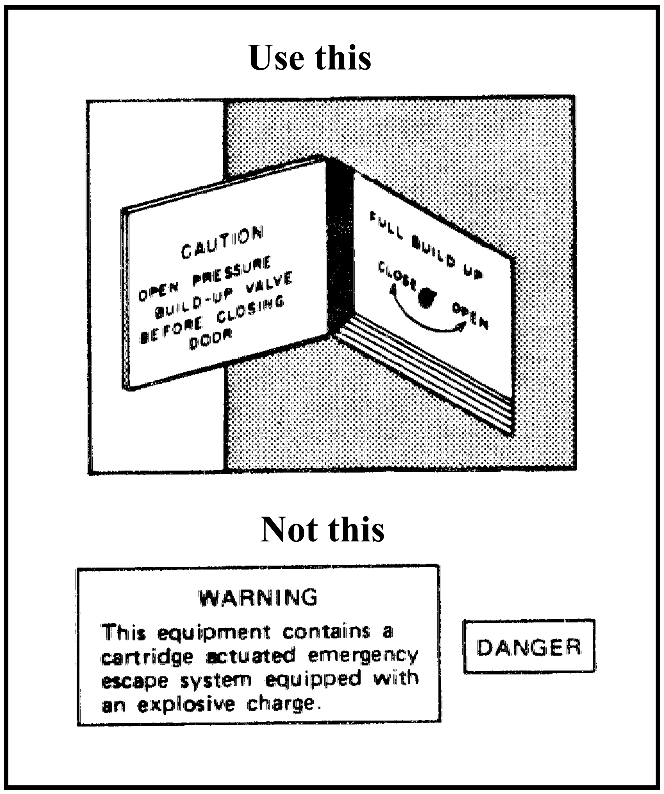
g. HAND GRASP AREAS-Hand grasp areas should be conspicuously and unambiguously identified on equipment.

h. PIPE, HOSE, AND TUBE LINE IDENTIFICATION-Pipe, hose, and tube lines for liquids, gas, steam, etc. should be clearly and unambiguously coded for contents, pressure, heat, cold, or other specific hazardous properties. MIL-STD-1247 or comparable industry standards should be used for further guidance.

i. LONG RUN CABLES, PLUMBING LINES, AND CONDUITS-These should be clearly identified or coded, not only at the terminal ends but also at periodic distances between ends to facilitate accurate tracing of lines.

2.3.2.15.3 Information content. Warning labels and placards should be as informative as possible given space constraints present (See Figure 2.3.9, Examples of warning labels).

Figure 2.3.9. Examples of warning labels.



2.3.2.15.4 Content of warning labels. Though content of warning labels will vary, they should inform the technician of (1.3.4.4.c):

a. Why a dangerous condition exists.

b. Places to avoid.

c. Behavior to avoid.

d. Sequence to follow to obviate the danger.

e. Where to refer for more information.

f. Precautions or procedures for hazards.

g. What to do in case of injury.

2.3.2.15.5 High visibility warnings. High visibility warnings should be erected when personnel may be subjected to harmful noise or a sudden increase or decrease in pressure or exposure to radiation.

2.3.2.15.6 Tolerance or safety load limits. Tolerance or safety load limits of an apparatus should be permanently displayed.

2.3.2.15.7 Format of warning signs and placards. Safety signs should be formatted to command the observers attention and to follow standard coding conventions:

a. Caution signs (alert for potential danger) should use black on yellow (though the word "caution is done with yellow characters on a black background).

b. Warning signs (notice of actual danger) should use a white on red (most common or red on white except when those signs are already standardized for the environment, i.e., magenta and yellow, or black and yellow for radiation areas and black on yellow for construction areas).

c. Safety equipment, including first aid supplies, should be identified using green letters and symbols on a white background or vice versa.

d. Radiation hazards shall be identified using magenta characters and symbols on a yellow background.

e. General advisory signs should be formed with white on black and black on white character background combinations.

Note: Except for facility specific situations, most required industrial safety signs are commercially available and they adhere to OSHA guidelines (19CFR1910). MIL-STD-1472F provides greater detail regarding format protocols for safety signs.

2.4 Equipment accessibility

Equipment accessibility refers to the relative ease with which an assembly or component can be reached for repair, replacement, or servicing. If the steps required are few and simple and the component can be reached by a suitably clothed and equipped user with applicable 5th and 95th percentile body dimensions, then the component is accessible. Accesses include entrance doors, apertures, inspection windows, and lubrication, pneumatic, and hydraulic servicing points.

Personnel workspace and accessibility are also covered in Section 3.1, Workspace and operations in non-workshop areas, of this document.

2.4.1 Goals of equipment accessibility. Accesses should be designed to make the repair or servicing operation as simple as possible. Accesses should provide:

a. Sufficient clearance to use the tools needed to complete the task.

b. Adequate space to permit convenient removal and replacement of components.

c. Adequate visual exposure to the task area.

2.4.2 Requirement for access. Access must be provided to all points, items which require or may require testing, servicing, adjusting, removal, replacement, or repair. In addition, formal access should be provided to equipment requiring maintenance must be provided to avoid use of expedient handholds and expedient footholds that may lead to equipment damage.

2.4.2.1 Rear access. Sliding, rotating or hinged equipment requiring rear access should be free to open or rotate their full distance and to remain in the open position without being supported by hand. Rear access should also be provided to plug connectors for test points, soldering and pin removal where connectors require such operations.

2.4.2.2 Accessibility priority. Components critical for system performance and safety which require rapid maintenance as well as those requiring the most frequent access should have the greatest ease of accessibility.

2.4.3. Facilitating access. Where possible and feasible, accessibility should be facilitated by:

a. Using hinged or removable chassis.

b. Designing major units and assemblies (especially engines, turbines, etc.) with removable housings to allow for complete inspections.

c. Correlating the design of unit accessibility features with the accessibility requirements of the overall system.

2.4.4 Obstruction. Structural members and permanently installed equipment should not visually or physically obstruct adjustment, servicing, removal of replaceable equipment or other required maintenance tasks. Panels, cases, and covers removed to access equipment should have the same accessibility as replaceable equipment.

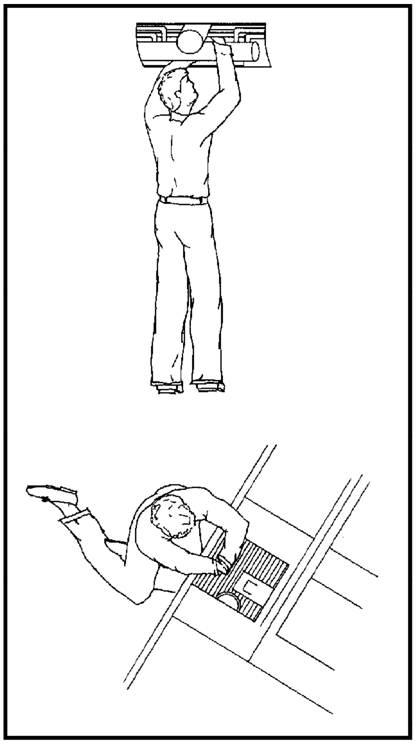
2.4.5 Packaging elements to avoid equipment or system disassembly. Elements or equipment within systems should be packaged so that removal of one malfunctioning element does not involve disassembling or damaging adjacent components. Elements that may have to be removed from a system should be situated so that they can be moved without interference in straight horizontal and vertical paths.

2.4.6 Use of accesses. Accesses should be designed and located, covered, and fastened to avoid the need for removing components, wires, etc. to reach the item requiring maintenance. Items that require visual inspection (e.g., hydraulic reservoirs, gauges) should be located so they can be observed without the removal of panels or other components.

2.4.7 General maintenance clearance. A nominal 914 mm (36 in.) maintenance clearance should be provided around all major system components and piping of 610 mm (24 in.) diameter and larger for general clearance.

2.4.8 Comfortable working positions. Systems should be designed and routed so that maintenance personnel can maneuver themselves around the systems and assume comfortable working positions. Forcing maintainers to assume a working position close to the floor should be avoided. Platforms, catwalks, and scaffolds should be provided to prevent the technician from having to work overhead with outstretched arms (See also Figure 2.4.1)

Figure 2.4.1. Poor working positions to be avoided.



2.4.9 Routing systems to allow use of lifting and movement aids. Systems should be routed around access paths and envelopes such as overhead cranes, other movement paths and equipment-hatch removal envelopes. Overhead clearance should be a minimum of 2.13 m (7 ft) above the floor for passage of personnel and removal of equipment. Where applicable, sufficient clearance should be provided to permit the use of vehicular or other transportation aids near the system.

2.4.10 Easy equipment access. Locations of grease fittings, adjustment points, test points, isolation points, and fill-and drain points on equipment should be positioned for easy access. Sufficient clearance should be provided around connectors and other equipment components requiring manual manipulations to allow firm grasping for mating and de-mating. Heavy units that are to be pulled out of their installed position should be mounted on rollers or slides when feasible.

2.4.10.1 Lubrication. Configuration of equipment containing mechanical items requiring lubrication should permit both lubrication and checking of lubricant levels without disassembly.

a. Extended fittings should be provided to lubricant ports that would not otherwise be readily accessible or visible.

b. Permanently lubricated items for which the lubricant lasts the life of the items are excluded.

c. A clear indication of completion of lube servicing should be provided to ensure proper servicing level.

d. Lube fittings should be sized to prevent cross coupling with improper lube servicing devices.

2.4.10.1.1 Labeling for lubrication. Where lubrication is required, type of lubricant and required frequency of lubrication should be specified on a label mounted at or near the lube port or grease fitting. A lubrication chart of permanent construction should be mounted at the operator station of the equipment; individual labels should not be required when the equipment has only one type of fitting and uses only one type of lubricant.

2.4.10.2 Lines and Cables

For guidelines related to line and cable access see Section 2.6, Line and cable design, in this document.

2.4.10.3 Fuses and circuit breakers. Fuses and circuit breakers should be readily accessible for removal , replacement, and resetting. The condition of fuses should be readily discernible without having to remove the fuse.

2.4.11 Determinants of type, shape location, and size of access. The type, shape, location, and size of accesses should be determined by thoroughly understanding

a. Operational location, setting, and environment of the unit.

b. Frequency with which the access must be entered.

c. Maintenance functions to be performed through the access.

d. Time requirements for the performance of these functions.

e. Types of tools and accessories required by these functions.

f. Work clearances required for performance of these functions.

g. Type of clothing likely to be worn by the technician.

h. Distance to which the technician must reach within the access.

i. Visual requirements of the technician in performing the task.

j. Configuration of items and elements, etc. behind the access.

k. Mounting of items, units, and elements behind the access.

1. Hazards involved in or related to use of the access.

m. Size, shape, weight, and clearance requirements of logical combinations of humans, tools, units, etc. that must enter the access.

2.4.12 Type of equipment access

2.4.12.1 Exposing equipment for maintenance without coverings or housings. Equipment should be left exposed (without coverings or housings) for maintenance whenever permitted by structural, environmental, operational, and safety conditions. This pertains especially to test and service points, maintenance controls and displays, and rack mounted units.

2.4.12.2 One cover. Access to inspect or replace an item should not require removal of more than one access cover.

2.4.12.3 Guidance for selecting type of equipment accesses.

Table 2.4.1, Equipment access selection criteria, provides guidance for selecting equipment accesses

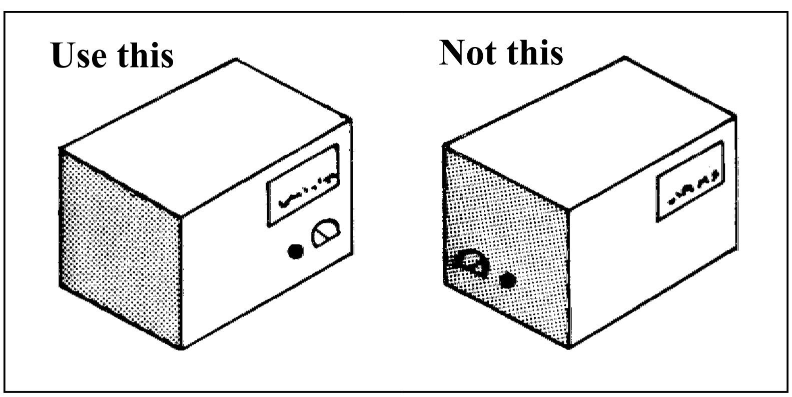
Desirability	For Physical Access	For Visual Inspection Only	For test and Service Equipment
Most Desirable	Opening with no Cover (Where contamination or other hazards are not present) or pullout shelves or drawers.	Opening with no cover	Opening with no cover
Desirable	Hinged door (if dirt, moisture, or other foreign materials must be kept out)	Plastic window (if dirt, moisture or other foreign materials must be kept out).	Spring-loaded sliding cap (if dirt, moisture or other foreign materials must be kept out)
Less Desirable	Removable panel with captive quick-opening fasteners (if there is not enough room for hinged door	Break resistant glass (if plastic will not stand up under physical wear or contact with solvents)	
Least Desirable	Removable panel with smallest number of largest screws that will meet requirements (if needed for stress or safety reasons)	Cover plat with smallest number of largest screws that will meet requirements (if needed for stress or safety reasons)	Removable panel with smallest number of largest screws that will meet requirements (if needed for stress or safety reasons)

2.5 Controls, displays, and protective devices.

2.5.1 Maintenance controls

2.5.1.1 Location of internal controls. Internal controls should be located so the technician will be able to manipulate the control while at the same time observe its related display.

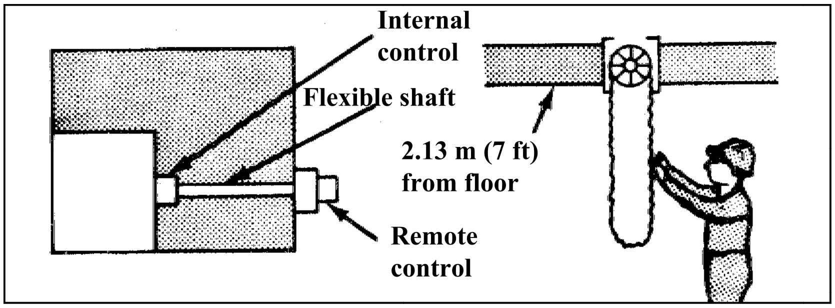
Figure 2.5.1. Locating internal controls.



NOTE: This design should be used only when the access, as shown, does not interfere with normal operation of the equipment.

2.5.1.2 Use of remote control. If it is impractical to provide an access to an internally located control, a remote control should be provided (See also Figure 2.5.2, Remote controls).

Figure 2.5.2. Remote controls.



2.5.1.3 Emergency controls. Emergency controls which may be operated by the maintainer should be located so that they may be activated from any position in the maintenance work area. if the work area is especially large and access to a single emergency control is difficult, duplicate controls should be provided.

2.5.1.4 Guarding sensitive controls and instrumentation. Sensitive controls and instrumentation should be protected from tampering or accidental movement. Techniques that are commonly used to provide varying degrees of protection are listed below:

a. Enclosures such as cabinets or cages which may be locked where desirable to provide a relatively high level of protection. For highly critical instrument systems, alarms to discourage unauthorized entry may be used to provide a further level of protection.

b. Barriers may be placed around vulnerable instrumentation and controls to provide a degree of protection while not impeding visual or reach access.

c. Controls with built-in locking features may be provided to minimize tampering or accidental disturbance (See also Figure 2.5.3, Controls with built-in locking provisions).

d. Wire-locked controls should be considered for highly critical control settings to prevent accidental disturbance or activation.

e. Tool-actuated controls for calibration setting or other functions may be used to discourage tampering (See also Figure 2.5.4, Tool actuated control).

Figure 2.5.3. Controls with built in locking provisions.

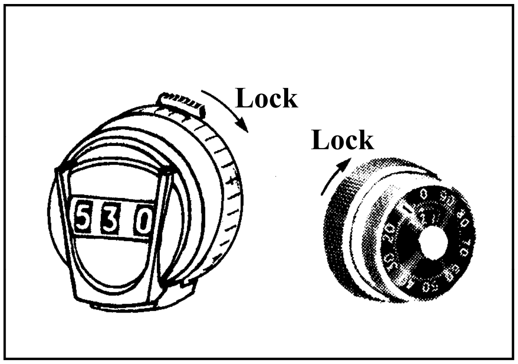
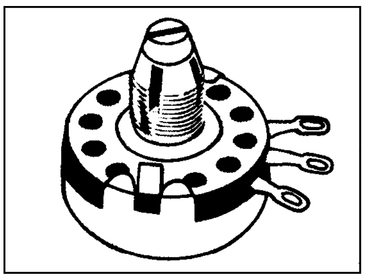


Figure 2.5.4. Tool actuated control.



f. Covers may be provided for controls that are vulnerable where accidental activation might have serious consequences (See also Figure 2.5.5, Covers for individual controls).

g. Controls, instrument panels, and gauges may be recessed to prevent accidental damage or disturbance; conversely, raised barriers may be provided for these items (See also Figure 2.5.6, Examples of recessed controls and panels and use of raised barriers).

h. Controls that offer resistance to easy movements may be used to avoid accidental activation

i. Attention getting placards and labels may be used to alert personnel to the possibility of equipment damage or inadvertent control activation.

j. Plant personnel and contractors should be trained to appreciate the significance and vulnerabilities of equipment and the consequences of equipment abuse.

Figure 2.5.5. Covers for individual controls.

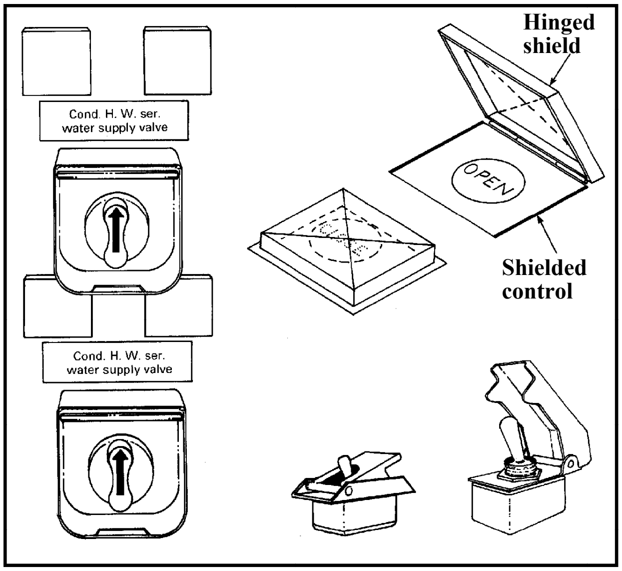
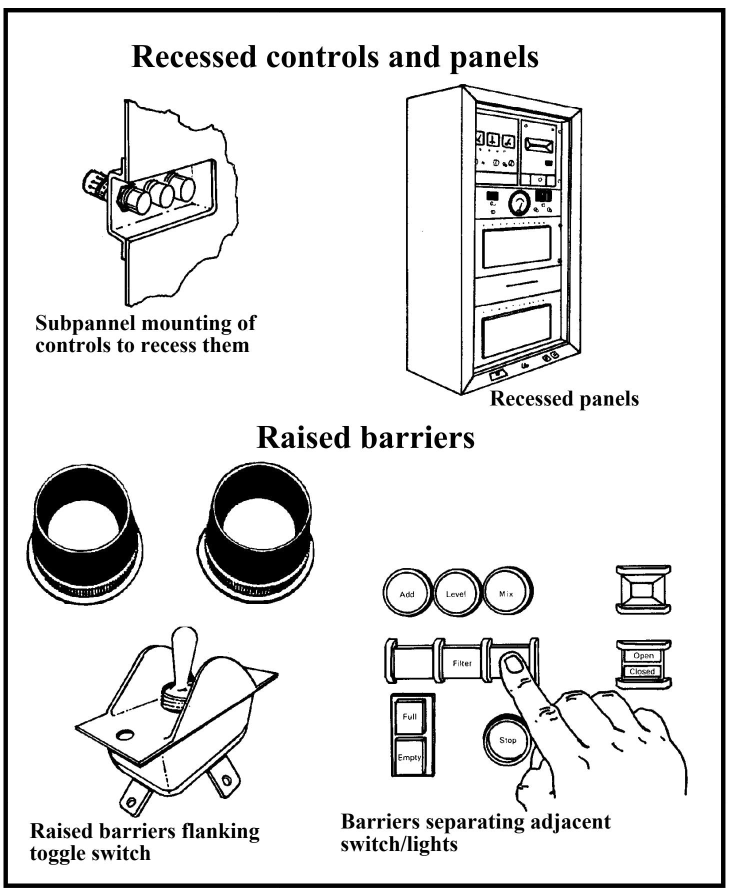


Figure 2.5.6. Examples of recessed controls and panels and use of raised barriers.



2.5.1.5 Tool-operated controls. Tool-operated controls should be designed to be operated with hand tools from the technician's standard tool kit. If a special tool is required, it should be attached near the control which it operates.

2.5.1.6 Maintenance controls located on operator's panels. Maintenance controls located on operators' panels should be shielded with removable covers so as not to interfere with the operator's performance while remaining accessible to the maintenance technician.

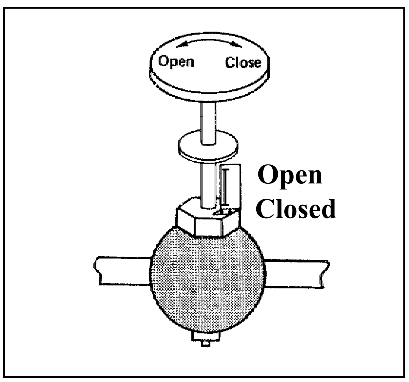
2.5.1.7 Valves

2.5.1.7.1 Tank and reservoir drain valves. Tank and reservoir drain valves should be located such that they may be removed from outside the tank or reservoir on the outside of the tank or reservoir so that the contents may be easily removed.

2.5.1.7.2 Direction of motion for rotary and hand wheel valve controls. Rotary and hand wheel valve controls should open the valve with a counterclockwise motion.

