Electrical Connector Assembly Ergonomic Design Criteria

SAE/USCAR-25 Revision 1
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ELECTRICAL CONNECTOR ASSEMBLY ERGONOMIC DESIGN CRITERIA

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1.0 SCOPE

This document describes the design, assembly force, and packaging guidelines for conventional hand-plug, mechanical assist and twist lock electrical connectors, as well as Connector Position Assurances (CPAs).

All possible designs and applications could not be anticipated in creating these guidelines. Where there are questions of adherence to this document, such as use of an “off-the-shelf” design, always consult the responsible Ergonomics Department.

Refer to SAE/USCAR-12 Wiring Component Design Guidelines for additional guidelines.

2.0 REFERENCED DOCUMENTS

SAE/USCAR-2 Performance Standard for Automotive Electrical Connector Systems

SAE/USCAR-12 Wiring Component Design Guidelines

See Appendix C for additional references

3.0 GENERAL

In all cases, ***assembly forces should be as low as possible*** while maintaining satisfactory electrical, mechanical and environmental performance.

Part packaging, process and workstation design requirements/constraints all have the potential to negatively impact the forces specified in this document. Such situations include but are not limited to:

- Obstructed access
- Awkward or non-neutral postures, such as wrist deviation or extended reaches
- Forces applied laterally across the body

This has necessitated the creation of a Hand Clearance Guidelines section. Consult the Ergonomics Department with any questions or if clarifications are needed**.**

4.0 DESIGN GUIDELINES - HAND-PLUG CONNECTORS

A hand-plug connector is an electrical connector which requires an operator to manually assemble/mate two connector halves or a connector to a device without the use of a mechanical assist. Hand-plug connectors fall into three classes as shown in Table 4.1 (see Page 7). Each class is defined by maximum assembly force and corresponding contact surface area requirements.

4.1 MAXIMUM ASSEMBLY FORCE

Under ideal conditions described in these Guidelines, the maximum assembly forces must not exceed 75 N. When these conditions cannot be met, the maximum assembly force is reduced (see Table 4.1).

4.2 CONTACT SURFACE CHARACTERISTICS

The contact surface is an essentially continuous plane upon which the operator can apply assembly force. Contact surface dimensions are derived from a large male gloved hand or a small female gloved hand as appropriate. Where possible, every effort should be made to design the connector to meet the target surface area dimensions. When this is not possible, the minimum contact surface area must be met. These dimensions are provided in Table 4.1.

4.2.1 For Class 1 and 2 connectors, a minimum contact surface dimension of 3 mm, not including the edge radius, is required (see Figure 1). Any surface measuring less than 3 mm in width or length cannot be considered as part of the contact surface area.

4.2.2 For Class 3 connectors, a minimum contact surface dimension of 4 mm, not including edge radius is required (see Figure 1). Any surface measuring less than 4 mm in width or length cannot be considered as part of the contact surface area. Contact stress limitations necessitate this larger contact surface dimension.

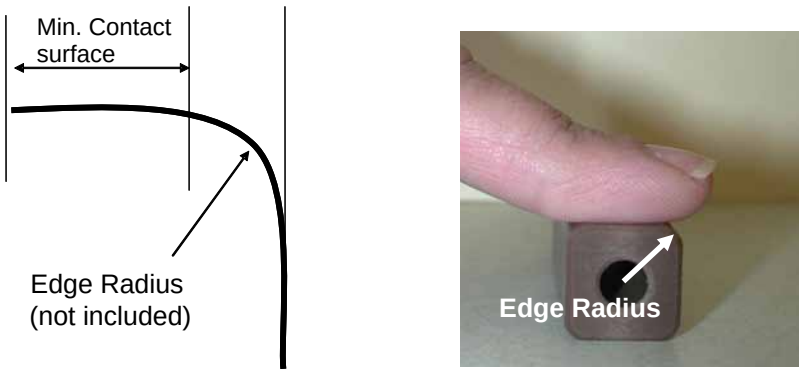
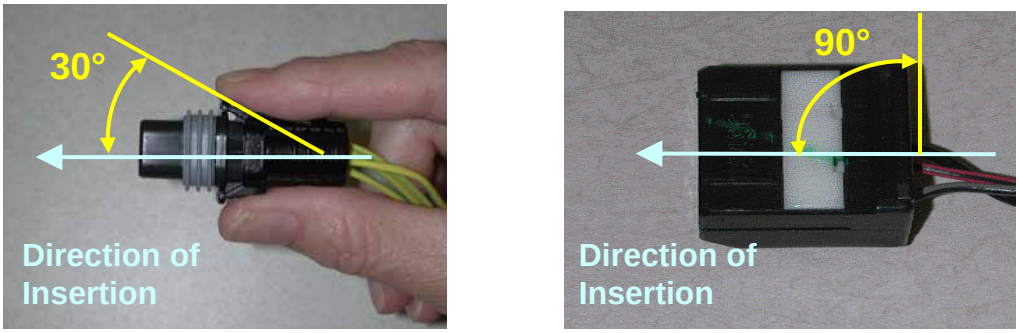


FIGURE 1. CONTACT SURFACE AREA AND EDGE RADIUS

4.2.3 Design potential contact surfaces with no uncomfortable pressure points. A design target of 3 mm edge radius on contact surfaces or edges likely to be contacted by the operator's hand is recommended. An edge radius less than 0.8 mm is unacceptable (see Figure 1).

4.2.4 Design contact surfaces to be continuous or near continuous. Surface voids, though not desired, can be acceptable if one of the dimensions (length or width) is ≤ 5 mm. Surface voids are not included in contact surface area calculations unless they measure ≤ 1 mm in width (see Appendix B).

4.2.5 Position contact surfaces optimally angled between 30° and 90° (perpendicular) from the direction of force insertion (see Figure 2) for maximum allowable assembly force per Table 4.1.



Acceptable Contact Surface: Optimally angled between 30° and 90° from the direction of force insertion

FIGURE 2. CONTACT SURFACE ANGLE

4.2.6 When no optimally angled surface is provided, maximum assembly force is limited by the ability to maintain a pinch grip rather than by the application of push force. In this case, knurls or serrations can be used to improve grasp on the connector provided they do not create uncomfortable pressure points. Knurls and serrations greater than 0.8 mm in height are not acceptable (see Figure 6).

4.2.7 Design connector to meet at least the minimum contact surface area requirements as detailed in Table 4.1. Only surfaces in contact with the finger/thumb can be included in the total contact surface area (see examples in Appendix B). For force applications that require a pinch or grasp posture, contact surfaces must be on opposing sides (i.e. top/bottom or left/right). See Figure 3.

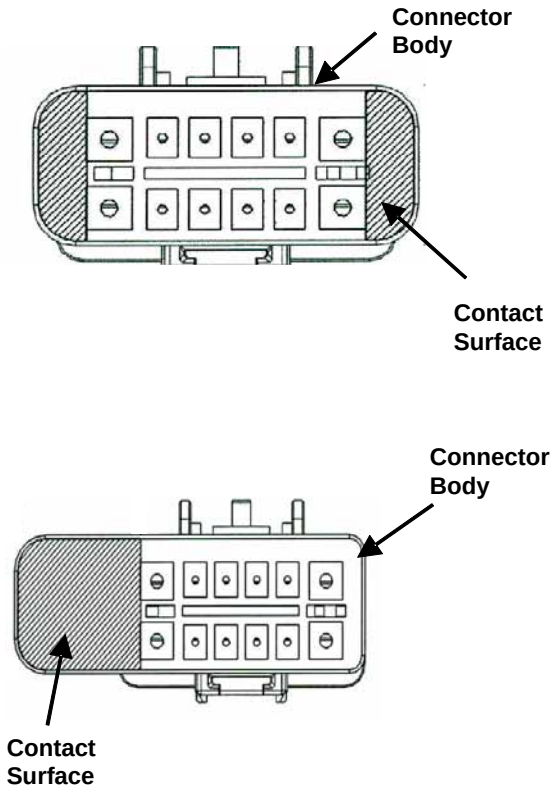
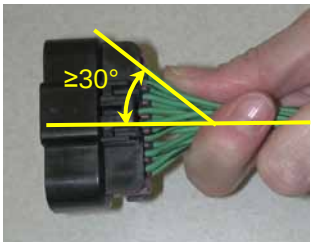


FIGURE 3. CONTACT SURFACE AREA EXAMPLES

4.2.8 Where the wire harness bundle is grasped during mating of the connector, the contact surface area can include the harness ramp surface created when the wires exit the connector housing. The harness ramp surface may be included in the contact surface area as long as that ramp is greater than 30 degrees in the direction of force application and the surface area requirements are met (see Figure 4 and example 3 in Appendix B).



The wire harness bundle may be considered a push surface if optimally angled ≥ 30° from the direction of force insertion

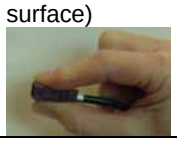
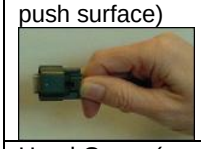
FIGURE 4. WIRE HARNESS BUNDLE CONTACT SURFACE AREA

4.2.9 The wire harness bundle, when grasped using a power grip, can be used for assembly of the connector when there is no optimally angled push surface. A power grip can only be achieved when the bundle diameter is between 15 mm and 50 mm. The bundle must be stiff enough to ensure that it does not flex when force is applied, which may create a connector misalignment condition.

4.3 DISENGAGE FORCE

Disengagement of the connector in the assembly plant may be required for testing. In these cases, values for the maximum disassembly force with the secondary lock or CPA released are the same as the maximum assembly force for each class (see Table 4.1).

