Motor terminal box connection methods, procedures

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Introduction

As with most tasks, there are many ways to terminate motor leads and each one has a following who believe it is the best method. Here we will discuss some of these procedures and outline a few of the advantages and disadvantages of each. We will not consider the starting method or internal connection of the motor, but only the methods used to connect the motor leads to incoming power.

Types of terminations

Acceptable methods of connection include compression lugs (both mechanical and crimp type) or split bolts. Not acceptable are connections that use only solder or twist-on connectors (wire nuts) [See *NFPA 79-2012 Electrical Standard for Industrial Machinery, National Fire Protection Association, 2012, Section 13.5.9*].

Mechanical compression lugs have a set screw that tightens on the wire (see **Figure 1**). These can be configured with anywhere from one to six or more barrels for wire. The set screw is tightened to the National Electrical Code (NEC) recommended torque values as shown in **Table 1** to secure the wire. The lugs are installed on both the motor leads and the power supply leads

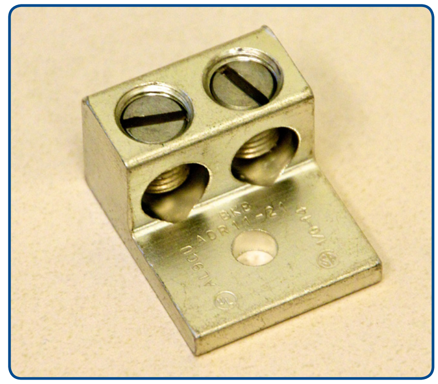

Figure 1. Mechanical compression lug.

and bolted together. Parallel motor leads and power supply conductors should use lugs that have the same number of barrels as there are leads. The bolt holding the lugs together should also be torqued to the correct value. If the material of the lug and the bolt are different, a Belleville washer can be used to maintain the torque

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Table 1. Torque values for lugs and split bolts.

Recommended Torque, N-m (lb – in)					
Conductor Size		Slotted Head #10 & Larger		Hexagonal Head	
AWG or kcmil	mm²	Slot width ≤ 1.2 mm (0.047 in) & Slot Depth ≤ 6.4 mm (0.25 in)	Slot width > 1.2 mm (0.047 in) & Slot Depth > 6.4 mm (0.25 in)	Split-bolt Connectors	Other Connectors
30-10	0.05-5.3	2.3 (20)	4.0 (35)	9.0 (80)	8.5 (75)
8	8.4	2.8 (25)	4.5 (40)	9.0 (80)	8.5 (75)
6-4	13.2 - 21.2	4.0 (35)	5.1 (45)	18.5 (165)	12.4 (110)
3	26.7	4.0 (35)	5.6 (50)	31.1 (275)	16.9 (150)
2	33.6	4.5 (40)	5.6 (50)	31.1 (275)	16.9 (150)
1	42.4	–	5.6 (50)	31.1 (275)	16.9 (150)
1/0-2/0	53.5 - 67.4	–	5.6 (50)	43.5 (385)	20.3 (180)
3/0-4/0	85 - 107.2	–	5.6 (50)	56.5 (500)	28.2 (250)
250 - 350	127 - 177	–	5.6 (50)	73.4 (650)	36.7 (325)
400	203	–	5.6 (50)	93.2 (825)	36.7 (325)
500	253	–	5.6 (50)	93.2 (825)	42.4 (375)
600 - 750	304 - 380	–	5.6 (50)	113.0 (1000)	42.4 (375)
800 - 1000	405 - 508	–	5.6 (50)	124.3 (1100)	56.5 (500)
1250 - 2000	635 - 1010	–	–	124.3 (1000)	67.8 (600)

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and reduce the stretching of the bolt as the lug material expands and contracts faster. An anti-oxidant material formulated for the purpose is a good practice and should be applied to the conductors and the mating surfaces of the lugs. This is suitable for all connections discussed in this article. Oxidation will increase the resistance and heating in the termination. The advantages of this connection are that it is simple to use and does not require special tools. Typically a hex key (Allen wrench) is all that is needed. Also, this connection can be used where the motor is terminated on a bus bar in the terminal box (see **Figure 2**). The disadvantage is that the secureness of the connection relies on the tightness of the set screws and bolts that hold the lugs together.