2.5.1.7.3 Labeling valve controls. Labels or other marking devices should be provided to clearly designate the position of a valve control. Valve controls should be provided with double-edged arrows showing the direction of operations; they should be labeled at each end to indicate the functional result. A rider may be attached to the shaft with marks to indicate the fully opened and fully closed positions.

Figure 2.5.7. Valve control labels.



2.5.1.7.4 Circular handles. When circular handles are used they should have crowns or should employ concave areas or convex projections along the periphery of the handle.

2.5.1.7.5 Color-coding valves. Valves should be color-coded by content of the substance which they control (For examples see Table 2.5.1, Examples of valve color coding schemes).

2.5.1.7.6 Location of safety valves. Safety valves should be located where they are readily accessible, but where pop-off action will not injure personnel or damage equipment.

2.5.1.7.7 Labeling drain cocks or valves. Drain cocks or valves should be clearly labeled to indicate open and closed positions, and the direction of movement required to open.

Table 2.5.1. Examples of valve color-coding schemes.

Contents	USAF Color
Fuel	Red
Water injection	Red-gray-red
Lubrication	Yellow
Hydraulic	Blue & yellow
Pneumatic	Orange & blue
Instrument air	Orange & gray
Coolant	Blue
Breathing oxygen	Green
Air conditioning	Brown & gray
Fire protection	Brown
De-icing	Gray
Compressed gasses	Orange
Electrical conduit	Brown & orange

Table 2.5.1. Examples of valve color-coding schemes (continued).

Contents	Navy color for valve handwheels & operating levers	Fed. Std 595 Color Number and Chip	Navy standard for interior pipe lines*
Steam	White	17886	A and B
Potable-water	Dark blue	15044	A and B
Nitrogen	Light gray	16376	A
H.P. air	Dark gray	16081	A
L.P. air	Tan	10324	A
Oxygen	Light green	14449	Light green
Salt water	Dark green	14062	A and B
Fuel oil	Yellow	13538	A
Lube oil	Yellow	13538	A
Fire protection	Red	11105	A
Foam discharge	Striped red/green	11105/14062	A
Gasoline	Yellow	13538	Yellow
Feedwater	Light Blue	15200	A and B
Hydraulic	Orange	12246	A
Freon	Dark purple	17100	A
Hydrogen	Chartreuse	23814	A
Sewage	Gold	17043	A

* Applies to valves on weather decks and interior piping only.

2.5.1.7.8 Drain cock motion. Drain cocks should always close with clockwise motion and open with counterclockwise motion.

2.5.1.8 Selecting and calibrating functionally related variables. If the maintenance task is one of selecting and calibrating several functionally related variables, a single control and a switching mechanism should be provided to allow simultaneous or sequential operation of each variable as desired.

2.5.1.9.Circuit breaker controls. Toggle bat and legend switches may be used to actuate circuit breakers. Push-pull type switches should **not** be used

2.5.1.10 Calibration controls. Calibration or adjustment controls should be provided with appropriate stops to prevent damage to the system. Calibration controls should provide an indication (visual or audible) when stops are reached.(

2.5.1.11 Adjustment controls. Appropriate, readily discernible, real-time, feedback should be provided for all adjustment controls. Adjustment controls should be reversible without deadband, slop, time lag, response alteration, or striction.

2.5.2 Maintenance displays

2.5.2.1 Location. Displays should be located so they are easily visible to the technician and so that they may be read with the required degree of accuracy in the normal operating or servicing positions. Their placement should not require the maintainer to assume an uncomfortable, awkward, or unsafe position.

2.5.2.2 Combining operator/maintainer information. Operator and maintainer information should not be combined in a single display unless the information content and format are well suited to, and time compatible for, both users.

2.5.2.3 Maintenance displays located on operator's panel. If maintenance and operator displays must be located on the operator's panel, maintenance displays should be separated and grouped away from operator displays.

2.5.2.4 Transilluminated displays (simple indicator lights, legend lights, and transilluminated panel assemblies)

2.5.2.4.1 Lamp redundancy. Incandescent display lamps should incorporate filament redundancy or dual lamps. When one filament or bulb fails, the intensity of the light should decrease sufficiently to indicate the need for lamp replacement, but not so much as to degrade the ability to determine its status.

2.5.2.4.2 Lamp testing. When display lights using incandescent bulbs are installed on a control panel, a master light test control should be incorporated. This test control should not significantly lower the life or reliability of the lamps it is used to test. When applicable, the design should allow testing of all control panels at one time. Panels containing three or fewer lights may be designed for individual press-to-test bulb testing. Circuitry should be designed to test the operation of the total indicator circuit. If dark adaptation is a factor, a means for reducing total indicator light brightness during test operation should be provided. (Note LED indicator lights with 100,000 hours or longer mean time between failure do not require this lamp test capability.)

2.5.2.4.3 Lamp removal method. Where possible, lamps should be removable and replaceable from the front of the display panel. The procedure for lamp removal and replacement should not require the use of tools and should be easily and rapidly accomplished.

2.5.2.4.4 Lamp removal safety. Display circuit design should permit lamp removal and replacement while power is applied without causing failure of indicator circuit components, or without imposing personnel safety hazards.

2.5.2.4.5 Display covers. If design of legend screen or display covers does not prevent inadvertent interchange, a means for checking the covers after installation should be provided to ensure that they are properly installed.

2.5.2.5 Instrumentation. Instrumentation should be designed for mounting and removal from a front panel.

2.5.2.6 Grouping. All maintenance displays which are relevant to a particular task should be grouped together and observable to the technician while performing the task.

2.5.2.7 Auditor warnings. Auditory as well as visual warnings should be provided to indicate malfunctions when maintenance must be performed in an area with a high degree of ambient illumination. Visual and auditory displays should operate on separate circuits.

2.5.2.8 Auditory warnings for critical malfunctions. If equipment is not regularly monitored an audio alarm should be provided to indicate malfunctions or conditions that would cause personnel injury or equipment damage. If auditory alarms would compromise covert operation of equipment, alerting should be through a visual display.

2.5.2.9 Power failure. Means of indicating power failure or interruption should be provided.

2.5.2.10 Indicating tripped circuit breaker. Means of indicating a "tripped circuit breaker" should be provided.

2.5.2.11 Out-of-tolerance. A display shall be provided to indicate when an equipment item has failed or is not operating within tolerance limits.

2.5.2.12 Instrument amplifiers. Instrument amplifiers should be located as close as possible to their indicators, which will require only one technician to make the needed calibrations.

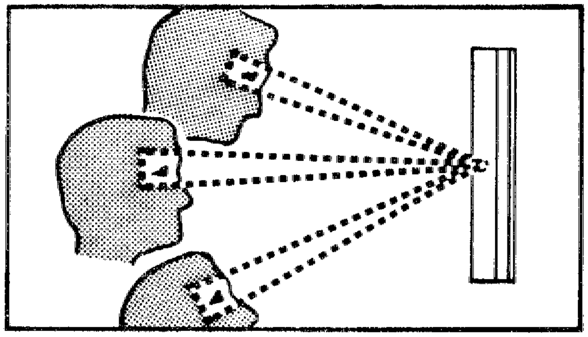
2.5.2.13 Liquid level indicators. Liquid level indicators should be located so that a minimum of visual parallax is present.

2.5.2.13.1 Use of liquid level indicators. Liquid level indicators should be used for oil tanks or similar reservoirs so that maintenance technicians can tell whether the reservoirs are filled properly.

2.5.2.13.2 Markings. Markings should be etched or painted on the glass of a liquid level indicator to eliminate the need for looking through the liquid to the scale.

2.5.2.14 Plug-in meters/displays. Plug-in meters/displays should be designed in such a way that they are visually accessible while performing a maintenance task (See also Figure 2.5.8, Minimizing visual parallax).

Figure 2.5.8. Minimizing visual parallax.



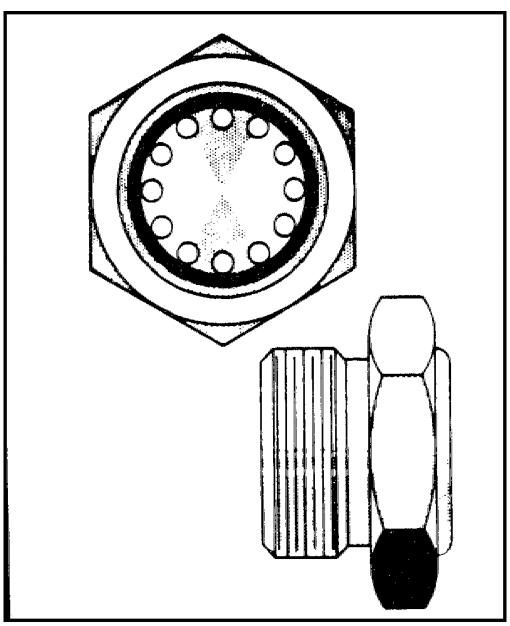
2.5.2.15 Direct-reading type indictors. Where possible, direct-reading type indicators should be used for hydraulic and other fluid tanks. For example, to facilitate quick visual inspection of the presence of oil in gear cases, oil level sight plugs may be used. This eliminates the need for dipsticks or fluid level gauges (See also Figure 2.5.9, Oil level sight plug).

2.5.2.16 Gauges and dipsticks

2.5.2.16.1 Gauges. Fluid level gauges are preferable to dipsticks because they allow rapid, immediate, and continuous inspection, and thus remove requirements for inspection tables.

2.5.2.16.2 Calibration units. If used, gauges or dipsticks should be calibrated in terms of functional units (quarts, pounds, gallons, etc.), rather than in general terms such as dry, low, add, etc. Where applicable, to avoid computational errors in weight and balance from a volumetric figure for fuel, a gauge should be provided which measures the weight of fuel in pounds.

Figure 2.5.9. Oil level sight plug.



2.5.2.16.3 Accessibility. If used, gauges or dipsticks should be immediately accessible.

2.8.2.16.4 Readability. Gauges or dipsticks should be quickly and easily read, i.e., there should be good contrast between the finish of the gauge and the fluid.

2.5.2.16.5 Guidance on acceptable levels. Fluid level indicators or labels should provide guidance on acceptable levels. Information about the effect on level of equipment operating condition(off, on, hot, cold, etc.) should be provided.

2.5.2.16.6 Zone banding. Zone banding e.g. use of pattern or color coding to show a critical range(s) on the scale should be considered when certain operating conditions should normally fall within this range

2.5.2.16.7 Gauges for condition of equipment. The lubrication system of an assembly should be provided with gauges necessary to keep the maintenance technician fully informed about the condition of the equipment, e.g., oil temperature and inlet and outlet pressure gauges should be provided.

2.5.2.16.8 Oil dipsticks. Oil dipsticks should be designed to:

a. Provide contrast between the finish of the dipstick gauge and clear thin oil.

b. Make interpolation of liquid level observations unnecessary by graduating the dipstick in increments.

2.5.2.17 Magnetic chip detectors. Magnetic chip detectors should be provided in lube systems rather than electrical detectors since the latter create maintenance problems.

2.5.3 Protective devices.

2.5.3.1 Operation. Protective devices such as vibration switches which shut down the equipment when vibration exceeds a set value may be used to reduce the consequence of system or equipment failure. Protective devices work in one of five ways:

- Draw attention to abnormal conditions (such as warning lights and audible alarms),
- Shut down equipment in event of failure,
- Eliminate or relieve abnormal conditions which follow a failure (safety valves, rupture disks),
- Take over from a device or equipment which has failed (redundant structural components), or
- Prevent dangerous situations from arising (guards)

2.5.3.2 Fail safe protective devices. Other things being equal, protective devices that are fail safe (e.g. where their failure is evident before what they are designed to protect against occurs) are preferred to those where failure is hidden.

2.5.3.3 Hidden malfunction. Functional reliability of protective devices where function is not evident can be increased by adding another device where necessary to make failure evident (for example, by using an alarm for a smoke detector to indicate that the battery is low), by using a more reliable protective device, by preventive or fault finding maintenance (for example, daily activating a testing circuit on a control panel to check to see that the alarm lights are working), or by using more than one protective device (e.g., redundancy).

2.5.3.4 Repair of protective devices. Where failure of the protected equipment or system may have serious consequences, when the protective device is being repaired the protected function should be shut down or alternative protection should be provided.

2.6 Line and cable design

Lines refer to any single length of pipe, wire, or tubing. Cables refer to a number of lines bound together within a single, permanent sheath.

2.6.1 General design objectives. Lines and cables should be selected, designed, bound, mounted, and routed to

a. Preclude wearout, breakage, or damage.

b. Facilitate logical and efficient divisions of maintenance responsibilities.

c. Allow for quick and easy:

- Troubleshooting, testing, checking and isolation of malfunctions.
- Tracing, removal, repair, and replacement.
- Connecting and disconnecting.

2.6.2 Standard sizes and varieties. Lines and cables should be designed to minimize the number of:

a. Types and varieties of lines and cables.

b. Different lengths of identical lines or cables.

c. Related connectors, fittings, and fixtures.

2.6.3 Shortest allowable runs. Lines and cables should be routed over the shortest runs allowable by lead, mounting, and other requirements.

2.6.4.Routing and accessibility.

2.6.4.1 Accessibility. Lines and cables should be routed and mounted to be accessible:

a. With minimum disassembly required or removal of other equipment or items.

b. At connect, test, mount, and splice points.

c. For complete removal and replacement in case of damage.

2.6.4.2 Clearance space around large piping. A nominal 914 mm (36 in.) clearance space should be provided around piping 610 mm (24 in.) in diameter or larger.

2.6.4.2.1 Accessibility in cable trays. Wire harness and fluid lines mounted in cable trays should be located for ready access.

2.6.4.3 Valves, thermowells, flow meters, and other instrumentation on piping runs. Components such as valves, thermowells, flow meters, and other instrumentation on piping runs should be reachable and within visual limits for inspection purposes. Due to size and weight, valves with diameters equal to or greater than 305 mm (12 in.) should be located as close to the floor as reasonable. Where it is necessary to place smaller valves or instrumentation in the overhead, formal means of access such as platforms and catwalks should be provided.

2.6.4.4 Placement of components for cables or piping runs. In general, components with the highest reliability should be placed highest in the overhead. Components which impact availability very little should be placed next highest in the overhead. Components impacting availability most or requiring frequent maintenance or inspection should be placed 0.91 - 1.52 m (3 - 5 ft) above floor level.

2.6.4.5 Welds. Sufficient space should be provided around piping and component welds to perform required examinations.

2.6.4.6 Routing for access around pumps and valves. Piping should be routed to leave access around pumps and valves for periodic operation tests.

2.6.4.7 Cables or lines routed through walls. Cables or lines that must be routed through walls should be designed for easy installation and removal without cutting and slicing lines.

2.6.4.8 High pressure or high voltage lines and cables. High pressure or high voltage lines and cables should be routed away from sensitive equipment, high temperature sources, work areas, controls, etc. where personnel may require access.

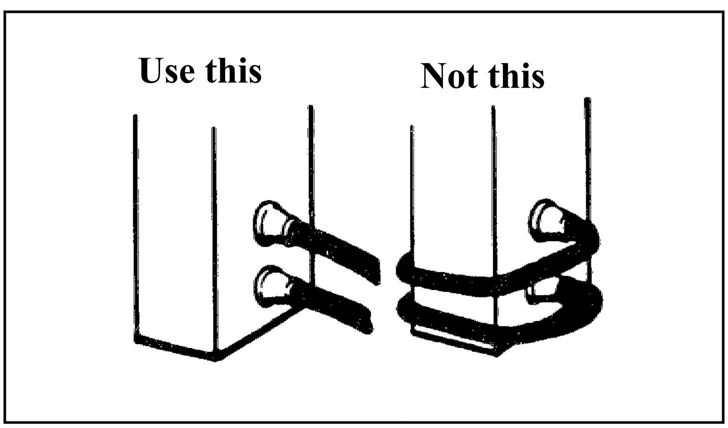
2.6.4.9 Remote switches or valves. Lines and cables should not be routed through remote switches or valves which may be inadvertently used while work is being performed on equipment.

2.6.4.10 Routing to avoid mishandling and obstruction. Lines and cables should be routed so they cannot be mishandled or obstructed (For example, see Figure 2.6.1, Proper routing of cable to avoid sharp bends).

a. Used for hand-/footholds.

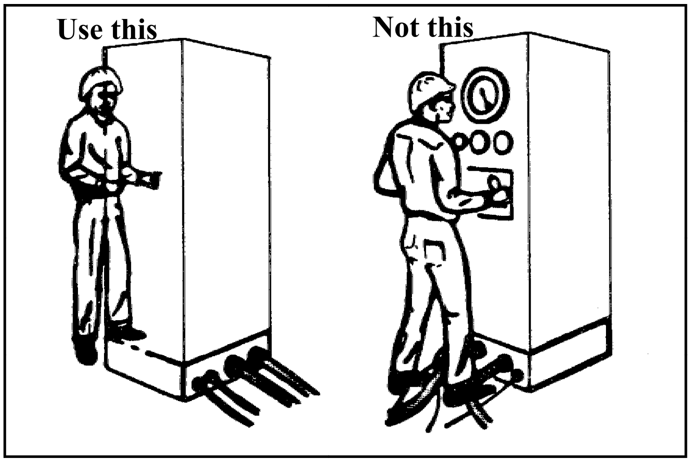
b. Bent or sharply twisted.

Figure 2.6.1. Proper routing of cable to avoid sharp bends.



c. Walked (or tripped) on or rolled over by heavy traffic.

Figure 2.6.2. Proper routing of cable to avoid walking on.



d. Pinched or stressed by loose objects, doors, lids, covers, sliding drawers, or roll-out racks.

e. Obstructing visual or physical access to equipment for operation or maintenance.

2.6.4.11 Cable protection. When cables must pass over sharp edges, insulation should be protected from fraying or other damage by grommets or equivalent means.

2.6.4.12 Piping systems in radioactive areas. Piping systems in radioactive areas should be routed to accommodate workers physically encumbered by protective garments, air bottles, and face masks or plastic hoods.

2.6.4.12.1 Use of reach rods. Reach rods should be used only in radioactive areas where direct access to the valves will result in exposure to radiation or other adverse environmental factors significantly exceeding that obtained through manual operation.

2.6.5 Mounting. Lines and cables should be mounted so that:

a. They will not interfere with other maintenance operations.

b. They will not chafe or flex excessively under predicted conditions of use.

c. Protection from metal edges is provided by grommets or pads.

d. They are securely anchored to the chassis by clamps or plates.

e. They are not terminated or mounted on the front of cabinets or control-display panels (test cables excepted).

2.6.5.1 Clamps or mounting plates. Unless wiring ducts or conduits are used, mechanically (not adhesively) mounted cable clamps or plates should be provided to ensure correct routing of electrical cables, to facilitate the mating of cables with their associated equipment, and to prevent chaffing due to contact with adjacent structures. Clamps or mounting plates used for mounting should:

a. Fit snug without deforming or crimping the line or cable.

b. Be spaced no more than 24 inches apart.

c. Be put at both ends of bends where the bending radius is 3 inches or less.

d. Be lined with heat resistant material if the line is likely to become extremely hot.

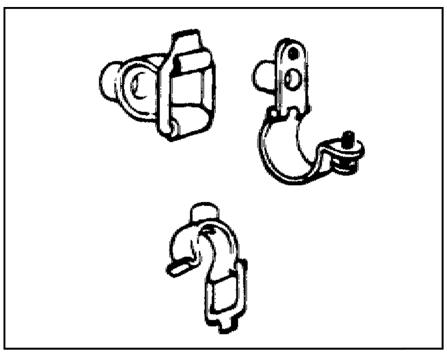
e. Be non-conductive or properly insulated if they are securing a conductor.

f. Require only one-handed operation with common hand tools.

g. Be of a quick release, hinged, or spring type if the line or cable must be frequently removed. Hinged clamps are preferred; they support the weight of the line during maintenance, freeing the technician's hands for other tasks (See also Figure 2.6.3, Quick release, hinged and spring type clamps).

h. For overhead mounting, be of a spring clamp type with a hinged locking latch over the open side of the clamp to prevent accidents.

Figure 2.6.3. Quick release, hinged and spring type clamps.

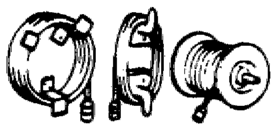


2.6.6 Storage and handling provisions. Adequate storage and handling provisions should be made for extension-type lines and cables such as:

a. Covered storage space in ground support equipment for storing lines and cables.

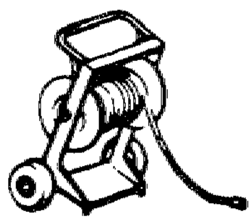
b. Suitable racks, hooks, or cable winders within the storage place to hold lines and cables conveniently (See also Figure 2.6.4, Lane and cable rack, winder, and hook).

Figure 2.6.4. Line and cable rack, winder, and hook.



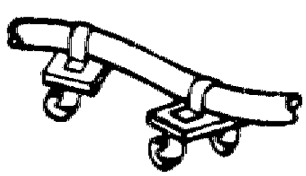
c. Reels or reel carts for handling large, heavy, or long lines or cables. Automatic rewind should be available, where possible, to minimize damage and kinking (See also Figure 2.6.5, Line and cable reel cart).

Figure 2.6.5. Line and cable reel cart.



d. Wheels or other mobile supports for especially large lines or cables that must be frequently moved (See also Figure 2.6.6, Line and cable mobile support).

Figure 2.6.6. Line and cable mobile support



2.6.7 Electrical wire and cable design

In addition to the general principles outlined above electrical wire and cable design should adhere to the guidelines listed below.

