

Ergonomics Specification for Electrical Connections

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ERGONOMICS SPECIFICATION FOR ELECTRICAL CONNECTIONS

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1. SCOPE

This specification describes the design relative to assembly force and hand clearance guidelines for conventional hand-plug, mechanical assist, twist lock, and high voltage electrical connectors, as well as Connector Position Assurances (CPAs). The minimum values associated with this design guide need to be evaluated against other critical characteristics that impact quality, efficiency, and other traits of assembly feasibility.

Non-routine repair tasks do not apply to this specification. In addition, ergonomic risk factors may be present in other subtasks related to connector mating - such as lifting the harness or manipulating it into position. These risk factors are not discussed within SAE/USCAR-25.

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

2. REFERENCED DOCUMENTS

- SAE/USCAR-2 Performance Standard for Automotive Electrical Connector Systems
- SAE/USCAR-12 Electrical Connector Design Requirements
- SAE/USCAR-37 High Voltage Connector Performance Supplement to SAE/USCAR-2

See Appendix E for additional references

3. GENERAL

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

3.1 Assumptions

Assembly force values are defined to accommodate strength capability of the working population for connector insertion tasks. The maximum assembly force identifies the maximum force which an operator can exert for cyclic assembly tasks. Non-routine repair tasks do not apply to this specification.

These force thresholds were developed with the assumption that postures, working zones, clearance, and force directions optimize an operator's ability to exert force. The thresholds do not consider subtasks outside of seating the connector, such as wire harness manipulation.

If the assembly scenario does not meet the assumptions outlined in Appendix D, the maximum acceptable force thresholds defined within this specification may require additional ergonomic assessment or consultation.

3.2 Assembling Connectors Outside of Assumption Conditions

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

- a. Obstructed access or inadequate clearance for hand, upper extremity, or whole body (see Section 9 for more information).
- b. Assembly outside of the working zone defined in the assumptions, such as extended or overhead reaches.

- c. Other awkward or non-neutral postures, such as wrist deviation.
- d. Assembly forces applied in a direction which does not optimize force exertion - such as force in an upward direction or laterally across the body.
- e. Additional forces on the hands such as heavy wire harnesses or shear or tensile forces on the wire harnesses resulting from too short of harness lengths for the assembly.

Consult the applicable Ergonomics Department with any questions or if clarifications are needed.

4. 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 include low voltage as well as high voltage connectors. Specific high voltage connector requirements can be found in Section 7. Hand-plug connector requirements also apply to pre-lock assembly tasks for mechanical assist connectors. See Section 5 for more information on mechanical assist connectors.

Hand-plug connectors fall into three classes as shown in Tables 4.1 through 4.3. Each class is defined by maximum assembly force and corresponding contact surface area requirements. Grip span specifications are provided for the different hand postures that may be used to manually assemble these connectors. Additional requirements related to wire harness used for connector assembly can be found in 4.4 and Table 4.4. In addition to the requirements found in Section 4, hand-plug connectors which are assembled manually must meet the hand clearance requirements found in Section 9.

4.1 Maximum Assembly Force

Assembly force values are defined to accommodate strength capability for the working population. Under the assumption conditions described in Appendix D, the maximum assembly forces shall not exceed 75 N (see Tables 4.1 through 4.4). When assumption conditions cannot be met, lower mate force connectors may be required. If the connector cannot be changed, refer to each OEM manufacturing process to address this ergonomic issue.

4.2 Contact Surface Characteristics

The contact surface is an essentially continuous plane upon which the operator can apply assembly force. Within this specification, contact surfaces refer to the surfaces of the connector which the operator interfaces (i.e., pinches, grasps, presses) to make a connection. Contact surface dimensions accommodate a gloved hand. The minimum contact surface area shall be met. These dimensions are provided in Tables 4.1 through 4.3.