Table 4.1 HAND-PLUG CONNECTOR DESIGN GUIDELINES

Class	Maximum Assembly Force	Typical Hand Posture Options for Design	Target Contact Surface Area	Minimum Contact Surface Area	Minimum Contact Surface Dimension	Grip Span
1	≤ 22 N	Fingertip push (with optimally angled push surface) 	19 mm x 6 mm	15 mm^2	3 mm	N/A
		Pinch Grip (without optimally angled push surface) 	23 mm x 6 mm provided on each opposing grip surface	100 mm^2 With a min. of 50 mm^2 provided on each opposing grip surface		0-10 mm or 55-75 mm
2	≤ 45 N	One Thumb or One Finger push (with optimally angled push surface) 	23 mm x 6 mm	100 mm^2	3 mm	N/A
		Pinch Grip with Thumb tip and fingertip push (with optimally angled push surface) 	19 mm x 6 mm push surface provided on each opposing sides of the wire bundle	100 mm^2 With a min. of 50 mm^2 push surface provided on two opposing sides of the wire bundle		N/A
		Hand Grasp (key grip without optimally angled push surface) 	26 mm x 6 mm provided on each opposing grip surface	100 mm^2 With a min. of 50 mm^2 provided on each opposing grip surface		10-55 mm
3	≤ 75 N* *Non-neutral postures or forces applied in an upward or lateral direction require further analysis.	Hand Grasp (key grip with optimally angled push surface) 	26 mm x 6 mm push surface provided on each opposing sides of the wire bundle	150 mm^2 With a min. of 50 mm^2 push surface provided on one side of the wire bundle (for the thumb)	4 mm	N/A
		Hand Grasp (power grip without optimally angled push surface) 	23 mm dia. wire bundle size with taped or conduit bundle	15 mm dia. minimum wire bundle size with taped or conduit bundle		15 mm minimum 50 mm maximum
		Pinch Grip with Thumb tip and two fingertip push (with optimally angled push surface) 	38 mm x 6 mm push surface on each opposing sides of the wire bundle	150 mm^2 With a min. of 50 mm^2 push surface provided on one opposing side of the wire bundle (for the thumb)		N/A
		Two Finger Push  	46 mm x 6mm push surface	150 mm^2 With a min. of 75 mm^2 provided for each finger		N/A

5.0 DESIGN GUIDELINES – MECHANICAL ASSIST CONNECTORS

Mechanical assist connectors utilize levers, cams or slides to provide a mechanical advantage to the operator in making the connection and thus reduce assembly force. Mechanical assist connectors fall into three classes as shown in Tables 5.1 and 5.2. Required push surface area and assembly force varies with each type of connector and class.

5.1 MAXIMUM ASSEMBLY FORCE

The maximum allowable assembly force is the peak force required to actuate the mechanical assist from its fully open position to its fully closed position. Forces at any point along the path may not exceed 75 N. This includes the force required to release the mechanical assist from its pre-locked position for those connectors that do not have auto-release. When ideal conditions cannot be met, the allowable assembly force is reduced as shown in Tables 5.1 and 5.2.

5.2 PUSH SURFACE CHARACTERISTICS

The contact surface is an essentially continuous plane upon which the operator can apply assembly force. Contact surface dimensions are derived from a large male gloved hand or a small female gloved hand as appropriate. Where possible, every effort should be made to design the connector to meet the target surface area dimensions provided in Tables 5.1 and 5.2.

5.2.1 For Class 1 connectors, a minimum contact surface width of 3 mm, not including the edge radius, is required (see Figure 5). Any surface measuring less than 3 mm in width cannot be considered as part of the contact surface area.

5.2.2 For Class 2 and 3 lever lock connectors, a minimum contact surface width of 5 mm, not including edge radius is required (see Figure 5). Any surface measuring less than 5 mm in width cannot be considered as part of the contact surface area. Contact stress limitations necessitate this larger contact surface dimension.

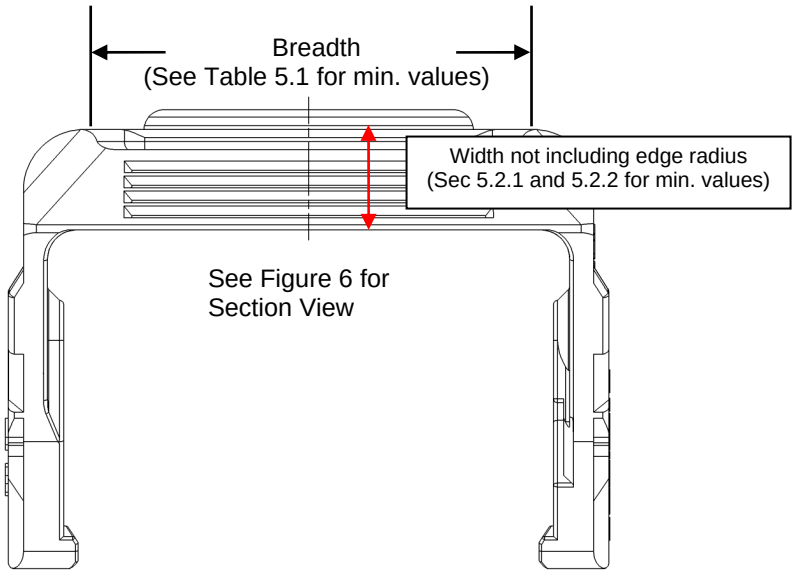


FIGURE 5. LEVER CONTACT SURFACE AREA

5.2.3 Push/pull contact surface area must meet the minimum allowable dimensions specified in Tables 5.1 and 5.2.

5.2.4 Design contact surfaces to be continuous or near continuous. Surface voids, though not desired, can be acceptable if one of the dimensions (length or width) is ≤ 5 mm. Surface voids are not included in contact surface area calculations unless they measure ≤ 1 mm in width.

5.2.5 Serrations, knurls, ridges, etc. are permissible with a maximum height of 0.8 mm (see Figure 6). Design connectors with no uncomfortable pressure points. A design target of 3 mm edge radius on contact surface area or edges likely to be contacted by the operator's hand is recommended. An edge radius less than 0.8 mm is unacceptable.

5.2.6 An optional end stop may be used to help prevent the thumb/finger(s) from sliding off of the lever. An end stop is defined as a ridge perpendicular to the push surface located at the distal edge of the surface. Dimensions of this feature are shown in Figure 6.

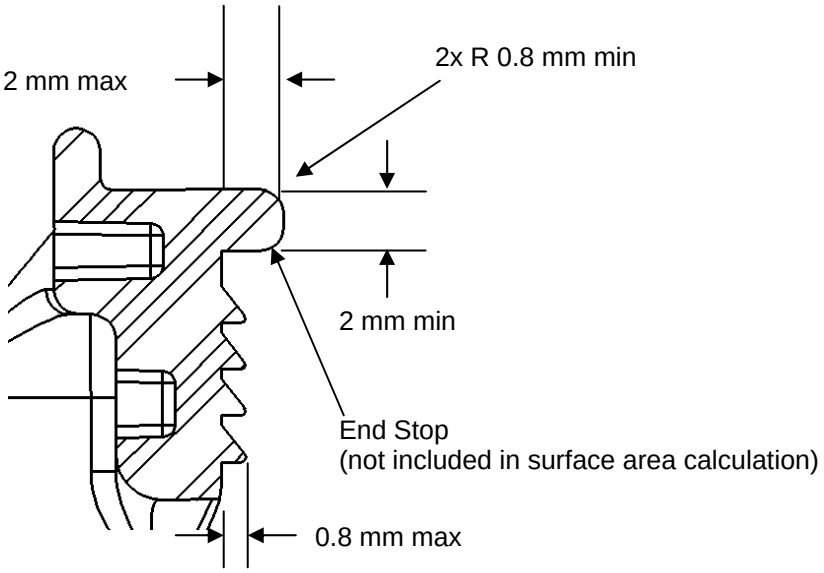


FIGURE 6. SECTION VIEW – DIMENSIONS OF OPTIONAL CONTACT SURFACE FEATURES

5.3 LEVER LOCK CONNECTORS

Lever lock connectors are the most common type of mechanical assist connector. See Table 5.1 for design requirements.

TABLE 5.1 LEVER LOCK CONNECTOR DESIGN GUIDELINES

Class	Maximum Assembly Force	Typical Hand Posture Options for Design	Target Contact Surface Area *	Minimum Contact Surface Area *	Minimum Contact Surface Width	Minimum Breadth Dimension (see Figure 5)
1	≤ 22 N	Fingertip 	19 mm x 6 mm	15 mm² (outside lever arms) OR 60 mm² (inside lever arms)	3 mm	5 mm 19 mm
2	≤ 45 N	1 Finger or 1 Thumb 	23 mm x 6 mm	115 mm²	5 mm	23 mm
3	≤ 75 N** **Non-neutral postures or forces applied in an upward or lateral direction require further analysis.	2 Fingers 	46 mm x 6mm	230 mm²	5 mm	46 mm

***Contact surface area must be provided perpendicular to the direction of push**

5.4 SLIDE LOCK CONNECTORS

Slide lock connectors are a specialized type of mechanical assist connector which utilize postures and force applications similar to hand plug connectors. Design slide lock connectors to meet the requirements in Table 4.1.

5.4.1 Slide lock applications where the connector is not stabilized/mounted typically require the opposing thumb to stabilize the part. Additional surface area of 100 mm² must be provided opposite the slide mechanism for the thumb.

5.5 CAM INSERTION CONNECTORS

Cam insertion connectors are another specialized type of mechanical assist connector which utilize postures and force applications similar to hand-plug connectors. See Table 5.2 for design requirements.