2.6.7.1. Simple layout and routing. The layout and routing of wires and cables should be predetermined and made as simple and functionally logical as possible by:

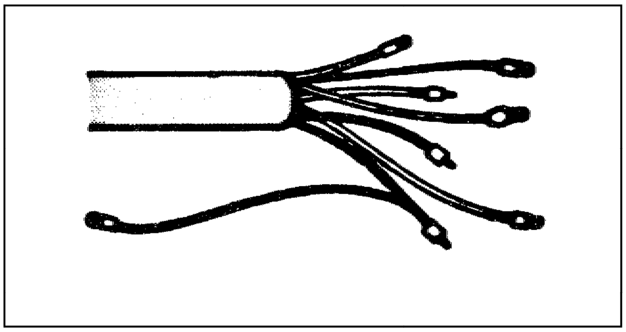
a. Combining conductors into cable wherever practical.

b. Combining conductors into harnesses wherever cables are not used.

c. Segregating conductors into and within cables or harness according to their functions and relationships to replaceable equipment.

d. Using preformed cables wherever possible to minimize wiring errors and to allow more flexible and efficient assembly methods. Provide spare leads in cables to allow for growth and to speed wiring time (See also Figure 2.6.7, Preformed cables).

Figure 2.6.7. Preformed cables.



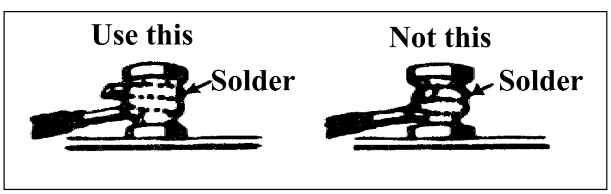
e. Where possible, use physical measures, such as cable length, to prevent interchanging units or components with the same or similar form, that are not, in fact, functionally interchangeable.

2.6.7.2 Wire connections. Wire connections should conform to the following recommendations:

a. For easy maintenance, plug-in contacts are better than screw terminals and screw terminals are better than solder connections.

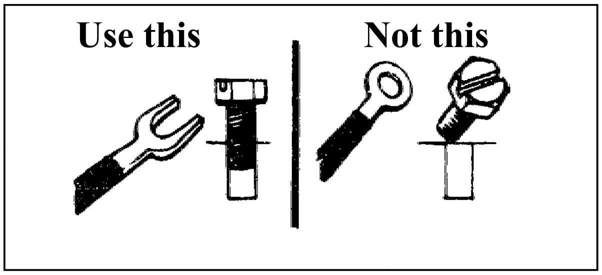
b. The end of a wire soldered to a terminal should be left out of the solder so that the wire will be easy to remove (See also Figure 2.6.8, Proper soldering of electrical wire).

Figure 2.6.8. Proper soldering of electrical wire.



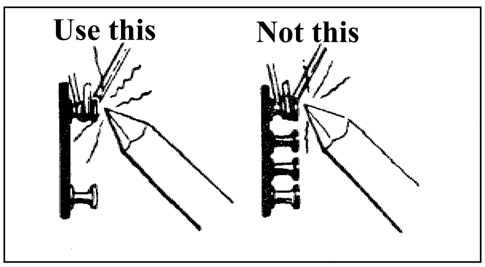
c. U-Lugs should be used rather than 0-lugs whenever practicable (See also Figure 2.6.9, U-type lugs).

Figure 2.6.9. U-type lugs.



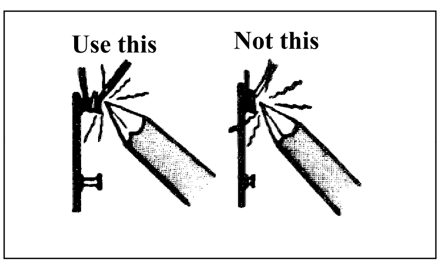
d. Separate terminals to which wires are to be soldered should be separated far enough apart so that work on one terminal does not damage neighboring ones (See also Figure 2.6.10, Proper spacing of wire loads).

Figure 2.6.10. Proper spacing of wire loads.



e. Terminals or other connections to which wires are soldered should be made long enough so that insulation and other materials are not burned by the hot soldering iron (See also Figure 2.6.11, Proper length of terminals and connections).

Figure 2.6.11. Proper length of terminals and connections.



2.6.7.3 Harnesses. Harnesses should:

a. Be designed, fabricated, and installed as units.

b. Be held securely with lacing twine or other means acceptable to the user.

c. Keep the individual conductors essentially parallel, so they do not intertwine, though twisted pairs may be used when required.

2.6.7.4 Lead lengths. Lead lengths should be as short as is consistent with the task to be performed, but long enough to allow:

a. Easy connection and disconnection, with enough slack to back the wire away from the point of attachment to facilitate removal of the unit.

b. Sufficient slack for at least two (preferably six) replacements of terminal fittings, electrical considerations permitting.

c. Movements of moving parts to which they may be attached (doors, covers, etc.) without undue stress or bending.

d. Connection, disconnection, or movement without requiring a bending radius of less than six times the diameter of the lead.

e. Movement of the units which are difficult to handle in their mounted position to a more convenient position for connection or disconnection.

f. Required checking of any functioning item in a convenient place; extension cables should be provided where this is not feasible.

2.6.7.5 Extension cables. Extension cables should be planned, designed, and provided to:

a. Increase the efficiency and ease of maintenance.

b. Avoid removal of assemblies or components for testing.

c. Allow each functioning unit to be checked in a convenient place.

d. Allow support equipment to be parked or set in convenient place.

e. Serve as many related functions as possible, yet avoid the possibility of misuse or misconnection.

2.6.7.6 Mounting of wires and cables. Mounting of wires and cables, in addition to satisfying the General Principles previously listed, should:

a. Ensure that lightly insulated wires clear parts normally at ground potential by at least 19 mm (0.75 in.) under operating conditions.

b. Employ raceways, stuffing tubes, conduit, junction boxes, and insulation as necessary to obtain the required degree of protection, security, mounting, and ease of maintenance.

c. Ensure that adequate accessibility is provided to raceways, stuffing tubes, etc.

d. Allow checking of the signal flow through each conductor by arrangement, location, and mounting of leads; provide test points where leads are unavailable for testing; and provide test points in connectors.

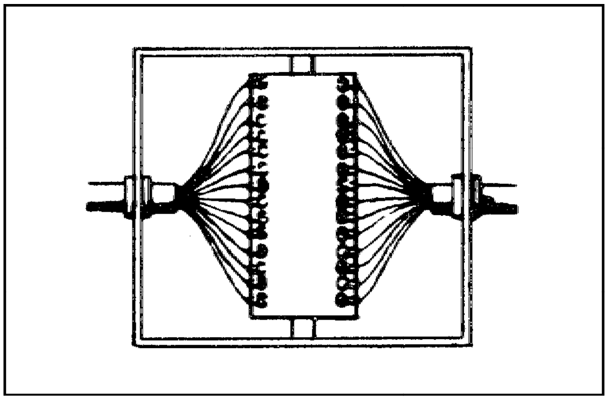
2.6.7.7 Leads. Leads should be mounted so they:

a. Do not bear the weight of the cable, harness, or other components.

b. Are provided with support at splices and points of connection.

c. Are "fanned out" to provide adequate clearance for the technician's hand and/or any tool required for checking or connection (See also Figure 2.6.12, Cable “fanning” for ease of maintenance).

Figure 2.6.12. Cable "fanning" for ease of maintenance.



d. Are oriented, where possible, in such a manner as to prevent erroneous connection or "crossing."

e. Do not allow flexing at weak areas, e.g., at splices, solder points, or where the conductor is bare or crimped, or strands are tinned together.

2.6.7.8 Leads or cables to moving parts. Leads or cables to moving parts, doors, drawers, racks, covers, etc. should have adequate slack and protection so they:

a. Allow movement of the part (door, drawer, rack, etc.) without their disconnection.

b. Fold out of the way automatically when the part is moved.

c. Do not chafe or break under the repeated flexing required.

d. Are not pinched or otherwise damaged by movement of the part.

2.6.7.9 Materials used for wire and cable applications. When determining materials to be used for wire and cable applications, the following should be considered:

a. Clear plastic insulation allows rapid detection of internal breaks.

b. When polyvinyl wire is used, care should be taken so there will be no cold flow of insulation due to tightness of lacing or mounting.

c. Neoprene-covered rather than aluminum-sheathed cable should be used in areas where intense vibration or corrosive substances may cause failures.

d. High-temperature wire should be used when wires are routed near ducts carrying pressures over 50 psi and/or temperatures above 2000° C (3920° F).

e. Metallic shielding unprotected by outer insulation should be secured to prevent the shielding from contacting exposed terminals or conductors.

2.6.7.10 Wire and cable insulation. Wire and cable insulation should be protected from termite destruction by coating them with compounds of creosote, antimony, or other mixtures acceptable to the user.

2.6.7.11 Coding insulated wire or cable. When cables contain individually insulated conductors with a common sheath, these cables should be coded. The coding should be repeated every 305 mm (12 in.).

2.6.7.11.1 Type of coding. Where coding is used, insulated wire or cable should be color- or number-coded in accordance with standards acceptable to the user (e.g., MILSTD-195; MILSTD-681).

2.6.7.12 Coding for equipment and connectors. Where applicable, cables should be labeled to indicate the equipment to which they belong and the connectors with which they mate.

2.6.8 Fluid and gas line design

2.6.8.1 Misconnection. Misconnection during servicing or maintenance operations should be prevented by:

a. Standardizing fittings so it is impossible to interchange lines that differ in content.

b. Using arrangement, size, shape, and color coding as necessary to prevent interchange of adjacent lines.

c. Identifying all fluid carrying lines by color bands.

2.6.8.2 Protecting personnel and equipment during disconnection. Spraying or draining on personnel or equipment during disconnection should be avoided by:

a. Locating connections away from work areas and sensitive components.

b. Providing shielding for sensitive components where required.

c. Providing drains and bleed fittings to allow draining or reduction of pressure prior to disconnection.

d. Providing high visibility warning signs at disconnect areas and other locations where the pressure or content of lines could injure personnel.

e. Providing a positive indication of gas or fluid pressure or flow to verify that the line is passive before disconnection; lines with quick disconnect couplings that are designed to be operated under pressure do no require such indicators.

f. Designing lines to minimize escape or loss of fluids, particularly toxic materials, during connect or disconnect operations.

2.6.8.3 Drainage problems. Drainage problems should be prevented by:

a. Designing lines to completely empty where required.

b. Avoiding low points or dips in lines that are difficult to drain.

c. Making bends, where possible, in the horizontal rather than the vertical plane, to avoid fluid traps.

d. Providing drains for low points where required to drain such traps.

2.6.8.4 Use of Flexible tubing. Flexible tubing should be used instead of rigid lines because it allows more flexibility in handling, can be backed-off easily, and is easier to thread through equipment when replacement is required.

2.6.8.4.1 Installation of rigid lines. Where rigid lines are used, they should be installed with fittings that do not require the line to be backed-off for disconnection.

2.6.8.5 Use of flexible hose. Flexible hose should be used rather than pipes or tubing where minimum space is available for removing, handling, or replacing lines.

2.6.8.6 Supports. Adequate supports should be provided for lines which run from external service or test equipment, or where extensions will be attached for other purposes. These supports must withstand:

a. The initial surges of pressure through the line.

b. The weight of the external extensions.

c. The rigor of handling and repeated connection and disconnection.

2.6.8.7 Mounting and installation of lines. Lines should be mounted and installed in such a way as to preclude kinking by:

a. Employing sufficient mounts and supports to prevent kinking.

b. Employing quick-disconnect fittings to reduce manhandling of lines during connection or disconnection.

c. Eliminating workspace restrictions around mounts and connections that may cause the technician to bend the line in installation, disconnection, or removal.

2.6.8.8 Clearance space for system components and piping. A nominal 0.91 m (3 ft) maintenance clearance space should be provided around all major system components and piping 609 mm (24 in) in diameter and larger. Overhead clearance should be a minimum of 2.13 m (7 ft.) above the floor for passage of personnel and removal of equipment.

2.6.8.8.1 Accessibility of valves and instruments on piping runs. Components such as valves, thermowells, flow meters, and other instrumentation on piping runs should be accessible to maintenance personnel.

2.6.8.8.2 Piping systems in radioactive areas. Piping systems in radioactive areas should be routed to accommodate men physically encumbered by protective garments, air bottles, and face masks or plastic hoods. Reach rods should only be used where direct access to the valves will result in a radiation exposure or other adverse environmental condition significantly exceeding that obtained by manual operation.

2.7 Connector design

A connector is any fixture designed and intended to join or connect lines (such as a single length of pipe, hose, wire, or tubing) or cable (e.g., a number of lines, bound together within a single, permanent sheath).

2.7.1 Selection, design, and use of connectors. Decisions affecting the selection, design, and use of connectors should be compatible and coordinated with:

a. Line and cable principles (See section, 2.6).

b. Fastener principles (See section, 2.11).

c. Mounting and configuration principles (See section, 2.2).

d. Environmental factors to be endured.

e. Maintenance routines in which connectors will be involved.

f. Reliability of the system in which connectors will be used. Connectors are causes of lowered reliability and should be considered as such in system design.

g. Reliability of components whose connection they affect. Components of low reliability should be easiest and fastest to disconnect.

2.7.2 Objective for use of connector. Connectors should be selected, designed, and mounted to:

a. Maximize the rapidity and ease of maintenance operations.

b. Facilitate the removal and replacement of components and units.

c. Minimize set-up time of test and service equipment.

d. Ensure compatibility between prime and ground support or auxiliary systems.

e. Minimize dangers to personnel and equipment from pressures, contents, or voltages of lines during the release of connectors.

f. Be operated by hand where possible, or with common hand tools. Requirements for special tools to effect connection, disconnection, or removal of connectors should be avoided.

2.7.3 Use of different types of connectors

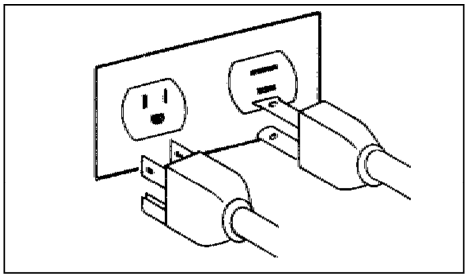
2.7.3.1 Plug-in connectors. Plug in connectors are the fastest and easiest to use, e.g., simply push in or pull out, but they also are the easiest to disconnect accidentally (e.g. have low holding power). Plug-in connectors should:

a. Be used where possible for all connections that will not be seriously stressed and particularly for those that must be frequently disconnected (See also Figure 2.7.1, Example of plug-in connector).

b. Not be used where stresses or pressures will overcome holding power.

c. Not be used where holding power is such that lines are likely to be damaged or connectors loosened by the pulling required to disconnect.

Figure 2.7.1. Example of plug-in connector.



2.7.3.2 Quick-disconnect devices. Quick-disconnect devices are very fast and easy to use. They exist in a variety of forms and include any type of connector that can be released by snap action, twisting up to a full turn, triggering a latch or spring device, or removing an external pin. Quick-disconnect devices should be:

a. Designed for hand operation including operation with gloved hands.

b. Designed to prevent loosening which allows leakage or overheating from pressures or voltages involved.

c. Provided with self-locking catches, as necessary, to prevent loosening, resist stress, and ensure secure connection.

d. Used for all connections of:

- Auxiliary, test, or support equipment to other major units.
- Units which require frequent disconnection or replacement.
- Units which require replacement within critical readiness times.

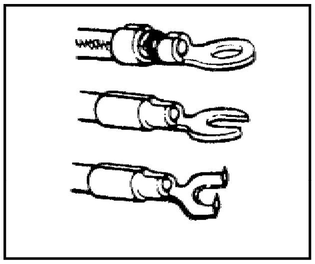
2.7.3.3 Lugs and crimp-on devices. These are most useful to connect or splice single wires. Both can be used, and are preferable to soldering, at elevated temperatures. They should have the following characteristics:

a. Lugs must be compatible with the terminal post requirements.

b. Where lugs and crimp-on devices are used, slack should be provided for at least six replacements of those devices which must be cut off.

c. Lugs and crimp-on devices should clamp the insulation as well as the conductor, to provide support for the line and preclude flexing of the conductor against the end of the connector (See also Figure 2.7.2, Example of proper attachment of crimp-on devices).

Figure 2.7.2. Example of proper attachment of crimp-on devices.



d. "U-Lugs" should be used rather than "eye-lugs."

- Are easier and faster to connect and disconnect.
- Do not require complete removal of the connecting fastener.
- Are more likely to disconnect rather than allow the line to break under extreme stress.

Figure 2.7.3. Example of quick-disconnect connector.

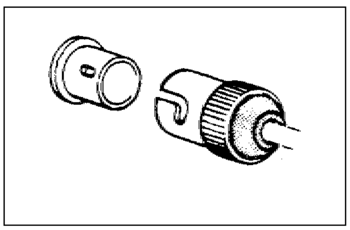
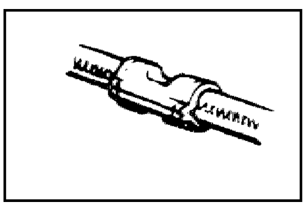


Figure 2.7.4 Example of crimp-on lug.



2.7.3.4 Bolt or screw assemblies. These provide a very secure connection, but also require time-consuming handling and operation of bolts or screws. They are particularly useful for connecting large or high-pressure lines. Bolt or screw connector assemblies must (See also Figure 2.7.5, Example of bolt assembly):

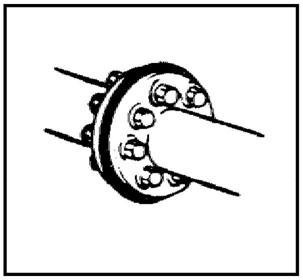
a. Satisfy fastener preferences and requirements (See section 2.11, Fastener design and application).

b. Ensure adequate work and tool clearances about these fasteners.

c. Use the minimum possible number of separate parts.

d. Satisfy gasket and seal requirements.

Figure 2.7.5. Example of bolt assembly.



2.7.3.5 Threaded connectors. Threaded connectors provide very secure connections, particularly when locked into place by set screws, retainers, or safety wires. They require more time to operate, depending upon the ease of use, number of turns required, and types of tools required. Threaded connectors should be right-hand threaded. They should also:

a. Require as few turns as are consistent with holding requirements.

b. Be operable by hand when used for electrical connection.

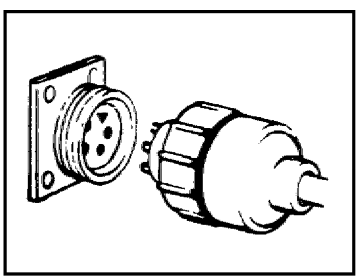
c. Require only common hand tools or special tools which are immediately accessible.

d. Be so designed that the line need not be backed-off to effect connection or disconnection, especially in the case of rigid lines.

e. Be designed and arranged to reduce the danger of loosening other connectors while working on one. This is a major problem with threaded fasteners on continuous pipe or tube systems.

f. Be designed so that aligning guides and connector pins are easy to engage and start to ensure accurate alignment before the threaded section makes contact (See also Figure 2.7.6, Example of threaded connector).

Figure 2.7.6. Example of threaded connector.



2.7.3.6 Soldering, brazing, or welding. Such methods provide the securest connection and are often the most efficient way of securing small connection points or maintaining hermetic seals, but such connections require considerable maintenance time for connection or disconnection. These connections should meet the following criteria:

a. Soldering should satisfy terminal post requirements.

b. Welding and brazing should be used only for connections that are very unlikely to require disconnection.

c. These methods should never be used to effect connection of lines or assemblies that may require disconnection by line maintenance personnel.

2.7.4 Electrical connections

2.7.4.1 Electrical contacts

2.7.4.1.1 Protecting against moisture. Whenever possible, superior insulating materials, corrosion-proof platings, and moisture-proof connectors should be used. If moisture-proof connectors cannot be used, the connector case should contain a drain hole. Vertical mounting of connectors should be avoided.

2.7.4.1.2 Protecting against corrosion. To protect against corrosion, all parts and mating surfaces of connectors should be coated with an electrical lubricating compound. Metal parts of all medium, very high, and ultra-high frequency (MF, VHF, and UHF) connectors should be silver plated inside and out.

2.7.4.1.3 Insertion forces. Insertion forces should be kept low to minimize the possibility of damaging contact surfaces on connector parts.

2.7.4.1.4 Clamps between metal and insulation. Contacts should be avoided which depend on wires, lugs, terminals, etc. clamped between metal and insulation. These contacts should be clamped between metal members.

2.7.4.1.5 Alligator clips. Both ends of static discharge lines and grouped wires should be securely fastened. Alligator clips may be used for **temporary** grounding or testing because they are fast and easy to use; they should not be used for permanent grounding because they may become inadvertently detached.

2.7.4.1.6 Spring contacts. Spring contacts should be used which are:

a. Relatively long to avoid concentrating stress and permit contact surfaces to wipe each other clean as contact is made.

b. Made of beryllium copper where contact is to be frequently stressed-copper is adequate for most other purposes.

c. Not stamped from flat metal-these tend to resume flat shape after a number of flexings.

2.7.4.1.7 Contact surfaces. Contact surfaces should be plated with non-tarnishing materials such as:

a. Gold-a perfect plating material but very costly.

b. Cadmium-satisfactory for most purposes.

c. Silver-may be used wherever its tendency to migrate in humid environments does not interfere with circuit operation.

2.7.4.2 Terminal posts

2.7.4.2.1 Terminal post location and construction. Loose or poorly arranged terminal posts require about three times as long to solder or connect than adequately secured ones. Therefore, posts should be located, constructed, and arranged so that:

a. They are accessible.

b. A maximum of three wires will be attached to a single post.

c. Good electrical contact is assured.

d. Posts will not loosen, rotate, or break with repeated usage.

e. Wires can be repeatedly removed and replaced, disconnected, and/or soldered without damaging or loosening the posts.

f. Adequate hand and tool clearances are provided for connection and disconnection.

g. Posts are far enough apart so work (particularly soldering) on one terminal does not damage neighboring connections, insulation, or other parts.

2.7.4.2.2 Solder type posts. Solder type posts should, in addition, be designed and mounted so that:

a. They are completely plated with tin or silver.

b. They are notched or provided with other means for mechanically securing the wire prior to soldering.

c. The free end of the wire sticks out of the solder and thus can be easily grasped with pliers to facilitate disconnection.

d. Supports are provided, where stranded copper wire is to be soldered, to prevent flexing where the strands are tinned together.

