

## Slip in Nonferrous Drawing Machines

By Peter J. Stewart-Hay

### Summary

This paper defines slip and drafting in wet, nonferrous drawing machines and described how it is used in the wire and cable industry.

### Bare Wire and the American Wire Gage

#### Solid Conductors

A good starting spot for this paper 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.

		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

Increasing Diameter





Increasing Diameter

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).

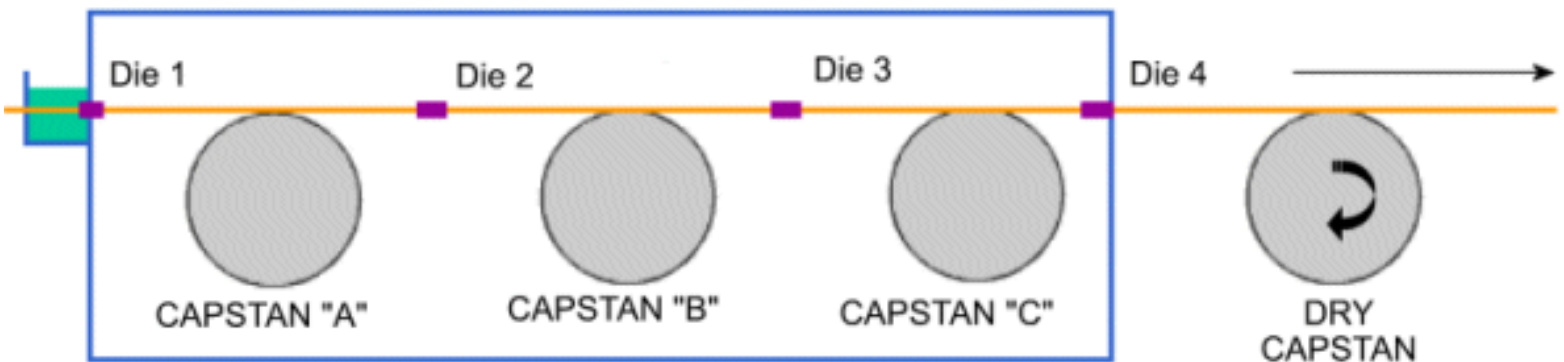
The first thing to notice is that there are 38 gage sizes (highlighted in green in Table 1) between 36 and 4/0 so it is very easy to see that one must go one more step (39 steps) to get from one of the defined wire sizes to the other. Thus the geometric progression cell multiplier can be determined from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

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

This results in a 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.)

### Drawing Machines, Drafting and Slip

This section is here only because drafting and slip in drawing machines tends to get mixed up with the American Wire Gage.



4 DIE COPPER ROD DRAWING MACHINE

**Drafting** is the reduction per die in a multiple die machine.

**Straight drafting** is the term used when the reduction is constant at each die throughout the machine. One example of this would be a drawing machine designed to reduce the wire diameter at each die in the normal AWG progression.

**Tapered drafting** is the term used when the reduction is not constant at each die. For instance, aluminum rod breakdown drawing machines often take a larger reduction at the first or first several dies than that found at the downstream balance of the dies. There is no standard on tapered drafting so each company manufacturing drawing machines usually has its own tapered drafting design.

**Slip**, generally in percentage, is defined as the difference between the actual wire speed on a capstan and the actual surface speed of that same capstan. Moreover the dry capstan is **assumed** to have zero slip because there is no lubrication at that point other than a surface film on the wire itself. The slip for copper wire drawing is generally between 1.5% and 3% and usually a constant between capstans. Likewise, slip is additive and that means it adds arithmetically as one progresses backwards through the machine (towards the wire entry point). For example a drawing machine with a constant 3% slip, would have the following slip on the capstans: Dry capstan 0%, previous capstan 3%, previous capstan 6%, previous capstan 9% and so on.

**Percentage Slip Calculation** If " x " equals the surface speed of the capstan and " y " equals the wire line speed on that capstan then the percentage slip is **100(x-y)/x**.

For any given unit of time, the same volume of metal must pass through each die. Thus it is very easy to calculate the wire speed at any point inside the machine. When these wire speeds are compared to the actual capstan surface speeds as computed from the machine gearing charts, it is easy to develop a slip table for that particular machine. Slip is usually designed to be accumulative, starting at "0%" at the dry capstan and then accumulating arithmetically backwards through the machine.

The wire speed " $V_W$ " on any capstan is determined starting at the dry capstan and then working back through the machine using the wire diameter "d" as follows:

$$V_{W(c)} = V_{W(dry)}[d_4]^2 / [d_3]^2$$

$$V_{W(b)} = V_{W(dry)}[d_4]^2 / [d_2]^2$$

### **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.

## **Why Do We Have Slip?**

Now that we have the mathematics and definitions out of the way, why do we have slip in the first place?

Well, let's look back at our 4 capstan machine. All of the capstans are driven by one motor (economical) and each capstan is geared so that the surface speed of that capstan (excluding the non-lubricated dry capstan) is faster than the elongated wire that the capstan pulled through the preceding die. For example, the surface speed of capstan "C" is faster than the speed of the wire that capstan "C" actually pulled through die #3.

The slip has to be there because the wet drawing process is not positive and therefore imperfect in its construct.

For example, the dies continuously wear larger, become out-of-round or actually are larger in diameter than that stamped on the body (quill) of the die. This is called over-drafting and slip is increased in these cases.

