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Engineering Note

Date: 10/28/96
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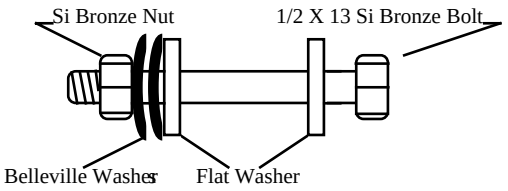
Project: Solenoid Energization, Controls, Interlocks and Quench Protection
Doc. No: H961028A

Subject: Solenoid Power Supply Bus Connections - Bolts, Torques, Contact Area, Prep

This note describes the standards to be used in the installation of the 5000 Amp bus which connects the solenoid power supply, filter, reversing switch, dump switch, dump resistor and water cooled bus.

1. **Bolts, Belleville springs, washers & nuts -** Silicon-bronze nuts and bolts (1/2 inch X 13 threads per inch), stainless steel flat washers, and Belleville washers (disc springs) shall be used for all connections as shown below. Note that silicon-bronze bolts, being 97% copper and 3% silicon[1], have the same temperature coefficient of expansion as copper thus preventing stretching or loosening of bolts when the copper expands & contracts with temperature variations.



2. **Bolt lubrication -** DO NOT lubricate the bolts or nuts before installing (torque will overstress bolt).

3. **Torque -** The nuts shall be torqued to 55 lb-ft. Note that each Belleville K1250-E-125 washer provides a flat load of 4,024 lb. Two of them together in parallel as shown provide a load of 8048 lb. The 55 lb-ft. torque on the 1/2 X 13 nut will provide a clamping force on the washers which can be roughly approximated as follows[2]:

   $F = T / (0.2 \times D) = 660 / (0.2 \times 0.5) = 6600$ lb.
   F = force in lbs.
   T = torque in lb-in = 55 lb-ft X 12 lb-in/lb-ft = 660 lb-in
   D = nominal diameter of bolt = 0.5".

   Thus the Belleville spring washers will be compressed to 6600 / 8048 = 0.82 or 82% of their flat load position. The spring washer will compensate for cold flow of the copper bars; and thermal expansion and contraction differences (if any) between the silicon bronze bolts and the copper bus.

   The stress on the bolts, which are rated at 75000 lb/in^2 minimum, will then be approximately as follows:

   $S = F / A = 6600$ lb / 0.1416 in^2 = 46,610 lb/in^2 (62% of bolt minimum strength)
   S = stress on bolt in pounds per square inch
   F = tensile force on bolt in pounds = 6600 lb
   A = stress area of 1/2" NC bolt in square inches[3] = 0.1416 in^2

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[1]Handbook of Enginnering Fundamentals - ESHBACK - Third Edition - pg 1326, table of chemical composition of metals.

[2]Mechanical Design & Systems Handbook pg. 24-4 - Rothbart - 1964

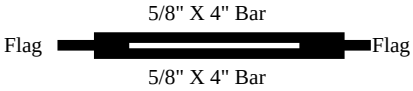
[3]Handbook of Enginnering Fundamentals - ESHBACK - Third Edition - pg 202, table of standard screw threads.

4. **Bolt hole diameter -** Bolt holes shall be 9/16" (0.562") diameter.

5. **Bolt hole spacing -** Bolt hole centers shall be spaced no closer than 27/32" (0.845") from the edge of a conductor; and no closer than 1-5/16" (1.3125") to any adjacent bolt hole center. This is to provide at least one hole diameter of material on connector edges; and clearance room for the flat washers between holes. If at all possible, use 1-3/4 bolt spacing which is a NEMA standard. This will allow quick connect test equipment, jumpers, loads etc.

6. **Connection preparation -** Bolted connections shall be cleaned with scotch brite, silver plated with 'Cool Amp' silver plating powder, and treated with 'Penetrox' no more than 3 hours before assembly.