2.7.4.3 Electrical plugs

2.7.4.3.1 Design to preclude misconnection. Plugs should be designed so that it is physically impossible to insert the wrong plug into a receptacle or insert a plug the wrong way into a receptacle. This may be accomplished by use of plugs of different sizes; different keys or alignment pins, different pin configurations, etc. for nearby connections. (See also example C and E from Figure 2.7.8, Plug and receptacle design and identification methods).

2.7.4.3.2 Coding techniques for pin-connector mating and alignment. Use of coding techniques for pin-connector mating and alignment. Coding techniques such as alphanumeric coding, color coding, painted (alignment) stripes, etc. should be use to increase ease of correctly mating the plug and its corresponding connector where proper orientation is not obvious (See examples A, B, and D from Figure 2.7.7, Plug and receptacle design and identification methods).

2.7.4.3.3 Pin identification. Each pin on each plug should be clearly identified, e.g., number and/or letter identification.

2.7.4.3.4 Quick-disconnect plugs. Quick-disconnect plugs or plugs that can be disconnected with no more than one turn should be used rather than plugs with fine threads that require numerous turns.

Figure 2.7.7. Plug and receptacle design and identification methods.

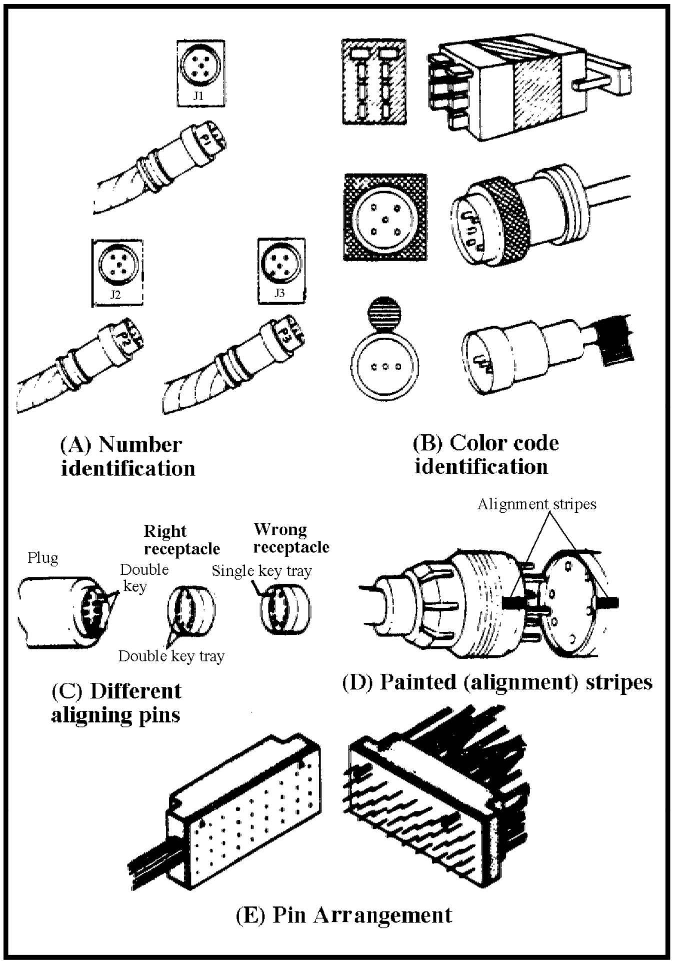
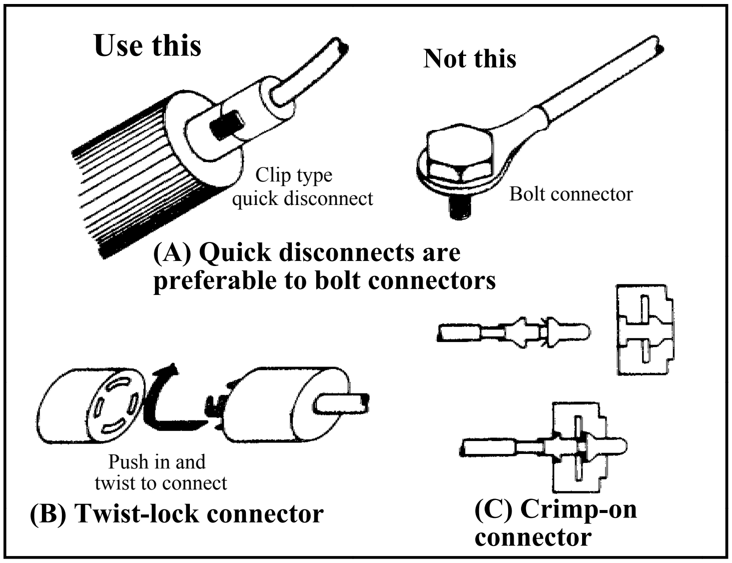
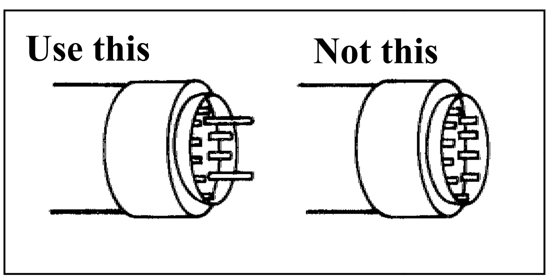


Figure 2.7.8. Examples of quick-disconnect plugs.



2.7.4.3.5 Aligning pins. Plugs should be used in which the aligning pins or keys extend beyond the electrical pins. This arrangement protects the electrical pins from damage through poor alignment or twisting of the plug when it is partially inserted (Figure 2.7.9, Example of extended alignment guides).

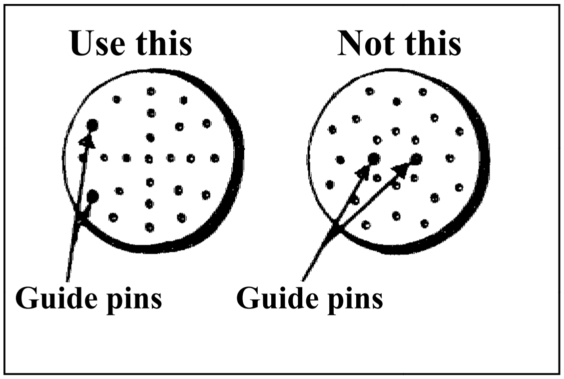
Figure 2.7.9. Example of extended alignment guides.



2.7.4.3.6 Assuring alignment before electrical contact. The configuration of aligning pins, keyways and other equivalent devices should insure that alignment is obtained before the electrical pins engage and contact is made.

2.7.4.3.7 Arrangement of aligning pins. Symmetrical arrangements of aligning pins or keys should be avoided so that plugs cannot be inserted 180° from the correct position (See also Figure 2.7.10, Example of asymmetrical aligning pin arrangement).

Figure 2.7.10. Example of asymmetrical aligning pin arrangement.



2.7.4.3.8 Space between connectors. Connectors should be located far enough apart so they can be gripped firmly for connecting and disconnecting. The actual space required will vary with the size of the plug and the type of clothing worn by the maintainer (for example, normal vs. protective clothing). Space between connectors should not be less than 25 mm (1 in.) except where connectors are to be sequentially removed and replaced and 25 mm (1 in.) clearance is provided in a swept area of at least 270° around each connector at the start of its removal replacement sequence. Spacing should be measured from the outermost portion of the connector (i.e. from the backshell, strain relief clamp, dust cover, etc.). Where high torque is required to tighten or loosen the connector, space should be provided for use of a connector wrench (See also Figure 2.7.11, Proper arrangement of electrical connectors).

2.7.4.3.9 Jerk-open plugs. When a part can be removed for maintenance, cables connecting the removable part with the rest of the machine or system should have plugs and receptacles that will disconnect before the cables will break, particularly if non-electronics personnel do the removing. A jerk-open plug will separate before any damage is done; a screw plug will not.

2.7.4.3.10 Plugs and receptacles for connecting cables. Plugs and receptacles should be used for connecting cables to equipment instead of pig-tailing them. Pigtailed connections are more difficult to replace (See also Figure 2.7.12, Plug vs. pig-tailing connections).

Figure 2.7.11. Proper arrangement of electrical connectors.

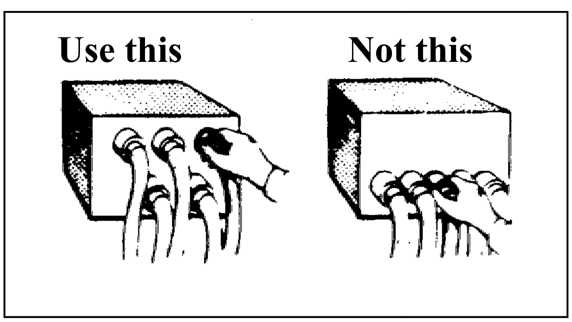
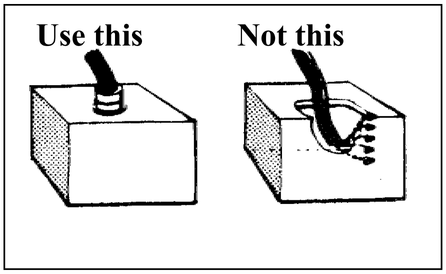
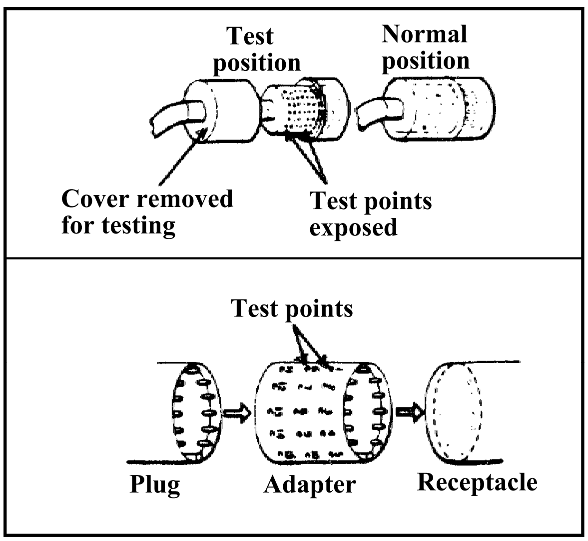


Figure 2.7.12. Plug vs. pig-tailing connections.



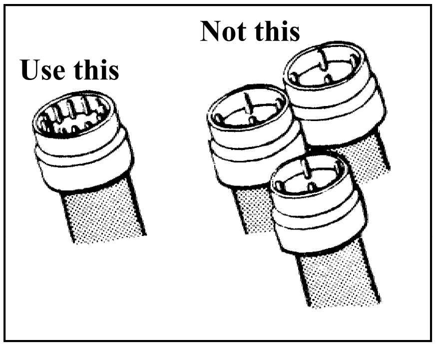
2.7.4.3.11 Integral test points. Plugs should be used with integral test points for each input and output that cannot be easily checked. Otherwise, an integral sliding cover for the test points in the plug should be provided if dust and moisture is a problem. As an alternative, a test point adapter may be provided for insertion between plugs and receptacles (See also Figure 2.7.13, Examples of plugs with integral test point or test point adapter).

Figure 2.7.13. Examples of plugs with integral test point or test point adapter.



2.7.4.3.12 Number of pins. Fewer plugs with many pins should be used rather than many plugs with few pins. It takes about the same amount of time to connect a plug with many pins as it does one with few pins (See also Figure 2.7.14, Example of proper use of plugs with many pins).

Figure 2.7.14. Example of proper use of plugs with many pins.



2.7.4.3.13 Shorting. Connectors should be used in which electrical contacts cannot be shorted by external objects.

2.7.4.3.14 Plugs "cold". Receptacles should be "hot" and plugs "cold."

2.7.4.3.15 Self-locking safety catch. Plugs should have a self-locking safety catch rather than require safety wiring. If safety wiring is required, holes and slots should be designed for most efficient and rapid attachment of safety wire.

2.7.4.3.16 Transmitting stored charges. Plugs and leads should be designed not to transmit stored charges when being disconnected.

2.7.4.3.17 Design to withstand rough use. Lead pins and plugs should be designed strong enough to withstand rough use.

2.7.4.3.18 Power disconnects. Individual power disconnects should be used to permit power to be turned off in one part of the system without disconnecting the entire system.

2.7.4.3.19 Labeling power receptacles. Power receptacles should be clearly labeled for primary, secondary, or utility systems to prevent injury to personnel or damage to equipment.

2.7.4.3.20 Disassembly and adapters. Disassembly of connectors to change pin connections should be performed without special tools. When adapters are required, they should be capable of being hand-tightened.

2.7.4.3.21 Drawer modules. Drawer modules for "remove and replace" maintenance should be provided with connectors mounted on the back of the drawer and mated with connectors in the cabinet to accomplish electrical interconnection between the drawer, other equipment in the rack and external connectors, where feasible. Guide pins or equivalent devices should be provided to aid in alignment.

2.7.4.3.22 Electronic modules. Replacement electronic items (e.g., modules and high-failure-rate components) should be provided with simple plug-in, rack-and-panel type connectors.

2.7.5 Fluid and gas connectors.

2.7.5.1 Location and installation of fluid and gas connectors. Fluid and gas connectors should be located and installed so that:

a. Backing-off of the line or removal of other components is not required to effect disconnection or removal of related items.

b. Draining, filling, or other maintenance involving the connectors can be accomplished without jacking up the equipment.

c. Leakage tests can be performed easily and without endangering the technician. Tests should be planned so the technician does not have to insert his head into areas of extreme noise, vibration, or other danger while equipment is running.

2.7.5.2 Gaskets and seals. Gaskets and seals used in connections of fluid and gas lines should be selected and installed to

a. Be replaceable or have renewable wearing surfaces, rather than require throw-away of the connector when the seal is damaged or worn.

b. Be easily replaceable without removal of other connector parts or disassembly of other equipment.

c. Be identifiable with part numbers so they can be easily ordered and handled logistically; the job instructions should specify the life of seals and gaskets and recommend when they should be changed.

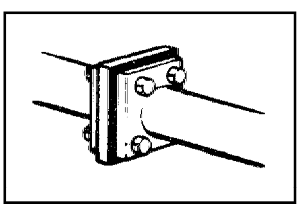
d. Contain or provide features, where required, which:

- Permit lubricant escape under conditions of high pressures.
- Prevent leakage of fluid when disconnect is made.
- Prevent air from entering disconnected lines where such air would create maintenance problems, as in hydraulic lines.
- Allow tightening to offset shrinkage, particularly of rubber seals and gaskets.

2.7.5.3 Gaskets and seals. Gaskets and seals should be used which:

a. Are visible externally after they are installed, to reduce the common failure to replace seals during assembly or repair (See also Figure 2.7.15, Example of externally visible gasket).

Figure 2.7.15. Example of externally visible gasket.



b. Do not protrude or extrude beyond the coupling. Tapered nylon or Teflon washers of appropriate size can be employed to prevent extrusion. (Protruding seals are chipped and shredded by vibration or contact which may in turn spread to cause internal damage).

2.8 Test and service point design

Test points provide a means for conveniently and safely determining the operational status of equipment and isolating malfunctions. Test points, strategically placed, make signals available to the technician for checking, adjusting, or troubleshooting.

Service points provide a means for lubricating, filling, draining, charging, and similar service function. Service points allow adequate adjustment, lubrication, filling, changing, charging, and other services to be provided on all equipment and components requiring such service between overhauls.

2.8.1 General principles for test and service point design

2.8.1.1 Avoiding need for frequent testing and servicing. Requirements for periodic or repetitive testing and servicing of components should be avoided when possible by using sealed bearings, oil impregnated bushings, highly reliable components, inexpensive components that may be discarded upon failure or replace at predetermined intervals to make failure unlikely, etc.

2.8.1.2 Standardization. To the degree feasible, service and adjustment points should be standardized to reduce the diversity of supporting materials and the likelihood that the wrong material or device might be used inadvertently. Servicing points should be designed to minimize the number and diversity of portable supporting adapters and connectors; where required, they should be built into the equipment as much as feasible. Where standardization is not feasible, the connectors or fittings should be distinctively identified so that the wrong material or device is not likely to be used inadvertently.

2.8.1.3 Test and service point compatibility. Test and service points should be designed for compatibility with checking, troubleshooting, and servicing procedures and test/service equipment. The need for cumbersome test equipment, accessory equipment, fittings, connectors, etc. should be minimized

2.8.1.4 Labeling dangerous test and service points. Dangerous test and service points should be labeled as such. The labeling should clearly identify the hazards and be readily visible, using capital letters.

2.8.1.5 Distinctively different connectors or fittings. Distinctively different connectors or fittings should be provided for each type of test or service equipment, probe, grease, oil, etc. to minimize the likelihood of error or misuse.

2.8.1.6 Location of test and service and adjustment points. Test and service points should be located so they are:

a Recessed, guarded, or otherwise protected from damage by personnel, moving cargo or equipment, dust, moisture, etc.

b. Within reach and/or readily observable as needed when the maintenance person is using related or corresponding controls, displays, fittings, switches, so that maintainer place-to -place movement is not required during the adjustment process.

c. Convenient for use with related maintenance support equipment and compatible, in terms of work space and clearance, with the use of such equipment.

d. Located to avoid safety hazards to personnel and equipment.

- Service points should be located away from electrical, mechanical, and other hazards to personnel, and guards and shields should be used as needed.

- Safety valves should be located so that they can be readily adjusted, but where the exhaust from their lifting will not endanger people or equipment.

- Fluid fill points should be located so as to avoid combustion (e.g., away from sources of heat, sparking, or potential voltage shorts) and spill hazards to personnel and easily damaged equipment.

e. Not hidden or obstructed by bulkheads, brackets, other units, etc., and so disassembly, removal, or support of other units, wires, etc. when testing, servicing, or troubleshooting is not required.

2.8.1.7 Indicating location of internally located points. Locations of internally located testing or servicing points should be indicated on the access plate or adjacent surface of the equipment.

2.8.1.8 Connectors or fasteners. Connectors or fasteners for test and service points should:

a. Use direct insertion or quick disconnects except on pressurized systems.

b. Be aligned or keyed on pressurized systems so that they are properly seated before an opening occurs, to prevent loss of gases or fluids and reduce the hazards involved.

c. Require only hand operation by common hand tools; special tools should not be required for the connection of test and service equipment.

d. Incorporate holding devices, clamps, and auxiliary shelves to support test probes, test sets, etc., and free the technician's hands for other tasks, such as making adjustments.

e. Incorporate guards and shields to protect personnel and test or service equipment, particularly if the equipment must be serviced while running.

f. Employ self-sealing elastomers or similar devices to allow probing into hermetically sealed units. Such devices should be provided with tool guides to ensure that proper contact is made.

2.8.1.9 Extended fittings and guides. Extended fittings should be provided for hard-to-reach points and guides should be provided for calibration tools that require blind operation.

2.8.1.10 Windows. Windows should be provided for visual inspections.

2.8.1.11 Coding for test and service points. Test and service points should be designed so they are easily distinguishable from each other and the equipment on which they are located. Color coding with a distinctive color may be used to meet this objective. Where used, the color(s) chosen for test points should be clearly different from the color(s) used for service points.

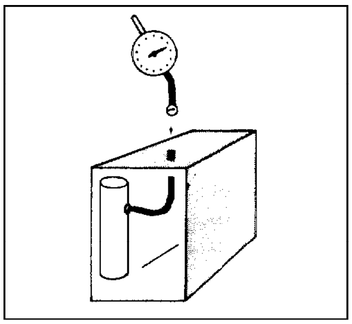
2.8.1.12 Use of luminescent markings. In low illumination luminescent markings for test and service points should be used if they must be used

2.8.2 Test points

2.8.2.1 Number of test points. Sufficient test points should be provided so that it is not necessary to remove sub-assemblies to accomplish troubleshooting/fault diagnoses.

2.8.2.2 Use of self-sealing elastomers. If internal probing of hermetically sealed units is required, accesses should be covered with self sealing elastomers, and needle probes should be used (See also Figure 2.8.1, Internal needle probe and self-sealing elastomer.)

Figure 2.8.1. Internal needle probe and self-sealing elastomer.

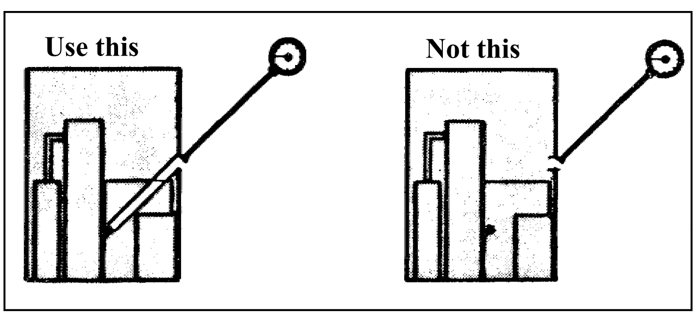


2.8.2.3 Use of guides. Suitable guides for test probes should be provided when test points are located internally or blind operation is required.

2.8.2.4 Use of high pressure test indicators. High pressure test indicators should be built wherever possible to avoid some of the dangers in temporary high pressure connections.

2.8.2.5 Use of a special ground point. A special "ground" point should be provided if a good grounding point is not available and connection to ground is required during tests of a given unit; technicians may have difficulty if only painted surfaces are available for ground connections (See also Figure 2.8.2, Test probe guides).

Figure 2.8.2. Test probe guides.



2.8.2.6 Test point for built-in and external test equipment.

2.8.2.6.1 Built-in test equipment. The location of test points depends on the testing method selected, primarily on whether built-in test equipment is used. With built in test equipment, especially automatic equipment, accessibility and convenience of test points are of relatively minor importance. A test capability built in as part of the equipment or installation is often most desirable for efficient maintenance and troubleshooting. Because some test equipment is large, heavy, and expensive, it may not be practical to design a built-in test unit such as that recommended above for each major component of a system and consequently partially built-in test units may be used. (See also Table 2.9.1, Advantages and disadvantages of types of test equipment in Section 2.9, Test equipment design.)