TABLE 5.2 CAM INSERTION CONNECTOR DESIGN GUIDELINES

Class	Maximum Assembly Force	Typical Hand Posture Options for Design	Target Contact Surface Area	Minimum Contact Surface Area	Minimum Contact Surface Dimension	Grip Span (Diameter)
1	≤ 22 N	See Table 4.1, Class 1, Pinch Grip with no optimally angled push surface				
2	≤ 45 N	Hand grasp (power grip without optimally angled push surface) 	26 mm x 6 mm on each opposing grip surface	100 mm^2 With at least 50 mm^2 provided on each opposing grip surface	3 mm	0-15 mm or 50-75 mm
3	≤ 75 N*	Hand grasp (power grip with optimally angled push surface) 	26 mm x 6 mm on each opposing side	150 mm^2 With a min. of 50 mm^2 push surface provided on one side (for the thumb)	4 mm	75 mm maximum
	*Non- neutral postures or forces applied in an upward or lateral direction require further analysis.	Hand grasp (power grip without optimally angled push surface) 	Full hand contact	150 mm^2 With at least 50 mm^2 provided on each opposing grip surface		15-50 mm

5.6 DISENGAGE FORCE

Disengagement of the connector in the assembly plant may be required for testing. In these cases, values for the maximum disassembly force with the secondary lock or CPA released are the same as the maximum assembly force for each class (Tables 5.1 and 5.2).

5.7 CONNECTOR PRE-LOCK

The pre-lock feature allows positioning of the connector prior to actuation of the mechanical assist.

5.7.1. Design the connector so that the force required to fully engage the connector into its pre-lock position complies with the hand-plug connector requirements of this document (See Section 4).

5.7.2. Design the pre-lock and lock features to give audible and/or tactile feedback.

5.8 INADVERTENT ACTUATION

5.8.1. Design assist mechanisms to prevent inadvertent actuation during shipping, handling and pre-assembly operations. Refer to SAE/USCAR-12 for specific guidelines.

5.8.2 Design connectors so that it is visually obvious to the Operator that the connector is correctly seated and locked.

6.0 DESIGN GUIDELINES – TWIST LOCK CONNECTORS

Electrical connectors which require a twisting motion for assembly are not recommended. If this connector design is selected, the maximum assembly torque is limited by the amount of torque that must be generated by the hand/wrist for engagement of the connector.

6.1 TORQUE REQUIREMENTS

The amount of assembly torque can not exceed 1 Nm maximum to fully engage the connector.

6.2 CONTACT SURFACE CHARACTERISTICS

6.2.1 Surface area must meet the minimum allowable contact surface area and grip span requirements as specified in Table 6.1. A minimum contact surface dimension of 3 mm, not including the edge radius, is required (see Figure 1). Any surface measuring less than 3 mm in width or length cannot be considered as part of the contact surface area.

6.2.2. Design contact surfaces to be continuous or near continuous. Surface voids, though not desired, can be acceptable if one of the dimensions (length or width) is ≤ 5 mm. Surface voids are not included in contact surface area calculations unless they measure ≤ 1 mm in width.

6.2.3. Serrations, knurls, ridges, etc. are permissible as long as they are less than 0.8 mm in height. Design connectors with no uncomfortable pressure points. A design target of 3 mm edge radius on contact surface area or edges likely to be contacted by the Operator's hand is recommended. An edge radius less than 0.8 mm is unacceptable.

TABLE 6.1 TWIST LOCK CONNECTORS

Maximum Assembly Torque	Typical Hand Posture for Design	Target Contact Surface Area	Minimum Contact Surface Area	Grip Span Diameter)
≤ 1 Nm	Hand grasp 	Full hand contact	150 mm^2 With at least 50 mm^2 provided on one opposing grip surface (for the thumb)	50 mm maximum

6.2.4 If a tab is provided on the twist lock connector for use as a lever to assist in locking the connector, then it is considered to be mechanical assist connector (see Figure 7). The direction of force application changes from a twist of the connector to a linear push/pull of the tab. Therefore the maximum assembly force and contact surface area from Table 5.1 would supersede the requirements from Table 6.1.

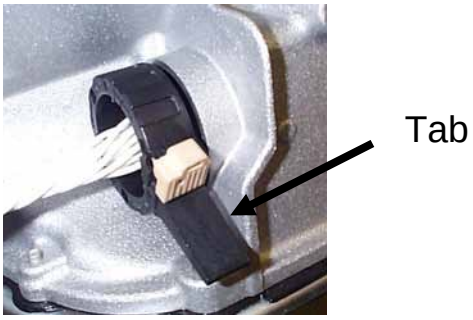


FIGURE 7. TWIST LOCK CONNECTOR WITH TAB

7.0 TESTING – HAND-PLUG AND MECHANICAL ASSIST CONNECTORS

Perform testing of the hand-plug and mechanical assist assembly force as specified in SAE-USCAR-2. Additional requirements may apply as specified in that document. For lever lock connectors, the optimum set-up to determine lever actuation force is such that force is applied perpendicular to the lever push surface and continues in an arc about the rotational axis of the lever. For slide lock style connectors, assembly force must be measured in-line with the direction of push.

8.0 DESIGN GUIDELINES - CPAs (CONNECTOR POSITION ASSURANCE)

The following guidelines apply to CPA devices:

8.1 Make the minimum contact surface area at least 15 mm^2 with a minimum dimension of 3 mm, not including the edge radius (see Figure 1).

8.2 Any surface measuring less than 3 mm in width or length cannot be considered as part of the contact surface area. Larger surfaces are preferred if possible.

8.3 Angled contact surface is acceptable. Contact surfaces should be optimally angled between 30° and 90° (perpendicular) from the direction of force insertion (see Figure 2).

8.4 Design the CPA actuation force to be ≤22 N (see SAE/USCAR-2 Misc. Component Insertion).

8.5 Design the CPA with no sharp edges or hard contact points on the part itself or along the travel path. An edge radius less than 0.8 mm is unacceptable.

8.6 Fully seated CPA push surface should be either flush or protruding above the surrounding surface of the connector. If the CPA must be recessed, provide adequate access for finger actuation. This is accomplished by providing a 30 mm diameter cylinder of clearance around the CPA push surface (see Figure 11).

8.7 The design should provide for audible/tactile feedback, but must provide visual indication that the CPA is closed. Examples of visual indication include, but are not limited to, designing the push surface of the CPA flush to the surrounding surface, and designing the push surface to have a shoulder that rests on the surrounding surface.

8.8 Serrations, knurls, ridges, etc. are permissible and if used, must have a maximum height of 0.8 mm (see Figure 6).

8.9 Integral CPAs are preferred over tethered designs.

9.0 HAND CLEARANCE GUIDELINES

While it is important that designers of electrical connectors utilize the design specifications outlined in the previous sections, the adherence to these specifications alone will not prevent the occurrence of unacceptable electrical connections during the assembly process. The next critical element is the packaging or working area in which the electrical connection is made. The presence of surrounding parts or structures can compromise the hand clearance available to the Operator. This section provides hand clearance dimensions to the design engineers for use early in the design/assembly of the vehicle.

In the design and packaging of electrical connectors, hand clearance and push surface area will directly impact the hand posture utilized by the Operator. Hand posture, force and push surface area are interrelated variables. Push surface area and corresponding assembly effort requirements will enable the design engineer to identify how much hand clearance is required. If the required hand clearance cannot be met, the maximum permissible force is reduced. Failure to provide adequate hand/finger clearance increases the risk of occupational injury, poor quality (disconnects, partial connections, no connections) and time for assembly.

9.1 GLOVES

An allowance has been added to all hand clearance requirements in this section which reflects the use of gloves during assembly. Based upon a sampling of typical work gloves used in vehicle and powertrain assembly plants, a 2 mm glove thickness was applied. Additional clearance may be required if glove thickness is greater than 2 mm.

9.2 HAND-PLUG CONNECTORS

Hand clearance for each class of hand-plug connectors is defined based upon a selection of typical hand postures used for assembly. The minimum hand clearance requirements for each posture are shown in Figures 8-13 on the following pages. It is important to note that the hand clearances shown are in the final assembly position. Additional clearance may be required in order to position the connector. All clearance areas must be kept clear of sharp edges or objects.

