A Study of Tension and Jamming When Pulling Cable Around Bends

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Abstract: Existing theory and research on the pulling (and jamming) of three cables through bends are reviewed. Pulling tension through bends is measured for three cable pulls with jam ratios from 2.4 to 4.3. These three cable pulls are compared to single cable pulls. Cable feed position and lubrication in three cable pulls are also analyzed.

Keywords: Cable Pulling; Jamming; Jam Ratio; Lubricants; Tension; Conduit Bend; Weight Correction Factor; Triangular; Cradled; Conduit Fill

I. INTRODUCTION

The "jamming" of three cables as they are pulled through a bend is well described in the literature. When the combined diameters of three cables roughly equal the interior diameter of the conduit, the cables can line up linearly as they are pulled around the bend. The cables then wedge against the conduit wall as they are forced towards the inside of the bend. The wedged (or jammed) cables are "stuck". To pull jammed cables with enough force to get them through a bend usually ruins the cable by ripping off the jacket or crushing the insulation.

The common technique to avoid jamming is to avoid pulling cables with an unfavorable ratio of cable OD to conduit ID (called Jam Ratio). However, unfavorable jam ratios cover a wide range, and to avoid them completely is not always possible.

Equation (1) presents the usual calculation of Jam Ratio:

$$J = 1.05\ ID/OD \qquad (1)$$

Where
J = Jam Ratio (dimensionless)
ID = Interior diameter of conduit in mm (in)
OD = Outer diameter of the cable in mm (in)

Note that a 1.05 factor is included to estimate the "ovalization" of the conduit at the bend.

While the literature is consistent that jamming can occur with a jam ratio around 3, there is inconsistency on the exact range of jam ratios that pose a problem. References [1], [2], [3], and [4] indicate the highest probability of jamming at jam ratios of 2.6 to 2.9; 2.9 to 3.3; 2.8 to 3.0; and 2.7 to 3.0 .

Reference [1] uses a probability approach to assess jamming. This is reproduced in Table 1. Table 1 provides a good target range of jam ratios for the pulling through bends study. Table 1 indicates there is some probability of 3 cables jamming from 29% to 52% conduit fill. This broad range of conduit fills includes those common in electrical construction.

Jam Ratio	Probability of Jamming
2.4 - 2.5	Low
2.5 - 2.6	Medium
2.6 - 2.9	High
2.9 - 3.0	Medium
3.0 - 3.2	Low

Table 1. Probability of Jamming

Another peculiarity in pulling three cables is described in recent studies of cable pulling [Ref. 3]. Three cables pull with higher tension than expected based on physical theory and how a single cable pulls. Reference [3] handles this issue by defining a higher coefficient of friction (COF) for three cables than a single cable. The reference recommends that the "three cable COF", which is 10% to 100% higher than the single cable COF, be used whenever three cables are pulled at sidewall pressures less than 2,180 N/m (150 lbs/ft).

Experienced cable pulling crews use a "trifurcater" or similar device in three cable pulls to maintain the feed of the cables in a consistent triangular position. Presumably, this prevents the cables from being forced to roll over each other and jam because they were allowed to change positions during the feed. But is there an optimal feed position?

The research in this paper provides data and information on some of the three cable pulling issues raised above.

II. BODY

Experimental Method and Measurement Apparatus

The test apparatus used in this work is described in Reference [5]. The apparatus was set up to pull cable around two 90 degree conduit bends. The incoming (or back) tension was varied and the pulling tension was measured. From this data, a coefficient of friction could be calculated, and effects from jamming, cable adjustment, cable jacket type, conduit type, lubrication, etc. could be measured.

Figure 1 below presents a simple diagram of the apparatus used.