2.8.2.6.2 External test equipment. When external test equipment is used, accessibility and convenience are major considerations. Depending on the equipment used, the arrangement of test points may also be a major consideration.

2.8.2.6.3 Integrated portable test units. If built-in-test equipment is not feasible or desirable an integrated portable test unit that essentially duplicates the functions of the built-in-test equipment should be used. Such a unit should be connected through a single, multi-prong contact on the end of a cable rather than being connected to a number of individual test points.

2.8.2.6.4 Built-in test panels for non-integrated portable units. If none of the alternatives described above is practical, a test panel should be provided on the equipment. With this arrangement, the outputs of each test point should be designed for checking by use of standard test equipment, and the points should be planned to provide a miniature block diagram of the system, with each block representing a line replaceable unit. Overlays for the test panel should direct the technician to test points he should check and indicate the order in which they should be checked. In-tolerance signals should be shown on the overlays, and test points should be coded on the panel with full instructions provided in the maintenance manual in the event the overlay is lost (See also Section 2.8.2.7.4, Location of test point on a central test panel).

2.8.2.6.5 Test points on replaceable units. Finally, if none of the above arrangements are practical, test points should be provided for the inputs and outputs on each replaceable unit. If possible, components should be mounted on one side of the board or chassis and wiring should be on the other side. Even if the wiring is mounted on the same side as the parts, test leads should be brought through to the back. An advantage in having test points on the back is that full identifying information for each test point can be marked on the back without being obscured by parts.

2.8.2.7 Location and grouping of test points

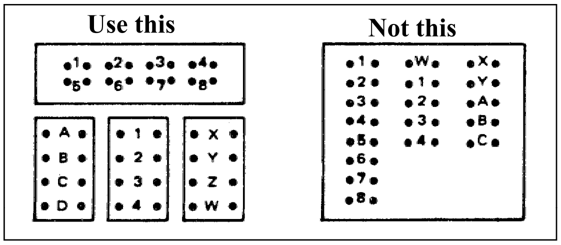
2.8.2.7.1 Determining location of test points. The location of test points should be fixed by determining from maintenance procedures the signals and controls that must be available to the technician and at what points they must be available. Test points should be located close to the controls and displays which are used in the checking operation. The technician should be able to activate the control and see the display at the same time.

2.8.2.7.2 Grouping test points. Test points should be grouped on a central panel to facilitate checking and troubleshooting.

2.8.2.7.3 Location of test points. Test points should be located so they are in a convenient arrangement for sequential checking.

2.8.2.7.4 Location of test point on a central test panel. When test points are located on one central test panel, they should be grouped according to the units which are used for testing (See also Figure 2.8.3, Proper test point grouping.)

Figure 2.8.3. Proper test point grouping.



2.8.2.7.5 High accessibility. Highly accessible test points should be provided for troubleshooting and checking.

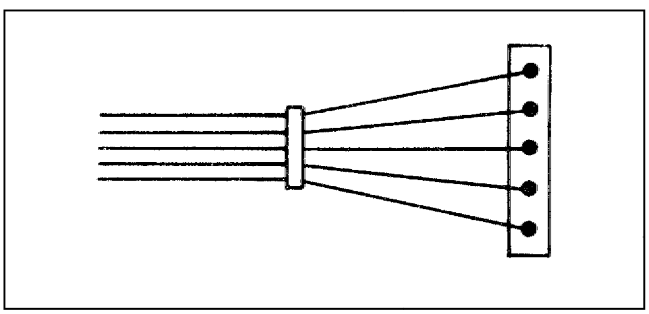
2.8.2.7.6 Test points for fuel hydraulic and pressure systems. Test points should be provided on fuel, hydraulic, and pressure systems to eliminate the need for:

- Removing fittings to attach test equipment.
- Removing components such as fuel pumps and actuators during troubleshooting.

2.8.2.7.7 Test access for mechanical components likely to wear. Test accesses should be provided for mechanical components likely to wear. For example, brake assemblies should be provided with an inspection opening or access to permit insertion of a gauge for determining the clearance between the brake lining and drum.

2.8.2.7.8 Fanning out of cables. On electrical equipment, cables should be fanned out on terminal strips if special test points are not provided (See also Figure 2.8.4, Fan out cables for test points).

Figure 2.8.4. Fan out cables for test points.



2.8.2.8 Labeling and coding test points

2.8.2.8.1 Label content. Test points should be labeled with the name of what is being tested. If it is not possible to include the name on the test point, it should be coded with a symbol. Each test point should be uniquely labeled and have a code number keyed to the maintenance manual. Explanations for symbols used should be in tables placed near the equipment or in job instructions. Test points should also be labeled with in-tolerance indications or tolerance limits of the signal being measured there.

2.8.2.8.2 Label location. Test point labels should be located consistently throughout the system and should be consistent with identifiers used in maintenance instructions.

2.8.2.8.3 Color coding test points. Color coding of test points should be considered for easy location. (See also 1.8.1.11, Coding for service and test points).

2.8.2.8.4 Use of phosphorescent or chemoluminescent markings. Phosphorescent or chemoluminescent markings should be used on test points, selector switches, and meters that require reading in low light conditions.

2.8.2.9 Service points

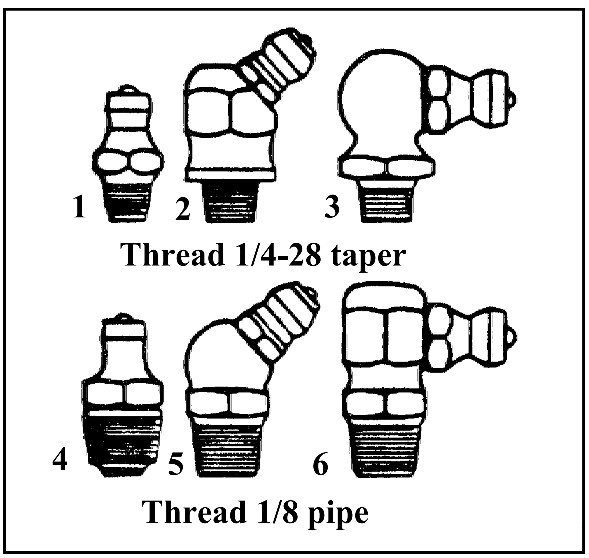
2.8.2.9.1 Lubrication points. Lubrication points should be designed with a reservoir to reduce the frequency of required lubrication.

2.8.2.9.2 Service fittings. Service fittings should be designed to be hand operable or to require only common hand tools. Petcocks and valves are preferred to drain plugs.

2.8.2.9.3 Guards. Guards should be provided around lubrication points which may be serviced while equipment is operating.

2.8.2.9.4 Standardized grease fittings. Grease fittings should be standardized for a given lubricant so that the number of different grease gun tips required is minimized. (See also Figure 2.8.5, Example of typical lubrication fittings.)

Figure 2.8.5. Example of typical lubrication fittings.



2.8.2.9.5 Oil filler caps. Oil filler caps should be designed so they (See also Figure 2.8.6, Example of well-designed oil filler cap):

a. Snap and remain open and closed.

b. Provide a large round opening for oil filling.

c. Permit application of breather vents, dipsticks, and strainers.

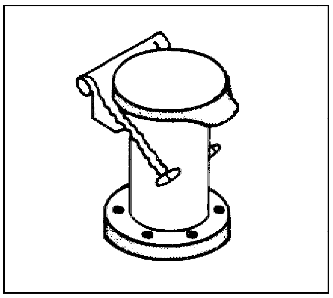
d. Use hinges rather than chains for attaching the lid.

e. Look different when opened or closed.

2.8.2.9.6 Pressure fittings. Pressure fittings should be provided for applying grease to bearings which are shielded from oil.

2.8.2.9.7 Fuels and lubricants. The same fuels and lubricants should be used in auxiliary or mounted equipment, as in the prime unit.

Figure 2.8.6. Example of well-designed oil filler cap.



2.8.2.9.8 Lubrication requirements. Lubrication requirements should be reduced to two types, if possible; one for engine and another for gear lubrication.

2.8.2.9.9 Lubrication points or easy access. If lubrication is required, lubrication points rather than equipment disassembly should be provided. If lubrication points are not feasible, easy access to equipment should be provided.

2.8.2.10 Fluid level indicators

2.8.2.10.1 Use of built in indicators and gauges. To reduce the number of test and service points required, built-in indicators, pressure gauges, direct reading fluid level gauges, etc. should be used for quick checks without the need of auxiliary equipment.

2.8.2.10.2 Direct reading gauges. Direct reading gauges are preferable to dipsticks or other methods of indicating fluid levels, because they allow rapid, immediate, and continuous inspection, and thus remove requirements for inspection tables.

2.8.2.10.3 Calibration units. If used, gauges or dipsticks should be calibrated in terms of functional units (quarts, pounds, gallons, etc.), rather than in general terms such as dry, low, add, etc.

2.8.2.10.4 Accessibility. If used, gauges or dipsticks should be immediately accessible.

2.8.2.10.5 Readability. Gauges or dipsticks should be quickly and easily read, i.e., there should be good contrast between the finish of the gauge and the fluid.

2.8.2.10.6 Guidance on acceptable levels. Fluid level indicators or labels should provide guidance on acceptable levels. Information about the effect on level of equipment operating condition (off, on, hot, cold, etc.) should be provided.

2.8.2.10.7 Zone banding. Zone banding e.g. use of pattern or color coding to show a critical range(s) on the scale should be considered when certain operating conditions should normally fall within this range (3.3.1.3.2, Pattern or color-coding/zone banding).

2.8.2.10.8 Direct-reading sightglasses. Direct-reading sightglasses should be marked to show which is the "up" direction to avoid an incorrect level indication if installed upside-down.

2.8.2.11 Drain points/bleed fittings

2.8.2.11.1 Use of drains. Drains should be provided on all fluid tanks and systems, fluid filled cases or pans, filter systems, float chambers, and other items which are designed or likely to contain fluid that would otherwise be difficult to remove.

2.8.2.11.2 Standardized drain fittings. Drain fittings should be limited to a few types and sizes which should be standardized according to application throughout the system.

2.8.2.11.3 Use of drain plugs. Valves or petcocks in preference to drain plugs. Where drain plugs are used, they should require only common hand tools for operation, and design must ensure adequate tool and work clearance for operation.

2.8.2.11.4 Labeling drain cocks or valves. Drain cocks or valves should be clearly labeled to indicate open and closed positions, and the direction of movement required to open.

2.8.2.11.5 Drain cock motion. Drain cocks should always close with clockwise motion and open with counterclockwise motion.

2.8.2.11.6 Instruction plates. Instruction plates should be provided as necessary to ensure that the system is properly prepared prior to draining.

2.8.2.11.7 Drain points. Drain points should be designed, located, and installed:

a. Where they are readily reachable and operable by the technician.

b. So fluid will not drain or spill on equipment or personnel.

c. At the lowest point in the system when complete draining is required or when separation of fluids is desired.

d. At other points in the system as required to permit selective draining or bleeding to facilitate maintenance procedures.

e. To permit drainage directly into a waste container without use of separate adapters or piping.

f. So fuel or other combustible fluids cannot run down to or collect in the starter, exhaust, or other hazardous areas.

2.8.2.12 Locating and grouping lubrication points

2.8.2.12.1 Accessibility of lubrication points. Lubrication points should be located so that they are easily accessible. Lead tubes or extended fittings should be provided if required to avoid equipment disassembly or locating a lubrication point in a hard to reach area.

2.8.2.12.2 Cases, covers, and equipment removal. The need to remove cases, covers, or other pieces of equipment to obtain access to lubrication points should be avoided by:

a. Locating oil dipsticks and other such level indicators so that they may be fully withdrawn without touching other pieces of equipment.

b. Locating lubrication test points close to corresponding lubrication add points, if possible.

c. Where possible, providing a central lubrication point or grouping of points for applying lubricant to all areas which require lubrication within a system, subsystem, or major component.

d. The oil quantity dipsticks should be placed in an accessible location.

2.8.2.13 Service for fuses. The following design features should be used to support easy identification and replacement of failed fuses

a. To the degree practical, fuses should be standardized.

b. Fuses should be mounted on the front panel with the failure easily identified. They should be grouped in a minimum number of central, readily accessible locations.

c. Fuses in removable fuse holders should be replaceable by maintainers without using tools. Fuse holder cups or caps should be of quick-disconnect rather than screw-in type and should be easily and safely removable by hand.

d. Spare fuses should be located near fuse holders.

e. Fuse values and functions should be clearly indicated by labels.

2.8.2.14 Batteries. The following design features should be used to support ready identification and replacement or recharging of discharged batteries:

a. The state of battery charge should be indicated or readily determinable. Labels should indicate acceptable levels associated with the charge.

b. Adequate accessibility should be provided for replenishing the electrolyte or replacing the battery. These operations should be performed by one person with a minimum of tools.

c. Caps should be provided so that battery terminals cannot contact metal surfaces during replacement.

2.8.2.15 Adjustment points and controls. The following design features should be used to support the use of adjustment points and controls for easy compensation for wear and degradation:

a. Labels or other features should clearly indicate the direction, degree, and effect of the adjustment.

b. Adjustment controls should be conveniently accessed and operated. They should be grouped either on a single panel or on the face of the equipment.

c. Controls with extremely sensitive or complicated adjustments should be avoided. Adjustments should be independent of each other whenever possible.

d. Equipment design should avoid the need for adjustment whenever possible. Parts subject to wear should be provided with compensation that is either automatic or readily performed manually.

2.8.2.16 Labeling and coding

2.8.2.16.1 Lubrication, fuel, and other filling points. Lubrication, fuel, and other filling points should be labeled with the type of lubricant or other material which is being replaced or replenished. A log and instructions for lubrication schedule should be included where possible.

2.8.2.16.2 Servicing instruction points. Servicing instruction plates should be provided adjacent to servicing points.

2.8.2.16.3 Overflow mechanisms. Cautions (or overflow mechanisms) should be provided adjacent to lubrication points where excess lubrication is unwanted.

2.8.2.16.4 Drain systems. Drain systems should be labeled to indicate proper position of equipment for draining.

2.8.2.16.5 Service points. Service points should be clearly distinguished from other fittings or breathing holes not to be lubricated or otherwise serviced

2.9 Test equipment design

2.9.1 Types of test equipment. Four general types of test equipment are used in maintenance tasks:

a. Built-in test equipment is an integral part of the prime equipment. It may be a complex automatic checker or a simple voltmeter with external leads.

b. Go, no-go test equipment provides only one of two alternative answers to any question. It tells only whether a given signal is in or out of tolerance.

c. Automatic test equipment checks two or more signals in sequence without the intervention of a technician. The test usually stops when the first out-of-tolerance signal is detected.

d. Collating test equipment presents the results of two or more checks as a single display. For example, a light may come on only if a number of different signals are in tolerance.

2.9.2 Design goals for test equipment. All test equipment should be designed to satisfy the following functions:

a. Simplify the job of the on-line maintenance technician.

b. Reduce the preparation or turn-around time for systems.

c. Reduce total maintenance costs.

d. Satisfy as many related testing requirements as practical.

e. Keep number of required testers and need for specialized testers to a minimum.

f. Be easily checked to determine that it is calibrated and functioning properly and allow easy calibration when needed; not require excessive or overly costly test equipment.

2.9.3 Selection of Test Equipment. Test equipment should be designed and selected so that it is easy, fast, and safe to use. The type of test equipment to be used should be decided upon in the early stages of prime equipment design. Actual selection of test equipment should be based on the following:

a. The mission and operational characteristics of the equipment.

b. The anticipated reliability of the equipment.

c. Personnel available.

d. Current maintenance system including procedures policies, symbols, codes, and test equipment familiar to the user.

e. Operational (physical) environment.

f. Task requirements including maintenance task assignment and transport of equipment to and from storage.

g. Logistics support requirements.

h. Development time and costs.

2.9.3.1 Advantages and disadvantages of types of test equipment. Advantages and disadvantages of various types of test equipment are listed below in Table 2.9.1, Advantages and disadvantages of test equipment.

Table 2.9.1. Advantages and disadvantages of types of test equipment.

Built-in Test Equipment

Advantages	**Disadvantages**
• Less likely than portable test equipment to be lost or damaged.	• Likely to add to the weight and space requirements of the prime equipment.
• Available when needed.	• More built-in test equipment may be required because a separate item is usually required for each prime equipment.
• No special storage facilities are required	• Requires additional self checking features to ensure that degradation of test facilities does not go unnoticed
• Transportation to the prime equipment for use in maintenance is not required	• Transportation of built-in test equipment to a point for convenient calibration may be more difficult than transportation of portable test equipment.
• Minimizes downtime required to trouble-shoot equipment; decreases service-induced failures and possible injury to maintainer by allowing fault isolation to be performed without needless probing into interior of equipment.	• Permanent installation of the test equipment may increase the complexity of wiring for the system and may even increase the amount of required maintenance for the prime equipment.
• Assures that modifications of prime equipment are made concurrently with integral test facilities.	• May be relatively inflexible.
• May result in earlier identification of performance degradation.	

Table 2.9.1. Advantages and disadvantages of types of test equipment. (continued)

Go, No-Go Test Equipment

Advantages	Disadvantages
• Presents information that is clear and unambiguous.	• Unique circuitry usually required for each signal value to be tested. Sometimes, however, ordinary displays can be converted to go, no-go by appropriate use of reference scales, such as a colored section on a meter dial.
• Usually easy to read.	• The increase in the number and complexity of circuits usually required adds to initial cost and development time; it is also likely to increase the rate of test equipment breakdown.
• Can simplify difficult tasks such as balancing circuits or checking complex wave shapes.	• Except in long, fast check sequences, go, no-go equipment is of relatively little help to the technician in checking common voltages or simple wave shapes.
	• Likely to require modification when prime equipment is modified. A special model may be required for each model of prime equipment.

Automatic Test Equipment

Advantages	Disadvantages
• Can make a rapid sequence of checks with little or no chance of omitting any steps.	• Cost, size, weight, and maintenance requirements are relatively high.
	• This type of equipment is relatively specialized, with little versatility.
	• Must almost necessarily have self-checking features to detect test equipment malfunctioning. This adds to cost and to problems of maintaining the test equipment.
	• More likely to require modification when prime equipment is modified. A special model may be required for each model of prime equipment.

Table 2.9.1. Advantages and disadvantages of types of test equipment. (continued)

Collating Test Equipment

Advantages	Disadvantages
• Reduce the number of displays the technician must read, thereby reducing check times and probably reducing errors.	• Similar to those for go, no-go and automatic test equipment.

Collating test equipment should indicate not only that all signals are or are not in tolerance; it should also provide an indication of which signal, if any, is out of tolerance. If only the collated display is presented, the equipment will not be an aid to troubleshooting.

2.9.4 Controls and displays for test equipment. Controls and displays required on test equipment should be kept to a minimum. They should also adhere to the design guidelines specified in Section 2.5.

2.9.5 Use of labels. Every item on the test equipment that the technician must recognize, read, or use should be labeled. A label should be placed on the cover or case of the set that states its name and purpose, use or function, the location where it is to be stored, the correct power source, and the precautions to be observed in using it.

2.9.4.1 Design of labels for test equipment. Labels should:

a. Be placed consistently above or below the associated panel elements with the major panel identifier top-most on the panel.

b. Be closer to the element being identified than to any other element.

c. Use a size-graduated hierarchical structure that emphasizes functional relationships of indicators and controls where applicable.

2.9.5 Steps to operate test equipment. The number and complexity of steps required to operate the test equipment should be minimal. This may be accomplished by "ganging" certain controls or by making certain operations automatic.

2.9.6 Operating instructions. Operating instructions for test equipment should be available to the technician, clearly written, and easily understandable. Instructions for operating portable test equipment should be provided on the face of the test equipment, in a lid, or in a special compartment. Instructions should be directly readable while test equipment is being operated. Periodic calibration records including tolerance check values should be placarded on the equipment where appropriate. Where applicable the instructions should include a reminder to calibrate the equipment and calibration procedures.

2.9.7 Test equipment leads and probes. Test equipment leads should be made retractable or should be removable. Test probes should be provided with handles long enough to be held comfortably and with contact points strong enough to prevent breaking:

2.9.7.1 Storage space. Test equipment should provide adequate storage space in the lid or cover for small removable items such as test leads, adapters, probes, or extensions. Fasteners or holders should be provided in the integral storage space to secure these items.

2.9.8 Error reduction. Test equipment should be designed either to prevent the technician from making errors or warn him of his errors.

2.9.8.1 Incorrect manipulation. Devices should be provided that will indicate whether the correct manipulation has been performed before the actual testing is done. For example, a signal or warning light on the test equipment display panel should light if an incorrect control is used.

2.9.9 Circuit breakers. Circuit breakers should be grounded on all test equipment to safeguard against damage if the wrong switch or jack position is used.

2.9.10 Fail-safe features. Fail-safe features should be incorporated into the test equipment to minimize the danger to the technician and equipment in case of equipment failure.

2.9.11 Test equipment ruggedness. Test equipment should be built to withstand the rigors of the job.

2.9.12 Test equipment rests and stands. When required to support operations or maintenance functions, rests or stands should be provided on which units can be placed. These stands should include space for test equipment, tools, technical orders and manuals. When permitted by design requirements, such rests or stands shall be part of the basic unit, rack, or console chassis.

2.9.12 Electrical connections

2.9.12.1 Selector switches. Selector switches should be used on test equipment instead of many plug-in connections (if the effects of switching will not degrade information desired).

2.9.12.2 Full view of relevant items. Test points, adjustment points, cable end connections, and labels should be in full view of the technician making connections or adjustments at that point.

2.9.12.3 Work position. The technician should not be required to assume an awkward position to make connections.

2.9.13 Test equipment operation and maintenance.

2.9.13.1 Operation by one technician. Test equipment should be designed for operation by one technician.

2.9.13.2 Go, no-go indicator. Test equipment should be easily calibrated or equipped with a go, no-go indicator or simple check to determine whether the instrument requires calibration or is malfunctioning.