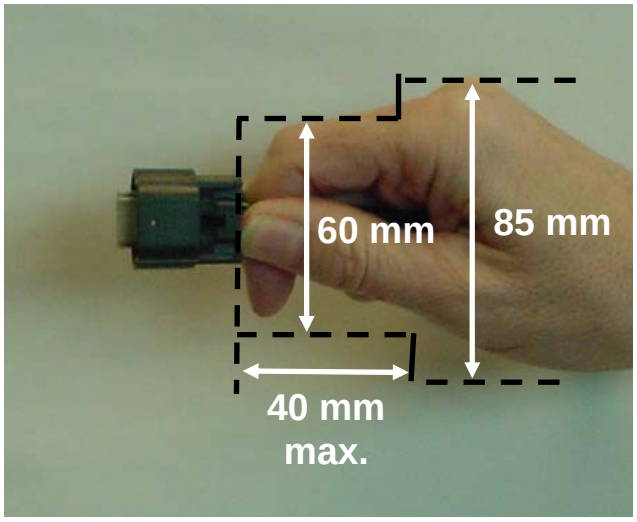


FIGURE 8A . HAND GRASP CLEARANCE
(SIDE VIEW - HAND IN LINE WITH CONNECTOR)

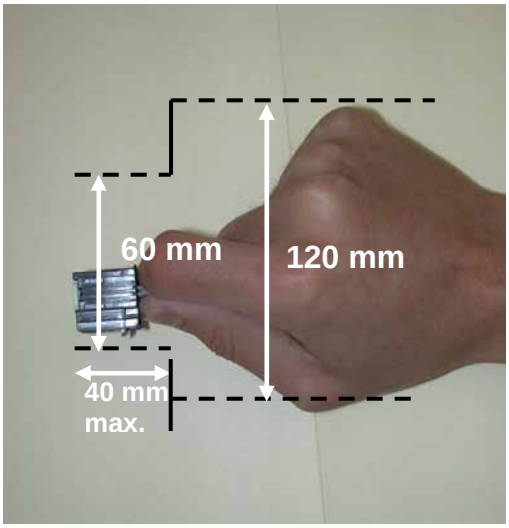


FIGURE 8B. HAND GRASP CLEARANCE
(TOP VIEW - HAND IN LINE WITH CONNECTOR)

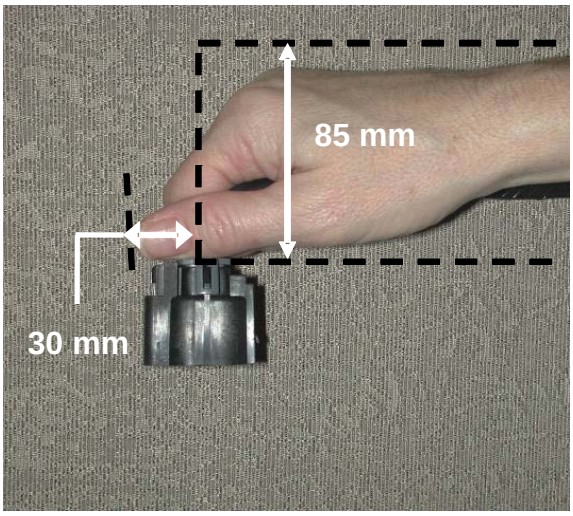


FIGURE 8C. HAND GRASP CLEARANCE
(SIDE VIEW – HAND 90° TO CONNECTOR)

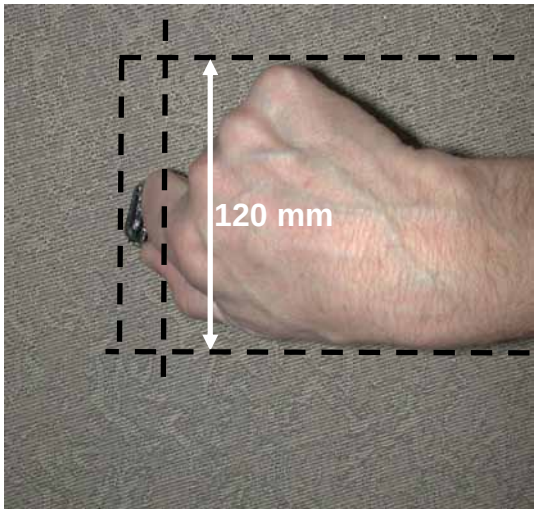


FIGURE 8D. HAND GRASP CLEARANCE
(TOP VIEW – HAND 90° TO CONNECTOR)

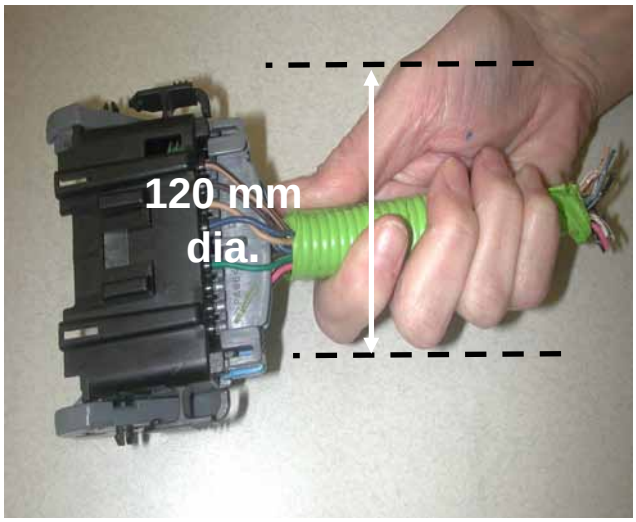


FIGURE 9. HAND GRASP CLEARANCE WITH BUNDLE

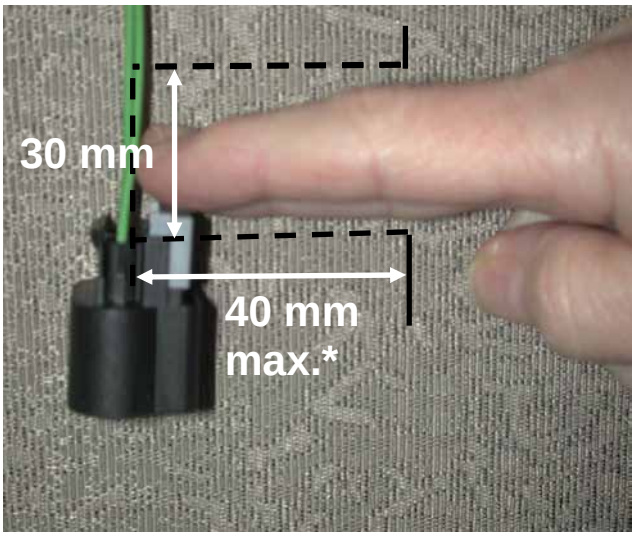


FIGURE 10A. TWO FINGER PUSH CLEARANCE (SIDE VIEW)

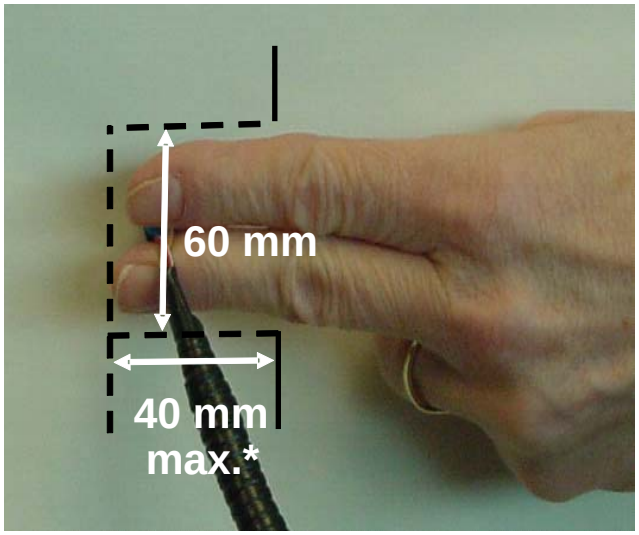


FIGURE 10B. TWO FINGER PUSH CLEARANCE (TOP VIEW)

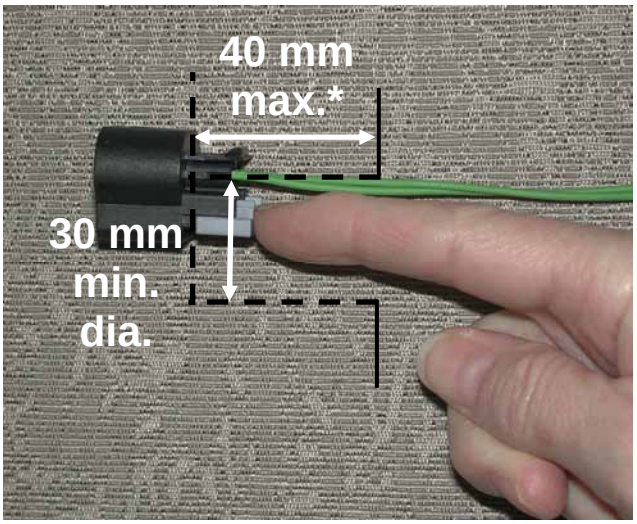


FIGURE 11. ONE FINGER/THUMB PUSH CLEARANCE (SIDE VIEW)

***NOTE: FOR FIGURES 10A, 10B AND 11 WHOLE HAND CLEARANCE OF 120 MM DIA MUST BE PROVIDED FOR DEPTHS GREATER THAN 40 MM TO ACCOMADATE THE HAND (SEE FIGURE 12)**

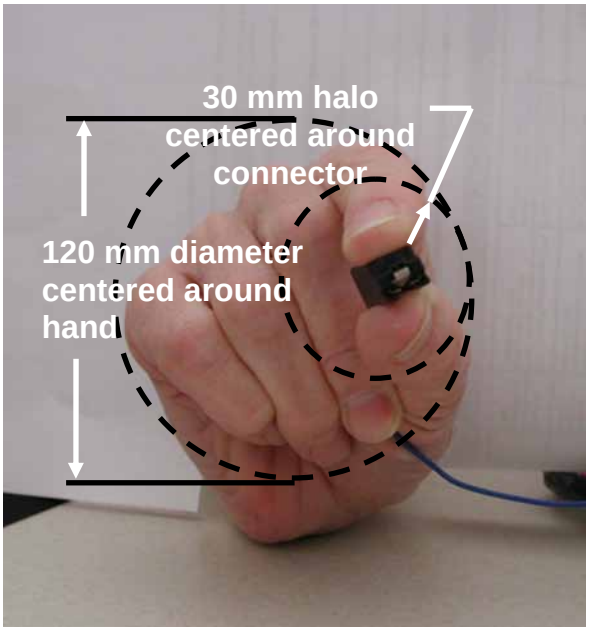


FIGURE 12. PINCH GRIP CLEARANCE (FRONT VIEW)

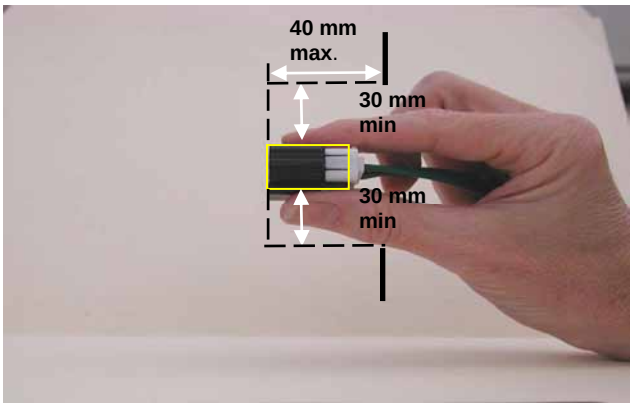


FIGURE 13. PINCH GRIP CLEARANCE (SIDE VIEW)

9.3 DECISION TREES – HAND-PLUG CONNECTORS

The ergonomic requirements for packaging of hand-plug connectors are presented through the use of two decision trees. The first begins with assembly hand clearance requirements and derives a maximum allowable force based upon the amount of hand clearance available (see Table 9.1). The second begins with the connector assembly force (determined by the testing protocol outlined in SAE/USCAR-2) and works toward identifying the minimum hand clearance requirements for assembly of the connector (see Table 9.2).