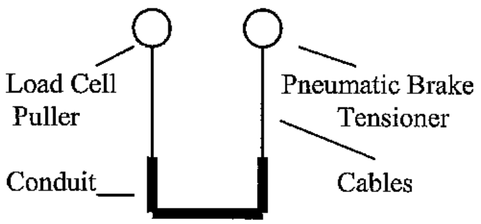

Figure 1. Diagram of Two Bend Pulling Tester

The cables were pulled through a typical underground conduit pattern; down through a 90 degree bend to the horizontal, and then back up through another 90 degree bend. The feed cable(s) could be tensioned with an adjustable pneumatic brake. The pulling winch had a force measuring load cell, attached via an RS 232 interface to a PC. The PC sampled data once per second throughout the pull, averaged the data, and calculated the coefficient of friction. Each data point represents the average of twenty tension readings. For additional details on the theory and calculations, see reference [5].

Cable Selection

Since this work focused on three cable pulls, a number of the variables known to affect COF (jacket type, conduit type, lubricant type, etc.) were held constant. Specifically, XHHW cable of different sizes, from one manufacturer, was pulled into 2" (50mm) Schedule 40 PVC conduit with factory bends. The cable sizes pulled were from 2/0 through 500 MCM. Table 2 presents some of the calculations for these cables on jam ratio, conduit fill (3 cables), and clearance (3 cables-triangular). All of the calculations are based on actual cable OD measurements and the actual conduit ID measurement.

Cable Size	OD mm (in)	Jam Ratio	Fill % (3 Cab)	Clearance mm (in)
2/0	12.7 (.50)	4.3	18.4	26.4 (1.0)
3/0	14.5 (.57)	3.8	23.6	22.9 (.90)
4/0	15.0 (.59)	3.7	25.8	21.6 (.85)
250	17.0 (.67)	3.2	33.0	17.3 (.68)
300	17.8 (.70)	3.1	36.0	15.5 (.61)
350	19.6 (.77)	2.8	43.6	11.5 (.45)
400	20.8 (.82)	2.6	49.4	8.4 (.33)
500	22.6 (.89)	2.4	58.9	3.3 (.13)

Table 2. Cable Data and Calculations

Configuration in the Pulling and Calculations

Three cables can ride through a conduit in two basic configurations. These are called "triangular" and "cradled" and are shown in Figure 2:

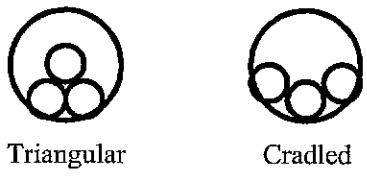

Figure 2. Three Cable Pull Configurations

Cables assume the triangular configuration when they are large enough that one rolls on top of the other two.

Reference [1] offers that triangular is the preferred configuration when D/d < 2.5 (or the OD of the cable > 40% of the conduit ID). Again, the literature presents a range on when the transition from cradled to triangular takes place and under what conditions.

In this research, an attempt was made to control the cable configuration through the bends. This was done by controlling the feed position of the cables. The cables were fed with two cables on the inside half of the conduit with one on the outside for "triangular", and one on the inside and two on the outside for "cradled". The configuration used during the feed is specified in the data presentation.

There are differences in the weight correction factor for the cradled vs. triangular configuration. The configuration assumption then influences the COF we calculate, as explained below.

Weight Correction Factor in the Calculations

In three cables pulls, an additional force factor develops because the cable is not rubbing on the gravitational "bottom" of the conduit The force on the cable is then somewhat higher than the gravitational force. In the literature, this factor is referred to as the "Weight Correction Factor" or the "Occupancy Factor". This is well explained elsewhere, and is specifically developed in [6].

The weight correction factor for three cables depends on the cable to conduit size ratio and the cable configuration (cradled vs. triangular). The calculated weight correction factors for our experimental cables are presented in Table 3 for both configurations:

	Weight Correction Factor	
Size	**Cradled**	**Triangular**
2/0	1.14	1.06
3/0	1.21	1.09
4/0	1.23	1.10
250	1.33	1.15
300	1.37	1.18
350	1.51	1.27
400	1.62	1.37
500	1.84	1.65

Table 3. Calculated Weight Correction Factors

The weight correction factor for cradled cables is always higher than for triangular. This means that cradled cables pull with higher tension when all else is equal. In our analysis, if we assume the wrong configuration when we back calculate a coefficient of friction to show relative performance, we can overstate or understate the COF. This will be discussed in the analysis.

