American Polywater's

# TechnicalTalk

ROUTE TO:

A PUBLICATION FOR ENGINEERS INVOLVED IN ELECTRICAL CABLE INSTALLATION

***Volume 1***

## ESTIMATING TENSION WHEN PULLING CABLE INTO CONDUIT

### The Problem

When you calculate cable pulling tensions, what friction coefficient should you use? User responses vary . . . some answer "0.5" . . . others "0.4," or "0.35". Who's right?? What coefficient of friction provides the best tension estimates and correlation for field planning and optimal cable system design?

### The Basics

To answer this question, we need to understand more about "coefficient of friction." What exactly is a "coefficient of friction" (COF). Can we find friction coefficients in an appropriate reference book?

Let's start with a simple physics class example . . . a wooden block (say, 5 kgs in weight) on a horizontal steel plate. Say it takes 2 kgs force (19.6 N) to pull (drag) the block across the plate. The coefficient of friction (wood on steel) is defined as the ratio of this "dragging force" (2 kgs) to the normal force (weight of 5 kg). In this case, the friction coefficient would be .4. Note that the COF is a dimensionless number.

Experience tells us that if we replace the wooden block with a 5 kg rubber block, it will take a greater force to drag the rubber block (say, 6 kgs force). The measured coefficient of friction (rubber/steel) would be 1.2. What's important to note from these examples is that there is no single coefficient of friction. *The friction coefficient varies with the rubbing surfaces.*

### Cable/Conduit

Replace the block with cable and the plate with conduit, and we have cable pulling . . . with a few complications. Neither the cable nor the conduit is flat. There may be more than one cable, which can result in complex rubbing surfaces. Pulls are not straight, and forces other than gravitational weight occur at conduit bends. Finally, our Polywater® Pulling Lubricants change and lower the friction coefficient.

Even with these differences, the friction coefficient in cable pulling continues to depend on cable jacket type, conduit type and lubricant type. "General" coefficients don't mean much. The most accurate tension estimates come from friction coefficients specific to the cable, conduit and pulling lubricant.

### Pulling Equations

Tension estimation in cable pulling is calculated using the cable pulling equations. The equations apply the physics from our simple example to the unique character of cable pulling. This includes the non-gravitational forces in conduit bends.

Looking at a simplified form of the equations will clarify:

Straight Conduit $T_{out} = T_{in} + LW\mu$

Conduit Bend $T_{out} = T_{in}\, e^{\mu\theta}$

Where:

- $T_{out}$ = Tension Out
- $T_{in}$ = Tension In
- $L$ = Length of Straight Run
- $W$ = Weight of Cable (per length)
- $\mu$ = Coefficient of Friction
- $\theta$ = Angle of Bend
- $e$ = Natural Log Base

Note the significant effect on tension that small changes in $\mu$ (friction coefficient) can cause, especially in conduit bends where this friction coefficient is in the exponent. Inaccurate friction coefficients lead to poor correlation of tension calculations with actual tensions. Unfortunately, it is in multi-bend pulls, where the tension and sidewall pressure are of most concern, that the use of an inaccurate coefficient of friction produces the greatest error.

Where can you find or how can you determine meaningful friction coefficients?

### EPRI Study Helpful

The Electric Power Research Institute (EPRI) is a utility funded research group in the United States. The EPRI study, "Maximum Safe Pulling Lengths for Solid Dielectric Insulated Cables," provides insight, and some surprises, on lubricated cable friction and its measurement.

The EPRI research showed that lubricated coefficient of friction changes with varying normal force (the force pushing the cable against the conduit wall). The EPRI report defines two different friction coefficients, one at "high sidewall bearing pressure" (High SBP) (going around bends) and the other at "low sidewall bearing pressure" (Low SBP) (straight pulls). Surprisingly, the High SBP friction coefficient is usually lower than the Low SBP friction coefficient, often lower by a factor of more than 2.

The EPRI report goes on to recommend that the High SBP friction coefficient be used in calculations when normal force on the cable is over 220 Kg/M (150 lbs/ft), and that otherwise the Low SBP coefficient of friction be used.