The factors used within the decision trees are assembly force, hand clearance and push surface area. As the hand clearance and/or push surface area decreases, a less than optimal hand posture will be required which will lead to a reduction in the allowable assembly force. Refer to Section 4.2 of this document for requirements related to push surface area for hand-plug connectors.

Table 9.1 Process to Determine Acceptable Assembly Force - Hand-Plug Connectors

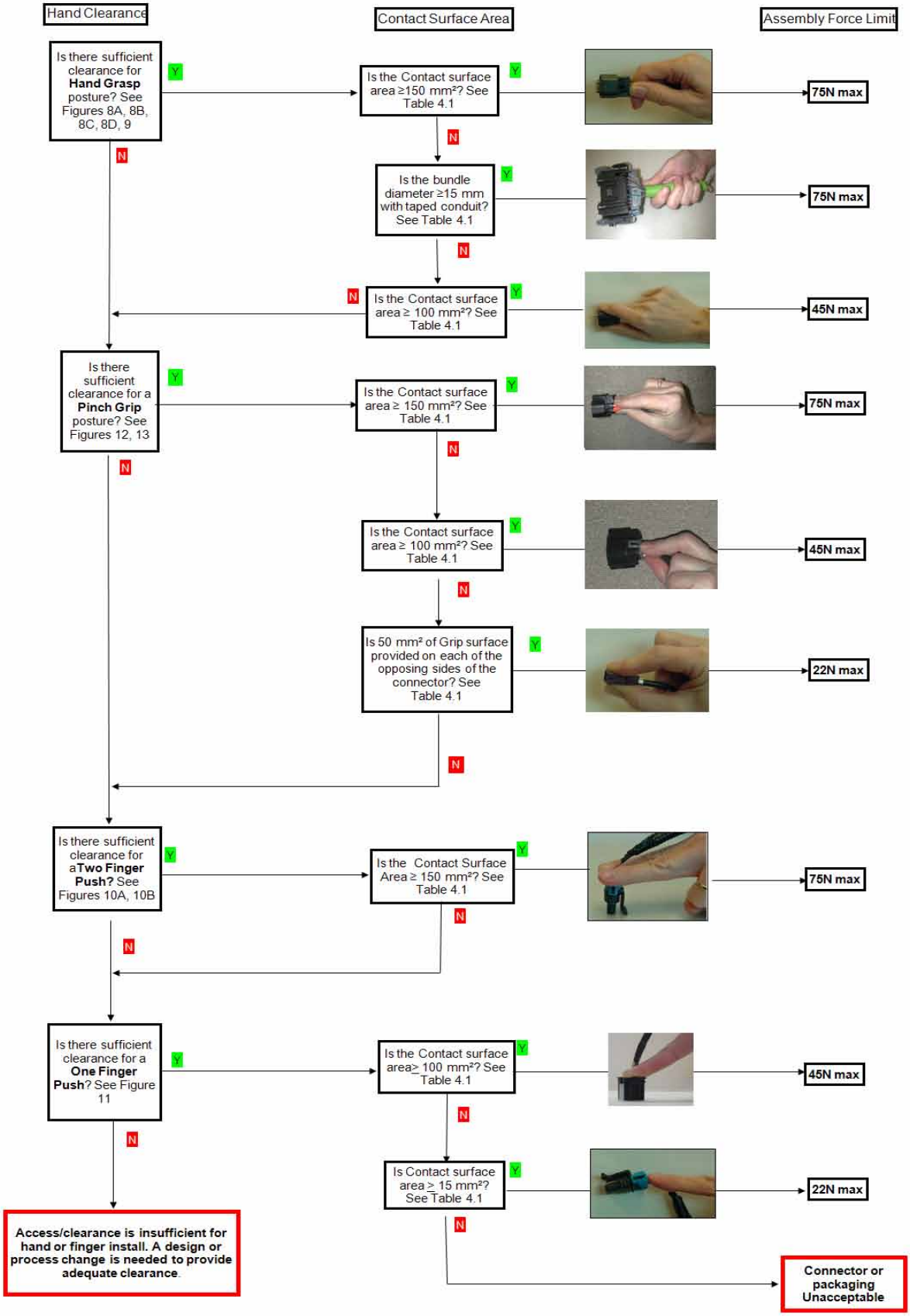
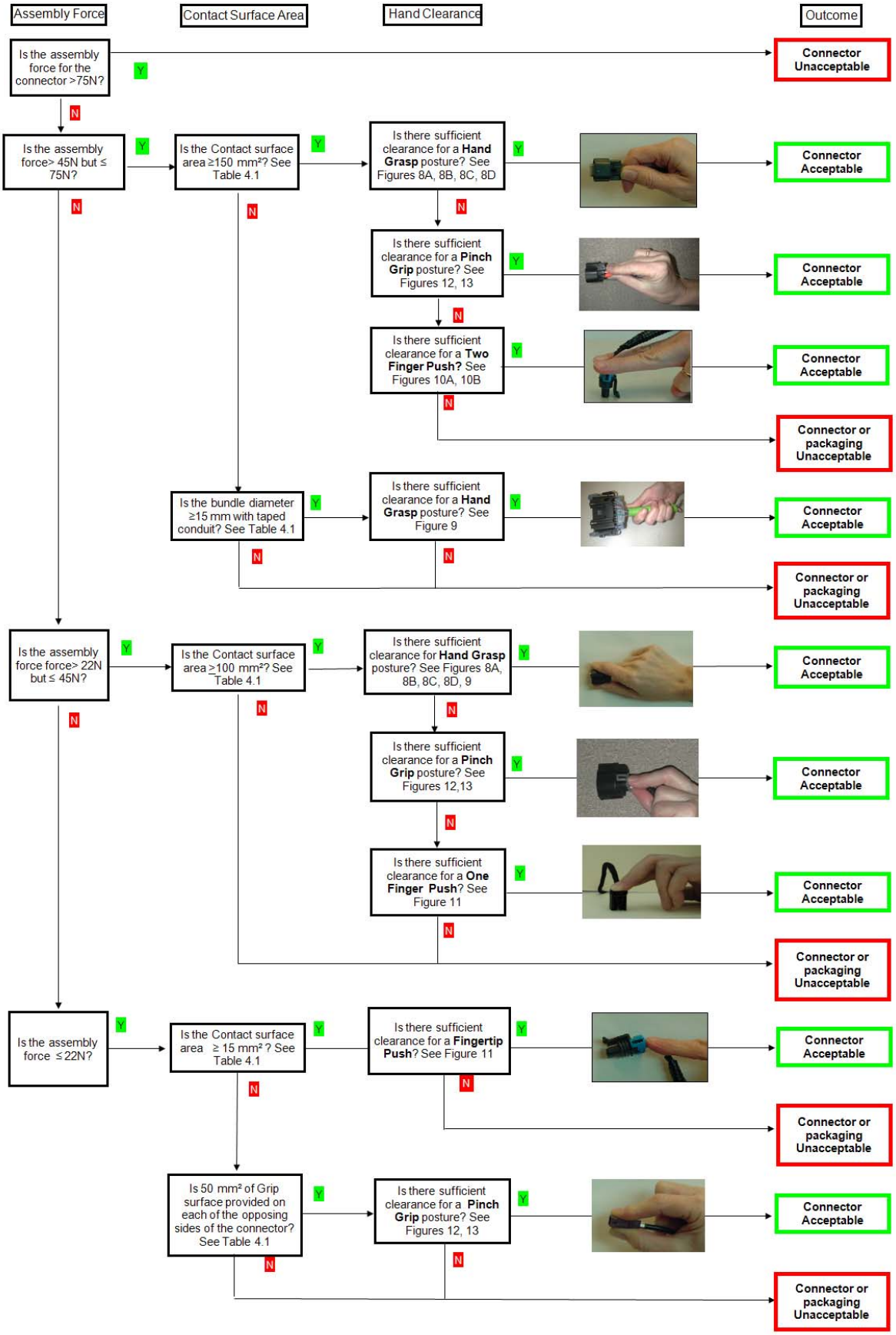


Table 9.2 Process to Determine Connector Packaging Acceptability - Hand Plug Connectors



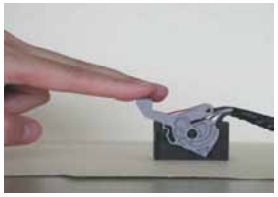
9.4 Mechanical Assist Connectors

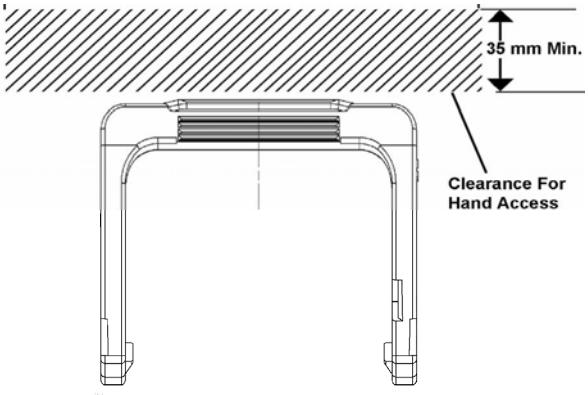
Hand clearances for each class of mechanical assist connector are defined based upon a selection of typical hand postures used for assembly (See Figure 14). For the purposes of assembly, the connector needs to be placed before the mechanical assist can be actuated. Therefore, hand-plug clearances as defined in Section 9.2 must be used to determine acceptable hand clearances. Additional clearances are required for the swing path of lever lock type mechanical assist connectors.