The weight correction factor also increases (predicts a higher tension) with increasing cable size. However, since the weight correction factor is used when we back calculate coefficient of friction from tension, friction data comparisons between different size cables should be meaningful, whereas direct tension comparisons would not.

The increasing weight correction factor should not be confused with the "higher" coefficient of friction for three cable pulls from [2]. This higher coefficient was developed from tension data via calculations where the "increased" weight correction factor was included.

Single Versus Three Cable Pulls - Lubricated

The data for lubricated 2/0 cable (single versus three) is graphed in Figure 3. The calculated coefficient of friction (COF) is plotted against the incoming tension on the cable.

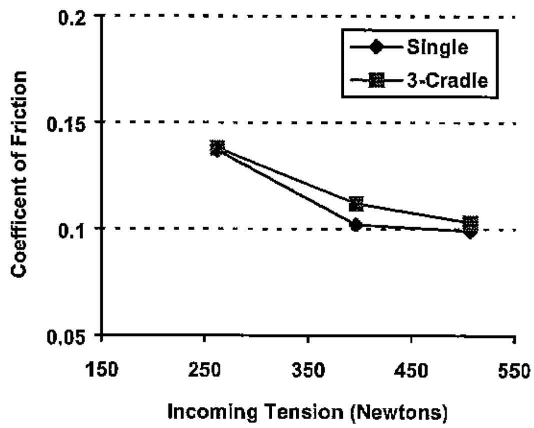

Fig 3. 2/0 Cable; Lubricated

In Figure 3, the COF slowly drops as the incoming tension is increased. This is typical of increasing normal pressure (sidewall pressure) and has been observed in a number of studies of this type ([2], [5]).

The graph shows that, at 262 Newtons (59 lbs) of incoming force on the single cable, we measured a pulling force of 405 Newtons (91 lbs), which calculated to a COF of 0.137. With the same cable pulled as three cables cradled, at 262 Newtons (59 lbs) of incoming tension, we measured 431 Newtons (97lbs) pulling tension, which calculated back to a 0.138 COF. These tension differences result in close to identical coefficients of friction (weight correction factor of 1.14 used in the cradled calculation).

In Figure 3, the three cables show friction coefficients that are very close to the single cables. There is no indication that a second higher COF is needed for more accuracy in calculations.

In Figure 3, the three cables were only fed cradled. For fills this low, it was not possible to feed triangular.

In this study, only one lubricant was used, a high performance, silicone-enhanced type. It was selected because it has proven to be extremely effective at reducing friction of XLPE jacket in PVC conduit.

Unfortunately, space does not allow graphical presentations of all cable sizes. The data is presented in table form in Table 4. Note that the small clearance did not allow the pulling of the 500 MCM.

Size	Incoming Tension	Single COF	3 Cradle COF	3 Triang COF
2/0	262	.137	.138	-
	396	.102	.112	-
	507	.099	.103	-
3/0	245	.143	.150	-
	351	.128	.121	-
	471	.107	.104	-
4/0	205	.175	.207	.215
	338	.132	.145	.145
	445	.114	.136	.13
250	222	.150	.156	.188
	351	.124	.113	.141
	467	.102	.105	.132
300	205	.19	.206	.233
	329	.148	.153	.175
	458	.113	.124	.146
350	205	.162	.238	.237
	338	.129	.179	.176
	449	.116	.145	.154
400	205	.185	-	.37
	325	.185	-	.283
	454	.127	-	.245

Table 4. COF Data (Lubricated)

Table 4 shows the 3/0, 250, and 300 MCM were similar to the 2/0, that is 3 cradled cables pulled with COF's similar to the single cable. The 4/0 is not as good a match, however.

The two larger cables (350 & 400 MCM) were quite different, however. The three cable COF is 60-75% and 90-100% above the single cable COF respectively. This is in the jam ratio area of 2.6 to 2.8, but really isn't jamming, because the cables kept moving. The cables were just harder to pull, considerably harder, and this is reflected in higher coefficients of friction.

