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Bare Wire and the American Wire Gage (AWG) - A Review
Part 1 The Fundamentals

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Summary

This paper simplifies the American Wire Gage (AWG) and shows how it is used in the wire and cable industry. Stranded conductors, including compact, compressed and other special designs are also reviewed along with various bare wire stranding techniques.

Bare Wire and the American Wire Gage - A Review

Solid Conductors

The starting spot is the definition of the American Wire Gage (Sometimes referred to as the Brown & Sharpe Wire Gage.) and this requires a review of simple mathematical progressions.

> 2,4,6,8,10,12 .... is an arithmetic progression with an increase of 2 between the individual cells.
> 2,4,8,16,32,64 .... is a geometric progression with a multiplier of 2 between the individual cells.

The American Wire Gage is also a geometric progression but it has a much different multiplier between each of the cells in the progression. Lets look at the wire gage numbers lined up in the 6 x 10 matrix in Table 1 below.

Increasing Diameter ↓

	49	39	29	19	9	2/0
	48	38	28	18	8	3/0
	47	37	27	17	7	4/0
56	46	36	26	16	6	5/0
55	45	35	25	15	5	6/0
54	44	34	24	14	4	
53	43	33	23	13	3	
52	42	32	22	12	2	
51	41	31	21	11	1	
50	40	30	20	10	1/0	

Table 1

The American Wire Gage is defined as a geometric progression of solid wire diameters in inches between the two defined diameters of 36 gage or 0.005 inches and 4/0 gage or 0.460 inches (both highlighted in violet in Table 1).

The first thing to notice is that there are 38 gage sizes (highlighted in green in Table 1) between 36 and 4/0 so it is very easy to see that one must go one more step (39 steps) to get from one of the defined wire sizes to the other. Thus the geometric progression cell multiplier can be determined from the following equation:

$$\sqrt[39]{\frac{0.460}{0.005}} \quad \text{or} \quad \sqrt[39]{92}$$

This results in an next larger size multiplier of 1.122933 and a next smaller size multiplier of 0.890525 The diameters of all solid wires are calculated in this way. (If you try this on your calculator however, we recommend that you use the scientific notation setting so that the fourth decimal point in the solution is always accurate.)

A Couple Of Simple Points To Remember

If you go from a large AWG diameter to the next smaller AWG diameter, say from 12 to 13 AWG, the new size (13 AWG) would have 20.7% less cross-sectional area and 26.1% more length.

If you go from a small AWG diameter to the next larger AWG diameter, say from 13 to 12 AWG, the new size (12 AWG) would have 26.1% more cross-sectional area and 20.7% less length.

Stranded Conductors

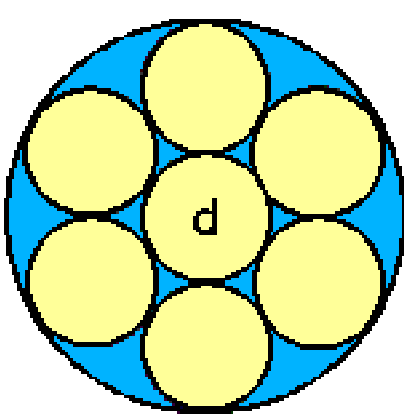


Figure 1
7 Strand Conductor

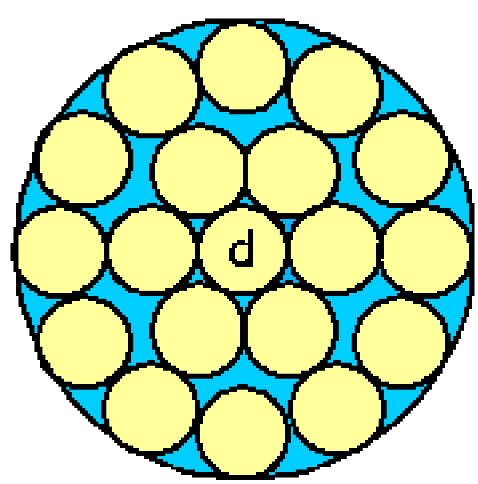


Figure 2
19 Strand Conductor

As the gage size decreases and the conductor diameter increases, a solid wire gets more rigid and harder to handle. Stranded conductors solve this problem but at a cost. The rule here is that a stranded conductor has an almost identical cross-sectional area to a solid conductor of the same gage size. This is by the sum of the areas of the individual strands making up that stranded conductor. The simplest way of showing examples of this is to use circular mils.

Circular Mils

A circular Mil (CM) is the area of a circle with a diameter of 1/1000 of an inch (often referred to as 1 mil). This gives an area of (¶/4)$(d)^2$ or 0.7854 x $(0.001)^2$and from this it is very easy to see that the area of a conductor can be defined in circular mils by squaring the diameter of the conductor in thousandths of inches.

For example the diameter of a solid conductor 36 gage wire is 0.005 inches so the area of the conductor is 5 x 5 or 25 circular mils. Likewise, 4/0 gage solid conductor has a diameter of 0.460 inches so the area of the conductor is 460 x 460 or 211,600 circular mils or 211.6 thousands of circular mils or MCM. This is now written as 211.6 KCMIL.

Calculating a Stranded Conductor Cross-Sectional Area in Circular Mils.