Measuring contact surface area shall be done by defining acceptable contact surface areas based on criteria defined in 4.2. Acceptable contact surface areas need to account for reasonable areas of the connector an operator would interface with to manually connect. Sum the acceptable contact surface areas to determine total available contact surface area. Appendix B provides specific examples on calculating surface area for different connector scenarios.

When determining reasonable areas of the connector an operator would interface with to manually connect, the type of connector plays a role in available surface area. Hand-plug connectors can be categorized into two types that will impact the available surface area (and therefore the hand posture) on the connector when mating the harness connector during vehicle assembly.

- 4.2.1 Shrouded harness connectors, typically sealed connection systems, have an outer shroud that can be held by the operator during the connector mating process. When shrouded harness connectors are mated to the device or male inline connector, the operator can hold the outer shroud while pushing the connector in the mate direction. To account for the reasonable area an operator would interface with, this means that acceptable contact surface areas include surfaces of the outer shroud that the operator would grasp with their hand.

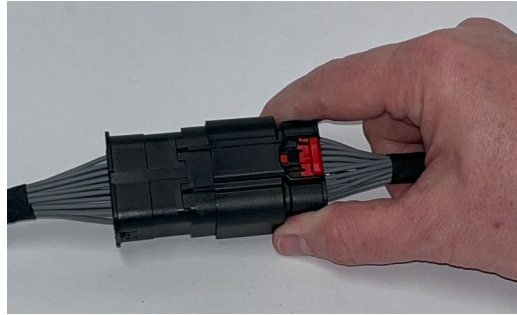


Figure 1 - Example of a shrouded connector

- 4.2.2 Unshrouded harness connectors, typically unsealed connection systems, do not have an outer shroud and the operator must push on the connector at the back of or behind the body of the connector. To account for the reasonable area an operator would interface with, this usually means that the acceptable contact surface areas are located behind the body of the connector.

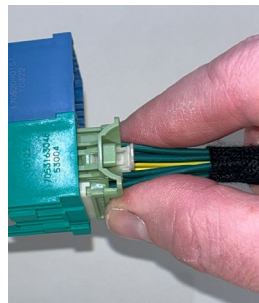


Figure 2 - Example of an unshrouded connector

- 4.2.3 For both shrouded and unshrouded connectors, the addition of a wire dress cover can increase push surfaces and hand grip areas for the operator. These allow the operator to grip behind the connector without influencing or holding the wires.
- 4.2.4 For Class 1 connectors, there is a minimum surface area requirement of 15 mm² for a fingertip hand posture, or 100 mm² (50 mm² opposing sides) for the pinch grip hand posture with a minimum dimension of 3 mm for either posture.
- 4.2.5 For Class 2 and 3 connectors, a minimum contact surface dimension of 5 mm, not including the edge radius, is required (see Figure 3). Any surface measuring less than 5 mm in width or length cannot be considered as part of the contact surface area. Contact stress limitations necessitate this larger contact surface dimension.