The data for the 400 MCM is presented in Figure 4 to visually demonstrate the differences.

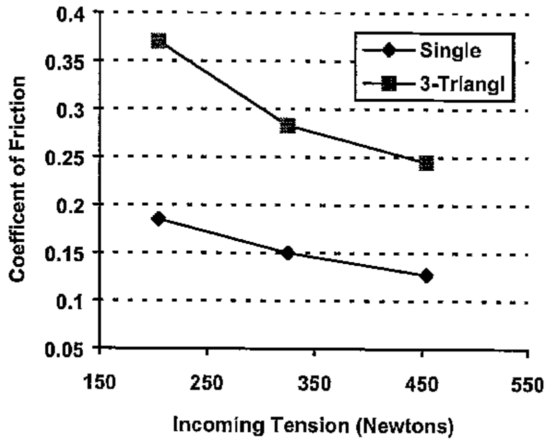

Figure 4. 400 MCM; Lubricated

Feed Configuration Differences

In the 4/0, 250, and 300 cables, the triangular configuration feed shows a higher COF. However, the tensions from the triangular fed cable are very close to the cradled tensions. The lower weight correction factor in the triangular calculations accounts for the difference. This indicates that the cable is switching to cradled before entering the bends. There does not seem to be any penalty for feeding triangled, there is simply no benefit. For three cable pulls at jam ratios above 3.1, calculations should use the cradled weight correction factor with no additional COF adjustment being necessary.

The 350 MCM cable, which is the only large cable we were able to pull with both feed configurations, is different. It is shown in Figure 5.

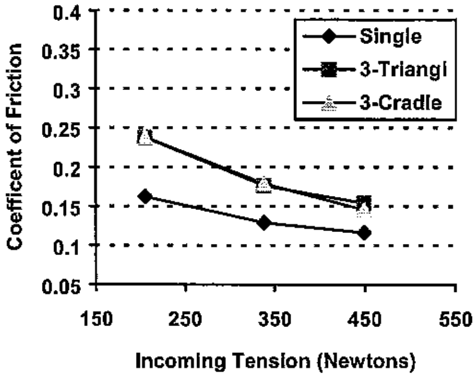

Figure 5. 350 MCM - Lubricated

Figure 5 shows the separation of <u>both</u> the 3 cable configurations mentioned previously. While the cradled and triangular performance look equivalent, they are not. The cradled pulled with notably higher tension, but its higher weight correction factor lowered the COF. <u>For this size cable (jam ratio = 2.8) the lowest tension in a three cable pull is obtained by feeding in the triangular configuration.</u>

<u>Pulls That are Not Lubricated</u>

The same data for the largest, smallest, and the middle cable sizes are presented in Table 4 for non-lubricated cables. Note that the 400 MCM could not be pulled unlubricated, so the 350 is the largest.

Size	Incoming Tension	Single COF	3 Cradle COF	3 Triang COF
2/0	231	.451	.477	-
	347	.416	.410	-
	454	.420	.382	-
4/0	245	.418	.468	.540
	356	.416	.432	.515
	463	.402	.466	-
350	214	.415	.463	.501
	334	.420	.402	.557
	458	.383	-	.435

Table 4. COF Data (Unlubricated)

Not surprisingly, the unlubricated cables show much higher friction coefficients across the board than the lubricated. While there may be some trending up of the 3 cable cradled COF, there is too much variation in the data to be sure.

However, just as in the lubricated, the triangular COF's are notably higher. The cradled weight correction factor is the most appropriate.

The friction reduction from unlubricated to lubricated is of similar magnitude whether a single cable pull or a three cable pull. Because the friction coefficients of the unlubricated were so much higher and less consistent, additional analysis is not possible.

<u>Cable Size Effects - Lubricated</u>

Figure 6 plots the lubricated COF's for a sweep of the cable sizes pulled as singles.

