A Pulling Tension Calculation Program Which Allows Coefficient of Friction to Vary Continuously with Cable Sidewall Pressure

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Abstract--A cable pulling tension calculation software program is developed which draws friction coefficients from a curve input by the user. Examples show how predicted tension and sidewall pressure vary with the coefficient of friction dependence on cable normal pressure. The software is intended as a "what-if" tool to help installation planners develop better approximations of cable pulling tension.

I. INTRODUCTION

Estimating and measuring the tension placed on cables as they are pulled into conduit is an important part of cable installation. Excess tension can damage cable, causing immediate failure or deterioration of cable life. The literature is full of recommendations and research on suitable and safe maximums for both tension and sidewall pressure on power cable, as in [1], [2], and [3].

Good correlation of calculated pulling tension with actual field tension is obviously important in planning cable installations. However, because of the great number of variables affecting tension, correlations of calculated tensions with field measurements have not been impressive, as in [4].

One source of error in tension calculations is the variation of coefficient of friction with the normal pressure on the cable. This variation has been described and measured in several research projects, as in [1], [5], and [6]. While the literature seems consistent on the variation of friction coefficient with normal pressure, the magnitude and nature of the variation can make a significant difference in the tension predicted by the equations.

Two different methods have been suggested to handle the "variation" of friction coefficient with sidewall pressure. Reference [1] suggests a step function (single step), where tension is calculated with a Low Sidewall Bearing Pressure (LSBP) coefficient; and, if this projects sidewall pressure in bends greater than 150 lbs./ft., the bend is recalculated with a High Sidewall Bearing Pressure (HSBP) coefficient.

An alternative method, as in [7], suggests ranging tension by calculating with several coefficients of friction, coefficients presumably based on the highest and lowest seen in variable sidewall pressure tests.

The purpose of this research was not to resolve the question of the magnitude or nature of friction variation with sidewall pressure, but, rather, to provide a tool which would allow flexibility in calculations. It is hoped such a tool would allow statistically defensible correlation studies of different methods, eventually leading to improvements in the prediction ability of the pulling equations.

II. BODY

A software program was developed which allows a multi-step curve (up to 20 steps) to be entered, a curve of friction coefficient versus sidewall pressure. This allows great flexibility in the variation of coefficient of friction with sidewall pressure. It can include a single step function at 150 lbs./ft., but it is not limited to that. The end-user controls both the magnitude and nature of the coefficient of friction curve.

Equations

The tension equations, sidewall pressure calculations, weight correction or occupancy factors, etc., used by the program are the accepted standard forms, as in [8]. However, in the calculation of tension for each bend, the program chooses a coefficient of friction appropriate for the resulting sidewall pressure; e.g., a coefficient of friction of .19 produces a sidewall pressure of 120 lbs./ft., and the input curve indicates the friction coefficient at 120 lbs./ft. is .19. This is done through an iterative method. Where exact

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agreement cannot be obtained, the closest conservative (higher) friction coefficient is used.

Example 1

Figures 1 and 2 below demonstrate the capability.

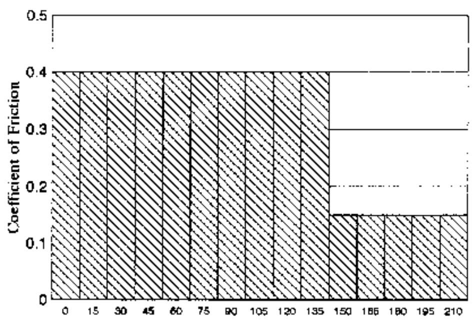


Figure 1. Two Step Function Relating Sidewall Pressure to Coefficient of Friction

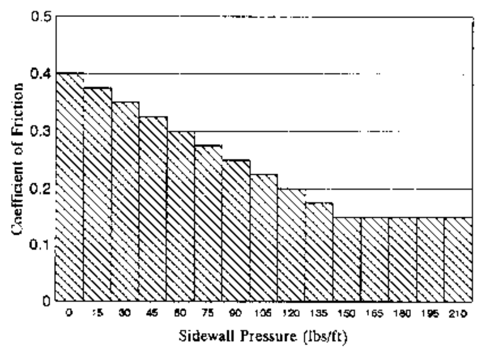


Figure 2. Straight Line Interpolation (11 step) Relating Sidewall Pressure to Coefficient of Friction

Figure 1 shows a one-step variation at 150 lbs./ft. The friction coefficients of .4 (LSBP) and .15 (HSBP) are for XLPE jacket in PVC conduit, as in [1]. Figure 2 is based on the same data, but substitutes a straight line variation between the LSBP and HSBP coefficients, by entering 11 segments that fall into a line.