2.9.13.3 Warm-up indicator. A warm-up indicator should be provided if applicable. Required warm-up time should be shown clearly near the display if no visual signal is provided.

2.9.13.4 Simple accuracy check. A simple check for testing the accuracy of results should be incorporated into the test equipment. .

2.9.13.5 Conversion tables. Conversion tables should be attached to test equipment when they are required (preferably such conversions should be made by selecting an option in the test equipment itself.) Standards and tolerances should be explicitly indicted by or on the test equipment.

2.9.13.6 Adjustments. Adjustments required by technicians should be limited to only those that are essential. They should be made by means of "low-go-high" type indicators. Feedback information to the technician should be by qualitative, positive signaling means, such as color-code signals and zero-center meters.

2.9.13.7 Misalignment. Controls and displays should be designed to prevent misalignment which may be caused by vibration, service use, or accidental contact.

2.9.13.8 Automatic shut-off. Automatic shut-off capability should be built into the test equipment to insure the equipment is turned off when not in use.

2.9.13.9 Power switches off when lid closed. Power switches should shut off automatically when instrument's lid is closed. The test equipment display panel should include a warning light which is lit during operation and which turns off when equipment is secured.

2.9.14 Safety

2.9.14.1 Shielding moving or cutting parts. Test equipment should be designed so that all exposed moving and cutting parts are shielded.

2.9.14.2 Covering protrusions. Protrusions, rails, corners, etc. that technicians might come into contact with on the test equipment should be covered with rubber or other appropriate materials.

2.9.14.3 High voltages. Internal controls should be located away from dangerous voltages. High voltage areas should be insulated or guarded.

2.9.14.4 Warning of hazards. Wherever a potential hazard exists, adequate warning should be provided

2.10 Cover, case, and shield design

Covers, cases, and shields refer to all protective and configuration devices which guard equipment from damage during shipping or during operation and maintenance on the job site. For standards relating to cover design and accessibility see Section 2.4.13, Access covers, in this document. Other relevant stands may be found in Section 2.11, Fastener design and application, Section 2.13, Handle and grasp area design, and Section 3.0, Workspace, storage, and workshop design, of this document.

2.10.1 Functions of covers, cases, and shields. When necessary to use, covers, cases, and shields should:

a. Maintain the degree of enclosure required by structural, operational, or environmental protection or control.

b. Divide enclosures into sections which differ because of temperature or ventilation control, types of cleaning methods to be used, etc.

c. Protect personnel from coming into contact with dangerous electrical or mechanical parts.

d. Protect moving parts, fuels, lubricants, etc. from dust, dirt, moisture, etc.

e. Protect delicate or sensitive equipment from damage by movements of personnel, shifting of cargo of loose objects, or actions involved in the installation and maintenance of nearby assemblies.

f. Provide and access whenever frequent maintenance operations would otherwise require removing the entire case or cover or dismantling an item of equipment.

2.10.2 Size/weight and ease of movement. Covers, cases, and shields should be:

a. Lightweight, if possible, but allow the degree of accessibility required.

b. Openable, removable, and transportable by one hand, one individual, or, at most, two individuals, in that order of preference.

c. Provided with lifting eyes and planned for crane handling if more than 100 lbs.

d. Provided with handles or tool grips if heavy or difficult to open or move.

e. Designed to allow sufficient clearance around enclosed components to minimize damage to these components and to avoid requirements for extremely fine or careful positioning end handling.

f. Designed and located so that bulkheads, brackets, or other units will not interfere with operation of the cover or case and so the cover or case, when opened, will not interfere with other maintenance operations.

g. Easy to use, in terms of equipment accessibility for maintenance (for example, quick release and connection covers, cases and shields, should be used with equipment that is frequently tested or adjusted).

2.10.3 Shape. Covers, cases, and shields should:

a. Be whatever shape is necessary to accomplish the degree of enclosure, allow the degree of accessibility, and provide the clearances required.

b. Make obvious, if possible, the manner in which the item must be positioned or mounted.

c. Make obvious, if possible, correct orientation to minimize damage to delicate components during removal or insertion.

d. Be free from sharp edges or protrusions which could injure personnel or damage lines and wires.

e. Be free of indentations or settling areas on top surfaces, to reduce rust, corrosion, and the accumulation of dirt and grease.

2.10.4 Mounting. Covers, cases, and shields should be designed, located, and mounted so they:

a. Do not bear any part of the structural load. It should not be necessary to support, download, or disassemble any equipment to remove the item.

b. Are completely removable and replaceable in case of damage. Irregular extensions and accessories should be readily removable.

c. Can be opened or removed as necessary when the equipment system is completely assembled and auxiliary equipment has been installed.

d. Do not cause the equipment to become unbalanced when opened. Props, retainers, or other support should be provided where required to prevent this.

e. Do not obscure or interfere with controls, displays, test points, or connections related to work within the access or enclosure, when in the open position.

f. Are provided with adequate stops and retainers to prevent them from swinging into or being dropped on fragile equipment or personnel.

g. Are provided with locking devices or retainer bars to lock them in the open position if they might otherwise fall or shut and cause damage, injury, or inconvenience (This is particularly necessary in strong wind conditions.)

2.10.5 Fasteners. Fasteners for covers, cases, and shields should be selected, applied, and mounted so that:

a. They optimally satisfy the applicable Guidelines in Section 1.11, Fastener design and application, in this document.

b. Maximum use is made of hinges and latches or catches to minimize the number of fasteners and requirements for handling and stowing covers and cases.

c. Fasteners for a given item or identical items are interchangeable, i.e., are the same type, size, diameter, and pitch of thread.

d. Fasteners align themselves with their retaining catches, nuts, blocks, or inserts without sticking and without damage to their threads or latches.

e. The cover or case will not open or loosen automatically under whatever stress, vibration, or other conditions are expectable.

f. It is obvious when a cover or case is not in place or securely fastened. Where feasible, fasteners should be spring-loaded so they stand out or the cover itself stays ajar when not secure.

2.10.6 Labeling. Labels and markings on covers and cases should

a. Provide opening, removal, or positioning instructions, if methods for accomplishing these are not obvious from the design.

b. Provide stock references so that covers, cases, and shields can be replaced when damaged.

c. Adequately reveal the functions of units behind the enclosure and/or the functions which are to be performed through the access, such as "Battery," "Fuel Pump," "Oil Here," etc.

d. Adequately warn against dangers or hazards involved in removing the cover or case or working within the enclosure.

e. Provide the proper orientation or connection of units, service equipment, etc. to go through the opening, if this is not clear or visible.

f. Not provide instructions which are subject to revision or change such as preventive maintenance instructions,

g. If use is required with the door open, be placed so that they will not be obscured by the open door (for example, on the structure behind or to the side of the access.) If instructions applying to a covered item are lettered on a hinged door, the lettering should be oriented to be read by the maintainer when the door is opened.

2.10.7 Types of covers, cases, and shields

2.10.7.1 Hinged doors, hoods, and caps. Hinges should be considered since they allow the fastest and easiest access, reduces the number of fasteners required, supports the cover so the technician does not have to handle it, and makes it unnecessary to disconnect wires or components mounted on the cover before entering the access. This type of cover, however, requires "swinging space," and may interfere with other operations or components.

2.10.7.2 Sliding doors or caps. Although large sliding doors may create structural design problems, sliding doors should be considered where "swinging space" is limited. Small, sliding caps are particularly useful for small accesses that do not require a close seal.

2.10.7.3 Removable doors, plates, or caps. Removable doors, plates, or caps may be useful where there are space limitations since they require little space for opening and, once removed, do not interfere with work space; however, their handling requires time and effort (searching, bending, reaching, etc.).

2.10.7.4 Removable panels or sections. Removable panels or sections may be useful when access to whole sides of a cabinet or equipment is needed. They discourage non-maintenance personnel from opening the access and do not require "swinging space;" however, they may be damaged easily and may be awkward to handle. They may also interfere with maintenance activities. (1.10.3.7.d)

2.10.8 Hinged doors, hoods, and caps

2.10.8.1 Double-hinged or split doors. Double-hinged or split doors should be used if opening space is a problem.

2.10.8.2 Placement of hinges when door is to stay open without being held. Hinges should be placed on the bottom; biased; or a prop, catch, or latch should be provided if the door is to stay open without being held.

2.10.8.3 Direction of opening. Adjacent hinged doors should open in opposite directions to maximize accessibility, and cabinets should be arranged so that functionally related cabinets are adjacent and open in opposite directions.

2.10.8.4 Hinged caps over service or test points. Hinged caps over service or test points should be designed not to interfere with the insertion or attachment of service or test equipment.

2.10.8.5 Stops and retainers. Stops, retainers, etc. should be provided when needed to prevent the door from swinging into adjacent displays, controls, or fragile components, and to prevent springing the hinges.

2.10.9 Sliding doors and caps

2.10.9.1 Positive locking. Sliding doors and caps should lock positively.

2.10.9.2 Jamming or sticking. Sliding doors and caps should be designed to avoid jamming or sticking.

2.10.9.3 No tools for operation. Sliding doors and caps should be easy to use and should not require tools for operation (unless limited or restricted access is intended).

2.10.9.4 Non interference. Their movement should not interfere with, damage, or have the potential for harmful contact with wires or other equipment items.

2.10.10 Removable doors, plates, and caps

2.10.10.1 Tongue and slot catches. Maximum use should be made of tongue and slot or similar catches for small plates, doors, and caps to minimize the number of fasteners needed .

2.11 Fastener design and application

Fastener refers to a device used to join two or more parts, components, or units together.
Fasteners include:

a. Quick disconnects.

b. Latches and catches.

c. Captive fasteners.

d. Combination head-bolts and screws.

e. Regular screws.

f. Internal wrenching screws and bolts.

g. Rivets.

2.11.1 Criteria for fastener design, selection, and application. Fasteners should be designed, selected and used based on:

a. Durability.

b. Speed and ease of operation.

c. Ease of replacement.

d. Stress and environmental factors the fasteners must withstand.

e. Work space, tool clearance, and wrenching space around the fastener.

f. Types of tools required for operation of the fastener, as a function of fastener type, application, and location.

g. Types and varieties of fasteners being used elsewhere in the system, or commonly used by the using utility.

h. The frequency with which the fasteners will be operated.

i. The time requirements of tasks involving operation of the fasteners.

2.11.2 Reducing variety and number of fasteners and tools required.

2.11.2.1 Minimizing types and sizes of fasteners. The number of types and sizes of fasteners used within a system should be minimized by:

a. Using the same type and size of fastener for the same application (e.g., all mounting bolts for a given type of item).

b. Avoiding requirements for special or close tolerance fasteners.

2.11.2.2 Reducing number of different torque requirements. The number of different torque requirements used within a system should be minimized by:

a. Using only a few basic values.

b. Keying values used to clearly differing types, sizes, or coded fasteners.

c. Where precise torquing is required, providing clearance for wrenches or sockets with variable torque settings.

2.11.2.3 Minimizing types of tools required. The number of tool types and sizes that are needed for fastener operation should be minimized.

2.11.2.4 Use of hinges, catches, etc. The use of hinges, catches, latches, and quick disconnect fasteners should be maximized to reduce the number of fasteners required.

2.11.2.5 Use of large fasteners. A few large fasteners should be used rather than many smaller ones (except where many are needed to maintain a fluid or air-tight seat).

2.11.2.6 Maximum of four fasteners. No more than four fasteners should be used to mount a unit. (A common fault is to use too many fasteners when a more rigid construction is preferred.)

2.11.2.7 Location for each fastener type obvious. When more than one size or type of fastener is used on the same equipment or cover, the fastener/equipment/cover should permit the maintainer to easily distinguish the intended location of each type of fastener.

2.11.3 Varying fastener size and shape to avoid improper connection. Screws, bolts, and units of different thread sizes should be clearly different in physical size or shape of the head to preclude being interchanged. This requirement may increase the number of types and sizes used.

2.11.4 Fastener fabrication. Fastener fabrication should:

a. Use corrosion-resistant materials (e.g., stainless, galvanized, cadmium-coated, non-ferrous).

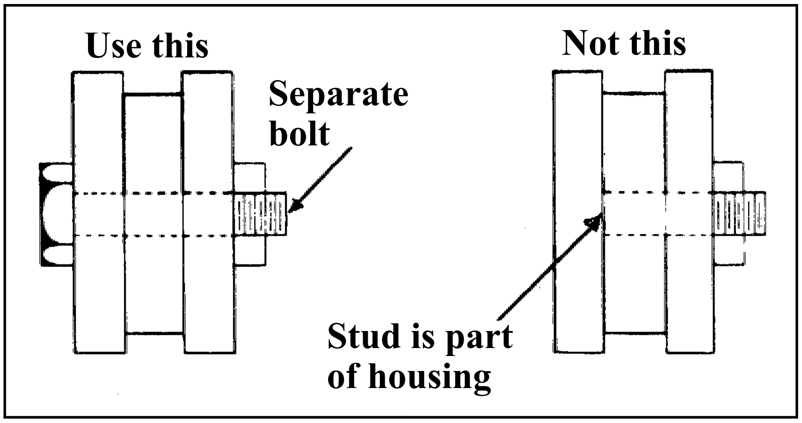
b. Not use aluminum alloy threaded into aluminum alloy parts.

c. Not use materials that cause galvanic action (e.g., a titanium fastener used with magnesium would cause galvanic corrosion).

d. Use metals where high tensile or shear strength is required.

2.11.5 Ease of replacing damaged fasteners. Ease of replacing stripped, worn, or damaged fasteners should be a design consideration. Fasteners, which are part of a unit's housing, should be avoided (See also Figure 2.11.1, Example of proper and improper design of bolt fastener).

Figure 2.11.1. Example of proper and improper design of bolt fastener.



2.11.6 Mounting fasteners. Fasteners should be mounted so that:

a. Fastener mounting holes or other tolerances are large enough to allow "starting" of fasteners without perfect alignment.

b. Hinges, catches, latches, locks, and other quick disconnect devices are attached by small bolts or screws, not rivets; however, the bolts or screws should not be so small that they are difficult to manipulate.

c. Bolts should have the head up so they will stay in position if the nut falls off.

d. Nuts and bolts (particularly those which are frequently operated or poorly accessible) are mounted so they can be operated with one hand or one tool by:

- Providing recesses to hold either the nut or bolt.
- Semi-permanently attaching either the nut or bolt.
- Using double nuts on terminal boards and similar applications.
- Using nut plates, gang-channeling, or floating nuts.

2.11.7 Fastener location. Fasteners should be located so they:

a. Can be operated without prior removal of other parts or units.

b. Can be operated with minimum interference from other structures.

c. Do not interfere with each other or other components.

d. Do not constitute a hazard to personnel, wires, or hoses.

e. Are surrounded by adequate hand or tool clearance for easy operation.

2.11.8 Fastener coding. Fasteners should be coded so that:

a. All external fasteners which are manipulated during normal maintenance provide strong color contrast with the color of the surface on which they appear.

b. All other external fasteners and assembly screws are of the same color as the surface on which they appear.

c. The heads of "special" bolts and screws are color- or stamp-coded to ensure that they are properly handled and are replaced by identical fasteners.

d. Only markings which designate the size, type, or torque value of the fastener are used. Manufacturers' names or trademarks should be omitted.

e. Fastener markings are etched or embossed to withstand exposure to chemicals, fuels, weather, or other operational conditions.

f. One fastener marking code is used throughout the system. This code should be determined and standardized ahead of time, and it should conform to prevailing standard practices.

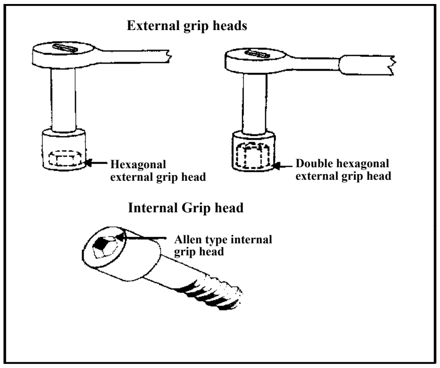
2.11.9 Tool-actuated fasteners

2.11.9.1 High torque fasteners. External hexagonal or external double hexagonal grip heads should be provided on all machine screws, bolts, or other fasteners requiring more than 14 Nm (10 ft-lb) of torque. When external grip heads cannot meet the mechanical function or personal safety requirements, or in limited access situations, and where use is protected from accumulation of foreign material, internal grip heads may be used. Where used, internal grip heads should of the Allen-head-type (See also Figure 2.11.2, Examples of external and internal grip heads).

2.11.9.2 Low torque fasteners. Hexagonal-type internal grip head, hexagonal-type external grip head, or combination-head (hex or straight-slot internal grip and hex-type external grip head) fasteners should be used where less than 14 Nm (10 ft-lb) of torque is required; however, internal-grip head fasteners should only be used where a straight or convex smooth surface is required for mechanical function or for personnel safety and where use is protected from accumulation of foreign material. Straight-slot or cross-recess type internal grip head fasteners should not be provided except as wood fasteners or where that type of fastener is provided on standard commercial items.

2.11.9.3 Torque labeling. When fasteners torquing to meet shielding, thermal conductance, or other constraints is required, an instructional label or placard should be provided in reasonable proximity to fasteners. The label should specify required torque value and torquing sequence as well as meet the requirements for labels specified in Section 2.3, Labeling, marking, and coding.

Figure 2.11.2. Examples of external and internal grip heads..



2.11.9.4 Tool access. Direct tool access should be provided to allow for torquing without the use of irregular extensions (See also Section 1.4, Equipment accessibility, of this document).

2.11.9.4.1 Tool head clearance. When only tool head access is required a 2.5 cm (1 in.) clearance should be provided around the fastener or drive stud for insertion, actuation, and removal of the drive end of the tool.

2.11.9.4.2 Tool handle clearance. A minimum of 76 mm (3 in.) should be provided for clearance between a tool handle engaged on a fastener or drive stud and the nearest piece of hardware through a full 180° sweep envelope.

2.11.9.4.3 Tool head-to-fastener engagement height. The tool socket/fastener head engagement height should be a minimum of 70 (0.3 in.) for single height grip heads and 140 mm (0.6 in.) for double height grip heads.

2.11.9.4.4 Tool handle offset. The maximum tool offset between the tool handle and the tool head should be 355 mm (14 in.)

2.11.10 Types of fasteners

2.11.10.1 Quick release fasteners (Cowl or panel fasteners). These are fast and easy to use, require no tools, may be operated with one hand, and are very good for securing plug-in components, small components, and covers. However, their holding power is low and they cannot be used where a smooth surface is required. These fasteners should:

a. Be carefully evaluated on the basis of type and application.

b. Be used wherever possible for components that must be frequently dismantled or removed such as during testing and adjusting.

c. Fasten and release easily, without the use of tools.

d. Fasten or unfasten in a maximum of one complete turn.

e. Clearly indicate when they are not correctly engaged.

f. Should be located, shaped, sized, or coded so that only the correct male section may be attached (See also Figure 2.11.3, Examples of quick-release type fasteners).

2.11.10.2 Latches and clamps. These are very fast and easy to use, require no tools, have good holding power, and are especially good for large units, panels, covers, and cases. They cannot be used where a smooth surface is required.

Latches should:

a. Have Long latch catches should be provided so that accidental springing is minimized (See also Figure 2.11.4, Example of effective latch catch fastener).

Figure 2.11.3. Examples of quick-release type fasteners.

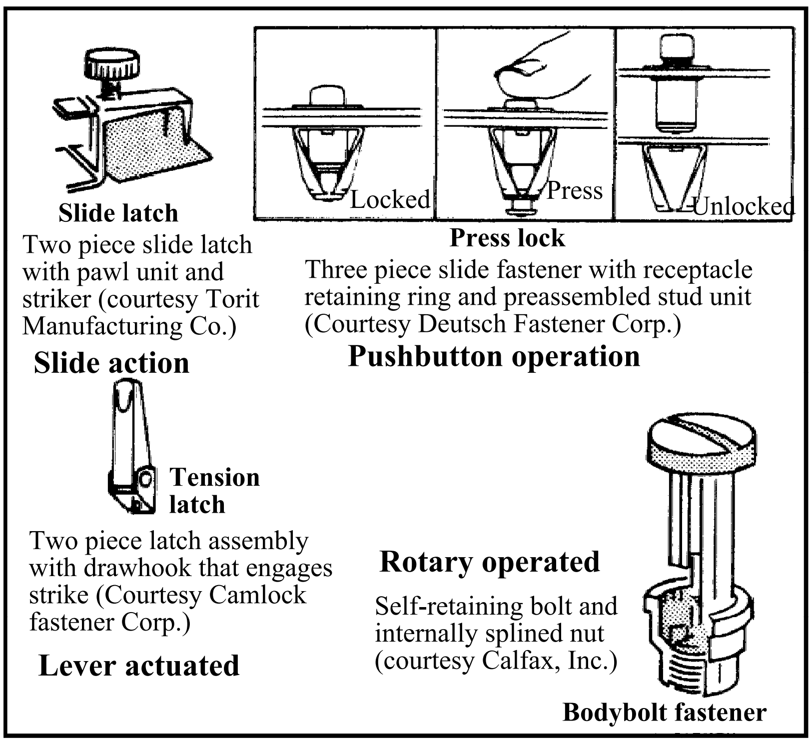
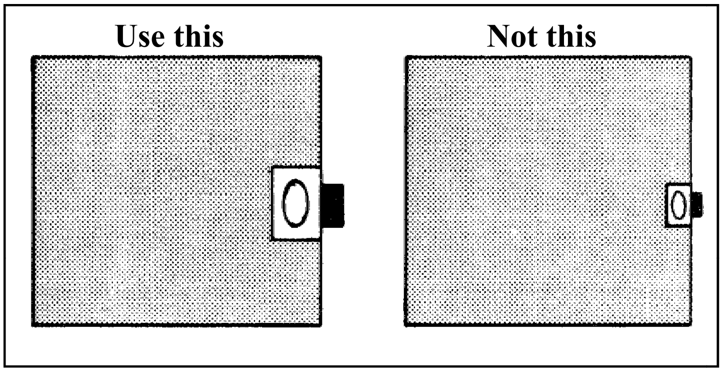
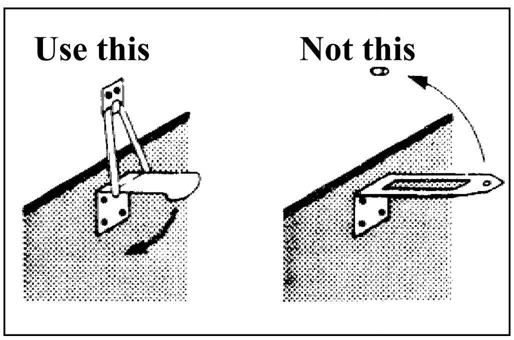


Figure 2.11.4. Example of effective latch catch fastener.



b. Along with their catches, be located and positioned so they will not open accidentally under usual operating conditions (See also Figure 2.11.5, Example of effective positioning of latches).