Crimped compression lugs require a mechanical or hydraulic tool to crimp the lug onto the wire (see **Figure 3**). These crimps may have different profiles such as indented, hexagonal, or lobed. The critical factor is that the proper tool be used for the size and type lug being used (see **Figure 4**). Manufacturers will provide the tool for their lugs; the use of the wrong tool can result in looseness, damage to the conductor strands or misshapen crimps (see **Figure 5** on Page 5).

Some crimp type lugs are made from a sheet of conductor material that is formed into a barrel. The indentation should be on the side opposite the seam in these lugs to prevent the seam from splitting and creating a loose crimp joint. These lugs are bolted together the same way the set screw type were as previously mentioned. One difference is that each parallel conductor will require a lug and the bolt will hold all the lugs together. There are no multiple barrel crimp type lugs for obvious reasons. The advantages of this connection are that it securely joins the conductor and lug if the proper tool is used. Also, this connection can be used where the motor is terminated on a bus bar in

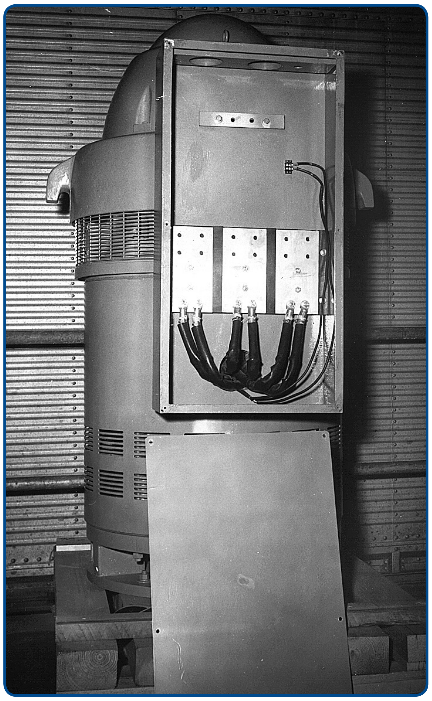

Figure 2. Line lugs terminated on bus in outlet box.

the terminal box. The disadvantage is that a special tool is required for each different lug. This can be minimized by selecting a manufacturer so that only one set of tools is needed. Smaller tools will often accommodate 3 or more wire sizes. Larger hydraulic sets can have multiple dies that fit in the tool for different lugs.

Split bolts are so called because the bolt has a split that allows the wire to be inserted (see **Figure 6** on Page 5). The nut is tightened to the prescribed torque on the bolt to mechanically hold the wires together. This places the conductors in intimate contact. The bolt and wire materials should be the same metallurgical family (such as copper or aluminum and their alloys) so that expansion does not result in wire damage or loosening of the connection. The advantages of this connection are that the number of mechanical connections that might cause problems are minimized and the conductors are in intimate contact. This will reduce the heating of the connection and the associated problems that result. One disadvantage is the limit of the num-

Figure 3. Crimp type compression lugs.

Figure 4. Crimping tool & dies.
Photo courtesy of Eaton's Power Systems Business.

ber of conductors that can fit into the split bolt. With large conductors with multiple in parallel, the split bolt may not be the best option. Another disadvantage is that this connection cannot be used where the motor is terminated on a bus bar in the terminal box.

Insulating the joint

For motors operating at less than 2kV, kits are available to insulate the

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splices. Some use epoxy resins and some have the various tapes required to make a well protected joint. The object of either is to electrically insulate the joint from its surroundings and mechanically protect it from damage due to vibration, heat or impact. The tape or epoxy kits will have manufacturer's instructions provided that must be followed. The following procedure will outline how to tape a joint without a kit (see **Figure 7** on Page 6).