FIGURE 14.TYPICAL POSTURES USED TO POSITION MECHANICAL ASSIST CONNECTORS

9.4.1 The clearance for the swing path of lever lock connectors is given in Figures 15 and 16. The required clearance is dependent upon the direction of actuation. The swing area of the lever must be kept clear of sharp edges or objects.

Lever Lock - Push





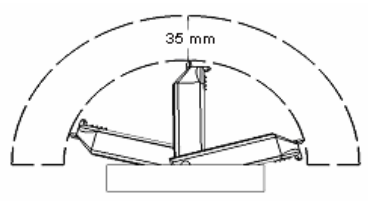
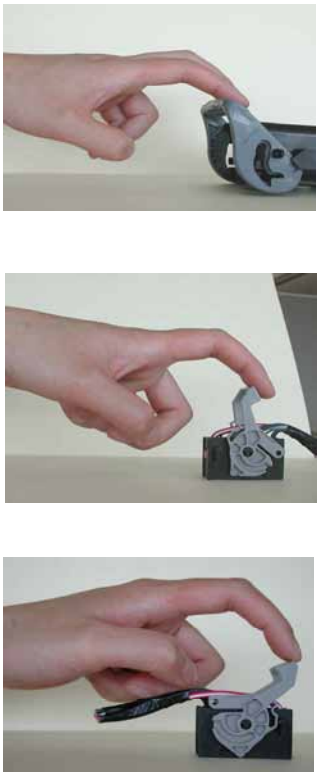


FIGURE 15. LEVER LOCK SWING PATH AND CLEARANCE – PUSH

Lever Lock - Pull



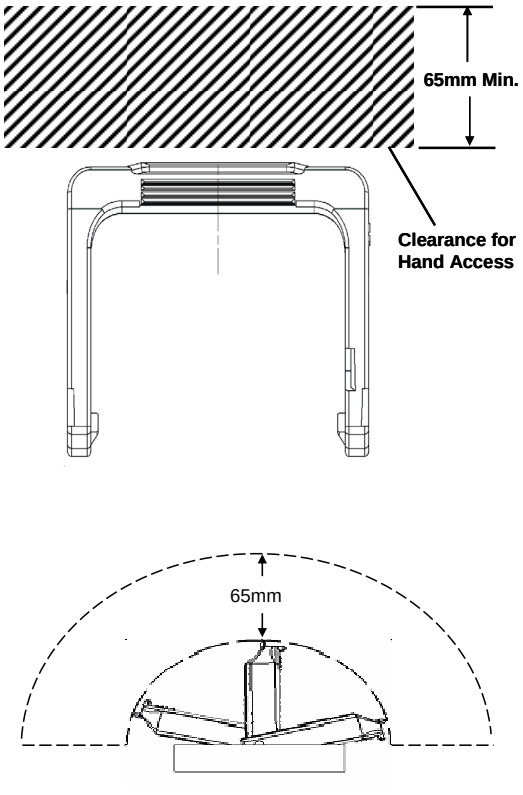


FIGURE 16. LEVER LOCK SWING PATH AND CLEARANCE - PULL

9.5 DECISION TREES – MECHANICAL ASSIST CONNECTORS

The ergonomic requirements for packaging of mechanical assist connectors are presented through the use of two decision trees. The first begins with assembly hand clearance requirements and derives a maximum allowable force based upon the amount of hand clearance available (see Table 9.3). The second begins with the connector assembly force (determined by the testing protocol outlined in SAE/USCAR-2) and works toward identifying the minimum hand clearance requirements for assembly of the connector (see Table 9.4).

Similar to hand-plug connectors, the factors used within the decision trees are assembly force, hand clearance and push surface area. However, mechanical assist connectors can be engaged by either pushing or pulling and therefore have different clearance requirements based upon the direction of force. As the hand clearance and/or push surface area decreases, a less than optimal hand posture will be required which will lead to a reduction in the allowable assembly force. Refer to Sections 5.2 of this document for requirements related to push surface area for mechanical assist connectors.

Table 9.3 Process to Determine Acceptable Assembly Force - Mechanical Assist Connectors

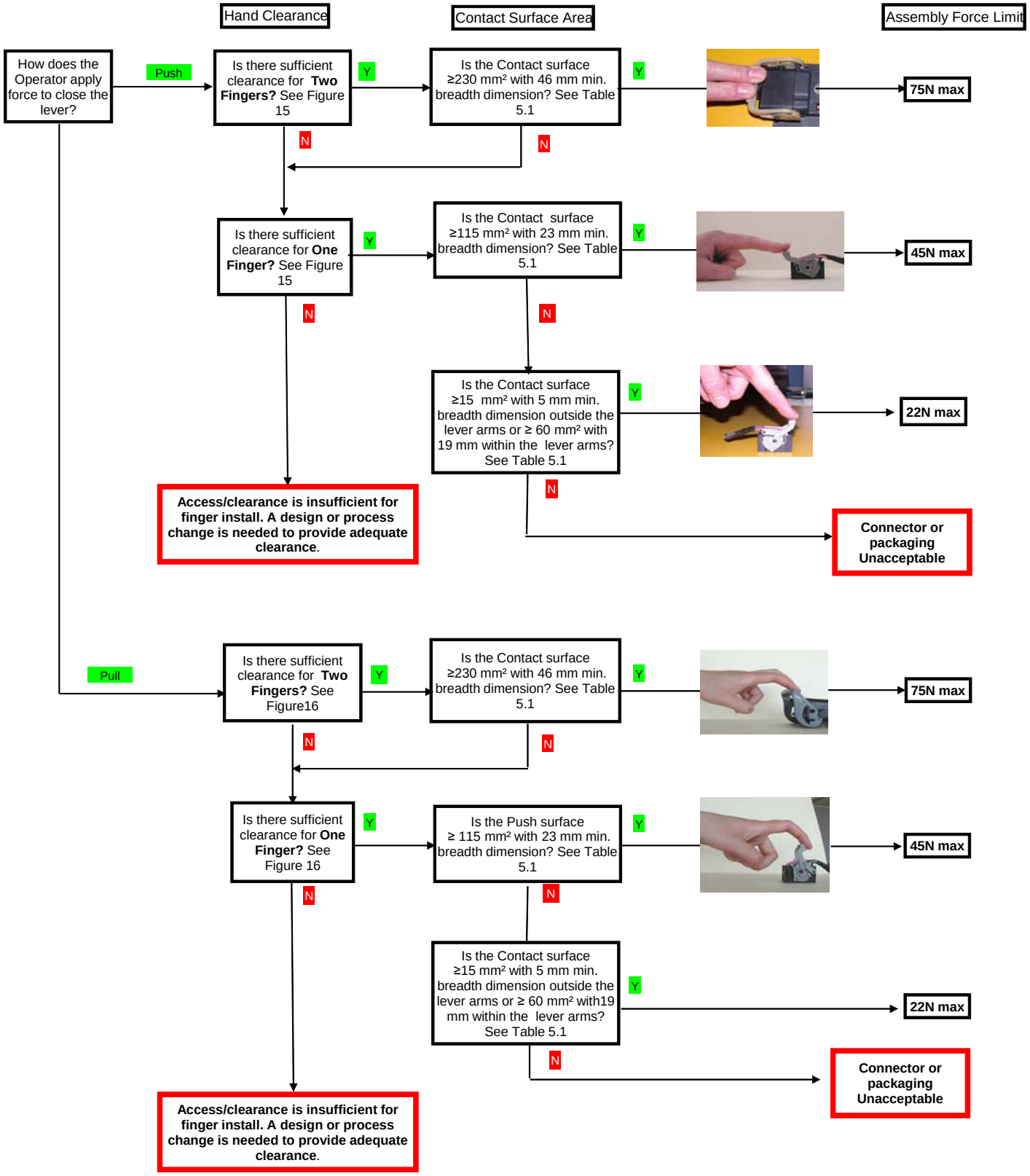
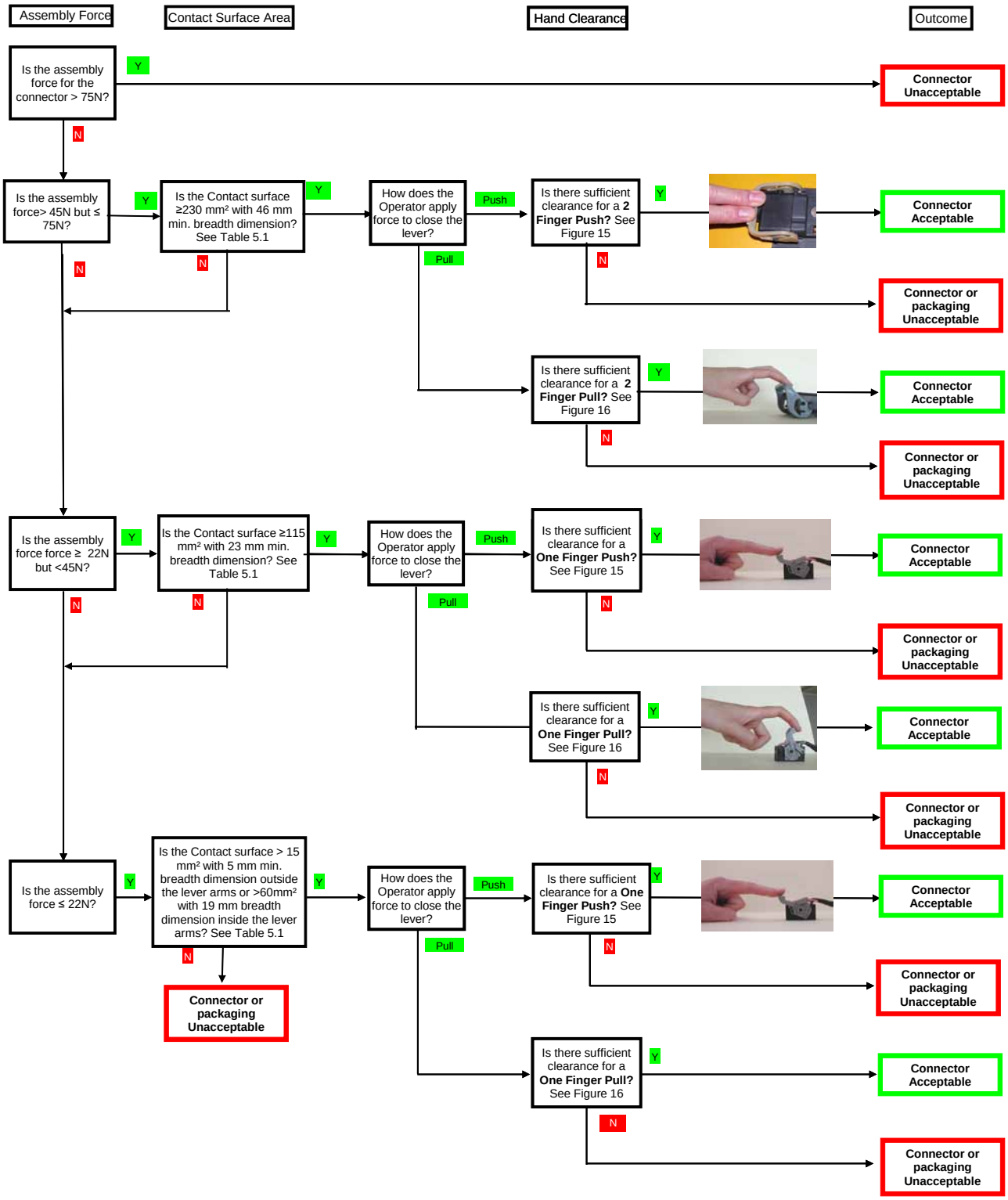