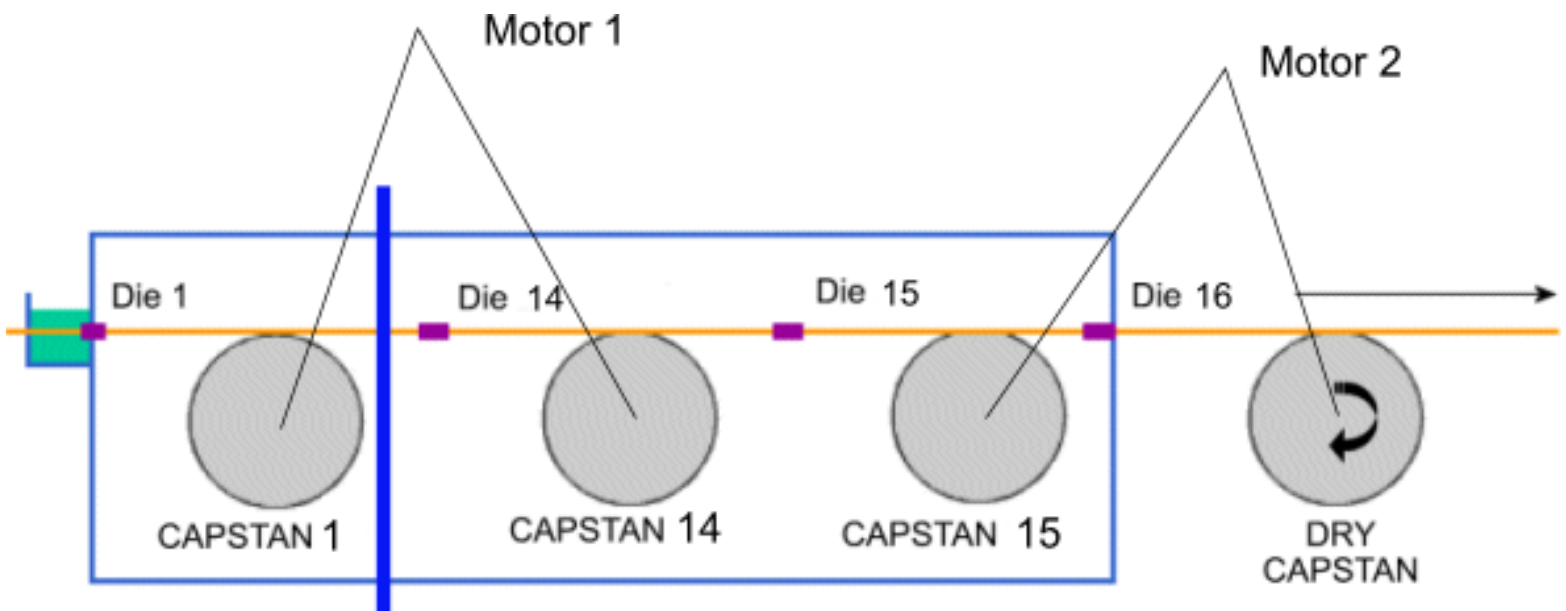
If the finish die in our example, die #4, was right on size and die #3 was too large, then, without slip, there would be a build up wire between die #3 and die #4 and this of course is impossible because the excess wire would bow outwards and break. Instead the wire continuously slips more than normal on capstan "C" and thus capstan "C" provides the exact amount of wire needed to fill the requirements of Die #4 and the dry capstan surface speed.

Likewise, if die #3 was poorly measured and smaller than it was supposed to be (under-drafting), then slip saves the day again. Without slip, there would be an inadequate amount of wire to fill the requirements of die #4 and the dry capstan surface speed. Thus the the wire would break. In this case, the slip on capstan "C" is reduced and capstan "C" still provides the exact amount of wire needed to fill the requirements of die #4 and the dry capstan surface speed.

## **Multi-Wire Drawing Machines**

There is nothing special about a multi-wire machine other than the fact that there many more capstans and dies. Each extra wire (end) in a multi-wire machine is nothing more than a clone of the first wire, the capstans and the dies for that first wire. Nothing more. Thus a six end multi-wire drawing machine is in reality equivalent to six single wire drawing machines.

## **Dual Motor Drawing Machines**



Dual motor drawing machines can be single wire or multi-wire machines and the obvious difference between these and the more historic single motor drawing machines is the two precise variable speed drives powering the capstans typically as shown in the 16 die drawing machine sketched above. As in standard machines, the % slip is fixed by mechanical design for capstans #1 through #14. Likewise, the mechanical relationship between capstans #15 and #16 (the dry capstan) is fixed. Thus the only place where a slip factor can be introduced is on capstan #15 and this is done by increasing or decreasing this capstan's rotational speed. For copper wire, this slip factor is set between 2% and 3% when all the dies and capstans are in use. So what's the advantage?

Well, suppose we want to draw one size larger than that shown in the sketch. All we have to do is remove dies 16 and 15 and reinstall die 15 in die 16's holder. Then we remove the turns from capstan #15 and synchronize capstan #15's rotational speed with capstan #14 (By PLC speed adjustment to motor #2.). This quick change procedure can be used for a number of different wire sizes and it significantly reduces die string inventory (die inventory) and drawing machine change over (set up) time. The drawing machine is running a bit slower now but the gage size is larger.

The dual motor design is therefore fundamental to the efficiency and cost overhead, especially for all multi-wire drawing machines.

## 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.