For voltages up to 2 kv, three types of tape are required: varnished cambric, rubber or rubber mastic, and vinyl. The quality of the tapes is important; this is not the place to be cheap. The connection should be free of dirt, oil, moisture or other contamination. The first course should be two half-lapped layers of varnished cambric. A half-lapped layer is one where the second lap of the tape around the joint covers one-half the lap below it. When finished, there will be two thicknesses of tape per side in each half-lapped layer. If the varnished cambric has adhesive, it should be turned outward. This layer will protect the sharp edges from piercing the other tapes.

Next should be four half-lapped layers of rubber tape. This tape does not usually have an adhesive. But if tension is maintained during the process, it will bond to itself. Next use at least two half-lapped layers of vinyl electrical tape. This will hold the rest of the tape together and add a level of electrical and mechanical protection. The tape should extend a couple of inches along the wires to help seal out contaminants and reduce the possibility of shorting.

Medium voltage stress cones

For motors with voltages above 2kV, shielded cable should be used. This will distribute the voltage stress along the length of the cable and prevent localized partial discharge at points where the cable is adjacent to metal structures. For the shielding to be effective, it should be continuous from the power supply to the motor termination. To avoid voltage build up, the shield should be grounded at each point that the conductor terminates, including splices. This will cause a circulating current in the shield that produces heat. If the current in the shield circuit exceeds 5% of the current in the conductor, the current carrying capacity of the conductor should be reduced. Since multiple variables are required to determine the heating effect, the wire vendor should be consulted for the appropriate derating factors.

Proper termination of the shielded cable will include stress cones to help

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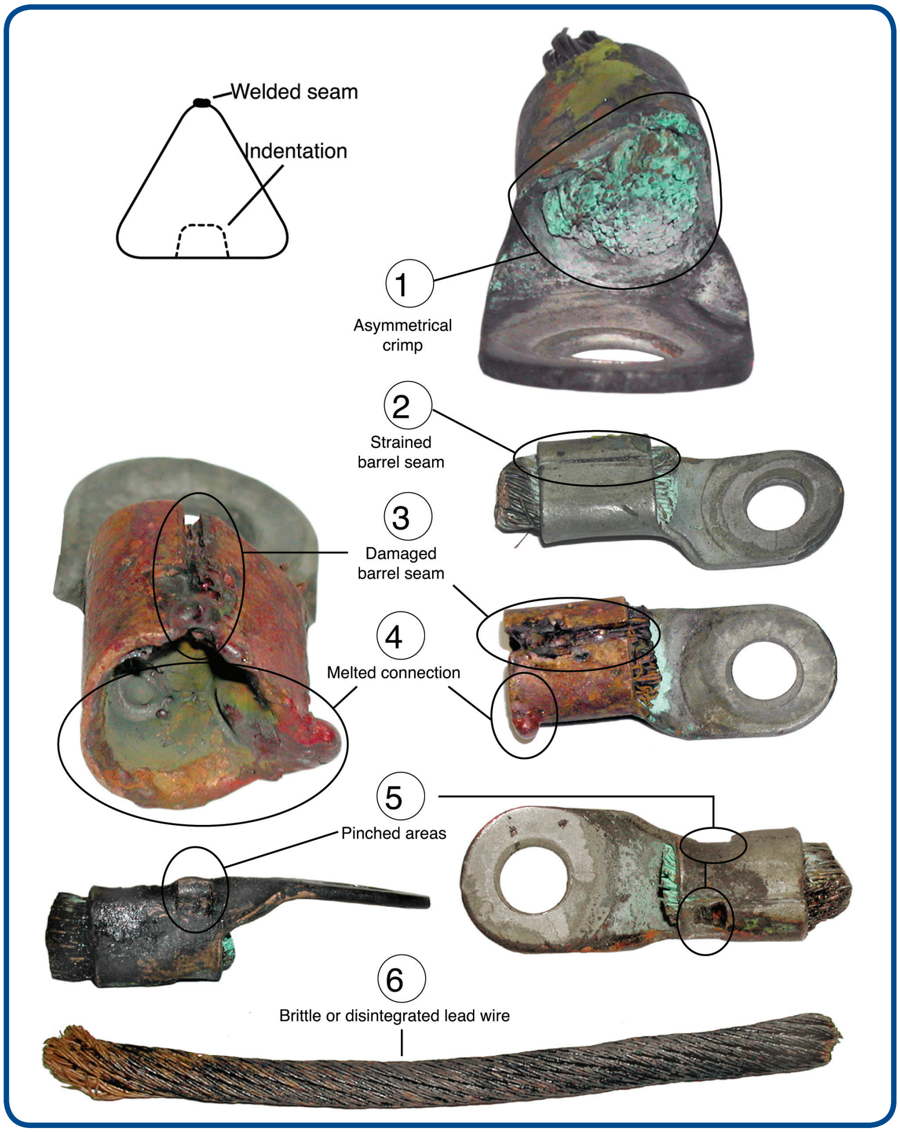