Table 9.4 Process to Determine Connector Packaging Acceptability - Mechanical Assist Connectors



9.6 Twist Lock Connectors

Twist lock connectors require use of the whole hand for actuation. A 30 mm halo must be provided for the thumb/fingers with a 120 mm minimum diameter required for the hand (See Figure 17).

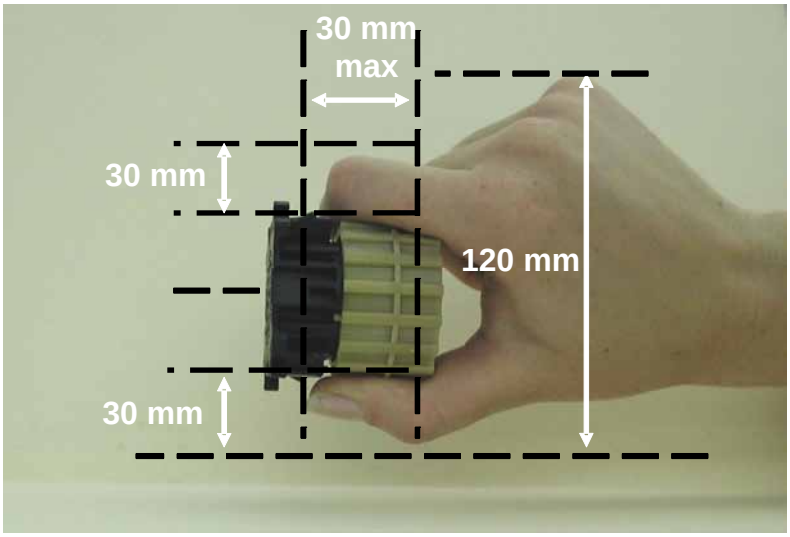


FIGURE 17. TWIST LOCK CONNECTOR CLEARANCE

APPENDIX A: GLOSSARY

Connector position assurance (CPA) – A lock on the latch that holds the two halves of a connector together or holds a connector to an electrical device. This is usually an optional feature. It prevents accidental release of the connector latch and serves as an indicator of full connector mating.

Contact surface area – The area available on the connector housing, mechanical assist, or wire harness bundle that the finger/thumb or palm must make contact with when exerting force for insertion or mating of the connector.

Finger push – Application of force by the finger pad(s) or tip(s).

Grip span – The distance between the thumb and opposing finger(s) which are in contact with the connector housing, mechanical assist, or wire harness bundle.

Grip surface – A contact surface that is not optimally angled and requires a pinch grip in addition to the force required for insertion.

Hand clearance – The amount of space required for access to assemble a connector as defined by either large male (95th percentile) for openings or small female (5^{th} percentile) for reach.

Hand grasp – A grip which allows the hand to fully surround the connector housing or wire harness bundle.

Hand-plug connectors – An electrical connector which requires an Operator to manually assemble two connector halves or a connector to a device/header without the use of a mechanical assist.

Key grip – Grasping of a connector housing or wire harness bundle between the thumb and the side of the index finger.

Maximum assembly force – The force required to mate male and female connector halves or to completely seat a connector in a device/header.

Mechanical assist connector – A means of minimizing the Operator effort required to mate two connector halves or a connector to a device/header. Typical means are a bolt, cam, slide, or lever.

Neutral wrist posture – A posture which aligns the hand and forearm naturally with minimal radial/ulnar deviation or flexion/extension of the wrist.

Optimally Angled Push Surface – A surface angled between 30° and 90° (perpendicular) from the direction of force insertion (see Figure 2).

Pinch grip – Grasping of a connector housing or wire harness bundle between the thumb and one or more fingers.

Power grip – Type of grip in which the thumb, fingers, and palm of the hand form a clamp around the object.

Push surface – A contact surface that is optimally angled which provides an area for application of force in the direction of insertion.

APPENDIX B: SURFACE AREA CALCULATIONS

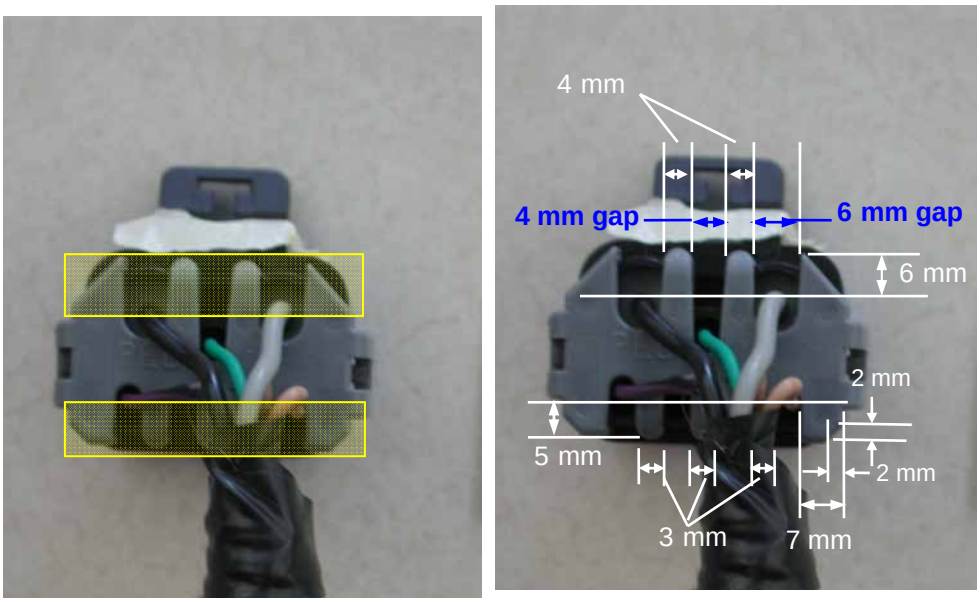
Example 1
Right and left sides used as push surface

Push surfaces on two sides of wire bundle
Measure length and width as shown on each side of bundle; add together for total push surface area

(7 x 18) – (0.5(7 x 6) – (0.5(2 x 2)) =103 mm² right side surface area
(7 x 18) – (0.5(7 x 6) – (0.5(2 x 2)) =103 mm² left side surface area

Total Surface Area 103+103 = 206 mm²

Example 2
Top and bottom used as push surface



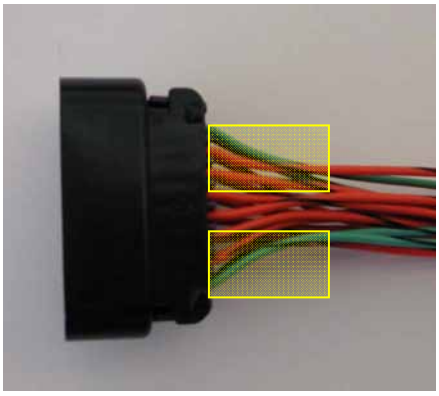
Push surfaces on top and bottom of wire bundle
Measure length and width as shown on the top and bottom of the bundle, add together for total push surface area.
Note – If gaps are ≥ 5 mm the surface is not considered continuous. If gaps are between 1 mm and 5 mm the surface can be considered continuous but the gap is not included in the surface area total (gaps ≤ 1 mm can be included in the total surface area).