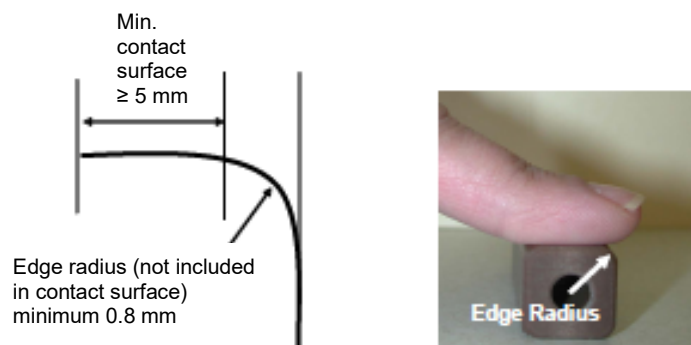


Figure 3 - Contact surface area and edge radius

- 4.2.6 Design contact surfaces to be continuous or near continuous. Voids in these contact surfaces are not desired, but may be acceptable under certain conditions:
- If both void dimensions (length and width) are ≥ 5 mm, the surface is not considered continuous and the area on either side of the gap may not be combined to meet minimum surface area requirements.
 - If one of the dimensions in the profile (length or width) of the contact surface is < 5 mm, the surface area may be considered continuous and the surface area on either side of the void may be combined to meet the minimum surface area requirements.
 - For voids with a dimension in the profile (length or width) of the contact surface between 3 and 5 mm, the surface can be considered continuous and surface area calculations combine the surface area on either side, but the void itself is not included in the total surface area.
 - Surface voids with at least one dimension in the profile (length or width) of the contact surface that measures ≤ 3 mm may be included in the total surface area.

See Appendix B for further explanation and examples on calculating surface voids.

- 4.2.7 Design potential contact surfaces with no uncomfortable pressure points. In some situations, knurls or serrations can be used to improve grasp, provided they do not create uncomfortable pressure points. Serrations, knurls, and ridges greater than 0.8 mm in height are not acceptable (see Figure 8). Contact surface areas or edges likely to be contacted by the operator's hand have a recommended edge radius of 3 mm. An edge radius less than 0.8 mm is unacceptable (see Figure 3).
- 4.2.8 Position contact surfaces optimally angled between 30 and 90 degrees (perpendicular) from the direction of force insertion (see Figure 4) for maximum allowable assembly force per Tables 4.1 through 4.3. A negatively sloped angle (91 to 180 degrees) does not qualify.

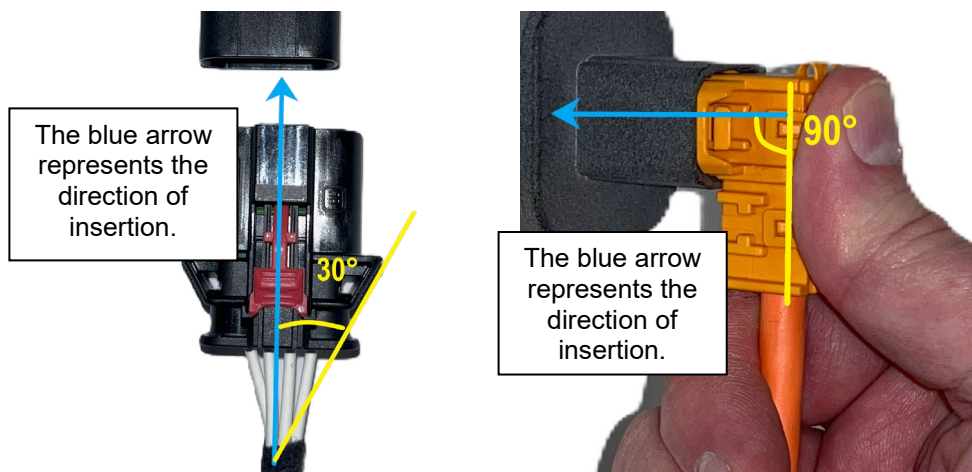


Figure 4 - The acceptable contact surface is optimally angled between 30 and 90 degrees from the direction of the force insertion

- 4.2.9 Only hand surfaces involved in active gripping or pushing of the connector can be included in the total contact surface area (see examples in Appendix B). In most cases, this refers to the thumb or fingers. For force applications that require a pinch or grasp posture, contact surfaces shall be on opposing sides (i.e., top/bottom or left/right). See Figure 5, where the picture on the left shows contact surfaces on opposing sides where an operator could grip the connector versus the picture on the right which shows contact surfaces behind the body of the connector which the operator can push on.

NOTE: The blue shaded areas in Figure 5 represent contact surfaces.