### Polywater Research Clarifying

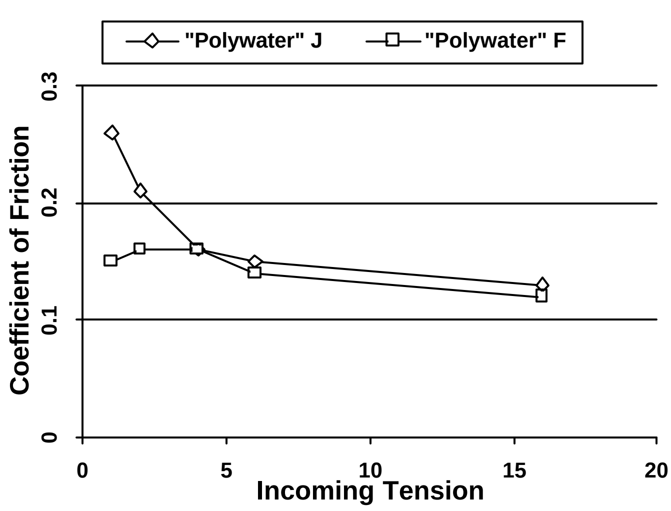
American Polywater studies confirm the variance in friction coefficient with normal pressure. We have determined that the friction at low normal bearing force is a measure of hydrodynamic friction, which is roughly proportional to lubricant viscosity (internal gel strength of the lubricant).

In contrast to the EPRI work, however, our research indicates the conversion in friction to the High SBP type occurs continuously and at bearing pressures much less than 220 Kg/M (150 lbs/ft).

### Pulling Tests

One test illustrating this "variable" friction coefficient involves pulling cable through multiple, consecutive 90° duct bends (a helix). The incoming cable tension and total degrees of bend can both be varied. From the pulling force (measured with a load cell) required to move the cable, we can calculate a coefficient of friction using the pulling equations we studied earlier.

The graph below shows measured friction coefficients plotted against the tension on the cable as it enters the conduit helix. For this graph, the conduit was high density polyethlene with 540° of bend. The cable had a polyethylene jacket.




To explain the graph, first you must know that Polywater® J and Polywater® F are two of American Polywater's high-performance cable pulling lubricants ("J" is usually used for electrical cable and "F" for fiber optic cable). They are similar chemically, except that "J" is a gel lubricant (higher viscosity) and "F" is a liquid.

Where the lines converge on the above graph, and the slope levels, the low bearing pressure friction has disappeared and the cable and lubricant are in a high bearing pressure mode. By calculating the sidewall-bearing pressures (defined as tension out of the bend divided by bend radius) at the point of convergence, we find that the change from Low SBP friction to High SBP friction is complete at 6 Kg/M bearing pressure.

Because power cable's stiffness and resulting "spring" tend to increase conduit contact pressure, power cable pulling ends up in the "high bearing pressure" mode most of the time. Field-measured tensions tend to support this conclusion.

On the other hand, lighter, flexible cables (fiber optic, etc.) often demonstrate both types of friction during pulling. This is one reason why a lower viscosity, liquid lubricant like Polywater® F is best for the installation of this type of cable.

### Pull-Plannerä 2000 Has Friction Data Base

We've seen that coefficient of friction varies with cable jacket and conduit type, and that it is necessary to use accurate coefficients to calculate meaningful pulling tensions.

American Polywater's laboratory has developed extensive friction data for different cable jacket and conduit types, at appropriate bearing pressures. This data is in an internal data base in our Pull-Planner™ 2000 for Windows™ Software.

The Pull-Planner™ 2000 provides a convenient way to calculate cable pulling tensions on a PC. It enables "what if" scenarios with cable, conduit, pull length, COF, incoming tension, and more. Lubricant quantities can be calculated, and calculations can be saved or printed out. The full version of the planner runs in metric or english units.

### Pull-Planner™ 2000 Preview

A preview of the Pull-Planner™ 2000 is available. Use the internet to go to www.polywater.com to preview or order the Pull-Planner™ 2000.

Our web site (www.polywater.com) also has copies of other technical studies of interest in cable installation. Visit and leave us **your e-mail** to stay up-todate.

Feel free to call or write us if you have questions or would like to discuss friction measurement or tension calculation. If you wish to view a 12-minute video on 'Cable Installation Engineering," please call and ask for our Customer Service Department.

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