Figure 5. Improperly crimped lugs.

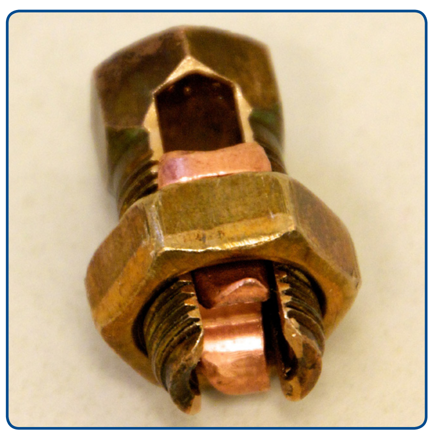

Figure 6. Split bolt.

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the transition from insulated conductor to conductor in air. See **Figures 8 & 9** on Page 6 for examples of stress cones. Partial discharge can occur at a point where a transition occurs. This can be emerging from a stator core, a pointed section of winding such as a stub connection in a form coil or, as discussed here, a break in the insulation and shielding system. In the case of the latter, a stress cone mitigates the effect of the partial discharge. ●

Conclusion

A properly connected and insulated motor connection can prevent problems such as that shown below in **Figure 10**.

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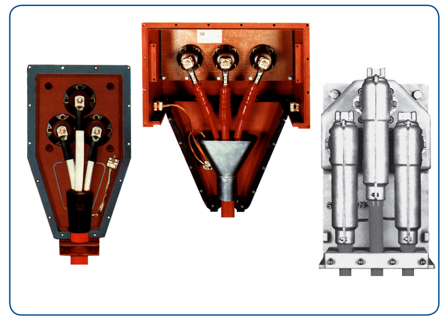

Figure 9. Stress cones in motor terminal boxes.

Figure 7. Taping a joint.

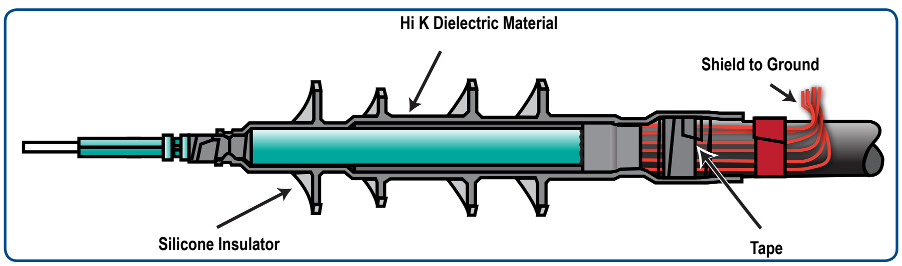

Figure 8. Cutaway of a stress cone.

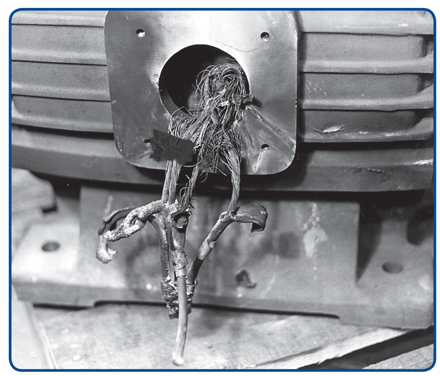

Figure 10. Motor connection failure.