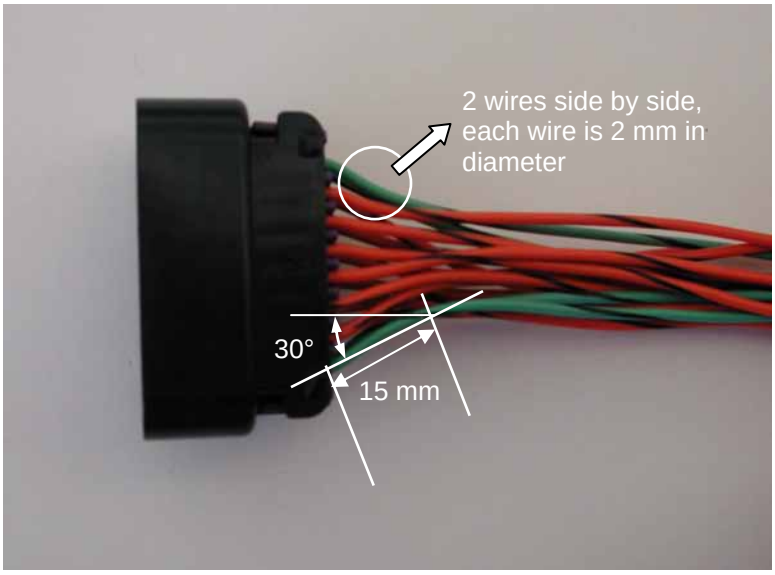
Top surface
The two outside gaps in top surface are greater than 5mm hence the surface cannot be considered continuous. Only the center area is included in the surface area total
$2(4 \times 6) = 48$ mm² top surface area

Bottom surface
The gaps in the bottom surface are less than 5mm so the surface can be considered continuous.
$2(5 \times 7) + 3(3 \times 5) – (2(0.5(2 \times 2))) = 111$ mm² bottom surface area

Total Surface Area 48+111 = 159 mm²

Example 3
Harness bundle used as a push surface





Push surface on right and left sides of wire bundle can be counted in the push surface calculation when the following criteria are met:

- wires are at an angle of at least 30°
- wire bundle width is minimum of 3 mm for Class 1 and 2 and 4 mm for Class 3

Measure the angled portion of the wire bundle only
15 x 2(2) = 60 mm² per side
Total Surface Area 60 + 60 = 120 mm²

APPENDIX C: REFERENCES

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APPENDIX D: REVISIONS

This standard was approved by USCAR/EWCAP in February of 2003.
Any revisions since that date have been incorporated into the specification. Revisions which altered the content of the specification are recorded below:

DATE	SECTION	SUMMARY OF CHANGES MADE	NOTES
2-24-03	All	Released	
DATE	SECTION	SUMMARY OF CHANGES MADE	NOTES
2-24-03	All	Released	
3-5-08	1.0	Packaging reference added to Scope	
	2.0	Appendix C added for additional reference	
	3.0	Hand Clearance Guidelines section reference added	
		Limited visibility note removed, force applied laterally across the body added	
	4.0	Previously section 6	
		Introduction text added	
	4.2	Sub section heading and text added	
	4.2.1	Minimum contact surface dimension changed to 3 mm.	
		Contact surface area definition added	
	Figure 1	New figure added	
	4.2.2	Previously included in sub-section 6.1	
		Target edge radius of 3 mm added	
		Note referring to Appendix B added	
	4.2.3	Previously sub-section 6.1	
		Acceptable surface void dimension changed to ≤5mm if not included in surface area calculation and <1mm gap included in calculation.	
		Reference to 1.5 mm wide picture frame of material surrounding contact surface area removed	
	4.2.4	New paragraph added	
	Figure 2	New figure added	
	4.2.5	New paragraph added	
	4.2.6	New paragraph added	
	Figure 3	Previously Figure 6.3	
		Drawing of circular connector removed, all dimensions removed	
	4.2.7	New paragraph added	
	Figure 4	New Figure added	
	4.2.8	New Paragraph added	
	4.3	Previously sub-section 6.3	
		Introduction text added	
	Table 4.1	Previously Table 6.3	
		Target Contact Surface Area, Minimum Contact Surface Dimension and Grip Span columns added	

		Target Contact Surface Area values revised	
		Photos added to illustrate Typical Hand Postures	
		Note added to ≤75 N category to reference non-neutral postures and forces applied in an upward or lateral direction	
	5.0	Previously section 4.0	
		Text revised	
		Reference to 5.1 and 5.2 added	
	5.1	Previously sub-section 4.2	
		Introductory text added	
		Prelock position note added	
	5.2	New sub-section heading added	
		Contact surface dimension derivation note added	
	5.2.1	New paragraph added	
	Figure 5	Previously Figure 4.1.1	
		Drawing updated, minimum dimensions updated	
		Minimum contact surface area changed from 10 mm to 3 mm	
	5.2.2	New paragraph added	
	5.2.3	New paragraph added	
	5.2.4	New paragraph added	
	5.2.5	Text previously included in paragraph 4.1.1	
		Edge radius notes added	
	5.2.6	Previously paragraph 4.1.2	
		Text revised	
	Figure 6	Previously Figure 4.1.2	
		Figure updated	
	5.3	Previously sub-section 4.1	
		Introductory text revised	
	Table 5.1	Previously Table 4.1	
		Title changed to Lever Lock Connector Design Guidelines	
		Pictures of typical hand postures added	
		Target Contact Surface Area, Minimum Contact Surface Width and Minimum Breadth columns added	
		Values for minimum contact surface area revised	
	5.4	New sub-section added	
	5.4.1	New paragraph added	
	Table 5.2	New Table added	
	5.5	Previously sub-section 4.3	
	5.6	Previously sub-section 4.4	
		Previous paragraph 4.4.1 now included in introductory text	
	5.6.1	Previously paragraph 4.4.2	
		Note changed to refer to newly numbered section	

	5.6.2	Previously paragraph 4.4.3	
	5.7	Previously sub-section 4.5	
	5.7.1	Previously paragraph 4.5.1	
	5.7.2	Previously paragraph 4.5.2	
	6.0	New section added	
	6.1	New sub-section added.	
	6.2	New subsection added	
	6.2.2	New paragraph added	Same as 5.2.3
	Table 6.1	New Table added	
	6.2.3	New paragraph added	
	Figure 7	New figure added	
	7.0	Previously section 5	
		Heading title changed to include Mechanical Assist connectors	
		Text revised to include mechanical assist connectors	
	8.0	Previously section 7	
	8.1	Previously sub-section 7.1	
		Minimum contact surface requirements changed from 5 mm x 3 mm to 15 mm^2 with a minimum dimension of 3 mm	
	8.2	New sub-section added	
	8.3	Previously sub-section 7.2	
		Reference to flashlight switch removed	
		Definition of angled surface added	
	8.4	Previously section 7.4	
		CPA actuation force of ≤22 N added	
	8.5	Previously sub-section 7.5	
		Edge radius note added	
	8.6	Previously sub-section 7.6	
		26 mm diameter cylinder changed to 30 mm diameter cylinder of clearance	
		Reference to Figure 11 added	
	8.7	Previously sub-section 7.7	
	8.8	Previously sub-section 7.8	
		Reference to Figure 6 added	
	8.9	Previously sub-section 7.9	
	9.0	New section added	
	9.1	New sub-section added	
	9.2	New sub-section added	
	Figure 8a, 8b, 8c, 8d, 9, 10a, 10b, 11, 12, 13	New figures added	
	9.3	New sub-section added	
	Table 9.1	New table added	

	Table 9.2	New table added	
	9.4	New sub-section added	
	Figure 14	New figure added	
	9.4.1	New paragraph added	
	Figure 15	Previously figure 5.1.1-2	
		Title changed to Lever Lock Swing Path and Clearance - Push	
		Photos added for clarification	
		2 finger clearance value added	
	Figure 16	New figure added	
	9.5	New sub-section added	
	Table 9.3	New table added	
	Table 9.4	New sub-section added	
	9.6	New sub-section added	
	Appendix A	New section added	
	Appendix B	New appendix added	
	Appendix C	New appendix added	
	Appendix D	Previously Appendix A	
		Items removed	
	4.5.3	Section removed	Not an ergonomics requirement
	4.6	Heading removed	
	4.6.1	Section removed	
	4.6.2	Section removed, all hand clearance information updated and moved to section 9	
	Figures 5.1.1-1, 5.1.1-2	Figures combined and included in Figure 15 in section 9.4.1	
	Figures 6.2-1, b, c, d, e, f	Figures removed, all hand clearance information updated and moved to section 9	
	6.3	Heading removed	
	7.3	Section removed	
	7.10	Section removed	