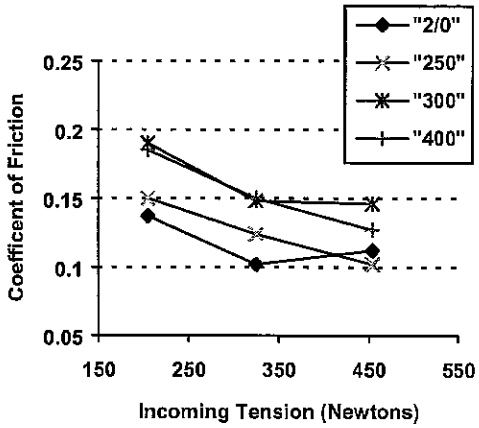

Figure 6. Single Cable Pulls - Lubricated

Figure 6 shows a slight increase in the <u>apparent</u> coefficient of friction as the cable size increases in the single cable pulls. This has been observed previously [5] and is a much smaller increase (10% to 20%) than the 60 to 90% increase for three cables in the jam ratios of 2.6 to 2.8. Presumably, this 10% to 20% comes from the increased force needed to bend and unbend the thicker conductors, rather than any real friction effect.

<u>III. CONCLUSIONS</u>

Classic jamming was not produced through the two bend conduit system, indicating that jamming is not automatic, even at the 2.6, 2.8 or 3.1 jam ratios.

On the other hand, three cables with the jam ratio of 2.6 and 2.8 pulled with a higher tension than expected, so this ratio area produces higher tensions when pulling through bends. If this performance can be reproduced in longer conduit systems, such pulls can be "planned" by assuming a higher coefficient of friction and staying within the cable's tensile and sidewall pressure limits. The increased tension in this 2.6 to 2.8 area may indeed be a mild manifestation of jamming, that is tempered by a properly fed and lubricated cable.

This does not mean that that if a cable jams it should be pulled through the jam. Jamming is a probability which can be minimized by lubrication and feed control, but pulls must be planned with an increased coefficient in the jam ratio area. There is no indication that this increased coefficient should only be used at under 2,180 M/m (150 lbs/ft) as in [2].

The use of a higher friction coefficient to estimate tension in a three cable pull is not necessary outside of the 2.6 to 2.8 jam ratio area. Assuming cradled configuration with the resultant weight correction factor is adequate.

Controlled triangled feed should be used in the jam ratio area. This means two cables to the inside of the bends and one to the outside. Controlled feed should be used on all three cable pulls.

There is no single coefficient of friction appropriate for estimating tension in cable pulling. The use of a properly selected range of coefficients that will produce a range of expected tensions is recommended.

IV. REFERENCES

[1] Thomas P. Arnold , C. David Mercier (Editors), "Southwire Company Power Cable Manual", 2nd Edition , Southwire Company, Carrollton, Georgia

[2] D. A. Silver, G. W. Seman, R. A. Bush, G. H. Matthews, "Maximum Safe Pulling Lengths for Solid Dielectric Insulated Cables", Electric Power Research Institute EL3333, Final Report, Feb 1984

[3] O. L. Willis (Editor), "Cable Installation Manual", 6th Edition, Cablec Industrial Cable Company, Marion, Indiana

[4] "Underground Extruded Power Cable Pulling Guide", AEIC Publication G5-90, AIEC Task Group 28, First Edition, May 1990

[5] J. M. Fee & D. J. Quist, " A New Cable Pulling Friction Measurement Method and Results", 1991 IEEE T&D Conference, Sep 1991

[6] R. C. Riffenberg, "Pipe Line Design for Pipe Type Feeders", AIEE Power Apparatus and Systems Conference, Dec 1953

V. BIOGRAPHIES

John M. Fee received a B.S. Degree in Chemistry from Massachusetts Institute of Technology.

He worked from 1968 to 1981 at the 3M Company, St Paul, MN on a variety of product development projects. Since 1981, he has been with American Polywater, and is currently President. He has worked extensively in the area of cable pulling and its theory.

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