Table 1 shows the software calculations for a 310-foot, horizontal pull with a 2 lbs./ft. single cable. There are 90° bends (four-foot radius) at 5′, 105′, 205′, and 305′.

TABLE 1

	Figure 1		Figure 2	
	Lbs. Tension	Sidewall Lbs./Ft.	Lbs. Tension	Sidewall Lbs./Ft.
5′ straight	4	–	4	–
#1 bend	11	3	11	3
100′ straight	91	--	91	–
#2 bend	170	43	156	39
100′ straight	250	--	236	--
#3 bend	470	117	356	89
100′ straight	550	--	436	--
#4 bend	696	174	552	138
5′ straight	700	--	556	--

Following the calculation through the Figure 1 curve, the number one, two, and three bend use the LSBP coefficient of friction (.4), while the fourth bend drops to the HSBP (.15). For the Figure 2 calculation, the program uses .4 for bend #1, .344 for bend #2, .261 for bend #3, and .15 for bend #4. This final predicted tension is lowered from 700 lbs. to 556 lbs., and the maximum sidewall pressure from 174 lbs./ft. to 138 lbs./ft.

Example 2

Suppose the coefficient of friction follows a more complex curve as is suggested in [6]. This is simulated in the 14-step entry shown in Figure 3 below.

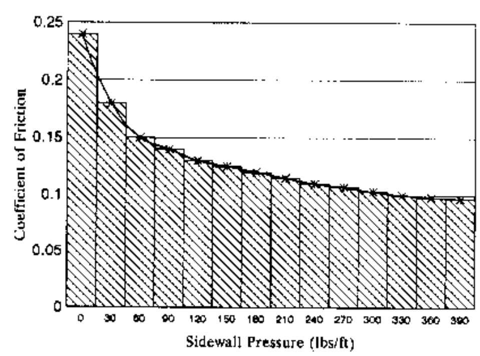


Figure 3. Curve Relating Sidewall Pressure to Coefficient of Friction

Using the same cables and conduit configuration as Example 1, the calculations for the Figure 3 curve are shown in Table 2.

TABLE 2

	Figure 3	
	Lbs. Tension	Sidewall Lbs./Ft.
5' straight	2	--
#1 bend	6	1
100' straight	54	--
#2 bend	79	20
100' straight	127	--
#3 bend	160	40
100' straight	208	--
#4 bend	264	66
5' straight	266	--

We see that the magnitude changes on this curve result in predictions less than 50% of those in Example 1.

The purpose of these examples is to show the flexibility of the software. The examples are not intended to recommend a particular magnitude or curve of friction coefficient.

While any of these problems can be worked with a good calculator and enough time, the software makes the calculations, and the option of "what-if" scenarios, both fast and easy.

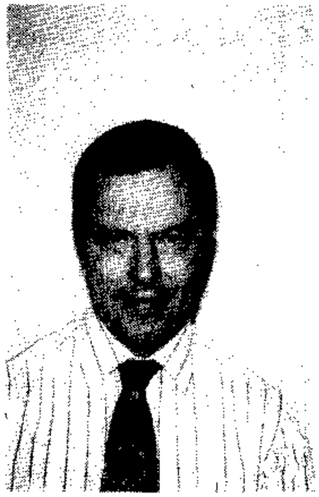
III. CONCLUSION

A piece of software has been developed which allows flexibility in the variation of coefficient of friction with normal pressure. Both the magnitude and nature of this variation are input by the end-user.

As expected, with decreasing coefficient of friction with increasing normal pressure, the software model with multi-steps estimates lower tension than a single-step model. The data in [4] indicate that this is the proper direction for better correlation with field-measured tensions.

The purpose of the software development is to have a tool available for valid correlation studies. It is hoped that such studies will be done, and can lead to improved tension prediction and pull optimization in the future.

IV. BIOGRAPHY



John M. Fee received a B.S. degree in chemistry from Massachusetts Institute of Technology in 1968.

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

Mr. Fee is a member of the ICC of the PES, and chairs a working group developing compatibility test standards for lubricants and cables.

V. REFERENCES

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