Lets use a 19 strand (Figure 2) 4/0 conductor which is made up of a central strand and two layers (one of 6 strands and the other 12 strands) wound helically at different points and in different directions around the central strand. All the strands have a diameter "d" of 0.1055 inches and the overall diameter of the stranded conductor is determined by the geometry (Figure 2). In this case it equals 5 x 0.1055 = 0.5275 or 0.528 inches. Likewise the cross-sectional area of the 19 strands is 19 x 105.5^{2} or 211,474.75 circular mils.

We previously calculated the cross-section area of our 4/0 solid conductor to be 211,600 circular mils and this this very close to our 19 strand cross sectional area (211, 474.75 circular mils). The difference between our solid conductor diameter of 0.460 inches and our stranded conductor diameter of 0.528 inches however is the penalty we pay for flexibility.

Square Millimeters

Often conductor cross-sectional areas are defined in square millimeters and this is especially true if the conductors are very large. The only difference here is that we are in another measurement standard, that's all. The single definition one has to remember is that there are 25.4 millimeters in an inch.

Calculating a Stranded Conductor Cross-Sectional Area in Square Millimeters.

Once again, lets use our 19 strand 4/0 conductor in Figure 2. All of the strands have a diameter "d" of 0.1055 inches or 0.1055 x 25.4 = 2.6797 or 2.68 mm and the overall diameter of the stranded conductor is is 5 x 2.6797 = 13.3985 or 13.40 mm. Likewise the cross-sectional area of a single strand is given by the equation (¶/4)$(d)^2$ or 0.7854 x 2.6797^2=5.6412 or 5.64 square millimeters (mm^2). Finally, the cross-sectional area of the conductor is 19 x 5.6412 or 107.18 mm^2. It's just that simple.

Stranded Conductor Designs

Before we get into this, we must first define some more properties of stranded conductors and cables.

Pitch

Regardless of how a stranded conductor is twisted, there are two basic definitions which deal with the repetitive nature of the twist. The first is the length of pitch and the second is the direction of pitch.

The "length of pitch" is that axial length along a conductor or a cable needed to make one complete rotation (360^0)of the hellically applied or helically laid components of that wire or cable. For this reason it is also sometimes referred to as the "length of lay".

The "direction of pitch" or "direction of lay" is the direction of the helix described in the length of pitch definition. It is referred to as right or left and can be very easily determined by looking along the axis of the wire or cable and noting the direction that the helix "drops" as the helix "moves" away from your eye. If it "drops" to your left it is a left pitch or lay and if it "drops" to your right it is a right pitch or lay.

Concentrically Stranded Conductors

In Figures 1 and 2, we noted there was a central strand with one or more layers of strand applied helically about that central strand. Concentrically stranded conductors are one of the original strand designs and all have the following basic properties. The direction of pitch is reversed on each layer and the length of pitch is also different on each layer. The direction of pitch on the outer layer is always left in the United States and Canada.
Although the design of the conductor is very stable, it is slow and expensive to manufacture. Table 2 shows how concentric strand conductors are assembled.

Layer Number (N)	Layer Strands	Total Strands (S)
Center = 0	1	1
1	6	7
2	12	19
3	18	37
4	24	61
5	30	91
6	36	127
7	42	169
8	48	217
		$S=3N^2+3N+1$

Table 2

It is also very easy to determine from Table 2 that the outside diameter of the concentrically stranded conductor is **$OD= d(1+2N)$**

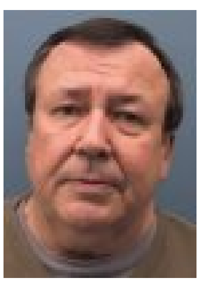
The American Society for Testing Materials (ASTM) specifies the construction of concentrically stranded conductors but before we look at those tables, we need a few more definitions to cover rope lay designs.

A rope lay conductor is a concentrically stranded conductor in which the individual strands making up the conductor are in reality sub-assemblies of already concentrically stranded or bunched conductors. The outer layer normally has a left pitch.

A bunched conductor is a stranded conductor in which the individual strands making up the conductor are twisted or "bunched" together into an open helix with a left pitch. There are no formally defined layers in a bunched conductor.

We now have enough information to actually design electrical conductors but as you know, things are never quite that simple. There are published standards for both the solid and stranded conductor diameters. There are also standards for the many different stranded conductor designs and for the conductor materials themselves. The Part 2 of this paper takes us into that world of specifications.

About the Author



Mr. Stewart-Hay holds a four year degree in mechanical engineering and is professionally registered in the Province of Ontario. For more than 30 years he practiced plant and process engineering in multinational wire and cable companies. His expertise is in the manufacture of telephone cable, optical fiber cable, data cable, instrument cable, building wire, and low, medium, high and, extra-high voltage power cable. He is the only engineer in the Western Hemisphere to have constructed a complete extra-high voltage MDCV (Mitsubishi Dainichi Continuous Vulcanizing) extrusion line, a horizontal machine capable of manufacturing 400,000+ volt polyethylene insulated power cable. The machinery for this project came from the six different countries and all were integrated on-site with a plc-based, DC drive distributed control system.

For the past few years he has been the owner and principal employee of Stewart-Hay Associates. Mr. Stewart-Hay holds patents in both the United States and Canada and is a lifetime member of the Wire Association International, Inc.