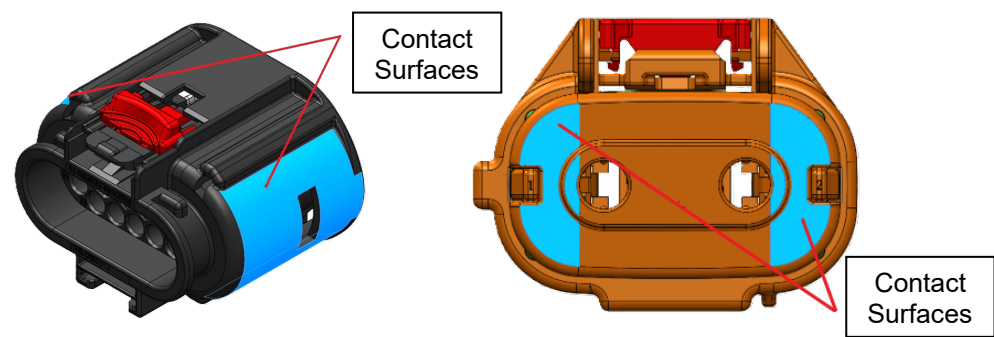


Figure 5 - Contact surface area examples

Table 4.1 - Class 1 hand-plug connector design guidelines

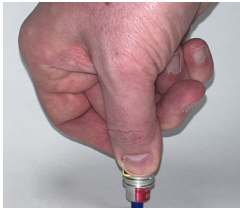
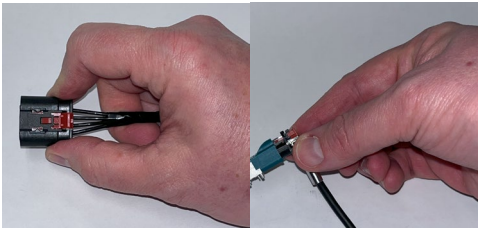
Maximum Assembly Force	Typical Hand Posture Options for Design	Minimum Contact Surface Area	Minimum Contact Surface Dimension	Grip Span
≤25 N	Fingertip (with optimally angled push surface) 	15 mm ²	3 mm	N/A
	Pinch grip on connector (without optimally angled push surface) 	100 mm ² with a minimum of 50 mm ² provided on each opposing grip surface	3 mm	75 mm maximum

Table 4.2 - Class 2 hand-plug connector design guidelines

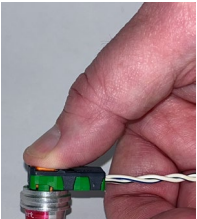
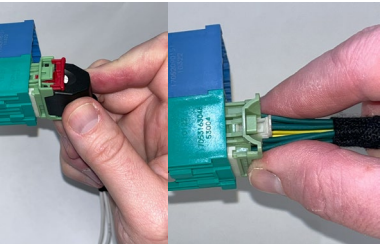
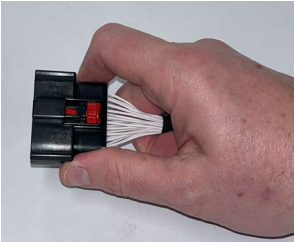
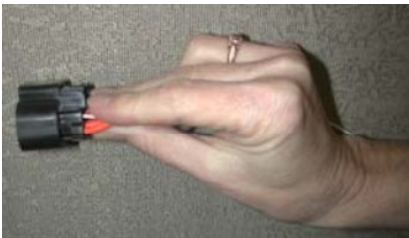
Maximum Assembly Force	Typical Hand Posture Options for Design	Minimum Contact Surface Area	Minimum Contact Surface Dimension	Grip Span
≤ 45N	One thumb or one finger push (with optimally angled push surface) 	100 mm ²	5 mm	N/A
	Pinch grip with thumb tip and fingertip (with optimally angled push surface) 	100 mm ² with a minimum of 50 mm ² push surface provided on two opposing sides of the wire bundle		75 mm maximum
	Hand grasp (key grip without optimally angled push surface) 	100 mm ² with a minimum of 50 mm ² provided on each opposing grip surface		10-55 mm
	Hand grasp (power grip without optimally angled push surface) 	100 mm ² with a minimum of 50 mm ² provided on each opposing grip surface		15-75 mm