Figure 2.11.5. Example of effective positioning of latches.



c. Have spring-loaded catches so they do not require positive locking, but lock on contact.

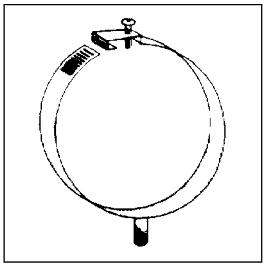
d. Use a latch loop and locking action if positive locking is necessary to meet structural or stress requirements.

e. When a handle is used, have the latch release located on or near the handle so that only one hand is needed for operation.

Clamps should:

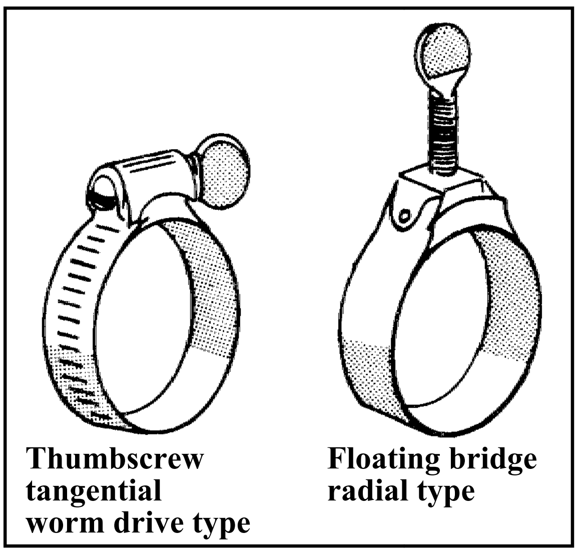
a. Be of the quick release type where not subjected to excessive force (See also Figure 2.11.6, Examples of quick-release clamp).

Figure 2.11.6. Example of quick-release clamp.



b. Only require one hand operation where more holding force is required (See also Figure 2.11.7, Example of clamp requiring one hand operation).

Figure 2.11.7. Example of clamp requiring one hand operation.



2.11.10.3 Captive fasteners. These are slower and more difficult to use (depending upon type), and require use of common (usually) hand tools; however, they stay in place, save the time spent handling and looking for bolts and screws, and require only one-handed operation. Captive fasteners should:

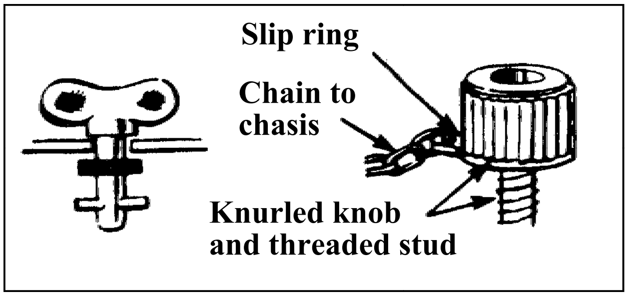
a. Be used wherever lost screws, bolts, or nuts might cause a malfunction or result in excessive maintenance time.

b. Be operable by hand or common hand tools should be used.

c. Be easily replaceable in case of damage.

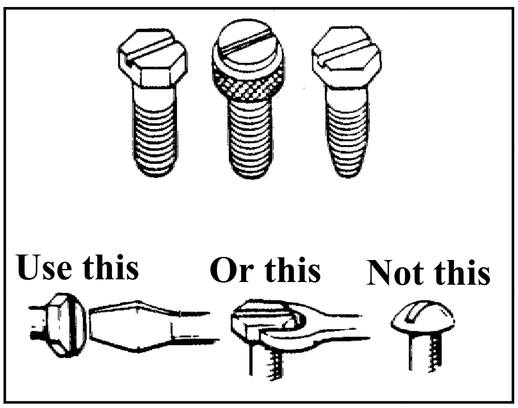
d. Be self-locking and have a spring-loaded action when they are the quarter-turn type (See also Figure 2.11.8, Example of captive fasteners).

Figure 2.11.8. Example of captive fasteners. (Ex. 1.11.7)



2.11.10.4 Combination head-bolts and screws. These should be used in preference to other screws or bolts simply because they may be operated more rapidly with either a wrench or a screwdriver. This allows use of the more convenient tool and reduces the possibility of slot damage and stuck fasteners. In general, slotted, hexagonal heads are preferable to knurled and slotted heads (See also Figure 2.11.9, Examples of combination head bolts and screws and slotted hexagon screws).

Figure 2.11.9. Examples of combination head bolts and screws and slotted hexagon screws.



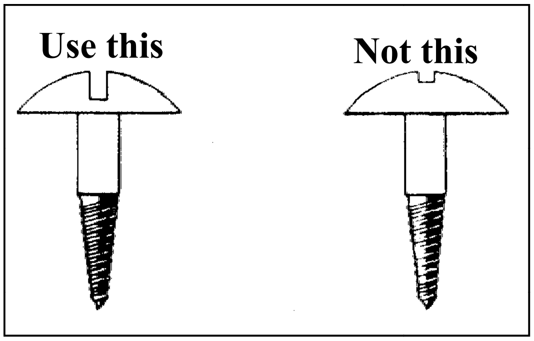
2.11.10.5 Regular screws. Round, square, or flatheaded screws require more time and are more subject to loss, slot damage, stripping, and misapplication than combination head bolts and screws; but they require less wrenching space, only one-handed action to operate, and do not involve a number of extra parts. Square-headed screws are generally preferable to round or flat since they provide better tool contact, are less subject to slot damage, and may be removed with pliers. When used, regular screws should:

a. Require less than 10 turns for lightening or loosening.

b. When tightened, fully engage to a distance at least equal to its diameter.

c. Have deep slots on screw heads to minimize slot damage and tool slippage (See also Figure 2.11.10, Example of deep-slotted screw heads).

Figure 2.11.10. Example of deep-slotted screw heads.



d. Be used only when screwdrivers may be used in a straight-in fashion.

e. Not require use of offset screw drivers.

f. Have a tool guide in the assembly if a screw must be operated blindly.

g. Have fine thread screws when used for pressurized units.

h. Be countersunk only where necessary to provide a smooth surface.

i. Be round-head rather than flat-head when used on panels less than 3/32 inch thick, so that they will not rip through the panel.

j. If self-tapping, have one type of head and be of one size, or a minimum number of sizes.

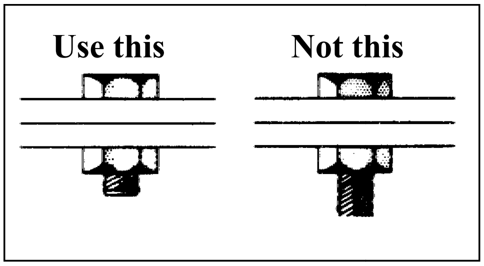
2.11.10.6 Bolts and nuts. Bolts are usually slow and difficult to use. They require two-handed operation, access to both ends of the bolt, and often use of two tools. They also require precise movements in starting nuts and have many loose parts to handle and lose (nuts, washers, etc.).

Latches should: have long latch catches should be provided so that accidental springing is minimized (See also Figure 2.11.4, Example of effective latch catch fastener).

2.11.10.6.1 Bolts:

a. Bolt length should not be more than required for a given purpose (See also Figure 2.11.11, Example of appropriate bolt length). When tightened, the bolt should extend a minimum of two threads beyond the nut.

Figure 2.11.11. Example of appropriate bolt length. (Ex. 1.1.10)



b. The number of turns to tighten a bolt should be less than 10.

c. When tightened, the bolt should extend a minimum of two threads beyond the nut.

d. Hexagonal-head bolts should be used generally, and especially for high torque usage.

e. Left-hand threads should be used only when stress conditions require; and both bolts and nuts should be clearly identifiable by marking, shape, or color.

f. Self-locking bolts (in tapped holes) should be used only when one surface must be smooth or is inaccessible and temperatures will be below 121°C (250° F).

2.11.10.6.2 Nuts:

a. Regular hexagonal nuts are preferred, in a few easily distinguishable sizes.

b. Different sizes of nuts should be used for different thread requirements.

c. Wing or knurled nuts, which require no tools, should be used for low tension applications. Wing nuts are the easier to use.

d. Self-sealing nuts should be used for fastening equipment to fluid tanks to prevent leaking around fastener (See also Figure 2.11.12, Example of self-sealing nut.).

e. Lock nuts may be used for mounting light components; but they must withstand heat requirements, and cannot be used where fallen nuts could damage equipment (See also Figure 2.11.13, Example of lock nut).

f. Clinch nuts should be incapable of rotating or moving with respect to the surface on which they are mounted (See also Figure 2.11.14, Example of a clinch nut).

g. Floating nuts should have an allowable shift of only plus or minus 1.6 mm (1/16) inch (See also Figure 2.11.15, Example of a floating nut).

Figure 2.11.12. Example of self-sealing nut.

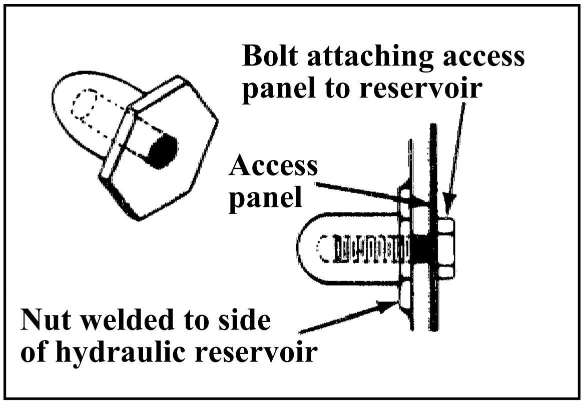


Figure 2.11.13. Example of lock nut.

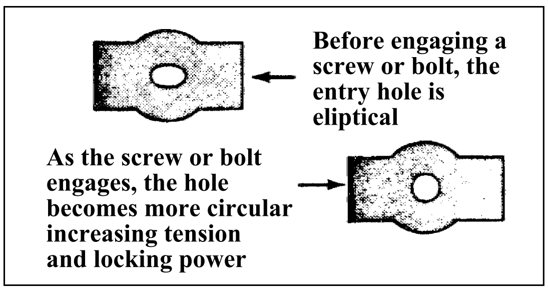


Figure 2.11.14. Example of a clinch nut.

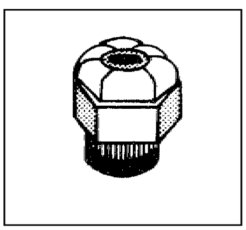
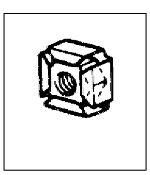


Figure 2.11.15. Example of floating nut.



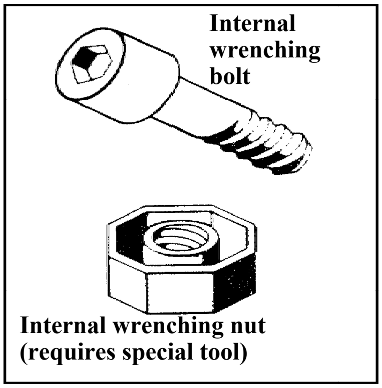
2.11.10.7 Internal wrenching screws and bolts. Internal wrenching screws and bolts allow higher torque, better tool grip, and less wrenching space. However, they are easily damaged, difficult to remove when damaged, and require special tools. Internal wrenching screws should be designed so that:

a. The number of different sizes is minimized to require only one, or as few as possible, tools.

b. Slots are deep to eliminate damage to the fasteners.

c. To allow and plan for the removal of damaged internal wrenching fasteners in terms of clearances, power outlets, etc. (See also Figure 2.11.16, Example of internal wrenching bolt and nut).

Figure 2.11.16. Example of internal wrenching bolt and nut.



2.11.10.8 Rivets. Permanent fasteners are hard and slow to remove and replace; they should not be used on any part which may require removal. Wire stapling or metal stitching is generally preferable to rivets for maintenance purposes. Rivets should:

a. Not be used on latches, hinges, or retainers.

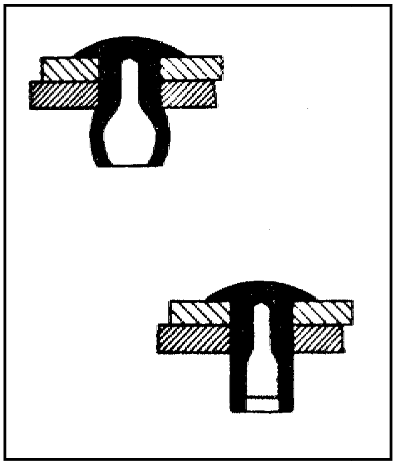
b. Be of softer material than the pieces they fasten.

c. For countersunk rivets, have heads larger than the thinnest of the pieces they fasten, to prevent them from ripping through.

d. For shear rivets which do not expand to fill the hole and consequently require holes drilled to close tolerances, maintenance instructions should specify these hole tolerances and the sizes of plug gauges and reamers to be used.

e. Expand by chemical charge rather than by peening for minor maintenance of light components. These rivets expand when heat is applied to a chemical charge contained within the rivet. Rivets are especially useful in blind applications (See also Figure 2.11.17, Example of chemical charge rivet).

Figure 2.11.17. Example of chemical charge rivet.



2.11.11 Fastener accessories

2.11.11.1 Washers. Washers should:

a. Fit tightly against the underside of the fastener head.

b. Fit the shaft snugly, but should be easy to remove.

c. Be split-ring lock washers if used with static loads in excess of 2 oz.

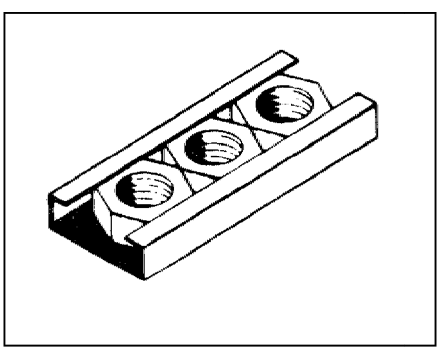
d. Be lock washers if used with lock nuts, for maximum locking action.

2.11.11.2 Metallic inserts and blocks. Metallic inserts and blocks should:

a. Be secured so that tightening of the screw or bolt will not loosen or move the insert or block.

b. Be used with gang-channeling of nuts to save time when there are many nuts in a straight line. Only channels should be used in which nuts can be replaced individually (See also Figure 2.11.18, Example of gang-channeled nuts).

Figure 2.11.18. Example of gang-channeled nuts.



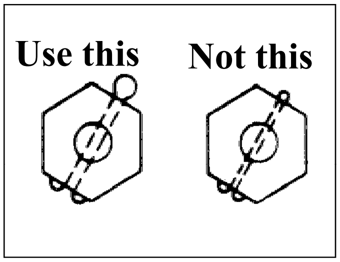
c. Only be used with nut-plates when several bolts are to be fastened on one surface and alignment is not a problem. (Nut-plates heavy and expensive to replace when a hole is stripped.)

2.11.11.3 Cotter pins and keys. Cotter pins and keys should:

a. Fit snugly, but should not require driving in or out.

b. Regarding cotter keys, have large heads to facilitate removal and prevent the keys from slipping through (See also Figure 2.11.19, Example of adequate size cotter key head).

Figure 2.11.19. Example of adequate size cotter key head.



2.11.11.4 Safety wire. Safety wire should:

a. Be used only when self-locking fasteners or cotter pins are not adequate to withstand the expected vibration or stress.

b. Be attached so it can be easily removed and replaced.

c. Be used where visible means of detection is required to determine if a fastener has become loosened or has changed position.

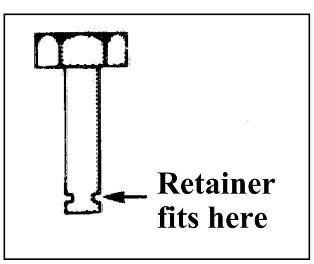
2.11.11.5 Retainer rings. Retainer rings should:

a. Easily removed and replaced when worn.

b. Hold with a positive snap action.

c. Use Spring tension to prevent loosening or unlocking of twist-to-lock rings (See also Figure 2.11.20, Example of retainer ring).

Figure 2.11.20. Example of retainer ring.



2.11.11.6 Retainer chains. Retainer chains should:

a. Be link, sash, or woven-mesh type chains; bead-link chain is not recommended because it breaks more easily than other types.

b. Be attached with screws or bolts; attachment should be strong and positive, but easily disconnected when required.

c. Have eyelets at both ends of the chain for the attaching fasteners.

d. Be attached externally rather than internally when used for filler caps to facilitate replacement and prevent broken parts from damaging equipment.

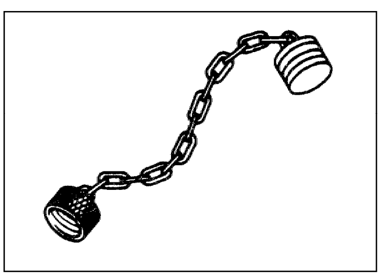
e. Not be used wherever they might interfere with moving parts.

f. Use chain covers that are flexible, durable, and easy to bend where they are required to prevent chains from becoming tangled.

g. Be used (locking bars may also be used) to:

- Keep hatches or doors from opening too far and springing their hinges.
- Turn doors or covers into useful shelves for the technician.
- Prevent small covers, plates, or caps from being misplaced.
- Secure small, special tools to the location in which they will be used.
- Secure objects which might otherwise fall and cause personnel injury (See also Figure 2.11.21, Example of retainer chain)

Figure 2.11.21. Example of retainer chain.



2.12 Drawer and rack design

Drawers and racks refer to pullout, roll-out, slide-out, or hinged equipment assemblies designed to (See also Figure 2.12.1, Examples of drawer and rack design, for examples of different designs):

a. Optimize work space, tool clearance, and accessibility.

b. Reduce the need for the technician to handle fragile or sensitive items.

c. Facilitate the handling and/or positioning of heavy or awkward items.

d. Facilitate the maintenance of items which must be frequently moved from their installed positions for checking, servicing, or repair.

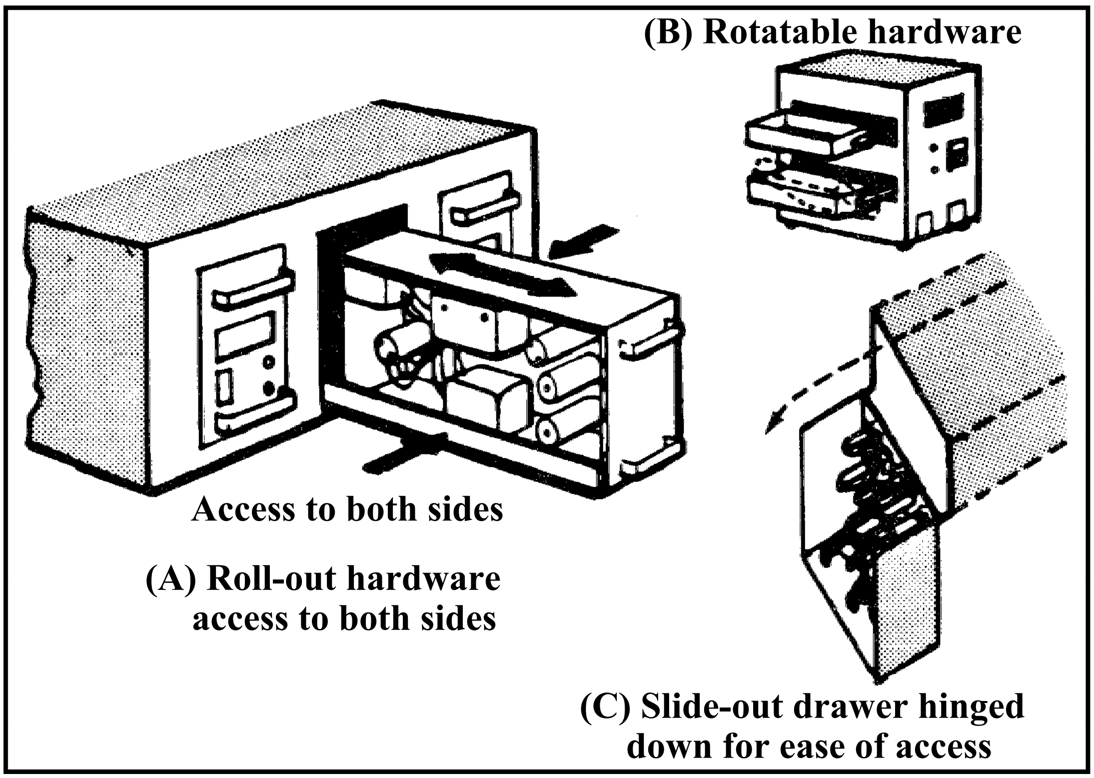
2.12.1 Minimum number of operations. Drawers and racks should require a minimum number of operations to open or release them.

2.12.2 Force to open. A force of less than 176 N (40 lbs.) should be required to open and release drawers and racks.

2.12.3 Bearing assembly. A smooth operating bearing assembly should be used, as needed.

2.12.4 Center of gravity. Rollout rack mounted in consoles should not shift the center of gravity to cause the console to be unstable. If this possibility exists the console or rack should be safely secured.