7. **Conductor cross sectional area -** All non-water cooled current distribution conductors shall be copper and have a cross sectional area of at least 1 in^2 per 1000 Amps.[4] Note: Make conductors from double pieces of 5/8" thick X 4" wide copper stock (5/8" X 4" X 2 pieces = 5in^2 . Thus, 5000 Amps / 5in^2 = 1000 Amps per in^2 . For example:



8. **Connection contact area -** Bolted connections shall have a contacting surface area of at least 1 in^2 per 1000 Amps[4].

9. **Connection contact force** - Bolted connections shall have a contact force of 2000 lb. per in^2 or greater[4]. Use the following table to choose contact dimension vs number of bolts to use; or use the procedure listed after the table. Note that the calculated contact area in the table is based on **two** conductors bolted to a single flag or connection; but the calculated contact force is based on a single connection since the contacts are "stacked" with the total force being applied to both surfaces:

Contact Dimension	Number of Bolts	Contact Area = L X W - Hole Area	Contact Force Required = Area X 2000	Contact Force Provided N X 6600
4" X 4"	5	14.8 X 2 = 29.6 in^2	29,600 lb	33,000 lb
4" X 3-1/2"	4 (NEMA pat.)	13.0 X 2 = 26.0 in^2	26,000 lb	26,400 lb

1. Calculate the contact area: $A_{contact} = L \times W - A_{holes}$

   $A_{contact}$ = area in square inches (must exceed 5 square inches to provide 1 in^2 per 1000 Amps)
   L = length in inches
   W = width in inches
   A_{holes} = area of anticipated holes in square inches = 0.248 X number of holes.

2. Calculate the total clamping force required: $F_{clamp} = A_{contact} \times 2000$

   F_{clamp} = force in pounds
   $A_{contact}$ = contact area in square inches

3. Confirm that enough bolts are being used to provide the required total clamping force: $F = N \times F_{bolt}$

   F = force in pounds (must equal or exceed F_{clamp})
   N = number of bolts
   F_{bolt} = force from each bolt = T / 0.2 X D = 660 / (0.2 X 0.5) = 6600 lb.
   T = torque in in-lb. = 55 lb-ft. X 12 lb-in/lb-ft = 660 lb-in
   D = nominal bolt diameter of 1/2" bolt in inches = 0.5 in.

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[4]Electrical guidelines for Electronics to be used in Experiment Apparatus at Fermilab - Electronics/Electrical Department Rev 2.1 12/22/94.

10. Parts List:

Part	Material	Source	Part Number
1/2" X 13 tpi, 3" Bolts	Silicon Bronze, tensile strength 75000 psi min, stress area 0.1416 in^2	McMaster-Carr cat. 103 (pg 2531)	2-1/2" = 93516A722 3" = 93516A724
1/2" X 13 tpi Nuts	Silicon Bronze	McMaster-Carr cat. 103 (pg 2558)	93439A650
1/2" Flat Washer	MS15795 Stainless Steel	McMaster-Carr cat. 103 (pg 2579)	98019A510
Beleville Washer	Carbon Steel	Key Belleville	K1250-E-125
Cool-Amp	Silver Plating Powder	Cool-Amp Conducto Lube Co.	1233-500

Note that for calculating bolt lengths required:

Flat washers = 1/16" thick
Bellville washers = 1/8" thick
Hex nuts = 7/16" height

Double 5/8" conductors on a 1/2" flag will require 2-9/16 (3" bolt). Double 5/8" conductor on a 3/4" flag will require 2-13/16 (3" bolt).

11. Acknowledgements:

The material in this note was either inspired or derived directly from work done by unknown authors in CDF[5]; and by Dave Eartly and John Morrison in DZERO[6].

[5]CDF procedure 11 - Connecting Copper Bus Bar for the CDF Solenoid - Rev C 10/11/91.

[6]Memo - Toroid flag bolt & thread insert test - Morrison to Eartly - 10/31/88. Also, memo - Torque values and procedures for making up D0 toroid coil jumper connection - Eartly to Robert Scherr, Safety - 11/11/88.