Table 4.3 - Class 3 hand-plug connector design guidelines

Maximum Assembly Force	Typical Hand Posture Options for Design	Minimum Contact Surface Area	Minimum Contact Surface Dimension	Grip Span
≤ 75N	Two finger push (single hand) (with optimally angled push surface) 	150 mm ² with a minimum of 75 mm ² provided for each finger	5 mm	N/A
	Hand grasp (key grip with optimally angled push surface) 	150 mm ² with a minimum of 50 mm ² push surface provided on one side of the wire bundle (for the thumb)		75 mm maximum
	Pinch grip with thumb tip and two fingertip (with optimally angled push surface) 	150 mm ² with a minimum of 50 mm ² push surface provided on one opposing side of the wire bundle (for the thumb)		75 mm maximum
	Hand grasp (power grip without optimally angled push surface) 	150 mm ² with a minimum of 50 mm ² push surface provided on each opposing grip surface		15 mm minimum 50 mm maximum

4.3 Grip Span

- 4.3.1 Under assumption conditions described in these guidelines, the optimal grip span for generating force with a power grip is between 15 to 50 mm. The maximum grip span required for any connector shall not exceed 75 mm. Acceptable grip spans vary based on posture and application. See Tables 4.1 through 4.3 for specifics.

4.4 Wire Harness Use for Connector Assembly

It is not considered best practice to use wires, cables, or wire harnesses where they exit the back of the connector as a method to assemble a connector.

Preferred assembly methods:

- a. Prioritize first the connector housing and designed-in push surfaces to apply force for assembly of connectors.
- b. The next best method for connector assembly is to add and use a wire dress cover to apply a push force on.
- c. If neither of the previous methods are feasible, the next best connector assembly method is to tape the bundle appropriately and apply a push force on the tape or convolute.

It is not recommended to apply force directly to the wires exiting the connector housing. Applying force or squeezing on the wires themselves will lead to high assembly forces, terminal damage, wire pull out, and damaged wires.

If using assembly method b or assembly method c, as described above, the wire harness bundle or cable must meet the following requirements:

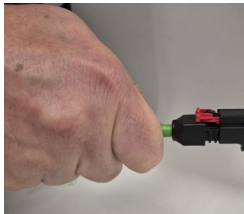
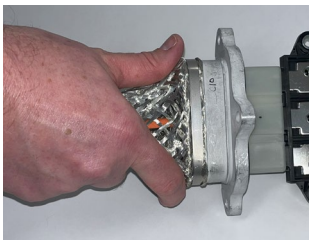
- 4.4.1 The wire, cable, or bundle shall be stiff enough to ensure that it does not flex when assembly force is applied.
- 4.4.2 The wire, cable, or wire harness bundle shall meet the surface area requirements of the given connector.
- 4.4.3 The wire, cable, or wire harness bundle shall meet the grip span requirements of the given connector.
- 4.4.4 Adequate clearance is available for assembly purposes. See Section 9.
- 4.4.5 Wire harness diameter measurements include taping and conduit bundles.
- 4.4.6 A power grip for maximal effort can only be achieved when the bundle diameter is between 15 and 50 mm. When these conditions cannot be met, the maximum assembly force is reduced.
- 4.4.7 The wire harness bundle diameter shall not exceed 75 mm for manual assembly purposes.
- 4.4.8 Some specialty cables and cable bundles, such as the coaxial and ethernet specialty cables, are sensitive to forces that occur when the wire harness/cable is used to assemble the connector. In instances where the operator is not permitted to use the wire, cable, or wire harness bundle for connector assembly, the connector shall provide adequate contact surface and grip spans for the given connector without engaging the wire harness or cable.