Figure 2.12.1. Examples of drawer and rack design.



2.12.5 Automatic locking. Where locking is required, drawers and racks should lock automatically in both servicing and operating modes. Unlocking of self-locking provisions should be accomplished by one hand.

2.12.6 Open/closed/locked status obvious. On visual inspection the status of the drawer or rack should be obvious e.g., if it is fastened/locked and if it is in the closed position.

2.12.7 Small, hinge mounted units. Small, hinge-mounted units, which must have access from the back, should be free to open their full distance and remain open without being held

2.12.8 Handles. Handles should be provided on drawers and racks, when necessary, to facilitate operation and handling.

2.12.9 Assemble accessibility. Assemblies should be accessible without breaking internal connections which are necessary for required maintenance.

2.12.10 Interlocks. Interlocks should be provided to improve safety and ensure disconnection of equipment that would otherwise be damaged by withdrawal of racks or drawers. Equipment design should obviate the need for interlocks.

2.12.11 Guards and shields. To prevent possible damage to fragile or sensitive parts during movement of the assembly, drawers and racks should be provided with guards and shields as necessary.

2.12.12 Rests, limit stops, guards, and/or retaining devices. Rests, limit stops, guards, and/or retaining devices should be provided as part of the basic chassis.
They should:

a. Prevent the assembly from being unintentionally pulled out from the rack.

b. Prevent heavy assemblies from tipping the equipment.

c. Allow complete and convenient removal of the assembly.

d. Allow the assembly to open to its full distance and remain open without being held.

e. Permit convenient overriding of stops for rack or drawer removal without use of a tool.

2.12.13 Leads or cables to drawer or rack. Leads or cables to drawers and racks should have adequate slack and protection so they allow movement of the drawer or rack without their disconnection.

2.12.14 Connection and disconnection of leads or cables. The connections should be designed to be easily disconnected/connected when the drawer is in the fully opened position.

2.12.14.1 Connectors attached so closing assembly establishes connection. If internal connection is not required for maintenance, connectors to the drawer or rack may be attached to the assembly so that closing the assembly establishes connection. This requires:

a. Connector parts to be mounted on the assembly's rear wall.

b. Locks to ensure that the connectors remain engaged.

c. Guides to ensure proper orientation of the assembly prior to pin engagement.

d. Insulation to the connectors, as needed, for safety.

2.13 Handle and grasp area design

Handles are for grasping removable or replaceable units. Grasp area refers to a surface used as a handhold during installation or removal.

2.13.1 Use of handles. Handles should be provided on all packages, units, components, and covers whenever these items are handled frequently, difficult to carry, hold fragile components, or weigh over 4.5 kg (10 lbs.)

2.13.2 The size, location, and positioning of handles. The size, location, and positioning of handles should be based on

a. Weight and center of gravity of the item or unit.

b. Number of persons, or hands, required to lift or carry the item.

c. Type of clothing and gloves worn.

d. Operational position of the item relative to other items.

e. Manner in which the item is to be handled or positioned

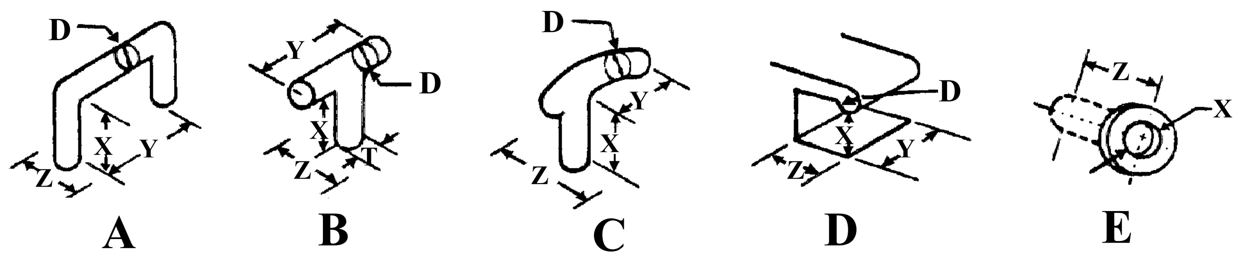
f. Distance over which the item must be carried.

g. Frequency with which the item must be handled or carried.

h. Additional uses the handles could serve.

2.13.3 Minimum dimensions for different handle designs. The recommended minimum dimensions for different types of commonly used handles are presented in Figure 2.13.1, Minimum dimensions for commonly used handle designs.

Figure 2.13.1. Minimum dimensions for different handle designs



Type of handle	Dimensions in mm (in.)								
	Bare hand			Gloved hand			Mittened hand		
	X	Y	Z	X	Y	Z	X	Y	Z
(See Figure A) Two-finger bar	32 (1.25)	64 (2.5)	76 (3)	38 (1.5)	76 (3)	76 (3)	Not applicable		
One-hand bar	48 (1.9)	112 (4.4)	76 (3)	51 (2)	127 (5)	102 (4)	76 (3)	133 (5.25)	152 (6)
Two-hand bar	48 (1.9)	216 (8.5)	76 (3)	51 (2)	267 (10.5)	102 (4)	76 (3)	279 (11)	152 (6)
(See Figure B) T-bar	38 (1.5)	102 (4)	76 (3)	51 (2)	114 (4.5)	102 (4)	Not applicable		
(See Figure C) J-bar	51 (2)	102 (4)	76 (3)	51 (2)	114 (4.5)	102 (4)	76 (3)	127 (5)	152 (6)
(See Figure D) Two-finger recess	32 (1.25)	64 (2.5)	51 (2)	38 (1.5)	76 (3)	51 (2)	Not applicable		
One-hand recess	51 (2)	108 (4.25)	89 (3.5)	89 (3.5)	133 (5.25)	102 (4)	89 (3.5)	133 (5.25)	127 (5)
(See Figure E) Finger-tip recess	19 (0.75)	---- ----	13 (0.5)	25 (1)	---- ----	19 (0.75)	Not applicable		
One-finger recess	32 (1.25)	----	51 (2)	38 (1.5)	----	51 (2)	Not applicable		

Curvature of Handle or Edge (Does not preclude use of oval handles)

Weight of item Minimum diameter

Gripping efficiency is best if finger can curl around handle or edge to any angle

Up to 6.8 kg (15 lb) D = 6 mm (0.25 in.) 6.8 - 9.1 kg (15 - 20 lb) D = 13 mm (0.5 in.)
120¤ or more.
9.1 - 18.1 kg (15 - 40 lb) D = 19 mm (0.75 in.)
Over 18.1 kg (40 lb) D = 25 mm (1 in.)
T-bar post T = 13 mm (0.5 in.)

2.13.3.1 Dimension for handles requiring a firm grip. Handles that must be gripped firmly should be at least 114 mm (4.5 in.) wide and 51 mm (2.0 in.) deep.

2.13.4 Location lifting handles and grasp areas. Whenever possible, handles, grasp areas or hoist points should be located to preclude uncontrolled swinging or tilting when lifted e.g. over the center of gravity. They shall be located to provide at least 50 mm (2 in.) of clearance from obstructions during handling and should allow the carried item to clear the carrier's legs. Handle location should not interfere with installing, removing, operating or maintaining the equipment. When two or more handles are required, they should be placed at equal distances from the center of gravity. (See also Figure 2.13.2, Handle location for easy carrying).

2.13.5 Handles for covers. Covers should be provided with handles to facilitate removing them and also for carrying the unit (See also Figure 2.13.3, Handle location for covers and carrying units).

Figure 2.13.2. Handle location for easy carrying.

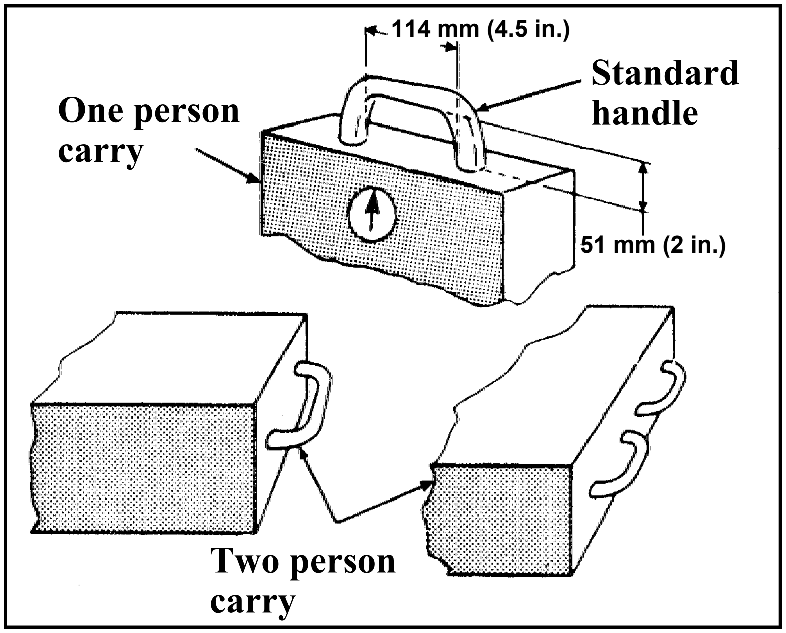
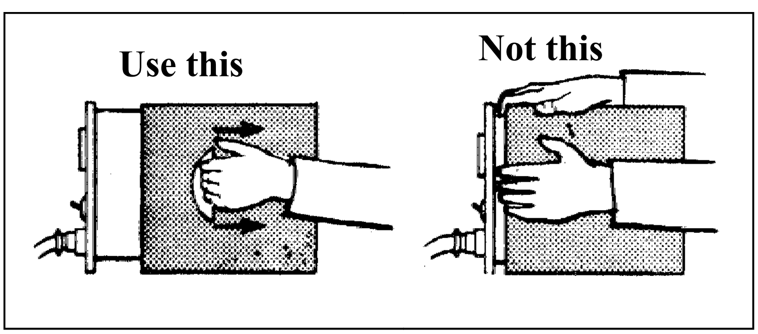


Figure 2.13.3. Handle location for covers and carrying units.



2.13.6 Lifting criteria for handles. Handles should meet the lifting criteria listed in Table 2.13.1, Lifting Criteria for handles.

Table 2.13.1. Lifting criteria for handles.

Weight to be lifted	Handle diameter	Finger clearance	Handle width
Under 11.3 kg (25 lb)	6 mm - 13 mm (0.25 - 0.5 in.)	51 mm (2 in.)	114 mm (4.5 in.)
Over 11.3 kg (25 lb)	13 mm - 19 mm (0.5 - 0.75 in.)	51 mm (2 in.)	114 mm (4.5 in.)
Lifted by gloved hand		64 mm (2.5 in.)	127 mm (5 in.)

2.13.6.1 Handles for heavier units. Units weighing more than about 11.3 - 18.1 kg (25 - 40 lb) (depending on the size and bulkiness of unit) should be provided with handles for two-person carrying. For units weighing more than 34 kg (75 lb) suitably labeled hoist eyes should be provided. A minimum of 102 mm (4 in.) clearance should be provided about the eye.

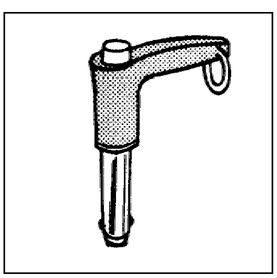
2.13.7 Molded handles. Handles should be comfortable and easy to grasp. When units must be frequently carried for long periods of time, a molded handle should be used to prevent size pressure on the fingers.

2.13.8 Recessed, concealed and folding, attachable (e.g., nonfixed) handles. Recessed grips should be provided near the back of heavy units to facilitate handling. Recessed, concealed, folding, or attachable handles may be used in place of fixed handles to conserve space, but they should be accessible without tools, should be capable of being placed into carrying position by one hand, and folding handles should remain securely folded when not in use. Hinged or fold out handles should have a stop position for holding the handle perpendicular to the surface on which it is mounted.

2.13.8.1 Tactile or visual indicators. Attachable/removable handles should incorporate tactile or visual indication of locked/unlocked status.

2.13.8.2 Quick release pins. Attachable handles should be equipped with quick-release pins to make them easier to insert and remove (See also Figure 2.13.4, Handle equipped with quick-release pins).

Figure 2.13.4. Handle equipped with quick-release pins.



2.13.9 Handles for printed circuit boards. Examples of handles used for the withdrawal and handling of printed circuit boards and their recommended use are shown in Figure 2.13.5, Examples of handles for withdrawing printed circuit boards.

2.13.10 Supplemental functions of handles. Handles may be used to fulfill a variety of supplemental functions which are illustrated below in Figure 2.13.6, Examples of miscellaneous uses for handles.

2.13.11 Grasp surface. Where an item's installation requires that its bottom surface be used as a handhold during removal or installation, a nonslip grasp surface (e.g. grooved, knurled, or frictional) shall be provided.

2.13.12 Handle and grasp surface material. Handles or grasp areas used with bare hands should have surfaces that are not thermally or electrically conductive. The surface should be sufficiently hard to prevent imbedding of grit and grime during normal use.

Figure 2.13.5. Examples of handles for withdrawing printed circuit boards.

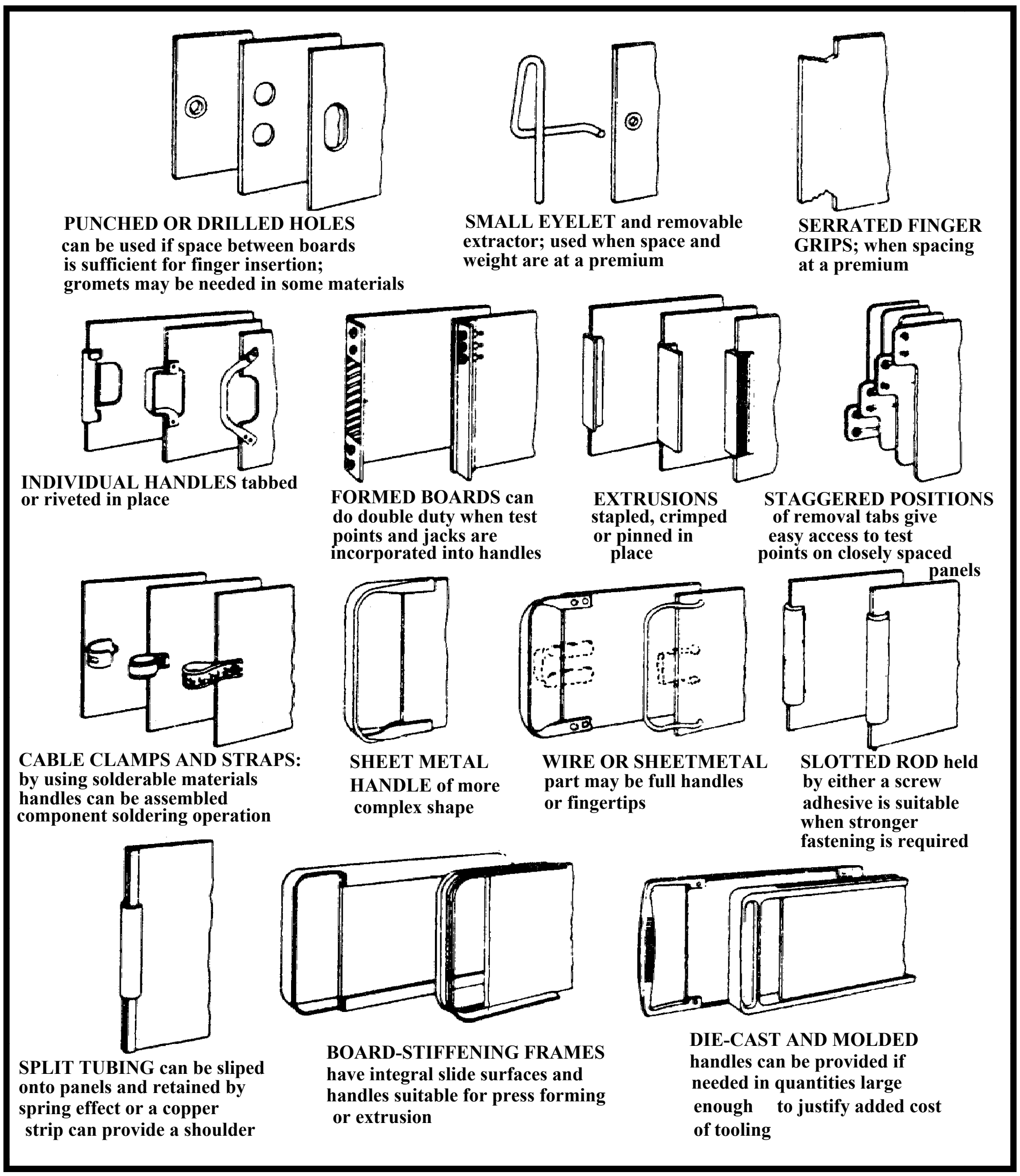
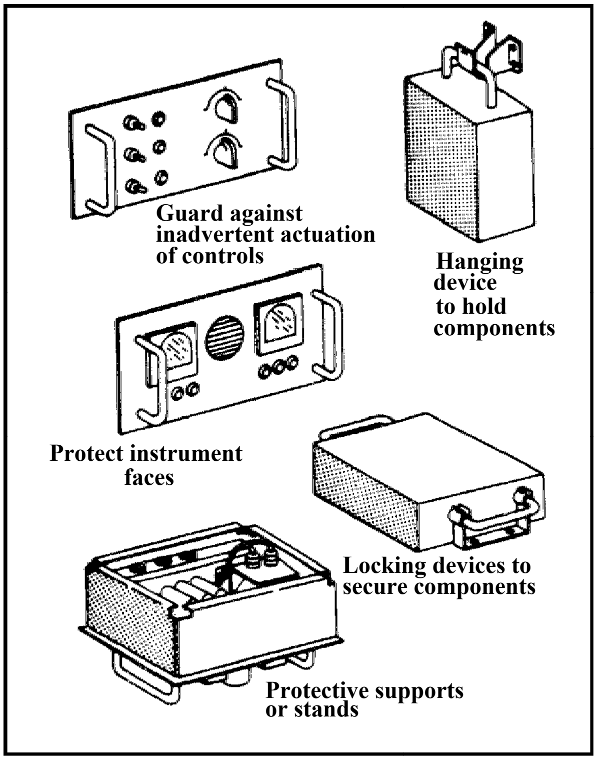


Figure 2.13.6. Examples of miscellaneous uses for handles.



2.14 Maintenance Safety. Human factors engineering/ergonomics in the performance of maintenance is a major factor in the design for maintainability and safety of the operation.

2.14.1 General: Design should reflect the safety-related human factors engineering/ergonomics criteria below, as well as other sections of this handbook. The order of precedence for satisfying system safety requirements is as follows:

a. Design for minimum risk

b. Incorporate Safety devices

c. Provide warning devices

d. Provide procedures and training

e. Personnel Protective Equipment

OSHA requirements (19CFR 1910.147) should be invoked to reduce all reasonable hazards to personnel.

2.14.2 Warning labels or placards. Conspicuous labels or placards should be placed on, or adjacent to, any equipment that presents a hazard to personnel (e.g., high voltage, heat, toxic vapors, explosion, or radiation). These labels or placards should describe the hazard and state precautions. Labels and placards should also describe the consequences of not complying with the stated warning. They should:

a. Be readable from a safe distance

b. Be located so as to be apparent to operators, maintainers, and transient personnel

c. Create no additional distractions, and

d. Not be hazardous themselves.

2.14.3 General equipment-related hazards

2.14.3.1 Interlocks and alarms. The operation of switches or controls which initiate hazardous operations should require the prior operation of a related or locking control. Where practicable, the critical position of such a control should activate a visual and auditory warning device in the affected work area.

2.14.3.1.1 Lockout/tag-out Devices. Lockout tag-out devices must be designed into the equipment to prevent maintenance activities from taking place prior to dangerous electrical or other dangerous conditions being eliminated. The lockout/tag-out devices must be under the control of the maintenance personnel (i.e., Lock on the electrical supply not removed until the maintenance activity is completed) in accordance with 19 CFR 1910.147.

2.14.3.2 Discharging devices such as shoring bars must be used to discharge high-voltage circuits and capacitors unless they discharge to less than 30 volts within 2 seconds after power removal. (EPRI-NP-4350, Chapter IV-C, Section4.4)

2.14.3.3 Access. Equipment should be located and mounted so that access can be achieved without danger to personnel from electrical, thermal, mechanical, chemical, radiological or other hazards. Adequate access area and walking/working surfaces must be designed into the workplace for personnel to safely accomplish maintenance activities.

2.13.3.3.1 Covers. Guards and Shields. Covers, Guards and shields must be designed into the equipment so that maintenance personnel are not injured by high-temperature, high-voltage, high-current, sharp and rotating parts or other hazards. (See also section 2.10)

2.14.4 Hazardous Materials and conditions. Hazardous materials and conditions must be contained and controlled so maintenance personnel are not exposed to explosive, toxic, dangerous chemical, radioactive, high-pressure, lack of ventilation, extremes of heat or cold, noise, or other hazardous materials and conditions.

2.14.5 Personnel Protective Equipment. In accordance with 29CFR 190.147, Personnel protective equipment must be available and used where necessary to prevent injury to maintenance personnel (i.e., face shield and leather apron for welding and cutting operations, respirators, eye and ear protection, hard-toed shoes, hard hats, gloves, etc.).

2.14.6 Special Tools and Test Equipment. Equipment should be designed so that standard tools may be used, when practical. When Special Tools and Test Equipment are necessary to safely accomplish a maintenance task (i.e. insulated, calibrated, non-conductive, non-magnetic tools and equipment) they should be provided as part of the equipment design and reflected in the procedures.

2.14.7 Configuration Management and Identification. An adequate and effective configuration management and identification program should be in place to prevent maintenance personnel from misidentification and inappropriate identification errors such as de-energizing one circuit and subsequently proceeding to work on a different circuit that is still energized.