Figure 6 - Example of a specialty cable: coaxial cable



Table 4.4 - Design guidelines for using the wire harness for connector assembly

Class	Maximum Assembly Force	Typical Hand Posture Options for Design	Minimum Contact Surface Area	Minimum Contact Surface Dimension	Grip Span
Class 2	≤45 N	Hand grasp (power grip without optimally angled push surface) - wire harness 	15-75 mm diameter wire bundle size with tapes or conduit bundles*	5 mm	15 mm minimum 75 mm maximum
Class 3	≤75 N	Hand grasp on wire harness (power grip without optimally angled push surface) 	15-50 mm diameter wire bundle size with tapes or conduit bundle*	5 mm	15 mm minimum 50 mm maximum

*If the operator is able to use wires to assist with aligning and seating the connector (as defined in 4.4).

4.5 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 Tables 4.1 through 4.3). Disengagement forces are applicable for cyclic assembly tasks. Non-routine repair tasks do not apply to this specification.

5. DESIGN GUIDELINES - MECHANICAL ASSIST CONNECTORS

Mechanical assists provide a mechanical advantage to the operator in making the connection and thus reduce assembly force. The mechanical assists described in this section are organized by the action an operator uses to engage the mechanical assist, these include levers, slides, and linear engagements. A mechanical assist connector may be utilized for high voltage connector assembly.

Mechanical assist connectors fall into three classes as shown in Tables 5.1 through 5.3. Required push surface area, grip span, and assembly force varies with each type of connector and class. In addition to the requirements found in Section 5, mechanical assist connectors which are assembled manually must meet the hand clearance requirements found in Section 9.

5.1 Pre-Lock Positioning for Mechanical Assists

For the purposes of assembly, the connector needs to be engaged into a pre-locked position before the mechanical assist can be actuated. SAE/USCAR-2 defines the pre-lock position as the point where the connector is positioned on the mating part and the mechanical assist is ready to be activated. Therefore, hand-plug design guidelines as defined in Section 4 shall be used to determine acceptable assembly conditions for the initial assembly or pre-lock positioning. Force should not be applied to the mechanical assist during the initial assembly or pre-lock positioning, but should occur after the connector is positioned on the mating part. Additionally, once the connector is properly mounted into the pre-lock position, the operator should not continue to apply engagement force in the mating direction without the use of the mechanical assist. Hand-mating the connector without the use of the mechanical assist will exceed the ergonomic limit.

5.2 Maximum Assembly Force for Mechanical Assists

This section shall define the guidelines for actuating the mechanical assist. For force requirements during pre-lock positioning, see Section 4. Assembly force values are defined to accommodate strength capability for the working population. 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. Under assumption conditions described in these guidelines, the maximum assembly forces shall not exceed 75 N (see Tables 5.1 through 5.3). 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 assumption conditions cannot be met, lower mate force connectors may be required. If the connector cannot be changed, refer to each OEM manufacturing process to address this ergonomic issue.

5.3 Contact Surface Characteristics for Mechanical Assists

The contact surface is an essentially continuous plane upon which the operator can apply assembly force. Contact surface dimensions accommodate a gloved hand. The minimum contact surface area shall be met. These dimensions are provided in Tables 5.1 through 5.3.

Measuring contact surface area shall be done by defining acceptable contact surface areas based on criteria defined in 5.3. Acceptable contact surface areas need to account for reasonable areas of the connector an operator would interface with to manually connect. Sum the acceptable contact surface areas to determine total available contact surface area. Appendix B provides specific examples on calculating surface area for different connector scenarios.

NOTE: The surface area used to engage the mechanical assist would not be used in surface area calculation for the pre-lock positioning task since force should not be applied to the mechanical assist during pre-lock positioning. To calculate the surface area for the pre-lock positioning task, see Section 4.

- 5.3.1 For Class 1 connectors a minimum contact surface dimension of 3 mm, not including the edge radius, is required (see Figure 3). Any surface measuring less than 3 mm in width or breadth cannot be considered as part of the contact surface area.
- 5.3.2 For Class 2 and 3 connectors a minimum contact surface dimension of 5 mm, not including edge radius is required (see Figure 3). Any surface measuring less than 5 mm in width or breadth cannot be considered as part of the contact surface area.